



BaltSe@nioR



POZNAN UNIVERSITY OF LIFE SCIENCES
DEPARTMENT OF FURNITURE DESIGN



and

GAZI UNIVERSITY
DEPARTMENT OF WOOD PRODUCTS
INDUSTRIAL ENGINEERING



THE XXVIIITH INTERNATIONAL CONFERENCE RESEARCH FOR FURNITURE INDUSTRY

Poznań 21st -22nd of September 2017

Organizers:

POZNAN UNIVERSITY OF LIFE SCIENCE
DEPARTMENT OF FURNITURE DESIGN

GAZI UNIVERSITY
DEPARTMENT OF WOOD PRODUCTS
INDUSTRIALENGINEERING

ORGANIZING COMMITTEE:

Ph.D. Beata Fabisiak, Ms.C. Wioletta Idzikowska, Ph.D. Robert Kłos, Ph.D. Julia Lange, Ms.C. Adam Majewski, Ph.D. Łukasz Matwiej, Ph.D. Tomasz Rogoziński, Prof. Jerzy Smardzewski, Ph.D. Krzysztof Wiaderek

Editor-in-chief:

Professor Jerzy Smardzewski, PhD.

Assistants to Editor-in-chief:

Julia Lange, PhD

SCIENTIFIC COMMITTEE:

Prof. Mustafa Altinok, Gazi University, Turkey; Prof. Musa Atar, Gazi University, Turkey; Prof. Thomas Bock, Technische Universität München, Germany; Prof. Stanisław Dzięgielewski, Poznan University of Life Sciences, Poland; Prof. Hasan Efe, Gazi University, Turkey; Prof. Yusuf Ziya Erdil, Mugla Sıtkı Kocman University, Turkey; Prof. Ivica Grbac, University of Zagreb, Croatia; Prof. Vassil Jivkov, University of Forestry, Sofia, Bulgaria; Prof. Ali Kasal, Mugla Sıtkı Kocman University, Turkey; Prof. Peter Niemz, Institut für Baustoffe, ETH Zürich, Switzerland; Prof. Barbara Ożarska, University of Melbourne, Australia; Prof. Silvana Prekrat, University of Zagreb, Croatia.

CONTENTS:

1. **MEHMET ACAR, ALI KASAL, ENGIN BALIKÇI, TOLGA KUŞKUN, YUSUF Z. ERDİL** COMPARISON OF THE SHEAR FORCE CAPACITIES OF H-TYPE FURNITURE JOINTS CONSTRUCTED OF SOME HEAT-TREATED WOOD SPECIES
2. **MUSA ATAR, MEHMET GUNES, HAKAN KESKIN** IMPACTS OF THE DOVETAIL TOOTH ANGLE ON DIAGONAL TENSILE STRENGTH IN THE LEG-TO-RAIL JOINTS
3. **KWADWO BOAKYE BOADU, CHARLES ANTWI-BOASIAKO** THE LINEAR RELATIONSHIP BETWEEN THE FIBRE MORPHOLOGICAL CHARACTERISTICS OF ENTANDROPHRAGMA CYLINDRICUM AND THE STRENGTH OF ITS MORTISE-TENON JOINT
4. **HARUN DILER, HASAN EFE, YUSUF Z. ERDİL 3, TOLGA KUŞKUN, ALI KASAL** DETERMINATION OF ALLOWABLE DESIGN LOADS FOR WOOD CHAIRS
5. **YUSUF ZIYA ERDİL, ALI KASAL, TANER DİZEL, SELÇUK DEMİRCİ, HARUN DİLER, MEHMET ACAR** COMPARISON OF THE SCREW HOLDING CAPACITY OF SOLID WOOD AND LAMINATED VENEER LUMBER (LVL) PRODUCED FROM TURKISH BEECH (*FAGUS ORIENTALIS L.*), SCOTCH PINE (*PINUS SYLVESTRIS L.*) AND YELLOW POPLAR (*POPULUS NIGRA*)
6. **IANCHO GENCHEV, NELLY STANEVA, DESISLAVA HRISTODOROVA** ANALYSIS OF DEFORMATIONS AND STRESSES OF UPHOLSTERED FURNITURE SKELETON WITH STAPLE CORNER JOINTS BY FEM
7. **VASSIL JIVKOV, BORISLAV KYUCHUKOV, RALITSA SIMEONOVA, ASSIA MARINOVA** WITHDRAWAL CAPACITY OF SCREWS AND CONFIRMAT INTO DIFFERENT WOOD-BASED PANELS
8. **VASSIL JIVKOV, RALITSA SIMEONOVA**
SPLITTING RESISTANCE OF PLYWOOD IN THE AREA OF COUNTERSUNK HOLES
9. **MUSA KAYA, HASAN OZGUR IMIRZI, CEVDET SOGUTLU** THE DETERMINATION OF OPTIMAL PROCESS PARAMETERS OF MDF IN POCKET MILLING USING CNC MACHINE
10. **HALIL KILIÇ, CAN ÖZCAN, HASAN EFE , ALI KASAL** COMPUTER AIDED ERGONOMICS IN FURNITURE DESIGN: BABY CRIB CASE STUDY
11. **JONSSON OSKAR, DALHOLM HORNÝÁNSZKY, ELISABETH, SPERLING, LENA & ÖSTLUND, BRITT** ELICIT PRODUCT EXPERIENCES: USER-SATISFACTION SCALE AND STRUCTURED INTERVIEWS WITH OLDER PEOPLE INTERACTING WITH CHAIRS
12. **SIGITA LIŠE, ANDREJS DOMKINS** LATVIAN FURNITURE INDUSTRY'S COMPETITIVENESS POTENTIAL IN THE BALTIC STATES
13. **JOANNA LISIECKA** THE ROLE OF USER IN DESIGN PROCESS. CREATING ADDITIVE EXPERIENCE
14. **MILAN ŠIMEK, BORIS HÁLA, PETR BRUNECKÝ** INFORMATION SYSTEM FOR FURNITURE INDUSTRY KNOWLEDGE BASE TRANSFER
15. **KRZYSZTOF PELIŃSKI, MARLENA WOJNOWSKA, MICHAŁ MASLEJ, MICHAŁ SŁONINA, JERZY SMARDZEWSKI** MODELING OF DENSITY OF PERIODIC STRUCTURES CORES OF HONEYCOMB PANELS
16. **KARLIS PUGOVICS, ULDIS SPULLE** WITHDRAWAL CAPACITY OF GLUED-IN RODS IN BIRCH PLYWOOD
17. **DAN-TIMON RUDOLPH , JÖRG GÜTTLER, KATHARINA LANGOSCH, THOMAS BOCK** CURRENT CONCEPTS FOR TECHNOLOGY ALLOWING INDEPENDENT AND ACTIVE LIVING FOR ELDERLY PEOPLE
18. **CEVDET SAÇLI, OSMAN PERÇİN, MUSTAFA ALTUNOK** THE ELDERLY AND DISABLED IN NURSING HOMES COMPLIANCE WITH HARDWARE FURNITURE IN MERSİN

19. **ANDREW SIRKKA, SARI MERILAMPI AND SIRPA SANDELIN** TOWARDS A GENERIC DESIGN FRAME FOR AGEING-FRIENDLY DEVELOPMENT FOR SENIORS
20. **MESUT UYSAL, EVA HAVIAROVA, CARL A. ECKELMAN** DETERMINING REASONABLE DESIGN VALUES OF REGTANGULAR MORTISE AND TENON JOINTS BY USING PROBABILISTIC APPROACHES
21. **KAMPERIDOU VASILIKI, BARBOUTIS IOANNIS** FEATURES OF FURNITURE DESIGN AND MANUFACTURING THAT CONSTITUTE RISK FACTORS FOR CAUSING ACCIDENTS TO USERS
22. **KEMAL YILDIRIM, MEHMET LÜTFİ HİDAYETOĞLU, SEMİH YILDIRIMTOP** DETERMINATION OF THE SUFFICIENCY OF WARDROBES IN PARENT BEDROOMS OF TODAY'S UPPER SOCIO ECONOMIC STATUS (SES) HOUSES
23. **ZORAN VLAOVIĆ, IVICA GRBAC, KRISTINA MARIĆ** HEAT CONDUCTIVITY AND MOISTURE PERMEABILITY THROUGH THE POCKET SPRING MATTRESS

COMPARISON OF THE SHEAR FORCE CAPACITIES OF H-TYPE FURNITURE JOINTS CONSTRUCTED OF SOME HEAT-TREATED WOOD SPECIES

Mehmet Acar¹, Ali KASAL¹, Engin Balıkçı², Tolga KUŞKUN¹, Yusuf Z. Erdil¹

¹Mugla Sitki Kocman University, Faculty of Technology, Department of Wood Science and Industrial Engineering, Mugla / Turkey

² Gumushane Vocational Education Center, Gumushane / Turkey

Key words	Abstract
<i>Wood, Heat treatment, H-type joint, Shear force capacity.</i>	Tests were carried out to compare the shear force capacities of H-type furniture joints constructed of heat-treated Siberian pine (<i>Pinus sibirica</i>), Iroko (<i>Chlorophora excelsa</i>) and common ash (<i>Fraxinus excelsior</i>) that are commonly used in construction of outdoor furniture. 120 specimens consisting of 3 wood species, 2 treatment processes (untreated, heat-treated), 2 adhesive types (polyurethane, polyvinyl acetate) and 2 joint techniques (mortise and tenon, dowel) and 5 replications for each were prepared and tested. As a result, the joints constructed of untreated common ash gave the highest withdrawal force capacity among the wood species. Overall, heat treatment reduced the share force capacity of joints by 17% as compared to control specimens. Mortise and tenon joints yielded 25% higher performance than dowel joints, and polyvinyl acetate adhesive gave higher results than polyurethane adhesive. The highest shear force capacities of heat-treated specimen obtained from the "Iroko - polyvinyl acetate - mortise and tenon" combination.

Corresponding author: macar@mu.edu.tr Acar M., Mugla Sitki Kocman University, Faculty of Technology, Department of Wood Science and Industrial Engineering, Mugla / Turkey

1. INTRODUCTION

Heat treatment of wood is a kind of the modification method that improves the properties of wood and resulted that produced a new material that more durable to environmental hazards as compare to the unmodified wood (Hill, 2006). Heat-treated wood is an eco-friendly alternative to impregnated wood materials and has a growing market in indoor and outdoor applications. Heat-treated wood can be used for garden, kitchen and sauna furniture, cladding on wooden buildings, bathroom cabinets, floor material, musical instruments, ceilings, inner and outer bricks, doors and window joinery, and a variety of other outdoor and indoor wood applications (Syrjanen 2001). In the process, wood is subjected to high temperatures (close or above 200 °C) for several hours in an atmosphere with low oxygen content. By this treatment process, dimensional stability and the biological durability of wood is increased but some mechanical properties are reduced (Viitaniemi 2000; Syrjanen 2001).

Mortise and tenon (MT) and dowel joints are most popular joint techniques that have been used for thousands of years by woodworkers around the world to join pieces of wooden members. They are still favored for furniture frame constructions. There are many factors that affect the

mechanical performance of MT and dowel joints, including the tenon size (length, width, and thickness) and dowel size (length and diameter), type of fit, shape of the plug and hole, thickness of the glue line, wood species, and adhesives used (Smardzewski 2002; Dzincic and Skakic 2012; Dzincic and Zivanic 2014)

Some factors that affect the strength of MT and dowel joints have been defined by previous studies. Milham (1949) demonstrated that the greatest joint strengths are obtained when a close fit is maintained between the tenon and mortise and that tenon shoulders have a significant effect on the capacity of the joint. Hill and Eckelman (1973) researched the effect of tenon length, tenon width, wood species and different adhesives on bending moment capacity of the joint. Results showed that a MT joint becomes stiffer as either tenon length or width is increased, and also that a shoulder on the rail member of a MT joint contributes to the stiffness of the joint. Eckelman et al. (2006) researched the effect of close-fitting shoulders on bending moment capacity of round mortise and tenon joints and results showed that close-fitting shoulders increased joint strength. Dupont (1963), working with rectangular mortise and tenon joints, indicated that optimum joint strength is obtained when adhesive is applied to both the tenon and sides (cheeks) of the mortise. Stress and strain analysis of double-dowel case-type furniture corner joint were investigated by Hajdarevic and Martinovic (2016). Results showed that dowel spacing, distance between the dowels, and edge of board have considerable impact on the stress state of the face and edge member; joints became stiffer when distance between the dowels and board edge were rationally defined.

The purpose of this study was to investigate the effect of the heat treatment, wood species, joint types and adhesive types on shear force capacity of T-type mortise and tenon (MT) and dowel joints which prepared of Siberian pine (*Pinus sibirica*), Iroko (*Chlorophora excelsa*) and Common ash (*Fraxinus excelsior*).

2. METHODS AND MATERIALS

WOOD MATERIALS, HEAT TREATMENT AND ADHESIVE

Siberian pine (*Pinus sibirica*), Iroko (*Chlorophora excelsa*) and Common ash (*Fraxinus excelsior*) were used as wood materials in this study. All the wood materials were provided commercially from a thermowood company in Turkey. The planks that heat treated materials were processed under 212 °C for 3 hours. Total heat treatment time was about 60h because of a risk of cracks forming while drying but the time of exposure to the highest temperature was 3h. The heat treatment was applied according to the method described in the Finnish ThermoWood Handbook (2003).

The untreated wood of the same species was used as control specimens. The planks that used for control specimens were dried in industrial drying kilns at a temperature of approximately 70 °C and 65% relative humidity (RH), with a prior moisture content of 11%–15%. Special emphasis is given to selection perfect (non-defect) wood material. Prior to the testing, both control and heat-treated specimens were conditioned at 23 °C and 65% RH until moisture equilibrium was achieved. The moisture content of the untreated control specimens was around 6%–8% and that of the treated specimens was around 3%–5%.

All joints were assembled with polyvinyl acetate (PVAc) and polyurethane (PU) adhesives. PVAc adhesive viscosity was 160-200 cps at 25 °C with a density of 1,1 g/cm³, and was applied

in accordance $150 \pm 10 \text{ gr/m}^2$. PU adhesive had viscosity of 3300–4000 cps at 25 °C with a density of 1,11 g/cm³.

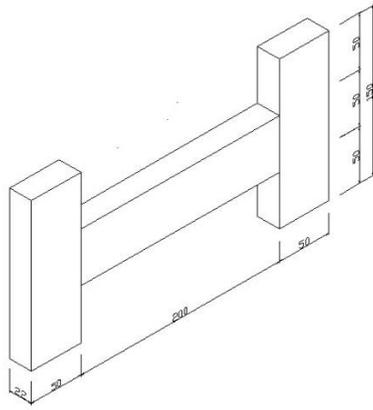
GENERAL CONFIGURATION AND CONSTRUCTION OF THE SPECIMENS

A total of 120 T-type joint specimens were constructed of Siberian pine, Iroko and Common ash with MT and Dowel joints and tested to determine their shear force capacity. The experimental design of the study is consisting of 3 wood species factor * 2 heat treatment factor * 2 adhesive types factor * 2 joint types factor * 5 replicates for each configuration (Table 1).

Table 1. Experimental design of the study

Wood Species	Heat Treatment	Adhesive Type	Joint Type	Replication
Siberian Pine	Heat Treated	PVAc	Dowel	5
			MT	5
		PU	Dowel	5
			MT	5
	Control	PVAc	Dowel	5
			MT	5
		PU	Dowel	5
			MT	5
Iroko	Heat Treated	PVAc	Dowel	5
			MT	5
		PU	Dowel	5
			MT	5
	Control	PVAc	Dowel	5
			MT	5
		PU	Dowel	5
			MT	5
Common Ash	Heat Treated	PVAc	Dowel	5
			MT	5
		PU	Dowel	5
			MT	5
	Control	PVAc	Dowel	5
			MT	5
		PU	Dowel	5
			MT	5
Total				120 Specimens

Each test specimen consisted of three structural elements, two post member and a rail member, that jointed together. The dimension of rail member is 50*21*200 mm and the post member is 50*21*150 mm as it is shown in Figure 1a. and real test specimens were shown in Figure 1b.

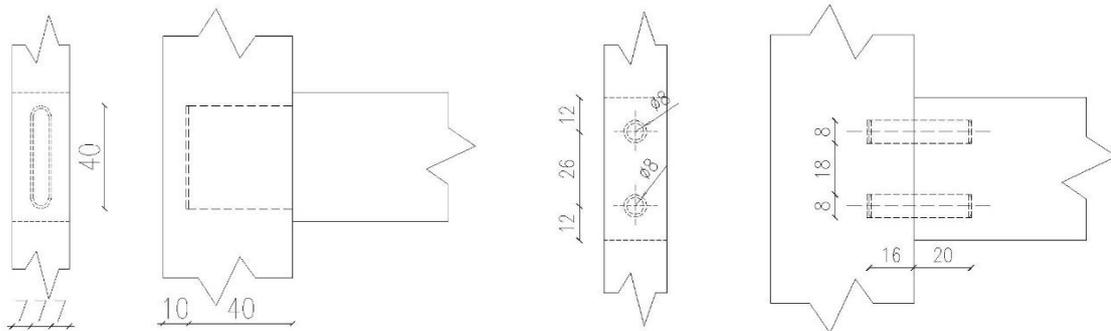


a

b

Figure 1. Test specimens (dimensions in mm)

Mortise and tenon joints had the following nominal dimensions: length = 40 mm, thickness = 7 mm and width = 40 mm as it is shown in Figure 2a. The detail of dowel joints is given in Figure 2b. The test specimens for this connection prepared according to TS 4539.



a

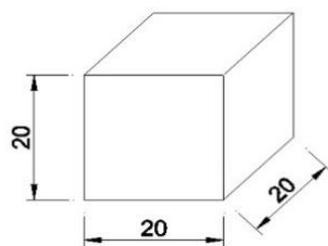
b

Figure 2. Mortise and tenon joints detail (mm)

TESTING METHOD

Density and Moisture Content

Density and moisture content (MC) of all the heat treated and untreated (control) wood materials were determined according to related standards. Determination of density was carried out according to TS 2472 and MC was carried out TS 2741. Sample dimensions illustrated in Figure 3a. and real specimens of density and MC is given at Figure 3b.



a

b

Figure 3. Density and moisture content specimens (mm)

SHEAR FORCE CAPACITY TESTS

The tests were carried out according to previous studies (Ors and Efe 1998; Dizel 2005; Balikci 2015). Tests were conducted on a 50-kN capacity universal-testing machine in the Physical and Mechanical Tests Laboratory of Wood Science and Industrial Engineering Department of Mugla Sıtkı Kocman University. Loading rate was operated 6 mm/min under static loading. The loadings were continued until fracture occurred on the joints or members. Test set-up illustrated at Figure 4. The max force that produced on H-type joint elements were recorded as bending moment capacity and calculated by following equation:

$$F = \frac{F_{\max m}}{2(N)} \quad (1)$$

F : Force

$F_{\max m}$: Maximum force in shear (N),

2 : Number of the joints.

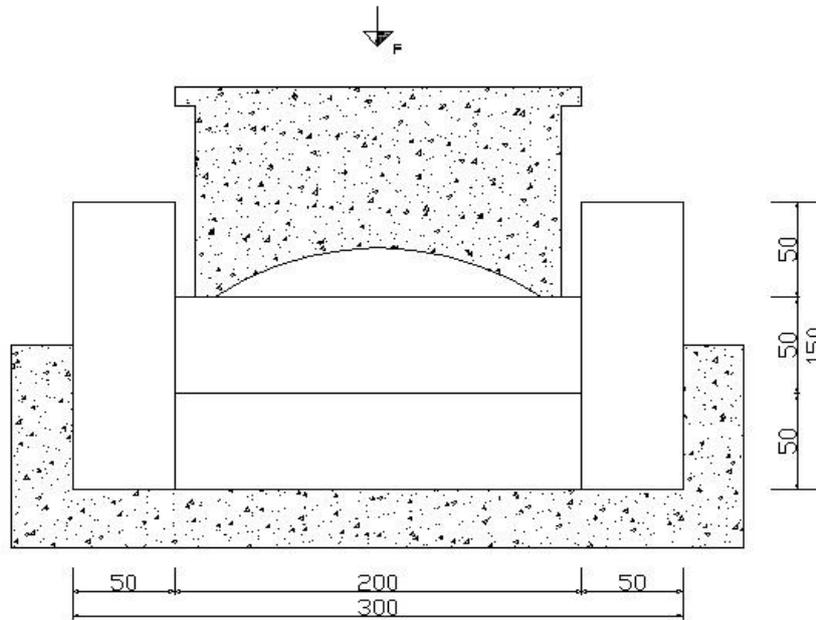


Figure 4. Test set-up (dimensions in mm)

DATA ANALYSIS

Multiple variance analysis (MONOVA) was performed to determine the differences among the factors. Least Significant Difference (LSD) test was used to determine if there was a meaningful difference among the groups.

3. RESULTS AND DISCUSSION

Result of density and moisture content (MC) of the specimens were given in Table 2.

Table 2. Result of density and MC

Wood Species	Treatment process	Test Moisture Content (MC) (%)	Oven Dry Density (δ_0) (gr/cm ³)	COV (%)	Density During the Test (δ_{I2}) (gr/cm ³)	COV (%)
Siberian Pine	Heat-Treated	4,5	0,35	2	0,36	2
	Control	6,77	0,38	4	0,40	4
Iroko	Heat-Treated	3,71	0,54	2	0,56	2
	Control	7,54	0,57	3	0,61	2
Common Ash	Heat-Treated	4,24	0,55	2	0,57	2
	Control	7,04	0,59	3	0,63	3

COV: Coefficient of Variation

Mean values and variation coefficient of bending moment capacity of T-type joints were given in Table 3.

Table 3. Mean values and coefficient of variation of T-type joints

Wood Species	Heat Treatment	Adhesive Type	Joint Type	Mean Value (N)	Coefficient of Variation (%)
Siberian Pine	Heat Treated	PU	Dowel	2826	11,06
			MT	2446	7,88
		PVAc	Dowel	2051	6,55
			MT	2510	11,65
	Control	PU	Dowel	2832	9,28
			MT	2880	8,65
		PVAc	Dowel	2273	13,30
			MT	3407	16,21
Iroko	Heat Treated	PU	Dowel	3763	13,14
			MT	5136	9,18
		PVAc	Dowel	3378	10,63
			MT	4814	7,58
	Control	PU	Dowel	3964	13,06
			MT	4080	19,89
		PVAc	Dowel	3750	5,95
			MT	5695	13,32
Common Ash	Heat Treated	PU	Dowel	3399	20,53
			MT	3376	8,21
		PVAc	Dowel	3495	15,15
			MT	3436	12,35
	Control	PU	Dowel	3671	7,51
			MT	4677	9,26
		PVAc	Dowel	3646	6,83
			MT	6838	6,17

Effect of multiple variation analyses results of wood species (WS), treatment process (HT), adhesive types (AT) and joint types (JT) on bending moment capacity of T-type joint are given in Table 4.

Table 4. Results of multiple variation analysis (MONOVA)

Variation Sources	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability (p<0,05)
WS	2	63743904,860	31871952,430	173,9464	0,0000
HT	1	10887157,118	10887157,118	59,4184	0,0000
WS- HT	2	7237462,381	3618731,191	19,7498	0,0000
AT	1	1188764,315	1188764,315	6,4879	0,0125
WS - AT	2	2880596,895	1440298,448	7,8607	0,0007
HT - AT	1	4442058,017	4442058,017	24,2433	0,0000
WS – HT - AT	2	695591,768	347795,884	1,8982	0,1554
JT	1	21249549,778	21249549,778	115,9729	0,0000
WS - JT	2	4273179,314	2136589,657	11,6608	0,0000
HT - JT	1	4764828,825	4764828,825	26,0048	0,0000
WS – HT - JT	2	7672005,539	3836002,770	20,9356	0,0000
AT - JT	1	7789169,147	7789169,147	42,5107	0,0000
WS – AT - JT	2	15635,711	7817,855	0,0427	NS
HT – AT - JT	1	3477986,129	3477986,129	18,9817	0,0000
WS – HT – AT - JT	2	1279682,618	639841,309	3,4920	0,0344
Error	96	17589946,561	183228,610		
Total	119	159187518,977			

NS: Insignificant WS: Wood Species HT: Heat Treatment AT: Adhesive Type JT: Joint Type

According to the results, all factors and interactions were found statistically significant except WS – HT - AT and WS – AT- JT. LSD tests were conducted for significant interactions on withdrawal force capacity of joints and some of LSD tests were investigated following. Results of LSD test for WS factor on shear force capacity of the joints are given in Table 5.

Table 5. LSD test results of WS factor

Wood Species	Shear Force Capacity (N)	
	X (N)	HG
Siberian Pine	2653	C
Iroko	4304	A
Common Ash	4067	B

LSD± 270,7 X: Shear force Capacity, HG: Homogeneity Group

According to the table, Iroko was given the highest value, common ash and Siberian pine followed the Iroko respectively. When compare the results, iroko was performed approximately 5% more resistant than common ash and 38% than Siberian pine. Indeed, common ash provided 35% more performance than Siberian pine. This result can be explained by relation of linear proportion between density and load carrying capacity.

Table 6. LSD test results of HT factor

Heat Treatment	Shear Force Capacity (N)	
	X (N)	HG
Heat Treatment	3374	B
Control	3976	A

LSD± 155,1

According to the table, H-type joint which constructed with heat treated wood materials were given low values than untreated wood materials (control group). Strength of the joints decreased by 17% when compared to the control group. It is thought that because of heat treatment process has negative effect on cellular composition of the wood materials.

There is various research in literature which investigated negative effect of thermal process on material strength. Thermal process can be resulted by strength loss that described as thermal degradation and substance loss due to applied temperature and time dependent (Rusche 1973). The strength and hardness of the wood decreases when heated while increases when cooled. It is thought that irreversible degradations on mechanical and technological properties of the wood caused by effect of thermal degradation on wood composition (Mitchell 1988).

LSD test results of adhesive type factor on shear force capacity of the H-type joint were shown in Table 7.

Table 7. LSD test results of AT factor

Adhesive Type	Shear Force Capacity (N)	
	X (N)	HG
PU	3575	B
PVAc	3774	A

LSD± 155,1

It is observed from the table that PVAc adhesive was given approximately 5% highest value than PU adhesive that means PU has showed lower resistance than PVAc adhesive.

LSD test results of joint type factor on shear force capacity of the H-type joints were given in Table 6.

Table 6. LSD test results of JT

Joint Type	Shear Force Capacity (N)	
	X (N)	HG
Dowel	3254	B
MT	4096	A

LSD± 155,1

According to results of two-way interaction of MT and dowel joints, MT joints were yielded approximately 25% more shear force capacity than dowel joints. This result can be explained because of bonding surface area. MT joints has more bonding surface area than dowel joints. LSD results of quadruple interactions that consist of WS-HT-AT-JT were given in Table 9.

Table 9. LSD results of four-way interactions on bending moment capacity of the joints

Wood Species	Heat Treatment	Adhesive Type	Joint Type	Bending moment capacity (N)	
				X (N)	HG
Siberian pine	Heat-Treated	PU	Dowel	2826	H
			MT	2446	HI
		PVAc	Dowel	2051	I
			MT	2510	HI
	Control	PU	Dowel	2832	H
			MT	2880	GH
		PVAc	Dowel	2273	I
			MT	3407	FG
Iroko	Heat-Treated	PU	Dowel	3763	DEF
			MT	4989	C
		PVAc	Dowel	3378	FG
			MT	4814	C
	Control	PU	Dowel	3964	DE
			MT	4080	D
		PVAc	Dowel	3749	DEF
			MT	5695	B

LSD± 537,4

Table 9. LSD results of four-way interactions on bending moment capacity of the joints-cont

Wood Species	Heat Treatment	Adhesive Type	Joint Type	Bending moment capacity (N)	
				X (N)	HG
Common ash	Heat-Treated	PU	Dowel	3399	FG
			MT	3376	FG
		PVAc	Dowel	3495	EF
			MT	3436	EF
	Control	PU	Dowel	3671	DEF
			MT	4677	C
		PVAc	Dowel	3646	DEF
			MT	6838	A

LSD± 537,4

As seen on Table 7, the highest value of bending moment capacity obtained from Common ash – Control – PVAc – MT combination and lowest value obtained from Siberian pine – Heat treated – PVAc – Dowel combinations.

When only heat treated combinations were investigated, Siberian pine gave the highest value with PU and dowel combination and gave lowest value with combination of PVAc and dowel joint. Iroko performed maximum value with both PU and PVAc adhesive and MT combinations while it gave its lowest performance with PVAc and dowel combination. It is seen that joint type has significant effect on shear force capacity of Iroko. Similar results observed with Common ash; however, adhesive type was considered to have significant effect in this combination. Common ash yielded maximum value with combination of PVAc adhesive and both MT and dowel joints while performed lower performance with PU adhesive and both MT and dowel joint.

4. CONCLUSIONS

In this study, shear force capacity of H-type joints constructed with heat-treated Siberian pine, Iroko and Common Ash were investigated with aid of engineering design principles. It is believed that results of this study will help design more durable frame constructions, especially outdoor sitting furniture constructions since most of their joints are exposed to shear effect under an applied force or negative weather conditions.

When the effect of wood species on shear force capacity was investigated, Iroko performed higher performance than Common ash and Siberian pine, respectively.

Statistically, all main factors and their interactions were found significant except for WS – HT - AT and WS – AT- JT. Iroko gave the best performance among the wood species. Control specimens performed 17% better than heat treated ones. This result proves that heat treatment has negative effect on mechanical properties of the wood materials. In the case of adhesive type factor, generally PVAc adhesive yielded better resistance almost at all combinations when compared to the PU. In the case of Joint type, MT joints yielded 25% more performance than dowel joints.

ACKNOWLEDGEMENT

This research was supported by Scientific Research Project Office of Mugla Sitki Kocman University with the project number of 14/023.

References

- Balıkçı E. (2015): Mechanical properties of the frame construction furniture joints prepared of heat treated wood. Master Thesis, Muğla Sıtkı Koçman University, Muğla, Turkey.
- Dizel T. (2005): Mechanical behaviour of properties of the frame type furniture joints constructed of laminated veneer lumber. Master thesis, Gazi University, Ankara, Turkey.
- Dupont W. (1963): Rationalization of glued joints in the woodworking industry. *Modern Holzverarbeitung* 30:176-180.
- Dzincic I., Skakic D. (2012): Influence of type of fit on strength and deformation of oval tenon-mortise joint. *Wood Research*, 57(3), 469-477.
- Dzincic I., Zivanic D. (2014): The influence of fit on the distribution of glue in oval tenon/mortise joint. *Wood Research*, 59(2), 297-302.
- Eckelman CA, Erdil YZ, Haviarova E (2006) Effect of shoulders on bending moment capacity of round mortise and tenon joints. *Forest Prod J* 56(1):82-86.
- Finnish ThermoWood Association (2003): *ThermoWood Handbook*, Helsinki, Finland.
- Hajdarevic S., Martinovic S. (2016): The effect of dowel spacing on the stress and strain of case-type furniture corner joint. *Proceedings of the 26th DAAAM International Symposium*, Vienna, Austria, 0391-0399.
- Hill M. D., C.A. Eckelman (1973): Flexibility and bending strength of mortise and tenon joints. *Purdue University J.*, 4578: 25-33.
- Hill C. (2006): *Wood Modification-Chemical, Thermal and Other Processes*, Wiley Series in Renewable Resources, John Wiley & Sons, Ltd.
- Milham RM (1949) A comparison of strength characteristics of the mortise and tenon joint and dowel joint. MS thesis, University of Michigan, Ann Arbor, Michigan.
- Mitchell P.H. (1988): Irreversible property changes of small loblolly pine specimens heated in air nitrogen oxygen. *Wood and Fiber Science*, 20(3): 320-355
- Örs Y., Efe H. (1996): Mechanical behavior of joint connectors on furniture (frame construction) design. *Turkish Journal of Agriculture and Forestry* 22: 21-27.
- Rusche H. (1973): Thermal degradation of wood at temperatures up to 200°C-Part-I: strength properties of dried wood after heat treatment. *Holz als Roh-und Werkstoff*, 31: 273-281
- Smardzewski J. (2002): Strength of profile-adhesive joints. *Wood Science and Technology*, 36(2): 173-183, 2002.
- Syrjanen, T., Oy, K., "Production and classification of heat-treated wood in Finland, Review on heat treatments of wood" Proceedings of the special seminar held in Antibes, France, 2001.

TS 2471 (1976): “Wood determination of moisture content for physical and mechanical tests”
Ankara, T.S.E.

TS 2472. (1976): “Wood determination of density for physical and mechanical tests” Ankara,
T.S.E.

TS 4539 (1985): „Wood Joints – The rules of dowel joints” Ankara, 1-3.

Viitaniemi P. (2000): New properties for thermally-treated wood”, Indust Horizons.

Corresponding author:

M. Acar

Muğla Sıtkı Koçman University, Faculty of Technology, Department of Woodworking
Industrial Engineering, Muğla / Turkey

macar@mu.edu.tr

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY)
license.

IMPACTS OF THE DOVETAIL TOOTH ANGLE ON DIAGONAL TENSILE STRENGTH IN THE LEG-TO-RAIL JOINTS

Musa ATAR¹, Mehmet GUNES¹, Hakan KESKIN¹

¹Gazi University, Faculty of Technology, Department of Wood Products Industrial Engineering, 06500 Besevler, Ankara – TURKEY

Key words	Abstract
<i>Diagonal tensile strength, Joint angle, Dovetail leg-to-rail joint, Adhesives, Woods..</i>	This study has been made in order to determine the effects of preparing the dovetail leg-to-rail joints, end to side grain joints and dowel joints, which are applied for furniture the leg-to-rail joints in various tooth angles on diagonal tensile strength. For this purpose, in compliance with the rules of ASTM D 1037, the diagonal tensile test was applied to the corners obtained with polyvinyl acetate (PVAc) and polyurethane (D-VTKA = Desmodur-Vinyl Triechetonole acetate) adhesives after drilling the joints on the specimens prepared from Oriental Beech (<i>Fagus orientalis</i> L.), European Oak (<i>Quercus petraea</i> Liebl.) and Scotch Pine (<i>Pinus sylvestris</i> L.) at 75°, 78°, 81° and 84°. According to this; the highest Diagonal tensile strength in terms of wood type, joining technique and adhesive type has been found O+P+II (1,184 N.mm ⁻²) and the lowest is S+D+V (0,2687 N.mm ⁻²). In terms of diagonal tensile strength, PVAc adhesive and 78° dovetail joint technique could be recommended for the leg-to-rail joints.

Corresponding author: musaatar@gazi.edu.tr Atar M., Gazi University, Faculty, Department, Department of Wood Products Industrial Engineering, 06500 Besevler, Ankara – TURKEY

1. INTRODUCTION

While designing furniture components, their functions, sizes and aesthetics are given a particular importance. The furniture is purchased by taking one or all of these factors into account. According to the place and purpose of use, the cost is of secondary importance. Apart from the factors, the lifetime of the furniture is directly affected by the construction that forms it (Ors et al. 1999).

The furniture, depending on the intended use, is faced with a variety of mechanical stresses. According to the form of the force that has an impact on these stresses, the deformations such as openings or relaxation in the joints of furniture elements, bending, cracking or breaks in the elements occur. The size of the deformation affecting the robustness and quality varies according to type of adhesive and woods and according to the construction which is applied in the joints (Altinok 1998).

The factors which affect the determination of the durability of furniture are the material used, the construction that is chosen, and the strength of the joint formed by arranging the auxiliary materials in a harmony. Deformations in the joints come into being as a result of mechanical stress by being exposed to external force. Many studies have been conducted to determine these deformations and the effects that the joints will expose (Eren and Eckelman 1998).

After the box-type furniture corners have been prepared from the oriental beech, sessile oak and scotch pine and medium density fiberboard at the tooth angles of 75°, 78°, 81°, 84° and 87° and joined with polyvinyl acetate and polyurethane adhesives, the diagonal compression and diagonal tensile tests have been performed and the tooth angle 81° has produced the best result in terms of compression and tensile strength performance (Ustundag 2008).

In the wood drawer, the highest tensile strength has been found in the screw joint that is joined by using medium density fiberboard and polyvinyl acetate and that is parallel to the mounting direction and the lowest tensile strength has been found in the tongue and groove joints, which are joined by using medium density fiberboard and polyvinyl acetate and which is made parallel to the mounting direction (Gode 2005).

Tensile strength tests have been performed in the Scotch pine, oriental beech and sessile oak specimens by joining them with D-VTKA adhesive in the transversal and radial direction. Tensile strength tests have been performed by joining the particle boards and fiberboards whose sides are solid and not solid with PVAc adhesive. The highest tensile strength has been reported in the fiberboard whose sides are solid and in the Oriental beech in the transversal direction (Ors et al. 1999)

In the study made in order to determine the impact of the dilution of PVAc with water in different proportions on the bonding strength of the oriental beech, sessile oak and scotch pine, it has been reported that the highest value has been obtained from the viscosity of the oriental beech + packaging and the lowest value has been obtained from the scotch pine + the adhesive that is added 40% water (Atar 2007)

At the end of the study made in order to determine the impacts of the material type, joining technique and adhesive type in the corner joints of the furniture drawer on the diagonal tensile strength, the highest tensile strength in terms of tensile strength has been found in the box joint (finger joint), the lowest tensile strength has been found in the dowel joint (Gunes 2006).

6, 8 and 10 mm dowels, edges of which are covered with 5, 8, 12 mm solid oriental beech material and which are on the waferboard that is not solid, have been bonded with PVAc adhesive by drilling holes in the depth of 25 mm. It has been reported that the highest dowel tensile strength has been seen in the solid waferboard (8 mm) and in the 6 mm dowel, the lowest tensile strength has been seen in the 10 mm dowel and in the waferboard that is not solid (Ors et al. 2000).

Fiberboard has gained an advantage over the particle board in the dowel joint processes, and it has been reported that PVAc adhesive showed the best result among other adhesives (Efe and Kasal 2000).

After some factors (Distance between the hole centers of biscuit type foreign laths, the distance between the outer edges of the board, board-type adhesion technique) affecting the resistance properties of the corner joints prepared with the Biscuit type foreign laths were studied, the strength was found high in the fiberboard in the joints with adhesive and without adhesive and it was found that 15 cm distance between the biscuit centers increased the strength in comparison with 10 and 12,5 cm distances; and 5-6, 5-7, 5 cm distances between the biscuit laths and the edges would not create any difference in terms of strength (Tankut 2004).

PVAc D4 adhesive has shown the best resistance against the forces that are trying to tense. The dowel joint has shown the best resistance in joint technique; and biscuit joint has shown the best resistance in the compression tests (Demirel 2008).

In order to determine the effects of the dovetail tooth angles on the tensile strength in longitudinal direction in the dovetail end to end-grain joint, the Oriental beech, Scotch pine and

European oak woods were bonded with D-VTKA and PVAc and the tensile strength test was applied. The highest tensile strength was found in the sessile oak, the lowest was found in the scotch pine and the highest tensile strength was found in PVAc in terms of adhesive and the lowest was found D-VTKA and the highest tensile strength was found in the angle 81 and the lowest was in the angle 84 in terms of tooth angle. End-on-end dovetail joints, sessile oak, PVAc adhesive and the angle 81 can provide advantage in terms of tensile strength (Atar 2008).

As box furniture constructions are exposed to compression and tensile stress, it has been recommended to use the dowel joint type and the polymeric adhesive in corner joints of the box furniture produced from coated MDF (Medium density fiberboard) (Tas et al. 2007).

In order to research the effects of wood type and dowel and dovetail joint techniques on the column feet (from the midpoint) strength, Scotch pine, oriental beech and polyvinyl acetate adhesive were chosen. The highest compression strength was determined in the beech feet with the dovetail joint (Altinok 1998).

The highest tensile strength was seen in the beech with the screw joint according to the wood type and joint technique. The weakest strength was obtained in the Scotch pine with the end to side grain joints. In addition, according to the stress analysis in the tests, dowel joints gave better results and end to side grain joints gave better results according to the strength transmission performance (Efe and Imirzi 2001).

This study was carried out to determine the impacts of different joint angles on the diagonal tensile strength of dovetail leg-to-rail joints; that is one of the leg and rail joints techniques.

2. MATERIAL AND METHOD

MATERIAL

WOODS

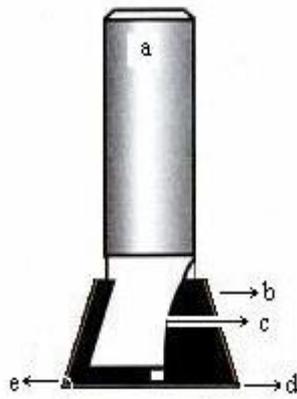
In this study, wood materials were used by random selection method from sellers in Ankara Sites from woods between Oriental beech (*Fagus orientalis* L.), European oak (*Quercus petraea* Liebl.), scotch pine (*Pinus sylvestris* L.), Wood materials are first class and they have proper fiber, do not have any cracks, knots, color or density difference, and (annual rings are vertical to the surfaces) and prepared from sapwood according to TS 2470 standards (TS 2470, 1976) Lumber were cut according to dimensions and stack in storage areas where sunlight does not enter and there is air circulation by putting lath between them and their air were made air-dried.

ADHESIVES

In this study, PVAc adhesives has been preferred which is used in wood works industry and massive furniture manufacturing because of easy application, quick hardening, being able to apply in room temperature, being inflammable and odorless. Polyvinyl acetate (PVAc) and Polyurethane (D-VTKA=Desmodur-Vinyl Triacetate) adhesives which are proper for cold pressing operations were used.

DOVETAIL TOOTH OPENING BLADE

These are drill shaped blades which are often used in dovetail thread fastening operations which is used in massive table corners. Dovetail channel blade were shown in figure 1 and parts of dovetail channel blade are given in figure 1.



a: Body, b: Cutter, c: Spiral, d: Cutting edge, e: Joint (cut) angle

Figure 1. Dovetail joints cutter

SURFACE AREAS OF THE JOINTS USED IN THE SAMPLES

The dovetail channel opening blade applied in the solid furniture was specially made at the angles of (75°, 78°, 81°, 84°) for this study. Adhesion surface areas of the joint types applied in the test samples are given in Table 2.

Table 1. Surface areas of the dovetail, dowel and end to side grain joints

Joint Technique	Area (mm ²)
75°	2916,13
78°	2820,21
81°	2725,15
84°	2631,66
Dowel	2858,64
End to side grain joint	3619,30

METHOD

PREPARATION OF THE TEST SAMPLES

Oriental Beech, European oak and Scotch Pine as wood materials; polyvinyl acetate (PVA) and polyurethane (D-VTKA) as adhesive, dovetail tail, dowel and end to side grain joint techniques at the angles of 75°, 78°, 81° and 84° as joining types have been chosen. The force has been applied as diagonal tensile strength.

DOVETAIL JOINT TEST SAMPLES

Four different angles (75°, 78°, 81°, 84°) have been applied in test specimens of the dovetail joint. Each test sample consists of two components A and B. Dovetail joint foot element have been prepared as (A) 40 x 200 x 40 mm and recording element have been prepared as (B) 21 x 50 x 160 mm. Measurements of the test specimens are given in Figure 2. Dovetail pinned joining elements were recessed on the face of the element A, and they were the tail in the end grain of the element B during the process.

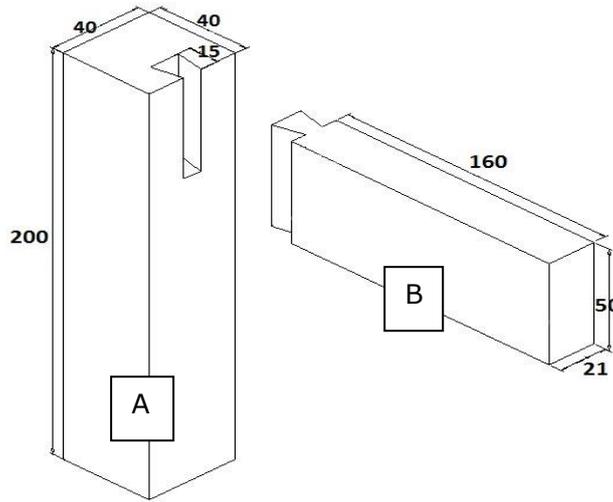


Figure 2. Dovetail test sample (mm)

After the joining surfaces of the elements A (pins) and B (tail) were bonded, the specimens were mounted. The drawing of the test sample is shown in Figure 2. The mounted specimens were kept waiting at 20 ± 2 C° temperature and relative humidity of $65\% \pm 3$ until the test time.

DOWEL JOINTS TEST SAMPLES

The dowel in the size of 8 mm diameter and 32 mm length was used in the dowel joint. After the adhesives to be applied to the joining surfaces of the elements A and B were applied as 160–200 gr per m², the specimens were mounted. About 2 N/mm² force was applied in mounting processes and after 24 hours, the press was opened. The drawing of the test specimens is shown in Figure 3. The mounted specimens were kept waiting at 20 ± 2 C° temperature and relative humidity of $65\% \pm 3$ until the test time.

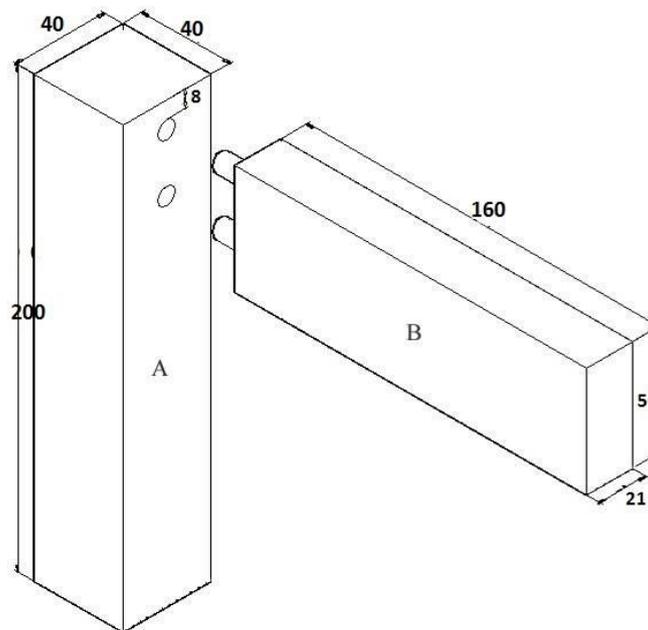


Figure 3. Wooden dowels test sample (mm)

MORTISE AND TENON JOINTS TEST SAMPLES

In end to side grain joints test specimens, the mortise was opened for the foot devices with the drill bit in 8 mm diameter and the tenon was opened to the recording element. After the adhesives to be applied to the joining surfaces of the elements A and B were applied as 160–200gr per m² the specimens were mounted. 2 N/mm² force was applied in mounting processes and after 24 hours, the press was opened. The drawing of the test specimens is shown in Figure 4. The mounted specimens were kept waiting at 20±2 C° temperature and relative humidity of 65% ± 3 until the test time.

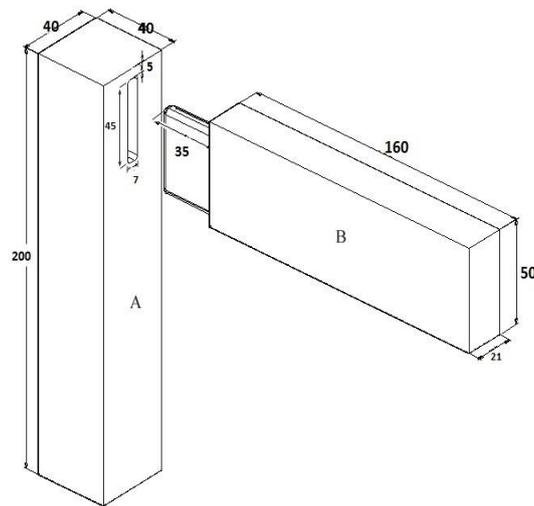


Figure 4. Mortise and tenon joints test sample (mm)

TEST EQUIPMENT

Universal Test Equipment having 5 ton capacity which is present in Gazi University technical Education faculty Furniture and Decoration department mechanics laboratory were used in tests. Loading speed can be adjusted manually. Loading speed has been adjusted as 2 mm/min way for providing application period between 30 to 60 seconds. ASTM D 1037 principles were followed in tests. Forces of test samples during deformation have been recorded in terms of Newton. (N) Robustness of furniture is the robustness of the joining location which is formed by joining of selected construction and ancillary tools in harmony. Compelling forces which corresponds to rail to leg joints may lead furniture subject to deformation in time. Several studies were made for determining these deformations by symbolizing the effects which joining places may subject to (TS 2470, 1976). Similar studies were utilized in test method and assemblies related to this are shown in figure 5.

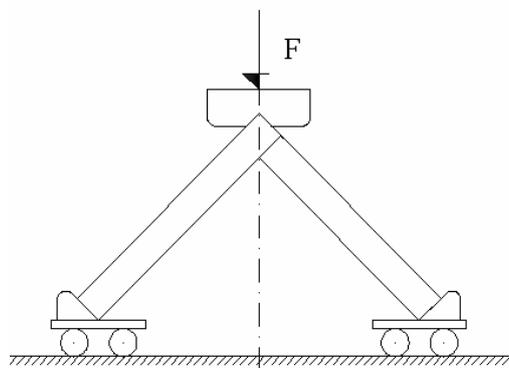


Figure 5. Diagonal tensile testing setup

DATA ANALYSIS

In this study, the effects of the wood type, joining techniques and adhesive type on diagonal tensile performance have been analyzed. Multiple variance analysis (MANOVA) was used to determine these performances. The DUNCAN test was applied to indicate the significance level on the condition that mutual interaction of the factors becomes significant with 5% error margin.

3. RESULTS AND DISCUSSION

Multiple variance analysis results regarding the effect of the wood type, joining technique and adhesive type on diagonal tensile strength are given in Table 2.

Table 2. Multiple variance analysis results regarding the effect of the wood type, joining technique and adhesive type on diagonal tensile strength

Variance Source	Degree of freedom	Sum of squares	Average of squares	F Value	P < 0,05
Wood Type (A)	2	0.963	0.481	95.0677	0,0000
Adhesive Type (B)	1	6.054	6.054	1195.5063	0,0000
A x B	2	0.367	0.183	36.2288	0,0000
Joining Technique (C)	5	1.260	0.252	49.7501	0,0000
A x C	10	0.297	0.030	5.8654	0,0000
B x C	5	1.043	0.209	41.1946	0,0000
A x B x C	10	0.137	0.014	2.7002	0.0054
Total	143	10.667			

Factor A: Wood Type (Oriental Beech, European oak, Scotch Pine),

Factor B: Adhesive Type (PVAc, Desmodur VTKA),

Factor C: Joining Technique (Dovetail 75°,78°,81°,84° Joint Dowel, Mortise and tenon joint)

The difference between diagonal tensile strengths of the wood type, adhesive type and joining techniques has been found statistically significant ($\alpha=0,05$). Duncan test was applied in order to determine between which groups the difference is significant. Diagonal tensile strength averages ($N.mm^{-2}$) of wood type, adhesive type and joining techniques are given in Table 3.

Table 3. Diagonal tensile strength averages of wood type, adhesive type and joining techniques

Wood Type*	X	HG
Oriental Beech (B)	0.6644	B
European Oak (O)	0.6951	A
Scotch Pine (S)	0.5083	C
Joining Technique**		
75° (I)	0.6587	B
78° (II)	0.7465	A
81° (III)	0.6443	B
84° (IV)	0.6177	B
Dowel (V)	0.4349	C
Mortise and tenon (VI)	0.6335	B
Adhesive type***		
PVAc (P)	0.8277	A
D-VTKA (D)	0.4176	B

*LSD: 0.02853, **LSD: 0.04035,***LSD:0.02330,

X:Arithmetic average, HG: Homogeneity Groups

According to the wood type, the highest diagonal tensile strength has been found in the European oak (0,6951 $N.mm^{-2}$), the lowest has been found in the Scotch Pine (0,5083 $N.mm^{-2}$)

²); according to the joining technique, the highest diagonal tensile strength has been found at 78° (0,7465 N.mm⁻²), the lowest has been found in the dowel joint (0,4349 N.mm⁻²); according to the adhesive type, the highest diagonal tensile strength has been found in PVAc (0,8277 N.mm⁻²), the lowest has been found in D-VTKA (0,4176 N.mm⁻²). Average values of the diagonal tensile strength according to the mutual interactions of the wood type, adhesive type and joining techniques are given in Table 4.

Table 4. Diagonal tensile strength averages according to the mutual interactions of the wood type, adhesive type and joining techniques

Wood Type + Joining Technique*	X	HG
B+I	0.7903	A
B+II	0.8080	A
B+III	0.6831	B
B+IV	0.6279	B
B+V	0.4045	DE
B+VI	0.6727	B
O+I	0.6966	B
O+II	0.7828	A
O+III	0.7734	A
O+IV	0.7004	B
O+V	0.5255	C
O+VI	0.6919	B
S+I	0.4716	CD
S+II	0.6664	B
S+III	0.4765	CD
S+IV	0.5250	C
S+V	0.3747	E
S+VI	0.5358	C
Wood Type + Adhesive Type**		
B+P	0.8878	B
B+D	0.4410	D
O+P	0.9507	A
O+D	0.4395	D
S+P	0.6445	C
S+D	0.3722	E
Joining Technique+ Adhesive Type ***		
I+P	0.7843	B
I+D	0.5332	C
II+P	0.9534	A
II+D	0.5780	C
III+P	0.9402	A
III+D	0.3485	E
IV+P	0.9149	A
IV+D	0.2821	F
V+P	0.5376	C
V+D	0.3322	EF
VI+P	0.8356	B
VI+D	0.4313	D
*LSD: 0,06989, **LSD: 0.04035, ***LSD: 0.05706		

In terms of wood type and joining technique, the highest diagonal tensile strength has been found in B+II (0,8080 N.mm⁻²), the lowest has been found in S+V (0,3747 N.mm⁻²); in terms of wood and adhesive type, the highest diagonal tensile strength has been found in O+PVA (0,9507 N.mm⁻²), the lowest has been found in S+D-VTKA (0,3722 N.mm⁻²); in terms of joining technique and adhesive type, the highest diagonal tensile strength has been found in II+PVAc (0,9534 N.mm⁻²), the lowest has been found in V+D-VTKA (0.3485 N.mm⁻²).

Table 5. Diagonal Tensile Strength Duncan Test Results

Process Type	X	HG*	Process Type	X	HG*
O+P+II	1.184	A	B+D+II	0.5698	HI
O+P+IV	1.095	AB	O+D+I	0.5193	IJ
B+P+II	1.011	BC	S+P+I	0.5182	IJ
B+P+IV	0.9837	CD	B+P+V	0.4870	IJK
B+P+III	0.9768	CD	S+P+V	0.4807	IJK
O+P+III	0.9765	CD	O+D+VI	0.4550	JKL
B+P+I	0.9605	CD	B+D+VI	0.4375	JKL
O+P+VI	0.9288	CD	S+D+I	0.4250	JKLM
B+P+VI	0.9080	CD	O+D+V	0.4060	JKLMN
O+P+I	0.8740	DE	S+D+VI	0.4015	KLMN
S+P+IV	0.7810	EF	B+D+III	0.3895	KLMN
S+P+II	0.7575	FG	O+D+III	0.3623	LMNO
S+P+VI	0.6700	GH	B+D+V	0.3220	MNO
S+P+III	0.6593	GH	O+D+IV	0.3052	NO
B+D+I	0.6555	GH	S+D+III	0.2938	NO
O+P+V	0.6450	H	B+D+IV	0.2720	O
O+D+II	0.5890	HI	S+D+IV	0.2690	O
S+D+II	0.5752	HI	S+D+V	0.2687	O

*LSD: 0.09883

In terms of wood type, joining technique and adhesive type, the highest diagonal tensile strength has been found O+P+II (1,184 N.mm⁻²), and the lowest has been found S+D+V (0,2687 N.mm⁻²). The graph is shown in Figure 6.

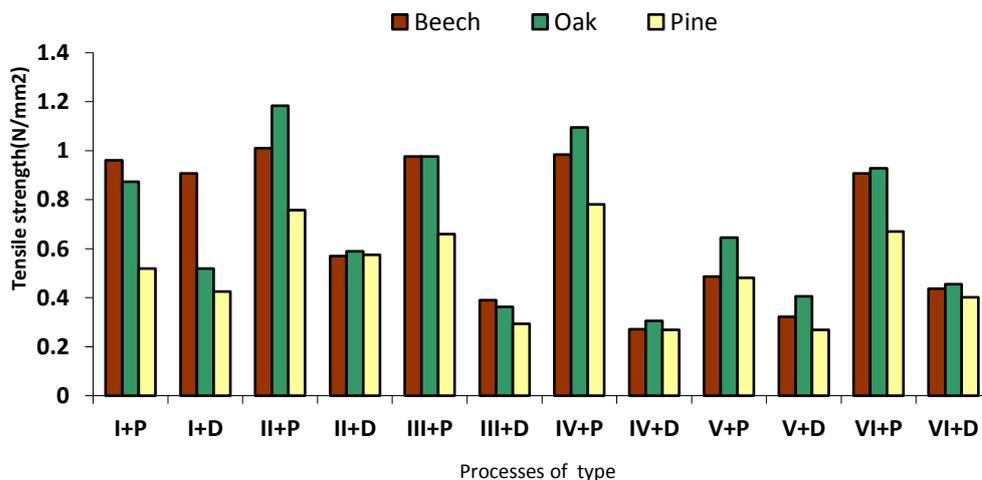


Figure 6. Tensile strength according to wood type, joining technique and adhesive type

4. CONCLUSIONS

With respect to type of wood diagonal tensile strength, highest has been found in European oak (0.6951 N.mm⁻²) and lowest in Scotch pine. According to this, tensile strength of European oak is 4% more than oriental beech and 27% more than Scotch pine. This case may be caused from different textural structure of oak (medullary rays, curvature of fibers) which transmits force with lower manner. With respect to joining technique, diagonal tensile strength is highest in 78° dovetail joint (0.7465 N.mm⁻²), and lowest in dowel joint. According to this diagonal tensile strength of 78° dovetail joining is 12% more than 75° dovetail angle, and 12% more than mortise and tenon joint, 14 % more than 81, 17% more than 84° angle and 42% more than dowel joint. This case may be caused from greater attaching surface in teeth which are cut with

78° angle. Hence, surface area calculation has been found 2820.21 mm² in 78°. With respect to adhesive type, tensile strength has been found as (0.8277 N.mm⁻²), in polyvinylacetate adhesive, and (0.4176 N.mm⁻²) in polyurethane (D-VTKA) adhesive. According to this, diagonal tensile strength of PVAc adhesive is 50% more than with respect to polyurethane D-VTKA adhesive. It can be inferred that most suitable adhesive is PVAc in the adhesion of the rail to leg joints which was made from massive wood material. With respect to type of wood and joining technique, highest diagonal tensile strength was found in the oriental beech at + 78° (0.8080 N.mm⁻²), and lowest in the Scotch pine+dowel (0.3747 N.mm⁻²). With respect to type of wood and adhesive interaction, the highest diagonal tensile strength has been found in Oak+PVAc (0.9507 N.mm⁻²), and lowest in Scotch pine + D-VTKA (0.3722 N.mm⁻²). With respect to joining technique and adhesive type, the highest diagonal tensile strength has been found in 78° + PVAc (0.9534 N.mm⁻²), and lowest in dowel + D-VTKA (0.3485 N.mm⁻²). With respect to type of wood, joining technique and adhesive, the highest diagonal tensile strength has been found in European oak + PVAc + 78° (1.184 N.mm⁻²), and lowest in Scotch pine + D-VTKA + Dowel (0.2687 N.mm⁻²). According to this, it can be said that adhesive is primarily effective in joining, and respectively type of joining and wood type are effective. Also, it can be said that the best diagonal tensile strength is obtained in the wood types which are fastened by PVAc adhesive at 78° with dovetail joint. Accordingly, in terms of diagonal tensile strength, it has been found important to use 78 ° tooth angle in the dovetail joint and PVAc adhesive which will be applied in the front leg-to-rail joint manufacturing for chair, armchair and similar furniture which will be manufactured from massive wood.

References

- Altınok M. (1998): Masa yapımında uygulanan sütun ayaklarda konstrüksiyon modellemesi,” GÜ Politeknik Dergisi 1/1-2: 105-109
- Atar M. (2007): PVAc tutkalında viskozite değişiminin bazı ağaç malzemelerde yapışma direncine etkileri, GÜ Politeknik Dergisi 10/1: 85-91
- Atar M., Keskin H., Yavuzcan G.H. (2008): Impacts of Adhesive Processing with Poly(vinyl acetate) and Desmodur-VTKA on the Shear Strength of Dovetail Joint, COST E 34, Bonding of Timber, Hungary Sopron
- Efe H., İmirzi, H.O. (2001): Çerçeve Konstrüksiyonlu Masif Mobilya T Birleştirmelerde Çekme Dirençleri Karşılaştırmaları”, GÜTEF Politeknik Dergisi 4: 95-101
- Efe H., Kasal A. (2000): Tabla tipi kavelalı köşe birleştirmelerde tutkal çeşidinin çekme direncine etkileri, GÜTEF Politeknik Dergisi 3: 67-72
- Eren S., Eckelman C. (1998): Edge Breaking Strength of Wood Composites, Holz Als Roh- Und Werkstoff Springer Verlag 56: 115-120
- Demirel E. (2008): Kutu tipi mobilya konstrüksiyonlarının köşe birleştirmelerinde kullanılan farklı birleştirme, tutkal ve malzeme türlerinin birleştirme mukavemetine etkileri, Yüksek Lisans Tezi, ZKÜ Fen Bilimleri Enstitüsü, Bartın
- Gode F. (2005): Ahşap çekmece köşe birleştirme performansının belirlenmesi, Yüksek Lisans Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara
- Güneş M. (2006): Mobilya çekmece köşe birleştirmelerinde diyagonal çekme performanslarının karşılaştırılması, Yüksek Lisans Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara
- Ustundağ A. (2008): Mobilya dişli köşe birleştirmelerinde diş açısının diyagonal basma ve çekme performansına etkileri, Yüksek Lisans Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara

- Tankut A.N. (2004): Effect of some factors on the strength of furniture corner joints constructed wood biscuits. *Tübitak Turk J. Agric. Forestry* 28: 301-309
- Tas H.H., Kodal S., Altinok M., Serin G., Fenkli M. (2007): Kaplamalı orta yoğunluklu lif levhada (MDF) köşe birleştirme titotoothin ve tutkal çeşidinin diyagonal basma ve çekme direncine etkisi, *Yapı Teknolojileri Elektronik Dergisi* 1: 7-14
- TS 2470 (1976): Odunda fiziksel ve mekaniksel deneyler için numune alma metotları ve genel özellikleri, TSE, Ankara
- Ors Y., Atar M., Ozçifçi A. (1999): Kenarları masifli ve masifsiz MDF levhalarında kavela çaplarının çekme direncine etkileri. *P.Ü. Mühendislik Bilimleri Dergisi* 5/23:1173-1177
- Ors, Y., Atar M., Ozçifçi, A. (1999): Farklı ağaç türleri ile YL ve Liflevhalarda PVAc veya D-VTKA tutkalı kullanılarak uygulanan kavelalarda çekme mukavemeti,” *Tr.J.Of Agriculture and Forestry* 23/1: 151-156
- Ors Y., Atar M., Ozçifçi A. (2000): Etiket yongalı levha (WFB) kenarına uygulanan farklı ölçülerdeki masif kalınlıkları ve kavela çaplarının çekme direncine etkileri. *GÜ Fen Bilimleri Enstitüsü Dergisi* 13/1: 15-22

Corresponding author:

M. Acar

Muğla Sıtkı Koçman University, Faculty of Technology, Department of Woodworking Industrial Engineering, Muğla / Turkey

macar@mu.edu.tr

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

THE LINEAR RELATIONSHIP BETWEEN FIBRE MORPHOLOGICAL CHARACTERISTICS OF *ENTANDROPHRAGMA CYLINDRICUM* AND THE STRENGTH OF ITS MORTISE-TENON JOINT

Kwadwo Boakye BOADU¹, Charles ANTWI-BOASIAKO¹

¹Kwame Nkrumah University of Science and Technology, Faculty of Renewable Natural Resources, Department of Wood Science and Technology, Kumasi / Ghana

Key words	Abstract
<i>Adhesive, Fibre diameter, Furniture, Joinery, Joint strength, Structural products.</i>	Fibre properties influence wood strength. However, information on the fibre morphological characteristics, which have the greatest effect on wooden furniture joint strength, is scanty. The relationship [using the Pearson Product-Moment Correlation Coefficient (r)] between the fibre characteristics of the sapwood and heartwood of <i>Entandrophragma cylindricum</i> and the strength of their mortise-tenon joints was studied in order to guide furniture manufacturers on the selection of timber for strong joints. For both the heartwood and sapwood of <i>E. cylindricum</i> , fibre diameter had the greatest positive influence on joint strength [i.e., r = 0.996 (heartwood); 0.994 (sapwood)] followed by fibre double wall thickness (r = 0.990 and 0.993 respectively) and fibre length (r = 0.968 and 0.992 respectively). Fibre lumen diameter negatively correlated with joint strength [r = -0.987 (heartwood); -0.978 (sapwood)]. For strong mortise-tenon joints, wooden furniture producers should consider timbers with large fibre diameters with small lumen.

Corresponding author: kbboadu.canr@knust.edu.gh, Kwame Nkrumah University of Science and Technology, Faculty of Renewable Natural Resources, Department of Wood Science and Technology, Kumasi / Ghana

1. INTRODUCTION

Wooden furniture is held together by joints. Proulx (1996) explained that the strength and durability of furniture lies in the structural integrity of its joints. Several factors are responsible for the strength of joints. These include their geometry, properties of the timber and type of adhesive used. Boadu and Antwi-Boasiako (2017) found that the geometry of dovetail joints improved their grain-to-grain surface connection in furniture products, offering these products with greater resistance to bending forces and warping than mortise-tenon joints. They further observed that working chairs produced with mortise-tenon and dovetail joints, which had longer, wider and thicker tails and tenons were stronger than those manufactured with shorter, narrower and thinner tails and tenons. Kiaei and Samariha (2011) noted that the anatomical, physical and mechanical properties of timber are the main influencers of the strength performance of wood in joints. They noted that furniture producers must have a better understanding of these properties to be able to select the right kind of timber for joint construction.

The influence of the mechanical properties of wood on joint strength has been extensively studied. For instance, Haviarova *et al.* (2013) found that the differences in the shear strength and Modulus of Elasticity (MOE) among timbers is partly responsible for variations in the

strength of the joints they produced. Boadu and Antwi-Boasiako (2017) found that joints from *Klainedoxa gabonensis*, a lesser-utilized tropical species, was stronger than those from *Entandrophragma cylindricum* due to differences in their shear strength and MOE. Barboutis and Vassiliou (2008) also observed a strong relationship between the shear strength of *Castanea dentata* and the bending strength of its finger joints. Unlike the case of mechanical properties, studies on the relationship between joint strength and anatomical properties of wood are scanty. According to Uetimane and Ali (2011), mechanical properties of wood are dependent on its anatomical characteristics. They explained that wood anatomy affect the strength of timber joints by altering the density and strength properties of the wood. Therefore, a good analysis of the best wood species that must be employed for the production of strong furniture joints must be based also on knowledge of the timber's anatomy. Many authors, including Uetimane and Ali (2011) and Jeong (2013), have predicted several wood properties from their anatomical characteristics using correlation and regression equation models. Jeong (2013) observed that compression parallel to the grain, Modulus of Rupture, porosity and shrinkage among several other wood properties could be predicted from a combination of anatomical characteristics. Since the anatomy of wood is largely responsible for timber's mechanical properties, which has been proven to affect joint strength, a relationship between the wood anatomy and joints strength is expected. However, few or no literature provides this information. Thus, in situations where the anatomy of a particular timber is known but its mechanical properties cannot be readily determined due to unavailability of equipment, furniture manufacturers will find it difficult to predict the timbers joint performance from its anatomy.

Anatomically, hardwoods are composed of several distinct cell types namely vessels, fibres, parenchyma cells and wood rays. Fibres are the principal elements that are responsible for the strength of wood (Toong *et al.*, 2014). Ziemińska *et al.* (2015) explained that variations in wood density and strength between and within species is mainly driven by fibre wall and fibre lumen properties.

According to Myburg *et al.* (2013) fibre morphological characteristics are important determinant of the suitability of wood for structural construction. However, the characteristics of fibre play different roles towards the strength of timber. Therefore, although it is broadly understood that fibres are responsible for the strength of wood and consequently that of manufactured joints, the specific fibre morphological characteristics, which have the greatest influence for improving the strength of joints of wooden products are unknown. Using linear correlations, this study sought to investigate the aspect of fibres that have the greatest influence on the strength of joints produced from the heartwood and sapwood of *Entandrophragma cylindricum*, a widely utilized tropical timber for furniture construction. The knowledge will guide manufacturers in their choice of timber for furniture construction in order to reduce frequent breakdown of wooden furniture joints.

2. METHODS AND MATERIALS

SAMPLING OF *E. CYLINDRICUM*

E. cylindricum logs (30 – 40 years and 60 - 80cm diameter) were harvested from Bobiri Forest Reserve in the Ashanti Province of Ghana (Lat. 6° 39'S and 6° 44'N; Long. 1° 15'E and 1° 23'W) (Addae-Wireko, 2008). They were quarter-sawn into boards and further processed into the standard dimensions for the various tests from defect-free heartwood and sapwood samples.

DETERMINATION OF FIBRE MORPHOLOGICAL CHARACTERISTICS

Match-stick sized samples (about 10mm long) were fully immersed in 99.8% glacial acetic acid and 30% hydrogen peroxide (1:1) in heat-resistant test tubes and incubated at 65°C for maceration (International Association of Wood Anatomists, 1989). The macerates were thoroughly washed with distilled water. A small sample was put in glycerol on a glass slide, teased with a pin (International Association of Wood Anatomists, 1989) and protected with cover slips for viewing under the Micromaster Infinity Optics microscope (10x eye piece, objective lens and a measuring scale of 200µm). Photomicrographs of straight and unbroken fibres (Figure 1) were obtained under a set magnification (40x) and measuring scale (50µm). Their lengths, diameters, lumen diameter and double wall thicknesses were measured from a total of 300 fibres.

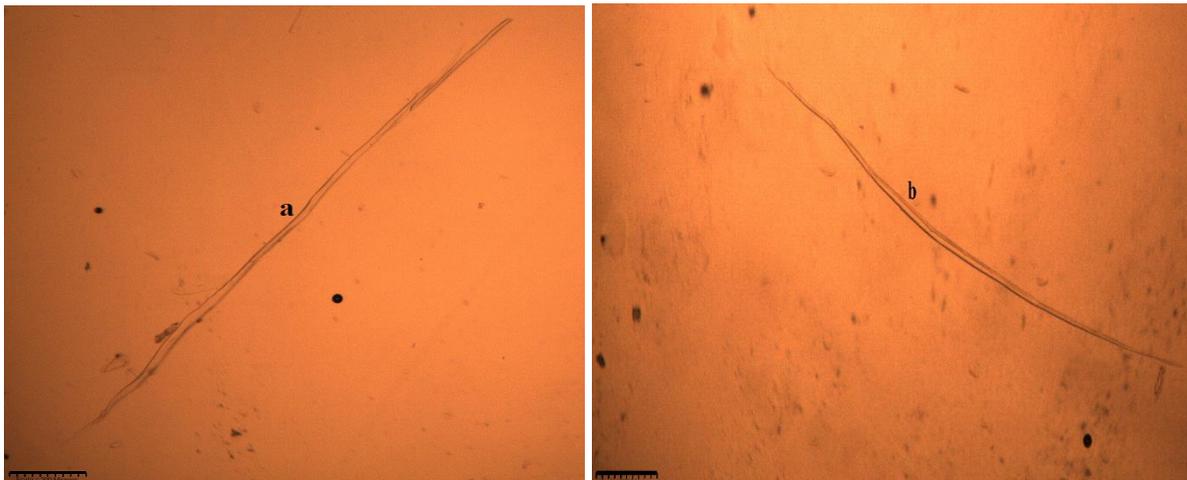


Figure 1. Fibres of *E. Cylindricum* heartwood (a) and sapwood (b).

DETERMINATION OF MORTISE-TENON JOINT STRENGTH

Straight-grained heartwood and sapwood of *E. Cylindricum* air-dried to 12% mc were planed and used to construct the leg (497.2x51x30 mm) and rail (355x64x30 mm) of a standard working chair. The positions of mortise (44x10x31.8 mm) and tenon (31.8x44x10 mm) on the respective leg and rail were marked and constructed. The joints were assembled using Fevicol SH synthetic adhesive (Tankut, 2007). Ten replicates of the joints were each made from the sapwood and heartwood of *E. Cylindricum*.

With a Universal Testing Machine, load was applied to the rail member of the joints (Figure 2) at a rate of 3 mm/sec. The maximum load (F) that caused rupture at the face of the joint was recorded and the ultimate strength of the joint (f)(Nm) calculated (Tankut, 2007):

$$f = F \times L \quad (1)$$

where:

L = distance between the point of application of the load and the face of the joint.

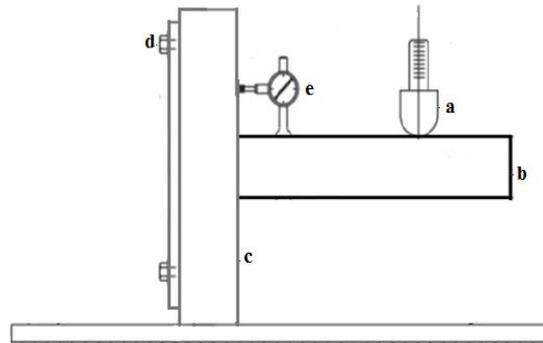


Figure 2. Schematic illustration of joint strength test [a – Machine cross head that applies the load; b - rail piece; c - leg piece; d - Aluminium alloy plate to hold the leg piece; e – dial gauge to measure deflection]

DETERMINATION OF THE RELATIONSHIP BETWEEN FIBRE MORPHOLOGICAL CHARACTERISTICS OF *E. CYLINDRICUM* AND MORTISE-TENON JOINT STRENGTH

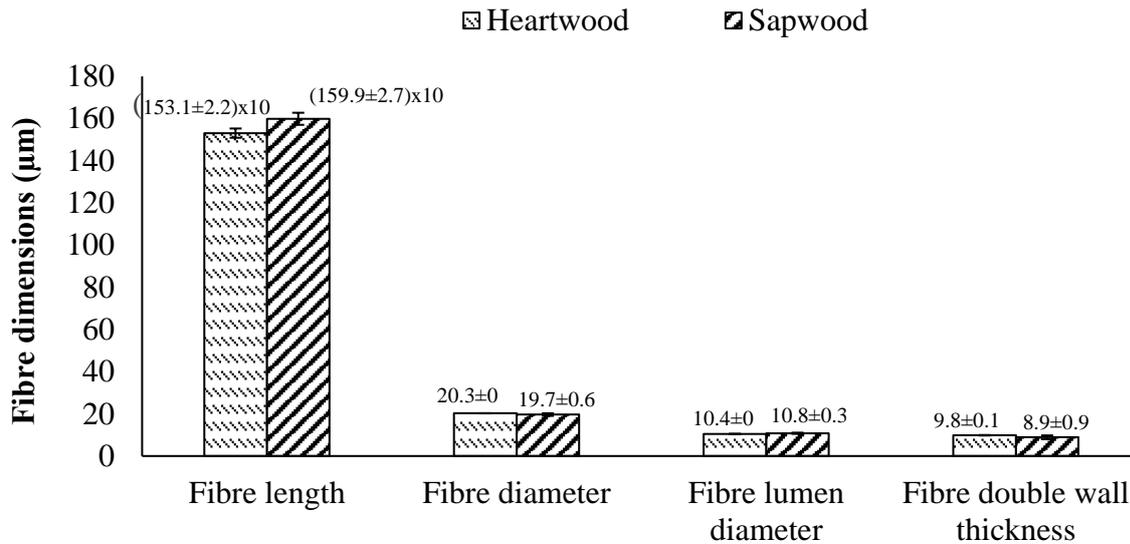
The relationships between the fibre characteristics of the sapwood and heartwood of *E. cylindricum* and the strength of their mortise-tenon joints were determined using the Pearson Product-Moment Correlation Coefficient (r). The Statistical Package for Social Scientists (SPSS) Software (version 20) was used to analyse the relationships through a stepwise Multiple Regression Method to generate Scatterplots that described the interaction at 95% confidence level.

3. RESULTS AND DISCUSSION

FIBRE MORPHOLOGICAL CHARACTERISTICS

Fibre dimensions for the heartwood of *E. cylindricum* [e.g. $20.3\mu\text{m}$ (fibre diameter); $9.8\pm 0.1\mu\text{m}$ (double wall thickness)] were greater than those of the sapwood [e.g. 19.7 ± 0.6 (fibre diameter); $8.9\pm 0.9\mu\text{m}$ (double wall thickness)], except for the lumen diameter. The differences were not significant ($p < 0.05$) (Figure 3).

The variations between the fibre characteristics of the sapwood and heartwood are consistent with the differences in fibre morphology from the pith towards the bark of *Casuarina equisetifolia* J.R. & G. Forst. by Chowdhury *et al.* (2012). Amoah *et al.* (2012) and Antwi-Boasiako and Apreko-Pilly (2016) explained that longer fibres in heartwood than those in the sapwood of tropical timbers could result from faster growth rate of the cambial initials during wood formation at the sapwood region, which results in shorter fibres. The greater wall thickness of fibres in the heartwood than sapwood would increase the density and strength of the former. Longer, wider and thicker fibres of the heartwood overlap each other better and appropriately transfer stress from one cell to the next, consequently increasing its load-bearing capacity than the shorter, narrower and thinner fibres of the sapwood (Sudin and Wahab, 2013). Martinez-Cabrera *et al.* (2009) noted that fibre lumen has a negative relationship with wood density; the wider the lumen, the less dense the timber and the lower its strength. Thus, the sapwood, which had wider fibre lumen would be lower in strength than the heartwood. Accordingly, the heartwood of *E. cylindricum* is more likely to give greater load-bearing capacity to wooden furniture than the sapwood.



Fibre characteristics

Figure 3. Fibre morphological characteristics of the heartwood and sapwood of *E. cylindricum* (Bars = Standard Error)

RELATIONSHIP BETWEEN FIBRE MORPHOLOGICAL CHARACTERISTICS OF *E. CYLINDRICUM* AND STRENGTH OF ITS MORTISE-TENON JOINTS

The mean bending strength recorded for joints made from the heartwood of *E. cylindricum* was 697.45 ± 22.5 N/mm² while that for the sapwood was 674.05 ± 47.09 N/mm². Boadu *et al.* (2017) explained that the strength of structures made from sapwoods are generally lower than those from heartwoods. This is due to differences in the anatomical characteristics between both stem positions. Grabner *et al.* (2005) also noted that the greater amount of extractives in heartwood than sapwood reduces pore spaces in the former, making it more compact and better able to resist bending. They found that the extractive content of the heartwood of *Larix* sp. directly enhanced its transverse compression strength and MOE than the sapwood. Yin *et al.* (2015) found greater mesopores in the sapwood than heartwood of Chinese fir (*Cunninghamia lanceolata*) due to deposition of extractives into the mesopores of the latter's cell wall during transformation from sapwood. Thus, heartwood of tropical timbers could better improve the strength of furniture joints than their sapwood counterparts.

Joint strength from both stem positions of *E. Cylindricum* correlated positively with the timber's fibre characteristics except with fibre lumen diameter, which showed a strong negative relationship (Figures 4-7; Table 1). Fibre diameter had the greatest linear association with joint strength [$r=0.996$ (heartwood); $r=0.994$ (sapwood)] followed by fibre double wall thickness ($r = 0.990$ and 0.993 respectively) and fibre length ($r = 0.968$ and 0.992 respectively). Uetimane and Ali (2011) noted that large diameter and thick-walled fibres generally have large sectional areas to support great amount of loads in structures. They observed that the fibre diameter of *Pseudolachnostylis maprounaefolia* had a positive relationship with its Modulus of Rupture ($r=0.527$) and Modulus of Elasticity ($r=0.530$), which are key mechanical properties that greatly determine the strength of wooden connections. Thus, fibre diameter and wall thickness likely influenced *E. cylindricum*'s mechanical properties, which produced joints with great strength. As stated earlier, increasing fraction of lumen diameter reduces the density and strength of wood and consequently manufactured joints. It was therefore not surprising to record a negative relationship between joint strength and fibre lumen diameter. Since fibre diameter and wall

thickness were the characteristics that influenced the timbers' joint performance most, they should be given keen attention in the selection of wood for joint construction. Generally, there was a stronger relationship between joint strength and the fibre characteristics of the heartwood than for those of the sapwood. This could be due to the greater fibre dimensions of the heartwood than the sapwood. Thus, heartwoods would better improve the strength of wooden connections in furniture construction than the sapwood.

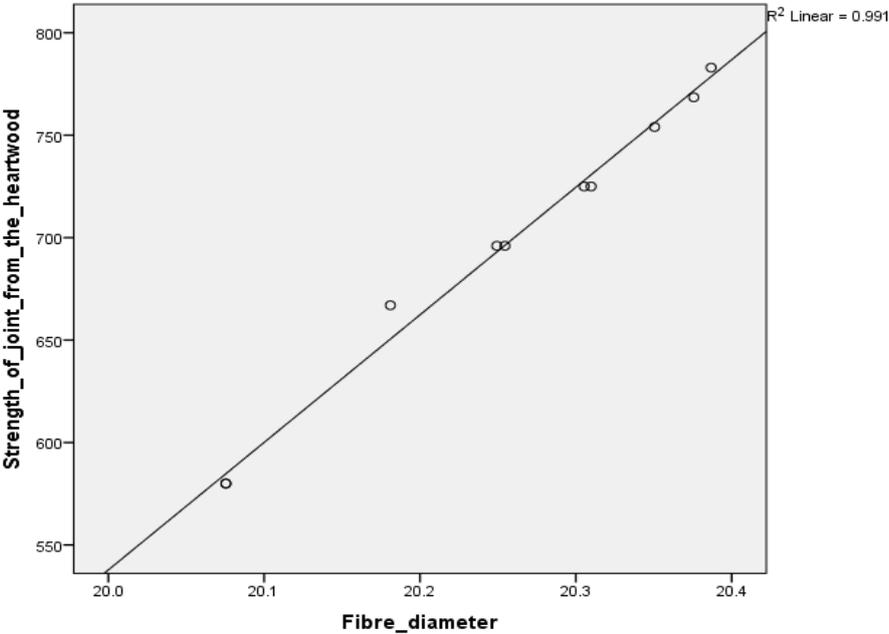


Figure 4. Correlation between fibre diameter and strength of joint from *E. cylindricum* heartwood

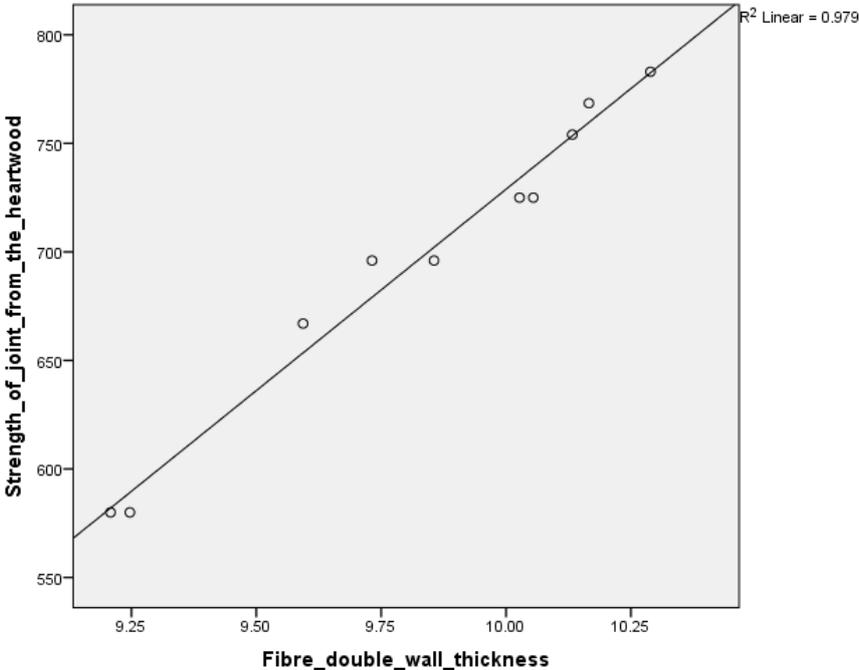


Figure 5. Correlation between fibre double wall thickness and strength of joint from *E. cylindricum* heartwood

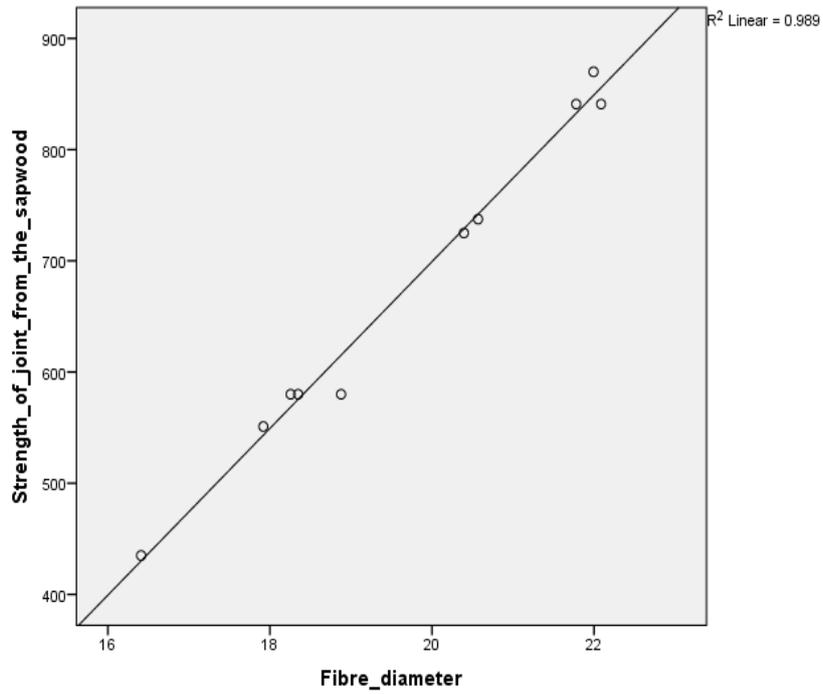


Figure 6. Correlation between fibre diameter and strength of joint from *E. cylindricum* sapwood

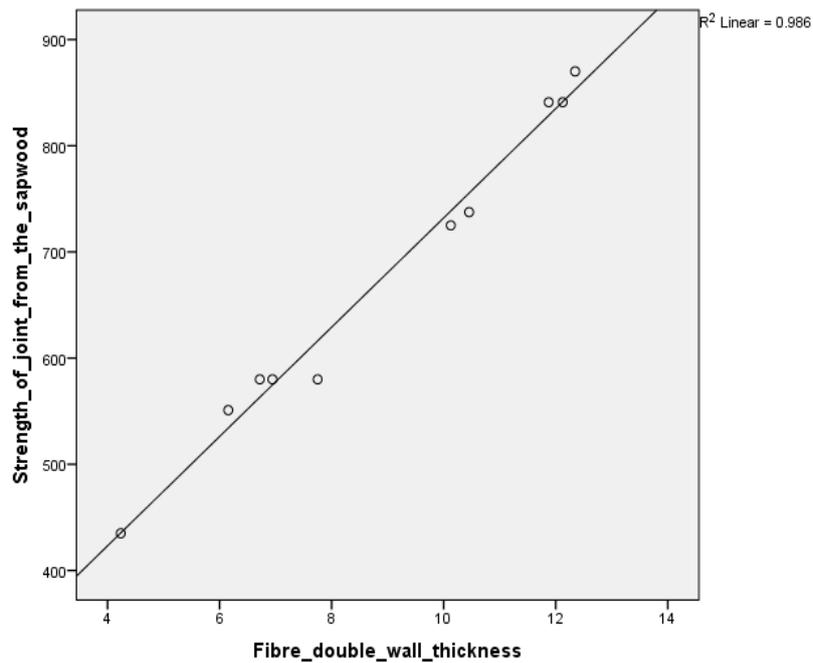


Figure 7. Correlation between fibre double wall thickness and strength of joint from *E. cylindricum* sapwood

Table 1. Linear correlation between fibre characteristics and strength of joint from the heartwood and sapwood of *E. cylindricum*

	Fibre characteristics	Correlation Coefficient (r)
	Fibre diameter	0.996

Strength of joints from the heartwood	Fibre wall thickness	0.990
	Fibre lumen diameter	-0.987
	Fibre length	0.968
Strength of joints from the sapwood	Fibre diameter	0.994
	Fibre wall thickness	0.993
	Fibre lumen diameter	-0.978
	Fibre length	0.992

4. CONCLUSIONS

The mean bending strength of joints made from the heartwood of *E. cylindricum* was greater than that for the sapwood. Accordingly, there was a stronger relationship between joint strength and the fibre characteristics of the heartwood than for those of the sapwood. Therefore, heartwoods could improve the strength of wooden connections in furniture construction better than sapwoods. Fibre diameter and wall thickness influenced *E. cylindricum*'s joint performance most and should be keenly considered in choosing wood for joint construction.

References

- Addae-Wireko L. (2008) Mapping distribution of butterflies in Central Bobiri Forest and investigation of logging and stage of regeneration on butterfly species richness and diversity Reserve. Thesis (MSc). International Institute for Geo-information Science and Earth Observatiuon (The Netherland) and Kwame Nkrumah University of Science and Technology (Ghana)
- Antwi-Boasiako C., Apreko-Pilly S. (2016): Tissue dimensions and proportions of the stem and branch woods of *Aningeria robusta* (A. Chev) and *Terminalia ivorensis* (A. Chev). *African Journal of Wood Science and Forestry*, 4(8): 254-273.
- Barboutis O., Vassiliou V. (2008): Bondability of Chestnut wood with PVAC adhesives for furniture production. *Proceedings 7th International Symposium*. June 18-19, Zvolen, Slovakia.
- Boadu K. B., Antwi-Boasiako C. (2017): Assessment of the bending strength of mortise-tenon and dovetail joints in leg-and-rail construction using *Klainedoxa gabonensis* Pierre Ex Engl. and *Entandrophragma cylindricum* (Sprague) Sprague. *Wood Material Science & Engineering*, 12(4): 242-250.
- Chowdhury Md Q., Ishiguri F., Hiraiwa T., Matsumoto K., Takashima Y., Iizuka K., Yokota S. and Yoshizawa, N. (2012) Variation in anatomical properties and correlations with wood density and compressive strength in *Casuarina equisetifolia* growing in Bangladesh. *Australian Forestry*, 75(2):95–99.
- Grabner M., Müller U., Gierlinger N., Wimmer R. (2005): Effects of heartwood extractives on mechanical properties of larch. *IAWA Bull*, 26 (2): 211-220.
- Haviarova E., Kasal A., Efe H., Eckelman C. A., Erdil, Y. Z. (2013): Effect of adhesive type and tenon size on bending moment capacity and rigidity of T-shaped furniture joints constructed of Turkish Beech and Scots Pine. *Wood and Fiber Science*, 45 (3): 1–7.
- International Association of Wood Anatomists (IAWA) (1989) List of microscopic features for hardwood identification. *IAWA Bulletin Leiden*.
- Jeong, G.Y. (2013): Relationship between anatomical and mechanical properties of Loblolly pine (*Pinus taeda*). *Forest Prod. J.* 63(1-2): 47-53.

- Kiaei M., Samariha A. (2011): Fiber dimensions, physical and mechanical properties of five important hardwood plants. *Indian Journal of Science and Technology* 4(11): 1460-1463.
- Myburg A. A, Lev- Yadun S., Sederoff R. R (2013) *Xylem Structure and Function*. In: eLS. John Wiley & Sons Ltd, Chichester. <http://www.els.net> [doi: 10.1002/9780470015902.a0001302.pub2]
- Proulx E. (1996): *Yankee Magazine's Make It Last: Over 1,000 Ingenious Ways to Extend the Life of Everything You Own*. Rodale Press, Incorporated, 5.
- Tankut, N. (2007): The effect of adhesive type and bond line thickness on the strength of mortise and tenon joints. *International Journal of Adhesion & Adhesives* 27: 493–498.
- Toong W., Ratnasingam J., Roslan M.K.M., Halis R. (2014): Wood anatomy and properties. *Bio Resources* 9 (3): 5184-5197.
- Uetimane Jr. E., Ali A. C. (2011): Relationship between mechanical properties and selected anatomical features of Ntholo (*Pseudolachnostylis maprounaefolia*). *Journal of Tropical Forest Science* 23(2): 166–176.
- Yin J., Song K., Lu Y., Zhao G., Yin Y. (2015): Comparison of changes in micropores and mesopores in the wood cell walls of sapwood and heartwood. *Wood Science and Technology* 49, Issue 5: 987–1001.
- Ziemińska A., Butler W. D., Gleason M. S., Wright I. J., Westoby M. (2013): Fibre wall and lumen fractions drive wood density variation across 24 Australian angiosperms. *AoB PLANTS*, 5: 1-13.

Corresponding author:

K. Boakye Boadu

Kwame Nkrumah University of Science and Technology, Faculty of Renewable Natural Resources, Department of Wood Science and Technology, Kumasi / Ghana
Kbboadu.canr@knust.edu.gh / patrendy2000@yahoo.com

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

DETERMINATION OF ALLOWABLE DESIGN LOADS FOR WOOD CHAIRS

Harun Diler¹, Hasan EFE², Yusuf Z. Erdil³, Tolga Kuşkun³, Ali Kasal³

¹Akdeniz University, Vocational School of Technical Science, Department of Materials and Material Processing Technology, Antalya, Turkey,

²Gazi University, Faculty of Technology, Department of Wood Science and Industrial Engineering, Ankara / Turkey

³Muğla Sıtkı Koçman University, Faculty of Technology, Department of Wood Science and Industrial Engineering, Muğla / Turkey

Key words

Abstract

*Allowable Design Loads,
Furniture Joints,
Frame Construction,
Structural Analysis.*

In this study, performances of wood chairs produced in Turkish furniture industry were determined, and numerical quantity was developed for categorization of chairs according to their performances. For this purpose, 21 different types of chairs were randomly obtained from Ankara, Kayseri, and Bursa markets that are considered to be the most important provinces of Turkish furniture industry. Chairs were tested according to ALA (American Library Association) specification that was developed for chair performance testing. Totally, 315 chairs including 21 different models with 3 different loading directions and 5 replications for each chair were tested. Obtained numerical database has been statistically analyzed and then classified according to their performances. As a result, acceptable light, medium and heavy design load values were determined for wood chair performances and these values are agree with the allowable design loads that were mentioned in ALA standards.

Corresponding author: alikalas@mu.edu.tr Kasal A., Muğla Sıtkı Koçman University, Faculty of Technology, Department of Wood Science and Industrial Engineering, Muğla / Turkey

1. INTRODUCTION

In Turkey and many European countries, no studies have been made or design loads have been identified with respect to the loads required to carry by furniture, specially the chairs according to their usage. The lack of a related database and the failure to implement performance testing methods and product engineering methodologies in R&D units of manufacturing companies, result in the appearance of products that display very different performance values, even though they are produced to serve the same purpose.

The cyclic stepped increasing test method appears best suited for use in chair performance tests. This method involves an interaction between “initial starting load”, “load increment”, “load cycles at each load level” and “total load cycles” (ALA 1982, Eckelman 1988).

In this method, a given load is applied to the furniture at a given cyclic rate for a specified number of cycles. After the prescribed number of cycles completed, the load level is increased

by a given increment, and the procedure is repeated. This process is continued until a desired load level has been reached, or until the furniture fails (Eckelman 1988).

Mortise and tenon joints are commonly used in the construction of chairs. Numerous studies have been carried out to relate the strength of these joints to their geometry and the adhesives used in their construction. Furniture constructed with a round mortise and a tenon joint is highly resistant to cyclic loading (Haviarova et al. 2001).

The strengths of school chairs constructed with pinned but unglued round mortise and tenon joints were compared with the strength of chairs with glued but unpinned joints by Eckelman and Haviarova (2006). The results indicated that chairs constructed with round mortise and tenon joints with small cross pins provide nearly the same strength and durability as comparable chairs constructed with glued joints; therefore, cross-pinning is an alternative method of joint construction when adhesives are in short supply.

It has been revealed that the chairs produced to serve the same function in Turkey, in other words home-use chairs, have a huge variation of performance differences in terms of strength properties, and a great instability between manufacturers and models has clearly emerged. It is believed that the reason of this situation depends on the lack of R&D culture of manufacturers or lack of knowledge/non-implementation of performance testing methods (Diler, 2013).

The main aim of this study is to obtain numerical data about the mechanical performance values of some chair models produced of Turkish beech wood for inhouse use by the companies operating in various cities in Turkish Furniture Industry and to classify chair types in terms of strength and consequently the determination of acceptable design loads for low, medium and high strength groups for the chairs produced in Turkey.

No work or any standards exists for acceptable design loads for chairs produced in Turkey. For this reason, producers do not have an idea of the strength of the chairs they produce. In other words, it is uncertain whether the manufactured chairs will be suitable for the purpose of use or they meet the possible loads that they may face depending on the mode of use.

2. METHODS AND MATERIALS

CHAIR MODELS USED IN THE STUDY

Numerical data of the strength properties of 21 different models of household chairs which were obtained from companies located in 3 different cities where Furniture Industry is at the forefront in Turkey. A total of 315 tests were performed on 21 different types of chairs with 3 different loading styles and 5 replications from each model chair and the data was obtained. The reason why all of the selected chairs have been produced from first class Turkish beech wood (*Fagus Orientalis Lipsky*) is the breadth of their spread in our country and their widespread use in the furniture industry. Chairs were chosen completely randomly from the market.

14 of the supplied chair types were joined together with adhesive and polyvinylsilate (PVAc) was used at the joints. The 7 types of chairs supplied are demountable and mechanical joints (socket screws) are used at the joints. A total of 21 types of chairs selected as 7 models each from Ankara, Bursa and Kayseri were randomly coded and the pictures of each model are given in Figure 3.

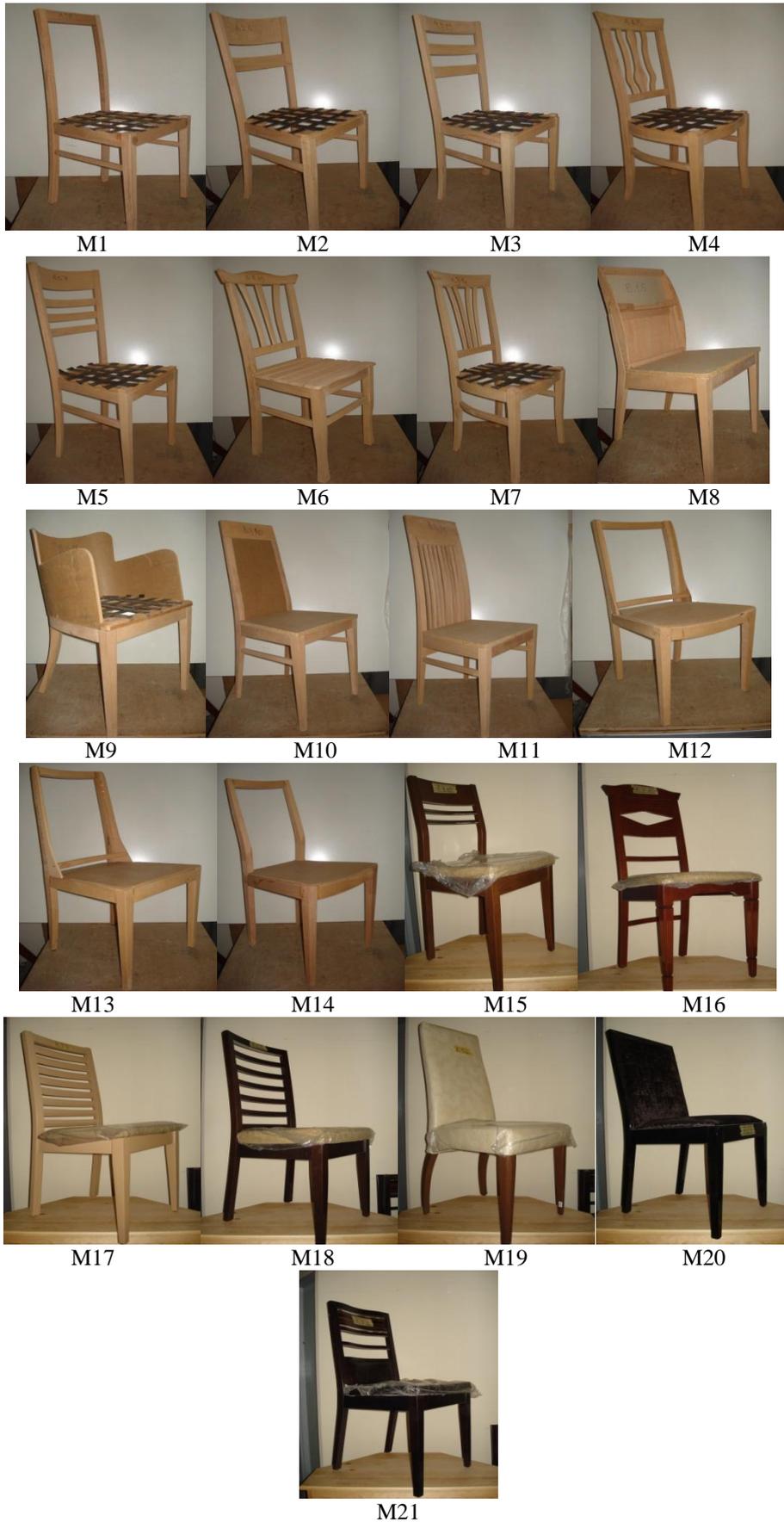


Figure 3. Within the scope of the study, 21 model samples supplied from the market

LOADING METHOD

The experimental method used in the study was developed by Carl Albert Eckelman in the Wood Research Laboratory of Forestry and Natural Resources, Purdue University in 1977 and was adopted in 1980 with the code FNAE 80-214 (Eckelman and Erdil, 2001a) as the Federal Standard. This standard has been used since 1980 in the performance tests of various types of seating furniture. This federal standard was re-revised by Eckelman and Erdil in 2001 and its technical drawings were updated to make it more visual and understandable and made available to use by publishing it with the code Fnr-176.

In the methodology of this test system, the "cyclic stepped increasing load" method is used, which represents the actual usage conditions of the chairs, in other words, rational application of the loading actions of the users. This method well simulates the performance that any product can struggle against the possible challenges encountered over the course of their life, by determining the first intersection point of their life curve and the effects of the coercive forces. Figure1) (Eckelman ve Erdil, 2001b).

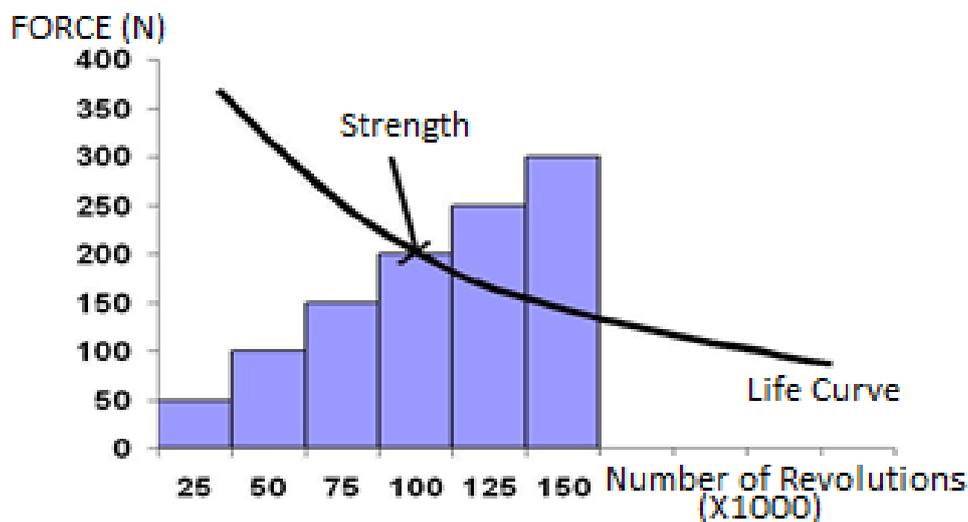


Figure1. The first intersection point with the cyclic loading method and the life curve

In the cyclic stepped increasing loading method, a predetermined load value for each performance test is applied to the furniture system at a certain speed and rate. When this step is completed, the first step is repeated by increasing the load value again in a predetermined range. These processes are continued until the acceptable design load values are reached or the deformities such as any opening, breakage, etc. in the furniture occur. The number of revolutions per step is 25000 and the speed is 20 rpm. This performance value is then evaluated for durability and necessary optimizations could be done by comparing to acceptable design load values predetermined in the standards for light, medium and heavy use (Eckelman ve Erdil, 2001b).

In this test method, "light use" refers to the use of indoor and private spaces, "moderate use" refers to use in places such as offices which are not very intensive, "heavy use" refers to use in hospitals, schools, libraries (Eckelman ve Erdil, 2001b).

STATISTICAL METHOD FOR CLASSIFICATION OF THE STRENGTH VALUES

In this study, the performance values obtained according to each loading direction were classified. For the sample group selected to represent the Turkey, a classification study was conducted for a total of 105 seats performance values, consist of 21 types tested by front loading and 5 replications from each type.

In this approach, the average of the data obtained for each loading direction is distributed as normal distribution and the group of 34%, containing a standard deviation and which are below the arithmetic mean value are considered as "weakly resistant" and the group of 34%, containing a standard deviation and which are above the arithmetic mean value are considered as "medium resistant". The group of 14% which are out of above range were considered as "inadequate" and 14% were considered as "highly resistant".

It is assumed that for each loading group at this stage the data show a regular distribution. This distribution and classification is shown in Figure 2.

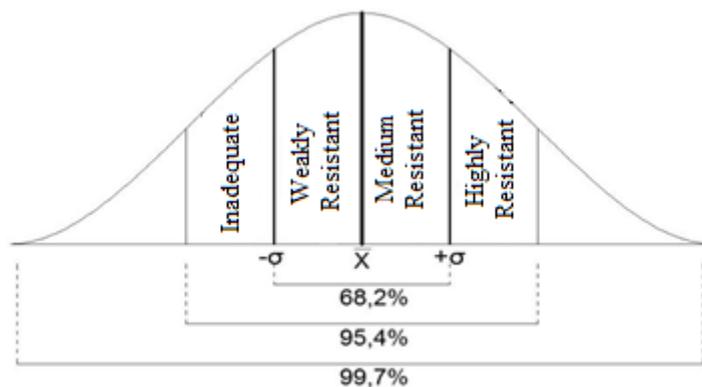


Figure 2. Regular distribution and classification

3. RESULTS AND DISCUSSION

SOME TECHNICAL PROPERTIES OF THE WOOD MATERIALS

The statistical data of the physical and mechanical properties of wood products used in the production of chairs are given in Table 1.

Table 1. Statistical values of some physical and mechanical properties of Turkish beech wood which determined after the experiments

Turkish Beech	X_{\min}	X_{\max}	X_{ort}	v (%)
Moisture content (%)	7,59	9,32	8,45	6,99
Density ($\rho \approx \%8$) (gr/cm^3)	0,64	0,73	0,68	8,12
Tension strength parallel to grain (N/mm^2)	98,32	121,84	110,08	6,24
Compression strength parallel to grain (N/mm^2)	55,68	65,49	60,58	5,22
Shear strength (N/mm^2)	15,12	17,65	16,38	3,26
Bending strength (N/mm^2)	109,00	152,00	130,00	11,71
Modulus of Elasticity (N/mm^2)	11063	15082	13072,5	12,23

X_{\min} : min. value X_{\max} :max value X_{ort} : Average Value v: Variation coefficient

CLASSIFICATION RESULTS OF FRONT TO BACK TESTS

In the classification for front-back loading test results, the results of the statistics according to the method that the data are considered to be regular distribution are given in Table 2.

Table 2. Statistical data obtained from front to back loading results

Average (N)	Standard deviation	Variation coefficient (%)	Average + Standard Deviation (N)	Average - Standard Deviation (N)
1449,8	517,7	35,7	1967,5	932,1

Accordingly, the mean of the group was 1449.8 N and the standard deviation was 517.7. The variation coefficient of the group is 35.7%. The high coefficient of variation shows once again the instability between performance values.

With the help of these data, 1450 N, the average value for the classification according to the new approach, is the lower limit value for the medium strength group of the chair models and 1968 N which is above the standard deviation is determined as upper limit. In other words, chair types which are among the values of 1450 to 1968 N for front-to-back performance values were accepted as "medium-strength" groups and evaluated as suitable for inhouse use. The 932N value which is below the mean value, was the lower limit for weak strength chair models. Accordingly, chair models between 932 and 1449 N for front-to-back performance values are considered as "weakly resistant" groups and are considered to need strength improvement optimizations. Chair types that perform above 1968 N, the upper limit of medium strength chairs, can easily be regarded as suitable types for inhouse use, as well as heavier uses such as libraries, restaurants.

The classification results determined according to the performances of the chair models are summarized in Table 3.

Table 3. Classification results based on front-to-rear loading results

Loading	Inadequate Strength	Weak Strength	Medium Strength	High Strength
front-to-rear loading	≤ 931 N	932 – 1449 N	1450 – 1968 N	≥ 1969 N

The chart showing the evaluation of chair models for the classification made is shown in Figure 13.

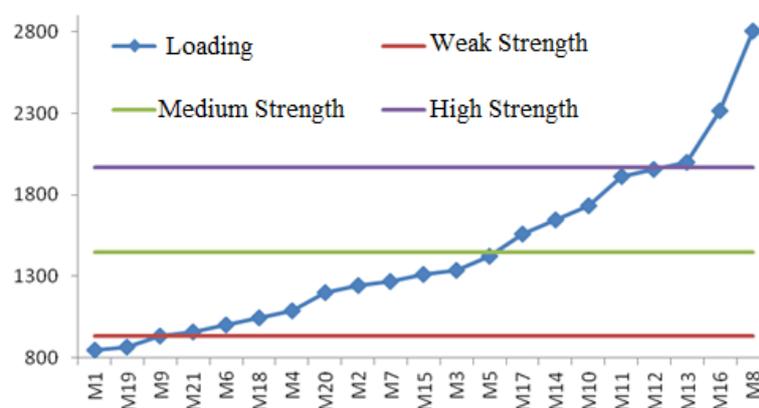


Figure 13. Front-to-back loading performances of chair types

According to this, 13 chairs of the 21 were tested, that is to say 62%, were below the medium strength group, and although they were produced for inhouse use, they were regarded as unable to fulfill these conditions of usage. According to classification of the chair models, 2 models

are defined as inadequate strength, 11 as low strength, 5 as medium strength and 3 as high strength. It could be defined that the serious strength improvement optimizations are required for the 13 models remaining under the medium strength group, and the three high strength models are much stronger than necessary for inhouse use conditions. Briefly, in this group, the number of types suitable for inhouse use in front-to-back loading conditions was only 5. Inadequate ones of other types are faced with technical problems such as the need of strength improvements or extreme strength models are faced with aesthetic and economic problems. These problems should be solved by engineering design approach.

CLASSIFICATION RESULTS OF BACK TO FRONT TESTS

Table 4 shows the results of the statistics of the classification of back to front performance values.

Table 4. Results of statistical data obtained from back to front loading

Average (N)	Standard deviation	Variation coefficient (%)	Average + Standard Deviation (N)	Average - Standard Deviation (N)
895,9	271,2	30,2	1167,1	624,7

Accordingly, the group average was calculated as 895.9 N and the standard deviation was 271.2. The variation coefficient of the group is 30.2%.

With the help of these data, 896 N, the average value for the classification according to the new approach, is the lower limit value for the medium strength group of the chair models and 1167 N which is above the standard deviation is determined as upper limit. In other words, chair types which are among the values of 896 to 1167N for back-to-front performance values were accepted as "medium-strength" groups and evaluated as suitable for inhouse use. The 625N value which is below the mean value, was the lower limit for weak strength chair models. Accordingly, chair models between 625 and 895N for back-to-front performance values are considered as "weakly resistant" groups and are considered to need strength improvement optimizations. Chair types that perform above 1167 N, the upper limit of medium strength chairs, can easily be regarded as suitable types for inhouse use, as well as heavier uses such as libraries, restaurants.

Table 5 summarizes the classification results determined according to the performances of the chair models.

Table 5. Classification results based on back-to-front loading results

Loading	Inadequate Strength	Weak Strength	Medium Strength	High Strength
Back-to-Front loading	$\leq 624 \text{ N}$	625 – 895 N	896 – 1167 N	$\geq 1168 \text{ N}$

The chart showing the evaluation of the chair models for the classification made is shown in Figure 14.

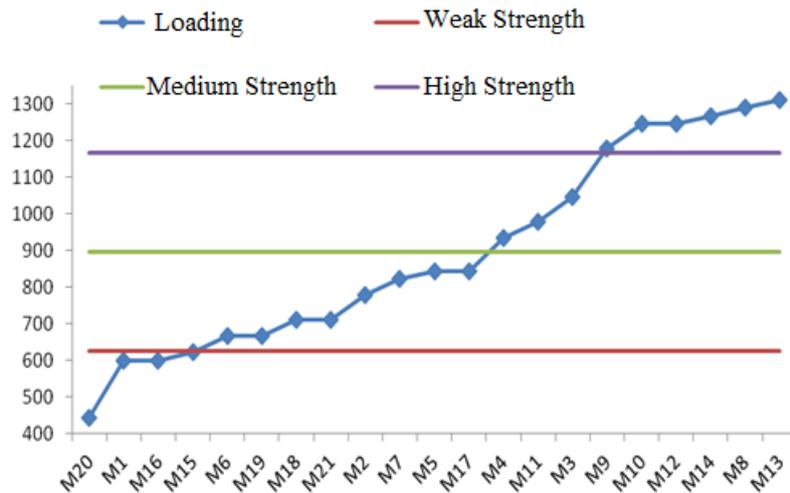


Figure 14. Back-to-Front loading performance of chair models

According to this, 12 chairs of the 21 were tested, that is to say 57%, were below the medium strength group, and although they were produced for inhouse use, they were regarded as unable to fulfill these conditions of usage. According to classification of the chair models, 4 models are defined as inadequate strength, 8 as low strength, 3 as medium strength and 6 as high strength. It could be defined that the serious strength improvement optimizations are required for the 12 models remaining under the medium strength group, and the 6 high strength models are much stronger than necessary for inhouse use conditions. Briefly, in this group, the number of types suitable for inhouse use in back-to-front loading conditions was only 3.

CLASSIFICATION RESULTS OF SIDETHRUST TESTS

The results for the lateral performance values of the chairs and the statistics according to the method considered as regular distribution of the data are given in Table 6.

Table 6. Statistical data obtained by lateral loading results

Average (N)	Standard deviation	Variation coefficient (%)	Average + Standard Deviation (N)	Average - Standard Deviation (N)
935,1	285,7	30,5	1220,8	649,4

Accordingly, the group average was calculated as 935.1 N and the standard deviation was 285.7. The variation coefficient of the group is 30,5%. The high coefficient of variation shows again the instability between performance values.

With the help of these data, 935 N, the average value for the classification according to the new approach, is the lower limit value for the medium strength group of the chair models and 1221 N which is above the standard deviation is determined as upper limit. In other words, chair types which are among the values of 935 to 1221N for lateral performance values were accepted as "medium-strength" groups and evaluated as suitable for inhouse use. The 649N value which is below the mean value, was the lower limit for weak strength chair models. Accordingly, chair models between 649 and 934N for lateral performance values are considered as "weakly resistant" groups and are considered to need strength improvement optimizations. Chair types

that perform above 1221 N, the upper limit of medium strength chairs, can easily be regarded as suitable types for inhouse use, as well as heavier uses such as libraries, restaurants.

For the first approach, the classification results determined according to the performance of the chair models are summarized in Table 7.

Table 7. Classification results according to lateral loading test results

Loading	Inadequate Strength	Weak Strength	Medium Strength	High Strength
Lateral Loading	≤ 648 N	649 – 934 N	935 – 1221 N	≥ 1222 N

The chart showing the evaluation of the chair models for the classification according to the new approach is shown in Figure 15.

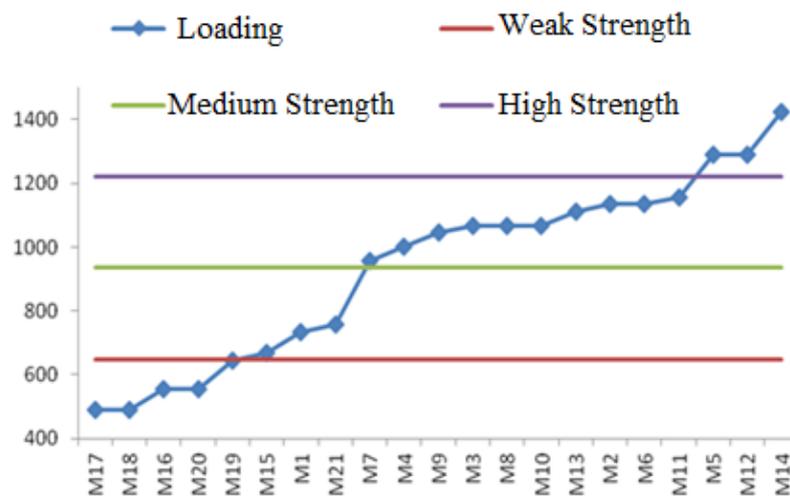


Figure 15. Lateral loading performances of chair models

According to this, 8 chairs of the 21 were tested, that is to say 38%, were below the medium strength group, and although they were produced for inhouse use, they were regarded as unable to fulfill these conditions of usage. According to classification of the chair models, 5 models are defined as inadequate strength, 3 as low strength, 10 as medium strength and 3 as high strength. It could be defined that the serious strength improvement optimizations are required for the 8 models remaining under the medium strength group, and the 3 high strength models are much stronger than necessary for inhouse use conditions. Briefly, in this group, the number of types suitable for inhouse use in lateral loading conditions was 10.

4. CONCLUSIONS

In this study, a sampling group was formed with the models obtained from the companies producing chairs in Turkey and the cyclic loading performances of the chairs in different loading directions were determined and classified in terms of strength. For this purpose, the

chair models supplied from the manufacturers operating in Ankara, Kayseri and Bursa (İnegöl), where chair production is concentrated, were taken into the scope of the study.

The most significant output of the study was the achievement of a significant numerical database with a significant number of performance test results of all chairs tested. Chairs gave performance values between 845 and 2802 N in front-to-back loads, between 445 and 1352 N in back-to-front loads, and between 489 and 1423 N in lateral loads. Judging from the results of the tests, it seems that there are great differences in strength between chair models.

The performance values obtained from the chair models are classified in terms of strength by applying various statistical methods. As a result, acceptable design loads for chair models produced in Turkey have been obtained. For the performance of the chairs produced in Turkey, it is determined for front to back load that; the ones between 932-1449N are in low strength, 1450-1968N are in medium strength (suitable for inhouse use), 1968 N and above are in high strength (suitable for hotel lobbies, restaurants, libraries etc.). For the back to front loads, it is determined that the ones between 932-1449N are in low strength, 1450-1968N are in medium strength (suitable for inhouse use), 1968 N and above are in high strength (suitable for hotel lobbies, restaurants, libraries etc.). The performance values for lateral loads are as follows; between 649-934 N are in weak strength, 935-1221 N are in medium strength and 1222 N and above are classified as high strength.

Converting the values obtained from this classification study into a national standard is important in order for the companies to design and optimize their chair models in terms of performance and damage conditions before they go into mass-production. The standardization, dissemination and presentation of such data to the service of companies will contribute to the production of better quality furniture, thus contributing to the increase in the consumer's life quality. In addition, economic benefits will be provided for producers.

References

- American Library Associations (ALA) (1982). "The use of performance tests and quality assurance programs in the selection of library chairs," *Library Technology- Reports* 18(5), 483-571.
- Diler, H., 2013, " Evaluation of The Strength Performance of Different Types of Household Chairs According to Engineering Design Concepts ", PhD Thesis, Gazi University, Institute of Science and Technology, 347p.
- Eckelman, C., A., "Performance Testing of Furniture. Part II. A Multipurpose Universal Structural Performance Test Method", *Forest Product Journal*, 38 (4): 13–18 (1988).
- Eckelman, C., and Haviarova, E. (2006). "Performance tests of school chairs constructed with round mortise and tenon joints," *Forest Products Journal* 56(3), 51-57.
WOS:000236292400010.
- Eckelman, C. A., Erdil, Y. Z., "General Services Administration Upholstered Furniture Test Method – FNAE 80 – 214 : A Description of the Method with Drawings", *Purdue University, Department of Forestry and Natural Resources, Extension Publication Fnr*, 176: 1159 (2001a).
- Eckelman, C. A., Erdil, Y. A., "Performance Test Method for Intensive Use Chairs-FNEW", *A Description of the Test Method with Drawings, FNR* 176, 83-269: 20 (2001b).

Haviarova, E., Eckelman, C., and Erdil, Y. Z. (2001). "Design and testing of wood school desk frames suitable for production by low technology methods from waste wood residues," Forest Products Journal 51(5), 79-88. WOS:000168740700011.

Corresponding author:

Kasal A.

Muğla Sıtkı Koçman University, Faculty of Technology, Department of Wood Science and Industrial Engineering, Muğla / Turkey

alikalas@mu.edu.tr

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

COMPARISON OF THE SCREW HOLDING CAPACITY OF SOLID WOOD AND LAMINATED VENEER LUMBER (LVL) PRODUCED FROM TURKISH BEECH (*Fagus Orientalis L.*), SCOTCH PINE (*Pinus Sylvestris L.*) AND YELLOW POPLAR (*Populus Nigra*)

Yusuf Ziya ERDİL¹, Mehmet ACAR¹, Ali KASAL¹, Taner DİZEL², Selçuk DEMİRÇİ³, Harun DİLER⁴

¹ Muğla Sıtkı Koçman University, Faculty of Technology, Department of Woodworking Industrial Engineering, Muğla / Turkey

² Pamukkale University, Denizli Vocational School of Technical Sciences, Denizli / Turkey

³ Ege University, Ege Vocational School of Technical Sciences, Department of Wood Science and Furniture Design, İzmir / Turkey

⁴ Akdeniz University, Department of Material and Material Process Techniques, Antalya / Turkey

Key words

Screw holding capacity, laminated veneer lumber (LVL), Solid wood.

Abstract

Tests were carried out to determine the screw holding capacity in parallel and perpendicular to grain direction of laminated veneer lumber (LVL) prepared of Turkish beech (*Fagus orientalis L.*), Scotch pine (*Pinus sylvestris L.*) and poplar (*Populus nigra*) veneers. Screw holding capacities of LVLs were also compared to the control specimens that constructed of solid wood of the same species. In producing the LVL specimens, polyvinylacetate (PVAc) and Ureaformaldehyde (UF) adhesives were utilized for laminating. Test results indicated that the influences of wood species on screw holding performance were found statistically significant. Furthermore, different glue types caused the differences in screw holding capacity of LVL specimens. In conclusion, the results from screw holding tests showed that in general, LVL had significantly lower screw holding strength than solid wood. Also, LVL of Beech, Pine and Poplar bonded with PVAc adhesive showed significantly higher screw holding than Beech, Pine and Poplar LVL with UF adhesive.

Corresponding author: erdil@mu.edu.tr Erdil Y., Muğla Sıtkı Koçman University, Faculty of Technology, Department of Woodworking Industrial Engineering, Muğla / Turkey

1. INTRODUCTION

Wood is becoming a more widely used material in wooden buildings and especially furniture manufacturing. But, increased demand for wood has caused a dramatic decrease in forest resources. With an increased demand for lumber worldwide, the amount of solid timber available has steadily declined. To meet this ever rising demand, it is crucial to use proper production techniques for the superlative yield. Composite materials manufactured from woods with different adhesives are being used increasingly in the construction of furniture frames and buildings.

Material made by parallel lamination of veneers into thicknesses common to solid sawn lumber is called Laminated Veneer Lumber (LVL). LVL has been developed as an alternative engineered wood product to solid wood (Aydın et. al. 2004). Another description for laminated

wood material has been given in TS EN 386 as a structural member that was made of wood fabricated from laminations of timber glued parallel to the longitudinal axis. Both softwoods and hardwoods are suitable for laminated structural members. The choice of species adhesive depends primarily on the cost, required strength, and demands of the application (USDA 1987).

LVL offers several advantages over typical milled lumber: it is stronger, straighter, and more uniform. It is much less likely than conventional lumber to warp, twist, bow, or shrink due to its composite nature. Made in a factory under controlled specifications, LVL products allow users to reduce the onsite labor. They are typically used for headers, beams, rim board, and edge-forming material.

The stability of any building system, composed of interconnected components, directly related to the performance of the fastening elements. The most widely used fastening elements that are found in the connections of solid wood materials are nails and screws. Especially, screws are commonly used in wooden structures and furniture construction, both as primary connectors and also to reinforce weaker joints for two to three hundred years. Their ability to resist both withdrawal and lateral loads makes screws excellent fasteners (Erdil 1998). Therefore, knowledge of the withdrawal strength of screws from wooden building elements will provide useful information about the durability and stability of the whole system. Besides, it is significant to have information about withdrawal strength of screws so as to achieve the efficient use of materials in the building systems.

Increasingly, manufacturers are using LVL in wooden buildings and furniture frame constructions. The rational product engineering of such constructions in which screws are used as structural fasteners requires that designers have realistic information of the screw withdrawal performance of LVL against to solid wood.

A considerable number of studies of the holding performance of screws in solid woods, particleboard, and medium density fiberboard (MDF) were conducted by the researchers. Eckelman (1974) tested seven different types of commercially available screws which were withdrawal strength from 12 mm thick particleboard specimens. The results of the test showed that there were almost no differences between the holding strengths of these screws. In a similar study, he investigated screw holding performance in selected hardwood and particleboard in order to evaluate design formulas that had previously been developed for predicting the holding performance of screws in such materials. Results of his research showed that shear strength parallel to grain is a better predictor of holding performance in solid wood than is specific gravity. Specific gravity is a good indicator for holding performance of screws in particleboard (Eckelman 1975). In another research, he studied type a pan head sheet metal screws. He tested the withdrawal performance of the screws on a wide range of hardwoods used in furniture construction. He concluded that the holding performance from side grain of the wood can reasonably be estimated by the equation:

$$F = 3.204D (L - D)^{.75} S_x \quad (1)$$

where:

F = holding performance,

D = screw diameter,

L = depth of penetration,

S_x = shear strength of the wood (Eckelman 1978).

Also, he indicated that holding performance of the sheet metal type of screws in the face of MDF could be estimated by means of the equation:

$$f = 39(IB)^{0.85}D^{0.5}(L - D/3)^{1.25} \quad (2)$$

where:

f = holding performance,

IB = internal bond strength,

D = diameter of the screw,

L = dept of embedment of the screw,

in the edge of the MDF could be estimated by the equation (Eckelman 1988) :

$$f = 18.4 (IB)^{0.85}D^{0.5}(L - D/3)^{1.25} \quad (3)$$

Özçifçi, evaluated the effects of screw type, pilot hole and layer thickness on the withdrawal strength of some screws in laminated veneer lumbers. According to the test results, it was found that the highest withdrawal strength was obtained in oak samples having 4 mm veneer thickness bonded with phenol-formaldehyde for 3.5 by16 screw as 23.14 MPa, the lowest was obtained for Uludag fir having 5 mm veneer thickness bonded with melamine-formaldehyde adhesive with 4 by 50 screw as 7.61 MPa. It was advised to use the proper size of pilot hole in order to avoid splitting of the face during insertion of screws as well as to obtain maximum withdrawal strength (Özçifçi 2009).

Although LVL panels with screw joints are widely used in the construction of the furniture frames, limited information is presented on screw holding performance of LVL panels. This study was carried out accordingly to determine the screw holding performance in parallel and perpendicular to grain direction of LVL constructed of three different wood species and two different glues.

2. METHODS AND MATERIALS

TEST MATERIALS

In this study, the wood species used were Turkish beech (*Fagus orientalis* L.), Scotch pine (*Pinus sylvestris* L.) and poplar (*Populus nigra*) which are widely used in the production of wooden buildings and furniture constructions. Wooden materials were randomly selected for this study from the timber industries in Turkey.

The screw (4 by 50 mm), having Turkish Standards TS 431 (TS 431, 2001) was used in this study. These screw were selected not only they are low-cost fasteners because they are readily available for the furniture industry, but also they have excellent holding strength in wood and wood based materials.

In producing the LVL specimens, polyvinylacetate (PVAc) and Ureaformaldehyde (UF) adhesives were utilized for laminating. TS 3891 standard procedure was used in application of PVAc adhesive. The density of PVAc was 1.1 g/cm³, the viscosity 16.000 ± 3.000 Mpa s, and pH value and ash ratio were 5 percent and 3 percent, respectively. A pressing time of 20 min for the cold process and 2 min and 80°C are recommended with 6–15 percent humidity for the joining process. After a hot-pressing process, the materials should be attended until its normal temperature is reached (TS 3891, 1983).

UF is shipped to engineered wood product plants as a colloidal aqueous solution with a solid content of about 65 percent. This liquid is odorless, slightly opaque, and, of course, not flammable. When shipped, the UF resin is already polymerized and cross-linked to a certain degree. Urea-formaldehyde reacts with a wooden cell wall hydroxyl. Adhesive is usually

applied on the surfaces 100–150 g /m². If cold press is applied at 20 °C, the period of press is 3-5 hours. In hot press, this period decreases to 3–5 *min* (Anon 1999).

LAMINATION PROCESS

All species of logs and veneers (2 mm thick) were obtained from commercial suppliers in Ankara, Turkey. Before the gluing process, veneers were kept in a controlled chamber until they reached about 12 percent moisture content (MC). Laminated specimens were produced from air - dry veneers (thickness 2 mm) according to TS EN 386 (TS EN 386, 2006). The adhesive was applied on single bonding surfaces of veneers at approximately 180 g/m² by using cylinder gluing device. After the gluing process, 11 layer veneers in 2 mm thick were pressed with the grain directions of all veneers being the same. Lamination process was done with Hydraulic veneer press machine, appropriate process of hot and cold press. The press conditions depending on the glue types are given in Table 1.

Table 1. The press conditions depending on the glue types.

Glue type	Press pressure (N/mm ²)	Press temperature (°C)	Press duration (min)
PVAc	0.8	20	120
UF	1.2	110	4

Before the tests, in order to eliminate moisture content variations, all specimens were stored into a controlled climate room which equilibrium moisture content (EMC) of 12 percent in the wood was maintained. Two different types of glue (PVAc and UF) were utilized for laminating the LVL specimens.

PLAN OF THE STUDY

Altogether, 36 sets of specimens consisting of 10 replications each, 3 wood species (Turkish beech, Scots pine and poplar), 3 material type (LVL: laminated veneer lumbers), 2 adhesive (PVAc and Urea-formaldehyde), and 2 direction (parallel to grain and perpendicular to grain) or a total of 360 specimens were prepared for screw holding tests.

TEST SPECIMENS AND TEST METHOD

Test samples (75 mm x 75 mm x 22 mm) were cut from the sapwood parts of solid woods and conditioned at a temperature of 20 ± 2°C and 65 ± 5 % relative humidity for three months until they reached equilibrium in moisture distribution. The determination process of moisture contents (MC) and densities of the wooden materials were performed according to the procedure of TS 2470, TS 2471, and TS 2472, respectively (TS 2470, TS 2471, and TS 2472 1976). Perpendicular to grain (a) and parallel to grain (b) test specimens are shown in Figure 1.

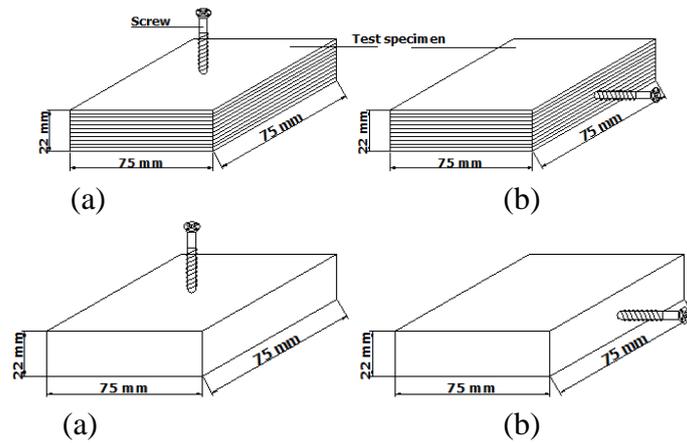


Figure 1. Diagram showing specimen with embedded to perpendicular to grain (a) and parallel to grain (b)

All of the tested were carried out on a 40 kN capacity Universal Test Machine. For the tests, the specimen-holding fixture was bolted down to the testing machine table and leveled to ensure withdrawal load direction parallel to screw penetration direction. The fixture allowed self-alignment of a joint specimen with the loading direction. Static load was applied for the tests. Rate of loading in both cases was 2 mm per minute. The loading was continued until a breakage or separation occurred in the specimens. In the tests, only the ultimate loads carried by the joints were recorded in Newton (N). Experiments mechanisms are shown in Figure 2.

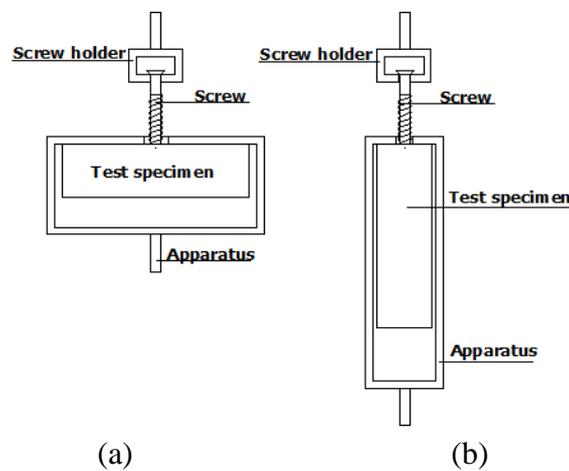


Figure 2. Test setups of screw withdrawal from face (a) and from edge (b)

3. RESULT AND DISCUSSION

Oven dry and air dry densities of specimens tested in this study are given in Table 2. The mean, average ultimate withdrawal strength values of tested joints with their coefficients of variation are given in Table 3.

Table 2. Moisture content and specific gravity values of the specimens.

Wood species	Material type	Test MC (%)	SG (Test MC)	SG (Oven dry)	SG (Air dry*)
Turkish Beech	Solid	7.54	0.65	0.63	0.66
	LVL - PVAc	7.05	0.66	0.65	0.68
	LVL - UF	8.45	0.68	0.64	0.67
Scotch Pine	Solid	8.49	0.48	0.46	0.49
	LVL - PVAc	8.09	0.56	0.54	0.57
	LVL - UF	8.93	0.60	0.57	0.60
Poplar	Solid	6.79	0.35	0.33	0.36
	LVL - PVAc	6.77	0.45	0.43	0.46
	LVL - UF	8.07	0.57	0.54	0.57

* Those values are adjusted based on the wood handbook (USDA, 1987). SG: Specific gravity

Table 3. Average ultimate withdrawal strength values of species with their coefficients of variation

Wood species	Material type	Parallel to grain		Perpendicular to grain	
		X (N)	COV (%)	X (N)	COV (%)
Turkish Beech	Solid	5184.59	11.58	3463.91	12.52
	LVL-PVAc	3741.53	16.32	2763.48	25.85
	LVL-UF	4070.17	11.03	2565.32	11.71
Scotch Pine	Solid	2974.39	13.03	1266.47	11.19
	LVL-PVAc	2747.78	17.43	1538.21	13.20
	LVL - UF	2578.07	16.06	1414.60	14.35
Poplar	Solid	1538.21	13.81	997.68	14.65
	LVL-PVAc	2580.03	9.627	1280.21	48.52
	LVL-UF	2168.01	28.79	1165.43	23.50

* COV: coefficients of variation.

Multiple variance analysis was performed on the data obtained from a total of 360 specimens for determining the effect of wood species, material type on the screw holding parallel to grain and perpendicular to grain. The results of the variance analysis are shown in Table 4.

Table 4. Summary of the ANOVA results for parallel to grain and perpendicular to grain tests.

Source	Degrees of freedom	Sum of squares	Mean squares	F value	Prob. (sig)
ANOVA for parallel to grain					
Wood species (A)	2	78740641.489	39370320.744	158.3847	0.0000
Material type (B)	2	1659921.489	829960.744	3.3389	0.0404
A x B	4	16766070.844	4191517.711	16.8623	0.0000
Error	81	20134493.300	248573.991		
Total	89	117301127.122			
ANOVA for perpendicular to grain					
Wood species (A)	2	55698617.867	27849308.933	182.4069	0.0000
Material type (B)	2	613332.867	306666.433	2.0086	NS
A x B	4	4616723.667	1154180.917	7.5596	0.0000
Error	81	12366825.200	152676.854		
Total	89	73295499.600			

NS: Not significant.

According to the results of this analysis, the effects of the main factors including wood species (*A*) and material type (*B*) were found to be statistically significant at the level of 0.05. Furthermore, two factor interactions of wood species x material type (*A x B*) were also statistically significant ($p \leq 0.05$). Therefore, the least significant difference (LSD) multiple comparisons procedure at 5 percent significance level were performed to determine the mean differences of screw holding values of tested specimens considering the effect of wood species, material type and wood species x material type interaction.

SCREW HOLDING CAPACITY PARALLEL TO GRAIN

Table 5 shows the mean separations for each wood species group. The highest screw holding strength was achieved in beech wood and the lowest was achieved in poplar wood. Screw holdings of Pine solid were significantly higher than ones of Poplar. This may be the result of this, beech wood has thick cell-wall, multi pore number, and little lumen and high material density where as poplar wood has thin cell-wall, big lumen and low material density.

Table 5. Results of mean comparisons of screw holding capacity parallel to grain for wood species

Wood species	Screw holding capacity (N)	
	X	HG
Turkish Beech	4315	A
Scotch Pine	2790	B
Poplar	2072	C

LSD value: 256.1 N

LSD: Least significant Difference

Table 6 shows the mean separations for each material type group. In general, solid wood showed significantly higher screw holding than LVL- PVAc and LVL - UF.

Table 6. Results of mean comparisons of screw holding capacity parallel to grain for material type

Material type	Screw holding capacity (N)	
	X	HG
Solid	3249	A
LVL-PVAc	2990	B
LVL-UF	2939	B

LSD value: 256.1 N

Table 7 shows the mean separations of material type for each wood species group. Within the Poplar, the screw holding of LVL bonded with PVAc was significantly higher than solid, while LVL with UF was significantly higher than solid screw holding. For the Pine, the screw holding of LVL with UF were significantly lower than solid, screw holding for LVL-PVAc and LVL-UF, respectively. For the Beech, LVLS were significantly lower than solid in screw holding, of solid for LVL-PVAc and LVL-UF, respectively.

Table 7. Results of mean comparisons of screw holding capacity parallel to grain for each level of wood species

Wood species	Material type	Screw holding capacity (N)	
		X	HG
Turkish Beech	Solid	5185	A
	LVL-PVAc	3692	B
	LVL-UF	4070	B
Scotch Pine	Solid	3045	C
	LVL-PVAc	2748	CD
	LVL-UF	2578	DE
Poplar	Solid	1518	F
	LVL-PVAc	2531	DE
	LVL-UF	2168	E

LSD value: 443.6 N

SCREW HOLDING CAPACITY PERPENDICULAR TO GRAIN

According to the effects of wood species the highest screw holding was achieved in solid beech wood because its early growth wood pores are great in number. The lowest was achieved in solid poplar wood because tracheids are great in number in poplar and they have wide diameter. Beech wood has higher specific gravity (0.63 g/cm^3) when compared with poplar wood (0.33 g/cm^3) and this can be another reason for this. As it's known the wood that has high density can endure effectively in nut's going in and out. Table 8 shows the mean separations for each wood species group.

Table 8. Results of mean comparisons of screw holding of capacity perpendicular to grain for wood species

Wood species	Screw holding capacity (N)	
	X	HG
Turkish Beech	2931	A
Scotch Pine	1407	B
Poplar	1148	C

LSD value: 200.7 N

According to the material type it was found that did not influence screw holding capacity. LSD test comparison results about wood species are given in Table 9.

Table 9. Results of mean comparisons screw holding of capacity perpendicular to grain for material type

Material type	Screw holding capacity (N)	
	X	HG
Solid	1909	A
LVL-PVAc	1861	A
LVL-UF	1715	A

LSD value: 200.7 N

Table 10 shows the mean separations of material type for each wood species group. Within the Beech, the screw holding of solid wood was significantly higher than LVL bonded with PVAc. For the Pine, the screw holding of solid were significantly lower than LVL-PVAc, screw

holding for LVL-UF and solid wood, respectively. Within the Poplar, the screw holding of LVL bonded with PVAc was significantly higher than solid, while LVL with UF was significantly higher than solid screw holding.

Table 10. Results of mean comparisons screw holding of capacity perpendicular to grain for material for each level of wood species

Wood species	Material type	Screw holding capacity (N)	
		X	HG
Turkish Beech	Solid	3464	A
	LVL-PVAc	2764	B
	LVL-UF	2565	B
Scotch Pine	Solid	1267	CDE
	LVL-PVAc	1538	C
	LVL-UF	1415	CD
Poplar	Solid	997.8	E
	LVL-PVAc	1280	CDE
	LVL-UF	1166	DE

LSD value: 347.7 N

According to the test result, success order according to screw holding sections, parallel to grain, perpendicular to grain. Wood rays hold the screw at parallel to grain. Early growth and autumn woods hold the screw circular at parallel to grain. Because of this screw holding is higher parallel to grain. Screw holding is lower since the screw is along the grain at perpendicular to grain.

According to the test results, the values of screw holding strength comparison are given in Figure 3 to Figure 5 for each wood species, material type and wood species-material type on the parallel to grain and perpendicular to grain.

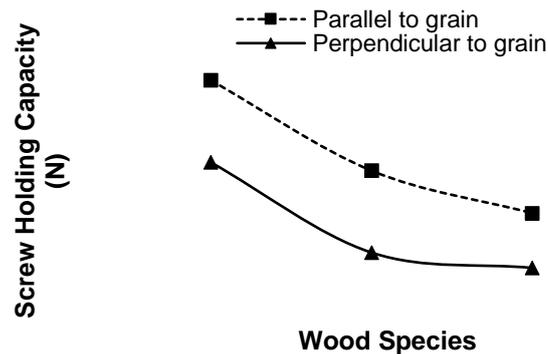


Figure 3. Results of mean comparisons of screw holding capacity for wood species

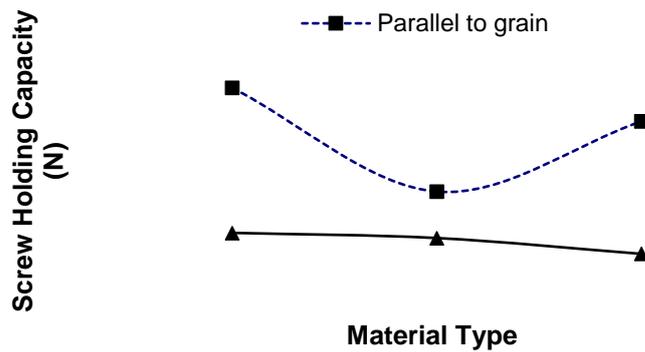


Figure 4. Results of mean comparisons of screw holding capacity for material type

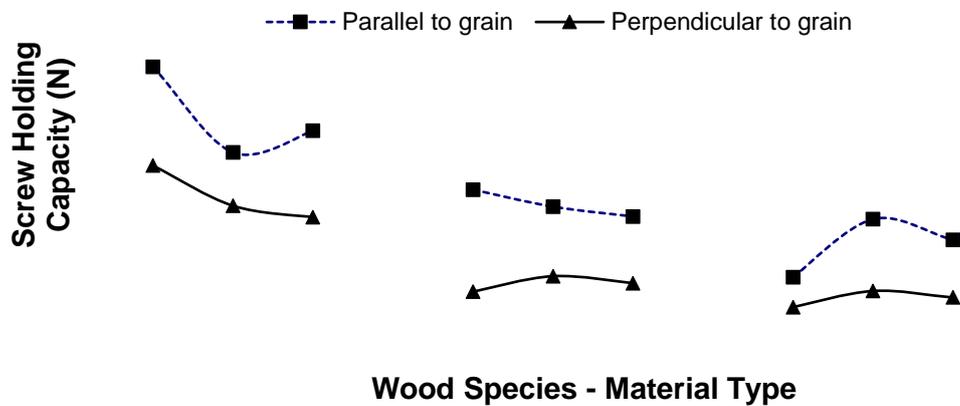


Figure 5. Results of mean comparisons screw holding of capacity parallel and perpendicular to grain for material for each level of wood species.

When the studies observed in literature we can see that screw holding strength is higher in wooden materials whose density is higher in wooden material whose density is high. This study also gives the same result. This study shows that screw holding strength increases when wooden materials are used which little lumens and high density.

4. CONCLUSION

Strength properties of LVL constructed of three wood species, Beech, Pine, and Poplar with two different adhesives, PVAc and UF were investigated through comparing with their solid properties.

The results from screw holding test showed that in general, LVL had significantly lower strength property. Also, LVL of Beech, Pine and Poplar bonded with PVAc adhesive showed significantly higher screw holding than Beech, Pine and Poplar LVL with UF adhesive.

Both parallel to grain and perpendicular to grain screw holding test results indicated that Beech solid had significantly higher strengths than Pine and Poplar materials. There were no

significances in both parallel to grain and perpendicular to grain strength between LVL-PVAc and LVL-UF.

In general, test results indicated that the influences of the wood species on screw holding properties were found statistically significant. Also, different adhesives caused the differences in strength properties of LVL specimens. In conclusion, it can be said that the LVL could be utilized instead of solid wood material in different areas such as building and furniture constructions because of the fact that most strength properties of LVL are at least as good as solid wood. Furthermore, LVL members especially provide design flexibility with different forms in the production of the frame type furniture.

It's known that moisture content equilibrium of wooden materials change according to where they are used. At the places with central heating system: %8-10, places heated with stove: %10-12, with garden furniture and outer side furniture: %12-15. According to this; the effect of moisture of wooden material and the effect of length, diameter and type of screw on the holding performance can be researched.

As conclusion, to increase screw holding strength in furniture construction designing wooden materials which have high density and parallel to grain can be prepared.

References

- Anon, 1999: Producer firm text, *Polisan*. Dilovası, Gebze. Instruction manuel. Turkey.
- Aydın, İ., Çolak, S., Çolakoğlu, G., Salih, E., 2004: "A comparative study on some physical and mechanical properties of laminated veneer lumber (LVL) produced from beech (*Fagus orientalis* L.) and eucalyptus (*Eucalyptus camaldulensis* Dehn.) veneers". *Holz als Roh-und Werkstoff*, 62 (3): 218-220.
- Eckelman, C.A., 1974: "Working formulas for screws", *Furniture Production* 37(264), 37(265), 37(266), 9 pp.
- Eckelman, C.A. 1974: "Which screw holds best? *Furniture Design and Manufacturing*, 46(9):184-, 2 pp.
- Eckelman, C.A. 1975: "Screw-holding performance in hardwoods and particleboard" *Forest Products Journal*, 25(6):30-35.
- Eckelman, C.A. 1978: "Predicting withdrawal strength of sheet metal type screws in selected hardwoods", "Forest Products Journal", 28(8):25-28.
- Eckelman, C.A. 1988: "The withdrawal strength of screws from medium density fiberboard", *Forest Products Journal*, 38(5):21-24.
- Eckelman, C. A. 1991: Textbook of product engineering and strength design of furniture. Purdue Univ. West Lafayette, IN.
- Erdil, Y., Z, 1998: "Strength analysis and design of furniture frames constructed of plywood and oriented strand board. *M.S. Thesis*, Purdue University. p.145.
- Özçifçi, A., 2009: "The effects of pilot hole, screw types and layer thickness on the withdrawal strength of screws in laminated veneer lumber", *Materials and Design*, 30 (7): 2355-2358.
- TS 431. 2001: "Wood Screw", *Institute of Turkish standards*, Ankara.
- TS 2470. 1976: "Wood - Sampling methods and general requirements for physical and mechanical tests", *Institute of Turkish standards*, Ankara.
- TS 2471. 1976: "Wood, Determination of moisture content for physical and mechanical tests", *Institute of Turkish standards*, Ankara.
- TS 2472. 1976: "Wood - Determination of density for physical and mechanical tests", *Institute of Turkish standards*, Ankara.

TS 3891. 1983: “Adhesives-polyvinyl acetate emulsions (for wood)”, *Institute of Turkish standards*, Ankara.
TS EN 386. 2006: “Glued laminated timber – Performance requirements and minimum production requirements”, *Institute of Turkish standards*, Ankara.
USDA,, Forest Product Laboratory. 1987: Wood Handbook. USDA Agricultural Handbook 72. *USDA Forest Service. Forest Product Laboratory*. Madison, WI, USA.

Corresponding author:

Erdil Y.
Muğla Sıtkı Koçman University, Faculty of Technology, Department of Woodworking
Industrial Engineering, Muğla / Turkey
erdil@mu.edu.tr

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

ANALYSIS OF DEFORMATIONS AND STRESSES OF UPHOLSTERED FURNITURE SKELETON WITH STAPLE CORNER JOINTS BY FEM

Key words	Abstract
<i>upholstered furniture, skeleton, staple joints, stresses, deformation, FEM.</i>	3D geometric model of one-seat skeleton for upholstered furniture with staple corner joints was created by CAD system. A linear static analysis was carried out by the method of finite elements (FEM) simulating different load conditions of the skeleton. The orthotropic material characteristics of pine solid wood (<i>Pinus sylvestris</i> L.) for the rails and particleboard (PB) for the side plates are considered in the analysis. Laboratory derived coefficients of rotational stiffness of used staple corner joints were taken into account in FEA to simulate semi-rigid joints. As results the distribution of stresses (von Misses and principal), displacements and equivalent strains in the 3D model of upholstered furniture skeleton with staple corner joints are presented and analyzed.

Corresponding author: nelly_staneva@yahoo.com Staneva N., University of Forestry, Faculty "Forest Industry", Department "Furniture Production", Sofia/Bulgaria

1. INTRODUCTION

In Bulgaria and worldwide the particle boards (PB) are widely employed plated wood composites for production of upholstered furniture skeletons. Nevertheless, in the literature there is a limited number of references concerning the deformation and strength behaviour of upholstered frames constructed with structure elements of PB.

Smardzewski (2001) has made an attempt to find an optimal solution for the construction of a supporting structure in a single-seat arm-chair made of wood and chipboard joined with staples taking into account that the problems of quality verification of supporting elements in armchairs and sofas have not been undertaken before that. Material optimization of construction has been performed only for the main component, but the materials have been considered as isotropic. The strength optimization has been carried out by a numeric method using Algor[®] computer program and has resulted in lower (68%) solid wood consumption, guaranteed optimal strength parameters.

Latelly Smardzewski and Prekrat (2009) have carried out laboratory and numerical investigations of two-person sofa frame with side elements from PB and beam elements from pine and beech wood and have taking account of orthotropic nature of used materials in the FEA with Algor[®] CAE. They have proposed new dimensions of the main construction elements and in the result consumption reduction of beech wood by 36% and that of PB by 25% without significant change of the rigidity and strength of the construction has been established.

More information concerning the deformation and strength characteristics of case furniture (cabinets, wardrobes, tables, kitchen and bathroom furniture, shelves (Jivkov et al, 2010) and etc.) and joints (Norvydas, 2012) for its made of PB is available:

Marinova and Kyuchukov (1997) and Kjutschukov and Marinova (1997) have carried out deformation and strength analyses of a double wardrobe with no inner fixed partition elements made of orthotropic veneered PB, subjected to the heaviest working load with the created FEM

methodology by Marinova (1996) for SAP software. Three types of corner joints have been considered - rigid, hinged and semi-rigid with taking account of test established rotational stiffness of joints with dowels and Swedish disassembly. The authors have reported that the most deformable was the case with hinged sides and the maximum stresses have been localized in the front part of the case. They have recommended the point of the applied exploitation horizontal force for its displacement to be located closer to the bottom and to the back of the case. Further Kjutschukov and Marinova (1998) have investigated the deformation of the same double wardrobe model by FEM applying external horizontal force in two variants: at a point 1600 mm from the floor and a point of the middle of the side and have established that the second variant is a better variant for displacement of a loaded piece of case furniture.

Nicholls and Crisan (2002) have analyzed the stress and strain state in corner joints made of chipboards with beech dowels and Minifix cam systems, typically found in furniture box-type structures with ANSYSTM by using FEA. Although isotropic characteristics of chipboards have been considered they have found that clear areas of stress concentrations were observed in the region where the fixing component are located.

Smardzewski and Ozarska (2005) have constructed a mathematical model of a semi-rigid screw joint of the confirmat type and a numerical model of cabinet furniture construction made of PB loaded with a bending moment. They have established that one of the most dangerous situations was when stresses become concentrated on edges of chipboards and lead to permanent shape deformations and reduction of the joint load carrying capacity.

Tora et al (2006) have studied the contribution of staples to the strength of adhesive joints made of PB for kitchen furniture. They have established that the joints with straight-driven staples had a better performance in bending than joints with staples driven at an angle.

Norvydas et al (2012) have laboratory tested the strength of the multidowel glued miter corner joints of case furniture from PB and have established that the bonding strength of the mitre joint of the wood particle board has exceeded the material strength by even 10% and it is possible to achieve maximal load bearing capacity of construction.

Archanowicz, E. (2012) has investigated semi-rigid furniture joints with two beech dowels made of one- three- and five-layered PB, modelled as linear orthotropic material with SolidWorks Simulation[®]. With numerical simulations he has established that the single-layer model had greater stiffness of closing joints and a smaller opening – increasing the number of layers model brings to the real density profil.

Imirzi and Efe (2013) have analyzed the bending strength and stiffness properties of L-type corner joints with dowels, dowels-screws and PVAc glue in cabinet type furniture made of PB with 14, 16 and 18 mm thickness laboratory and by FEM (ANSYS[®]). The comparisons have revealed that computer model have showed more rigid behavior than the experimental element and have reached the fracture as the maximum difference of 12,61% have been established for dowel-screw joints and 14 mm PB.

Yuksel et al (2014) have investigated the effects of panel thickness on moment resistance on L-type corner joints and stiffness of four-member cabinets made of PB. They have established that 16 mm PB cabinets yielded higher stiffness values than those of 18 mm.

The literature study revealed a limited number of publications on skeleton studies of upholstered furniture with staple joints made of pine and PB.

The aim of this study was to define and analyze the displacements and stresses of one-seat skeleton of upholstered furniture with staple joints by CAD/CAE using the method of finite elements (FEM).

2. METHODS AND MATERIALS

3D model of one-seat upholstered furniture skeleton with length 600 mm, width 680 mm and height 625 mm was created with Autodesk Inventor Pro® – Fig.1. The used rails are with cross section 25x50 mm.

A linear static analysis of 3D modeled skeleton was carried out with CAD/CAE system Autodesk Simulation Mechanical® by the Finite Elements Method (FEM).

The static analysis was performed with plate elements – Fig.1. The generated mesh (Midplane mesh) has 5258 orthotropic finite elements and 33616 DOF. The contacts between the elements of the skeleton were set corresponding to the physical model.

Orthotropic materials type was used for construction elements of the skeleton:

Scots pine (*Pinus sylvestris L.*) for rails with measured density 435,50 kg/m³ according to BDS EN 323:2001 and elastic characteristics: $E_L=12567.10^6$ N/m², $E_R=700.10^6$ N/m², $E_T=545.10^6$ N/m², $G_{LR}=1230.10^6$ N/m², $G_{RT}=800.10^6$ N/m², $G_{LT}=500.10^6$ N/m², $\nu_{LR}=0,030$, $\nu_{RT}=0,38$, $\nu_{LT}=0,040$ according to Pencik, J. (2014).

Particleboard (PB) for side plates with thickness 16 mm and measured density 678,06 kg/m³ according to BDS EN 323:2001. The physical and mechanical characteristics of the used PB panels are: modulus of elasticity in bending $E_L=1600.10^6$ N/m² and $E_{\perp}=2700.10^6$ N/m²; bending strength 11.10⁶ N/m²; resistance to perpendicular tensile stress (internal bond) 0,35.10⁶ N/m²; Poisson ratios $\nu_{12}=0,18$ and $\nu_{21}=0,30$, according to Bodig J. and B. Jayne (1982):

$$\frac{\nu_{12}}{E_1} = \frac{\nu_{21}}{E_2} \quad (1)$$

Support boundary conditions were set: bottom front rail – no translation on y direction and bottom rear rail no translation on x -, y - and z direction.

In order to simulate semi-rigid connections between rails and side plates of the skeleton two actions were performed:

First – zones were created in the place of joints in FEA model with lower elastic modules of the used materials.

Second - the laboratory determined coefficients of rotational stiffness of the joints with 2 staples (type M1) and PVA glue, loading under compression (Hristodorova, 2017) were introduced in the nodes of the respective corner joints - case butt joints ($c=940,57$ N.m/rad) and end to face butt joints ($c=814,98$ N.m/rad).

Four different loads were set on the seat of the FEA model - Fig.1:

L1: load $F_{rail} = 800$ N on the upper front rail of the seat;

L2: load $F_{rail} = 800$ N on the upper rear rail of the seat;

L3: load $F_{rail} = 800$ N in the middle of the upper rails;

L4: load $F_{rail} = 800$ N on 100 mm in front of rear rail;

Both loads *L3* and *L4* are distributed only between upper rails of the seat, simulating upholstery base made of zig-zag springs;

The changed angle γ between the joint shoulders at the upper rail of the seat was measured by vectors with the program Autodesk Simulation Mechanical®.

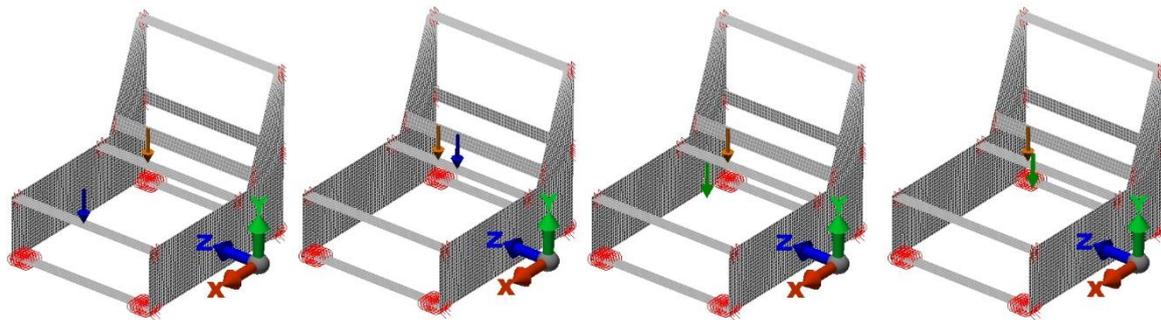


Figure 1. FEM skeleton model and loading L_1 , L_2 , L_3 and L_4

3. RESULTS AND DISCUSSION

The results of static analysis for linear displacements u , nodal rotations θ , von Mises stresses $\sigma_{von\ Mises}$, maximum principal stresses σ_1 , minimum principal stresses σ_3 and equivalent strains $\epsilon_{von\ Mises}$, as well as the changed angle γ between the joint shoulders at upper rails of the seat for four loads are shown in Fig.2 to Fig.6 and in Table 1 to Table 3 for the skeleton and for the side plates of the skeleton respectively. The visualizations of the deformed model are shown with a scale factor 1% of model size for the skeleton and with a scale factor 5% of model size for the side plates.

In Fig.2 the distribution of resultant displacement is presented. The maximal resultant displacements for all loads are received in the middle of the responding upper rails of the seat and are determined mainly by the y -displacements (u_y) – Fig.2, Table 1 and Table 2. For load L_4 the maximal resultant displacement in the rear upper rail is almost 9 times bigger than the same in the front upper rail of the seat. This is due to the nature of the applied force on the seat with application point of 100 mm in front of the rear upper rail (Genchev, 2017), which coincides with the application of the weight of the discrete model of the skeleton – Fig.1.

In the side plates of the skeleton the maximum values of the resultant displacement are received in the places of the base of the seat where dissolution of the side plates is observed – (Fig.3) for loads L_2 and L_4 . This is due to the fact that the resultant displacements are determined mainly by z -displacements (u_z) – Table 2. For loads L_1 and L_3 the maximum resultant displacement is received in the area of the joints - Fig.3.

The established by FEM linear y -displacements in the model at loads L_1 to L_4 were compared with corresponding laboratory received – Table3. For L_1 and L_2 the vertical displacements of the real skeleton model are measured in the middle of the upper rails, for L_3 and L_4 in the middle by length and in the inside of upper rails. It is evident that the values are very closed.

The maximal values of the rotation displacements θ in the whole model and in the side plates are given in Table 1 and Table 2.

For loads L_1 and L_2 they are determined mainly by rotations about z -axis and x -axis and for the loads L_3 and L_4 they are determined mainly by rotations about x -axis.

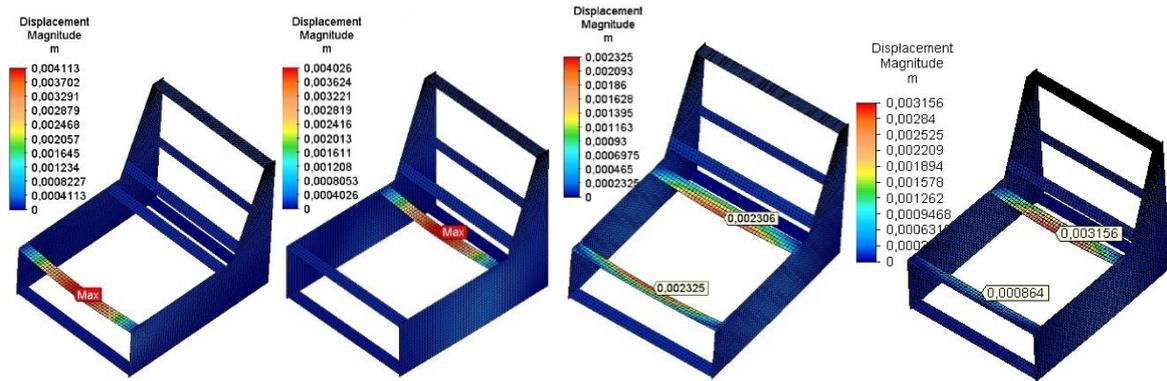


Figure 2. Distribution of linear resultant displacements for L_1, L_2, L_3 and L_4

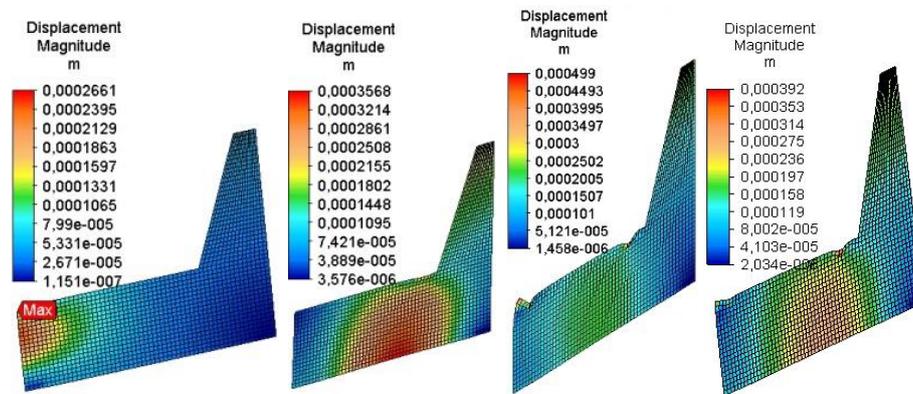


Figure 3. Distribution of resultant displacements in the side plates for L_1, L_2, L_3 and L_4

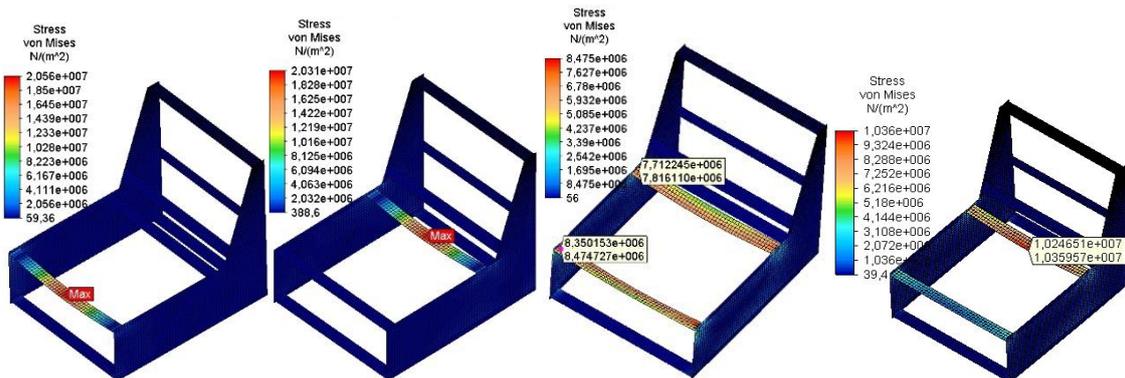


Figure 4. Distribution of von Mises stresses for L_1, L_2, L_3 and L_4

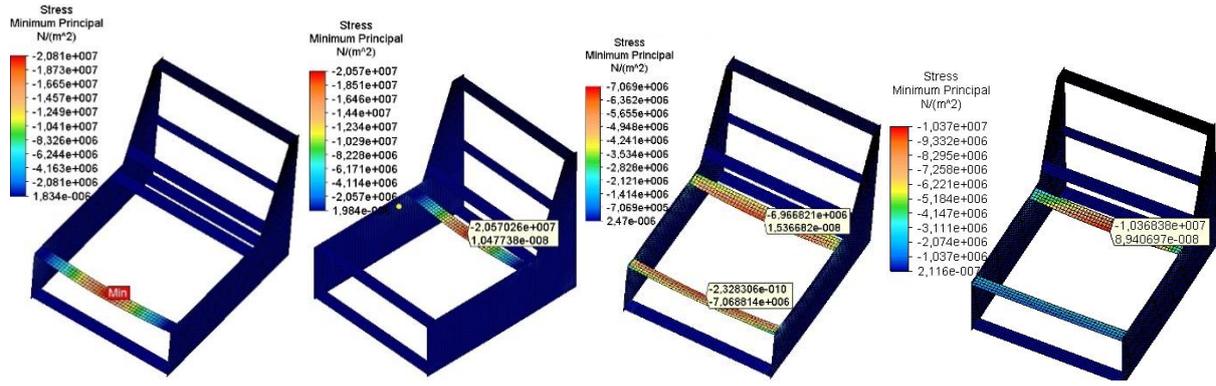


Figure 5. Distribution of minimum principal stresses for L_1 , L_2 , L_3 and L_4

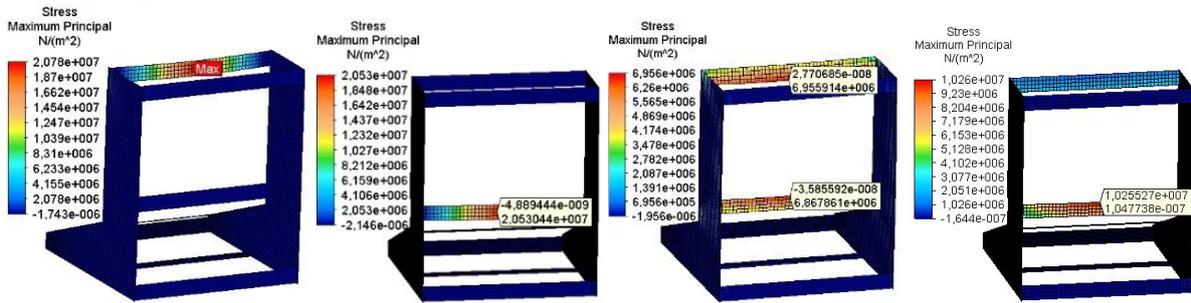


Figure 6. Distribution of maximum principal stresses for L_1 , L_2 , L_3 and L_4

The maximal resultant nodal rotations are located in the front upper rail for L_1 and in the rear upper rail for L_2 . The resultant nodal rotation is bigger in the rear upper rail than the same in the front upper rail of the seat for L_4 . Maximal values of resultant nodal rotation in the side plates are received in the contact field with the upper rails.

Table 1. Maximal displacements and stresses for the model

Parameters	L_1	L_2	L_3	L_4
u_{res} , [mm] front rail	4,11	4,04	2,32	0,86
u_{res} , [mm] rear rail	-	-	-2,31	3,16
u_x , [mm]	0,06	0,21	-0,22	0,25
u_y , [mm] front rail	-4,11	-	-2,32	-0,86
u_y , [mm] rear rail	-	-4,04	-2,31	-3,16
u_z , [mm]	2,41	0,34	-0,17	0,24
θ_{res} , [°]	1,13	1,09	2,08	1,65
θ_x , [°]	1,12	1,09	0,65	0,87
θ_y , [°]	0,32	0,46	0,22	0,28
θ_z , [°]	-0,07	0,04	2,08	0,38
$\epsilon_{von Mises}$, [m/m]	0,012	0,009	0,033	0,0245
γ , [°] front rail	89,49	-	89,65	89,88
γ , [°] rear rail	-	89,53	89,68	89,58

Table 2. Maximal displacements and stresses for the side plates

Parameters	L_1	L_2	L_3	L_4
u_{res} , [mm]	0,266	0,357	0,499	0,309
u_x , [mm]	0,059	0,214	-0,280	0,219
u_y , [mm]	-0,145	-0,156	0,436	0,384
u_z , [mm]	0,238	0,335	0,165	0,241
θ_{res} , [°]	0,994	0,932	1,108	0,940
θ_x , [°]	0,993	-0,932	-0,597	-0,763
θ_y , [°]	0,323	0,425	0,221	-0,275
θ_z , [°]	-0,074	-0,042	1,072	-0,598
$\epsilon_{von Mises}$, [m/m]	0,013	0,009	0,032	0,0242
Stress von Mises, [N/mm^2]	2,27	2,48	4,809	3,645
Max Principal stress, [N/mm^2]	1,09	1,94	5,195	3,079
Min Principal stress, [N/m^2]	-2,052	-1,88	-4,569	-4,070

Table 3. Comparison of the linear vertical displacements

Parameters	L_1		L_2		L_3		L_4	
	FEM	laboratory	FEM	laboratory	FEM	laboratory	FEM	laboratory
u_y , [mm] front rail	4,11	4,93	-	-	2,32	2,65	0,86	0,90
u_y , [mm] rear rail	-	-	4,04	4,42	2,31	2,74	3,16	3,35

The change of angle γ between the joint shouders at upper rail for front rail is bigger for load L_1 . For rear rail the change of the angle γ is almost equal for L_2 and L_4 .

For L_3 the maximal values of von Mises stress are concentrated in the upper rails of the seat near by the side plates, while for the uther loads the maximum values of stresses are concentrated in the middle of the upper rails of the seat due to the location of the biggest bending moments – Fig. 4.

The maximal resultant nodal rotations are located in the front upper rail for L_1 and in the rear upper rail for L_2 . The resultant nodal rotation is bigger in the rear upper rail than the same in the front upper rail of the seat for L_4 . Maximal values of resultant nodal rotation in the side plates are received in the contact field with the upper rails.

For L_3 the maximal values of von Mises stress are concentrated in the upper rails of the seat near by the side plates, while for the other loads the maximum values of stresses are concentrated in the middle of the upper rails of the seat due to the location of the biggest bending moments – Fig. 4.

The maximum principal stresses (tension) have maximum values located in the middle of the coresponding rails at the bottom for all loads. The maximal values of minimum principal stresses (compression) are located on the top of the coresponding rails in the same locations - Fig.5 and Fig.6.

For load L_4 the stresses in the rear upper rail are about 11 times bigger than the stresses in the front upper rail of the seat due to the nature of the applied force – Fig.4 to Fig.6.

Stresses in the side plates have maximum values in the coupling zones of the front and rear rails.

4. CONCLUSIONS

From the results of this study by FEM with CAE program Autodesk Simulation Mechanical® on the deformations and stresses of one-seat upholstered furniture skeleton made of Scots pine and PB with corner joints with staples and glue several conclusions can be derived:

Under light-service loads on the seat of the upholstered furniture skeleton the critical joints have been established – the corner joints between upper rails and the side plates.

To improve the deformation and strength behavior of the skeleton side plates made of PB, the upper rails of the seat should be further strengthened in the joints with the side plates.

At load 100 mm in front of rear rail the most loading construction part of the skeleton is the rear upper rail where the maximum values for linear displacements, nodal rotations and stresses are received due to the nature of the applied force on the seat. This load is the most unfavorable for the seat and for whole skeleton.

The most uniform load on the structural members of the skeleton is obtained at load in the center of the seat.

The created approach for defining of stress-strain state in the 3D model of upholstered furniture skeleton with taking account of pliability of staple corner joints with CAE system Autodesk Simulation Mechanical® by the Finite Element Method (FEM) gives correct results and can be successfully used in designing and optimisation of upholstered furniture constructions.

References

- Archanowicz E. (2012): Stiffness Modelling of Semi-rigid Furniture Joint with Eccentric Connector, *Forestry and Wood Technology* 77: 27-32.
- Bodig J., Jayne B. (1982): *Mechanics of Wood and Wood Composites*, Van Nostrand Reinhold Co. Inc., New York.
- Genchev Ya. 2017. *Special Productions and Wood Products. Production of Upholstered Furniture*, Publish house – Univ. of Forestry, Sofia, in print (in Bulgarian).
- Jivkov V., Yordanov Y., Marinova A. (2010): Improving by Reinforcement the Deflection of Shelves Made of Particleboard and MDF. 1st International Conference Processing Technologies for Forest and Biobased Products Industries, Salzburg University of Applied Sciences, 7-8 October, Kuchl, 205-207.
- Hristodorova D. (2017): Stiffness Coefficients in Joints by Staples of Skeleton Upholstered Furniture, *Innovation in Woodworking Industry and Engineering Design (INNO)*, in print.
- Kjutschukov G., Marinova A. (1997): Festigkeitsdimensionierung von Korpusmöbeln Mittels eines Rechnergestützten Programms, das nach der Methode der Finiten Elemente und mit Ablesung der Nachgiebigkeit der Eckverbindungen Ausgearbeitet Wurde. VIII Interkatheder Zuzammentreffen von Okonomisten und Organizatoren der Holzindustrie, ISEODI' 97, Zagreb, Croatia, 153 ÷159.
- Kyuchukov G., Marinova A. (1998): Case Furniture Deformation Depending on the Point of Application of External Force in Order to Displace it under Conditions of Service Load. 12 Konferencja Naukowa Wydzialu Technologii Drewna SGGW "Technologia Drewna – Innowacyjnosc Badan w Przemysle i Nauce", Warscawa, 311 ÷ 317.
- Marinova A. (1996): Methodology of Stress and Strain Furniture Structure Analysis, *Proceeding of Intern. Sci. Conference "Mechanical Technology of Wood"*, Sofia, 257-267 (in Bulgarian).
- Marinova A., Kyuchukov G. (1997): A Study on Deformation of Case Furniture by Use of a Computer Program Based on the Finite Element Method Taking Into Account the Corner Joints Flexibility. *Proceedings of the 3-rd Intern. Conference on the*

- Development of Forestry and Wood Science/Technology, volume II, Belgrade, Serbia, 555 ÷ 559.
- Nicholls T., Crisan R. (2002): Study of the Stress-Strain State in Corner Joints and Box Type Furniture Using Finite Element Analysis (FEA). *Holz als Roh- und Werkstoff* 60: 66-71
- Norvydas V., Baltrusaitis A., Juodeikiene I. (2012). Investigation of Miter Corner Joints Strength of Case Furniture from Particleboard. *Materials Science*, 18 (4): 352-357.
- Pěňčík J. (2014). Modelování Dřeva Pomocí Ortotropního Materiálového Modelu s Kritérii Porušení, *Stavební Obzor*, 1–2: 6-7 (in Slovak).
- Smardzewski J. (2001): Construction Optimisation of Upholstered Furniture. *Folia Forestalia Polonica, Seria B, zeszyt 32*: 5-19.
- Smardzewski J. and Ozarska B. (2005): Rigidity of Cabinet Furniture with Semi-Rigid Joints of the Confirmat Type, *Electronic J. of Polish Agricultural Universities*, 8(2) Wood Technology.
- Smardzewski J., Prekrat S. (2009): Optimisation of a Sofa Frame in the Integrated CAD-CAE Environment. *Electronic J. of Polish Agricultural Universities*, 12(4) Wood Technology.
- Tora S., Cassen D., Haviarova E. (2006). Properties of Hot-Melt Adhesives Used in Kitchen Cabinets. *Forest Products Journal* 56(11-12): 43-50.
- Yuksel M., Yildirim N., Kasal A., Erdil Y., Demirci S. (2014): Effect of the Panel Type and Panel Thickness on Moment Resistance of Screw-Jointed Corner Joints and Stiffness of Four-Member Cabinets. *BioResources* 9(4): 6340-6349.
- www.autodesk.com - Autodesk Simulation Mechanical – user manual.

Corresponding author:

Assoc. Prof., PhD N. Staneva
University of Forestry, Faculty “Forest Industry”, Department “Furniture Production”,
Sofia/Bulgaria
nelly_staneva@yahoo.com

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

WITHDRAWAL CAPACITY OF SCREWS AND CONFIRMAT INTO DIFFERENT WOOD-BASED PANELS

Vassil JIVKOV¹, Borislav KYUCHUKOV², Ralitsa SIMEONOVA¹ Assia MARINOVA¹

¹ University of Forestry, Faculty of Forest Industry, Department of Interior and Furniture Design, Sofia / Bulgaria

² University of Forestry, Faculty of Forest Industry, Department of Furniture Manufacturing, Sofia / Bulgaria

Key words

withdrawal capacity of screw, wood-based panels, screw for wood, Confirmat.

Abstract

Information about the withdrawal capacity of screws and Confirmat is particularly important for proper strength design of furniture and wood constructions. The aim of this study is to determine the impact of combination of different wood-based material into a new sandwich panel on the withdrawal capacity of screws and Confirmat and to compare with those achieved from standard panels. For the purpose of the study has been chosen laminated particleboards (18mm), plywood made from beech, birch and poplar veneer (18mm), non-laminated MDF (18mm), cherry veneered MDF (18mm) and OSB (18mm). Three different sandwich panels have been produced additionally with combination of particleboards (12 mm) and LHDF (3 mm) and MDF (4 and 6mm). Test has been done according to BDS EN 13466:2003. Results indicated that the type of the materials has significant influence on the specific withdrawal capacity of the universal and Confirmat screws. Combination of materials into a sandwich panel performed good withdrawal resistance.

Corresponding author: v_jivkov@ltu.bg Jivkov V., University of Forestry, Faculty of Forest Industry, Department of Interior and Furniture Design, Sofia / Bulgaria

1. INTRODUCTION

Withdrawal resistance of screws and one-piece connector Confirmat is of great interest to both designers and furniture constructors as well as furniture fittings manufacturers as it is decisive for the strength and durability of furniture and wood structures. Most of the dismantlable joints in the contemporary furniture production are mainly made with screws or screw driving assemblies. Furthermore, a large part of the functional fittings, such as hinges, sliding door systems, drawer slides, storage mechanisms for various products, etc. are connected by screws to the structural elements. Screws for wood-based materials and one-piece connector Confirmat are mainly used in furniture and interior and exterior constructions made from wood and wood-based materials.

The use of metal screws as a fastener began in 15th century in Europe. The first patent registered to Job and William Wyatt of Staffordshire in 1760 regarding the industrial manufacture of wood screws is an English. The first sample of a contemporary Confirmat screw appeared in 1830 (White 2005). Now a day furniture and construction industry are huge consumer of many types of screws used to join different materials.

Withdrawal capacity of screws and Confirmat into wood-based materials depends on the type of materials used in the constructions and on the direction of the axes of the joining elements relative to the plane of the board and wood. The test method, the diameter of the screws, the diameter of the screw pilot hole and the screw thread parameters, the degree of alignment of the joining element and the direction of the force for its withdrawal, the preparation of the test samples for testing and etc. are factors with influence on the withdrawal capacity of screws (Kyuchukov and Jivkov 2016).

Evaluation of withdrawal capacity of screws and Confirmat into different wood-based structural elements makes it possible to obtain comparable results in terms of both, the type of joining elements and the type of wood material, which is the basis for their rational use in the design of furniture and wood structures.

Many studies about the withdrawal capacity of screws from different solid wood species are done in the past in Bulgaria. These include certain coniferous and deciduous species (Kjučukov and Enčev 1977a; Kjučukov and Enčev 1977b; Kyuchukov and Yosifov, 1968; Kyuchukov and Yosifov 1971; Kyuchukov et al. 2011). Most of them determined that direction of insertion and diameter of pilot hole of the screw and wood density are the most important factors for screw withdrawal capacity.

Screwholding performance in different hardwood presented by Eckelman (1975) indicates that the withdrawal strength of screws from the side and end grain can be predicted by means of the expression. In the study of Kilic et al. (2006) are given data for nail and screw withdrawal resistance of fir, cherry, walnut and oak wood. According to this study highest resistance is achieved on the radial cut surfaces of oak and as the specific gravity increases, the nail and screw resistance increase as well. Withdrawal resistance of wood screw in beech, hornbeam and poplar has been investigated from Taj et al (2009). The results show that hornbeam species have higher withdrawal resistance than beech and beech is higher than poplar. The influence of the pitch on the holding power of Confirmat screws in Scots pine wood has been evaluated by Sydor et al. (2015) and has only little influence on the holding force for the screws placed perpendicular to the tangential plane. The authors also concluded that overall screw strength properties perpendicular to the tangential plane were 15% higher to the radial plane. Chen et al. (2016) investigated withdrawal resistance of screws in reconstructed bamboo lumber. The conclusion is that face and edge screw resistance in reconstructed bamboo is higher compare to medium density fiberboard (MDF) and particleboard (PB).

Nail and screw withdrawal strength of laminated veneer lumber (LVL) made of hardwood (beech) and softwood (poplar) layers has been evaluated by Celebi and Kilic (2007). Based on the results of that study, layer thickness did not influence on the withdrawal strength in transverse direction but strength values increased with increasing the specific gravity of the samples in this direction. Research with LVL with combination of oak and Uludag fir has been conducted by Özcifci (2009). He studied the effect of pilot hole, screw types and layer thickness on the withdrawal strength of screws. Highest capacity was obtained in oak samples having 4 mm veneer thickness bonded with phenol-formaldehyde adhesive for 3.5×16 screw as 23.14 MPa, the lowest was obtained for Uludag fir having 5 mm veneer thickness bonded with melamine-formaldehyde adhesive with 4.0×50 screw as 7.61 MPa. The use of proper size of pilot holes is advised in order to avoid splitting of the face during insertion of screws as well as to obtain maximum withdrawal strength.

Holding strength of screws in plywood have been studied by some authors (Erdil et al. 2002; Simeonova 2015; Bal et al. 2016; Bal 2017). Erdil et al. (2002) tested three type of southern pine plywood, one Douglas-fir plywood and one hardwood plywood and obtained a predictive expression which enable the withdrawal strength of screws to be predicted as function of screw diameter and depth of penetration, and density of the material. Simeonova (2015) evaluated the withdrawal capacity of $\text{Ø}5 \times 50$ mm screw into two type of beech plywood in face and edge

direction. It has been established that the direction of the inserting of the screw perpendicular to the plain of board is giving 18.7% higher capacity compare to parallel. Bal et al. (2016) investigated the holding capacity of plywood produced in combination of eucalyptus, beech and poplar veneer in 5 ply. The greatest withdrawal strength has been achieved from plywood with combination of beech-eucalyptus-beech. Similar research has been done by Bal (2017) where poplar veneer plywood was reinforced. The effect of reinforcement of the poplar plywood is significant for the screw holding capacity of the material.

Particleboards and MDF are also very often object of the scientific researches. Eckelman (1975) gave expressions for predicting the holding strength of screws in PB and in MDF (Eckelman 1988). He reported that withdrawal strengths were about 13% higher when optimum pilot holes were used. The influence of the size of the pilot hole have been studied by Rajak and Eckelman (1993). They reported that the pilot holes not only help to locate screws but also facilitate their insertion in a desire direction and additionally the use of pilot holes with a proper diameter significantly increased the holding strength of the screw. Semple and Smith (2006) found out that the model of Eckelman (1975) did not match to their data and proposed a model for 5/8-inch particleboard with sufficient correlation to IB of the panels. According to the same study face screw withdrawal resistance is 25% higher than in edge. Analysis of axial screw withdrawal resistance in reinforced MDF has been done by Sydor and Wolpuik (2016). The results showed 100% increase of screw resistance for universal screws and 50% for euro screws. Bal et al. (2016) published results for screw-holding capacity from melamine-faced fiberboards and PB. Authors have been tested screw withdrawal performance perpendicular and parallel to the plain of the boards and screw head pull-through strength according to ASTM 1037-12. The conclusion is that screw-holding capacity of melamine-faced particleboard is higher than that of melamine-faced fiberboard. Colakoglu (2009) determined screw withdrawal strength in melamine-coated particleboard, MDF and “new wood” made of polystyrene. The obtained results are confusing. According to the methods given in this study, screw withdrawal capacity has to be evaluated in $N.mm^{-2}$. However, in the article the results are given either in $kg.mm^{-2}$ or in $N.mm^{-2}$ but with the same values. Generally, values of the results in both dimensions differ a lot from the other data found in the literature. Withdrawal resistance of screw in wood-based materials has been evaluated by Joscak et al. (2014). The conclusion is that the resistance depends mainly from screw diameter and material density. Commercial wood-plastic composite, together with MDF and particleboard were tested by Haftkhani et al. (2011) for evaluation of withdrawal resistance of various screw in face and edge direction. The results of their study have shown that withdrawal resistance of screw in wood-plastic composites is higher than those of MDF and PB. Some studies about the influence of the particleboard density to the screw holding capacity are done in Bulgaria (Kyuchukov and Yosifov 1979). Results indicated that the size and the pilot hole of screw and the density of the particleboard are essential for the holding capacity of the screws.

Vassiliou and Barboutis (2005) investigated screw withdrawal capacity of connecting screws of furniture connectors. Results of the study indicated that there is a near linear increase of the face withdrawal capacity of the screws as the density of the particleboard increases.

Many studies are related to the determination of the strength and in recent years also the deformation characteristic (stiffness) of the end and middle corner joints with screws and one-piece connector Confirmat (Jivkov 2002a; Jivkov 2002b; Jivkov and Marinova 2003; Jivkov and Marinova 2005; Zhang et al. 2005; Jivkov and Marinova 2009; Marinova 2010; Kasal, et al. 2011; Jivkov and Grbac 2011; Simeonova 2015; Yuksel et al. 2015). Main conclusion of these studies is that Confirmat is giving higher strength and stiffness of the joints compare to the universal screw.

In the most of the studies for evaluation of the withdrawal resistance of the screws have been used universal screws with diameter of $\varnothing 4$ mm but with different length – 12 mm (Joscak et al.

2014), 25 mm (Taj et al. 2009), 35 mm (Joscak et al. 2014; Sydor and Wolpuik 2016), 40 mm (Kjučukov and Enčev 1977a; Kjučukov and Enčev 1977b; Kyuchukov and Yosifov 1968; Kyuchukov and Yosifov 1979; Özcifci 2009; Kyuchukov et al. 2011), 45 mm (Bal 2016), 50 mm (Özcifci 2009; Sydor and Wolpuik 2016; Bal et al. 2016a; Bal et al. 2016b). Some researchers have been used screws with diameter of Ø3,5 mm with length of 16, 18, 25, 40 mm (Özcifci 2009; Chen et al. 2016), diameter of Ø5 mm with length of 40 or 50 mm (Kilic et al. 2006; Simeonova 2015; Chen et al. 2016) and diameter of Ø6 mm with length of 12 or 40 mm (Joscak et al. 2014; Chen et al. 2016).

Very few studies have been conducted for evaluation of the withdrawal resistance of Conformat type of screw (Joscak et al. 2014; Sydor et al. 2015). Joscak et al. (2014) have been making comparison of the load carrying capacity according to the calculation model of EC 5 and experimental value where the difference between predicted and experimental values for particleboard is obvious.

The criteria, used for evaluation of the withdrawal capacity of the screws into wood and wood-based materials, cited in the literature, can be divided in 4 groups. In the first group obtained forces are given in Newtons (Sempe and Smith 2006; Taj et al. 2009; Joscak et al. 2014; Bal et al. 2016; Bal 2017) or in pound-force (Eckelman 1988; Erdil et al. 2002). In the second, is the ratio of the force to the length of the screw embedded in the material in N/mm (Hafkhani et al. 2011; Kyuchukov et al. 2011; Sydor et al. 2015; Sydor and Wolpiuk 2016; Chen et al. 2016). In the third group results are calculated according to the EN 13446 where the withdrawal capacity is the ratio of the force to the diameter and length of the screw embedded in the material in N/mm² (Colakuglu 2009; Simeonova 2015; Bal et al. 2016). Same calculation method is used in EN 320 „Fibreboards - Determination of resistance to axial withdrawal of screws”. Only Colakoglu (2009) has been conducted his study according this standard. In the fourth group, another European standard is used, EN 1382 where withdrawal strength is obtained as a ratio of the force to the surface of the screw embedded in the material in N/mm² (Celebi and Kilic 2005; Özcifci 2009). This standard refers to the withdrawal capacity of timber fasteners. The conclusions of the most of the studies cited above indicate that the type of material, the type of screws, the pilot hole and the direction of the axis (face or edge, tangential or radial) of the screw have the greatest influence on the withdrawal resistance of screws into wood and wood-based materials.

Although Conformat type of screw is common used in furniture construction, there is not enough research reports in the exiting literature giving information about their withdrawal capacity into wood-based materials.

Often used in furniture are not only commercial wood-based material like MDF and particleboard but some combination of them which are giving an opportunity to improve their characteristics or to reduce the price, for an example, 3-ply board produced as a combination of particleboard core and outer layer of HDF or MDF. No data about withdrawal capacity of such wood-based materials were found in the literature. Regarding that fact, in this study withdrawal capacity of screws and “Conformat” into different commercial and self-produced wood-based materials were evaluated.

2. METHODS AND MATERIALS

WOOD-BASED MATERIALS

The tests were carried out on commercial laminated particleboard -18 mm (LPB), MDF - 18 mm, Cherry veneered-face MDF - 19 mm (ChrVMDF), poplar plywood - 18 mm (PoPIW), birch-faced lightweight plywood - 18 mm (BiPIW), beech plywood - 20 mm (BePIW) and OSB - 18 mm. Additionally, three types of 3-ply wood-based panels were produced (Fig. 1). The

first one (3PI-LHDF) is combination of particleboard (12 mm) core layer and 2 outer layers of laminated high-density fiberboard with thickness of 3 mm with total thickness is 18 mm. The second one (3PI-MDF-20) is from particleboard (12 mm) and 2 layers of MDF (4 mm) with thickness of 20 mm and the third one (3PI-MDF-24) is from particleboard (12 mm) and 2 layers of MDF (6 mm) with thickness of 24 mm. PVA adhesive, class D2 and membrane press were used for production of all 3 panels. Nominal thickness (t_n , mm), measured thickness (t_m , mm) and density (ρ , mm) followed by descriptive statistic included values of standard deviation (SD , kg/mm^3) and coefficient of variation (CoV , %) of all tested materials are given in Table 1.

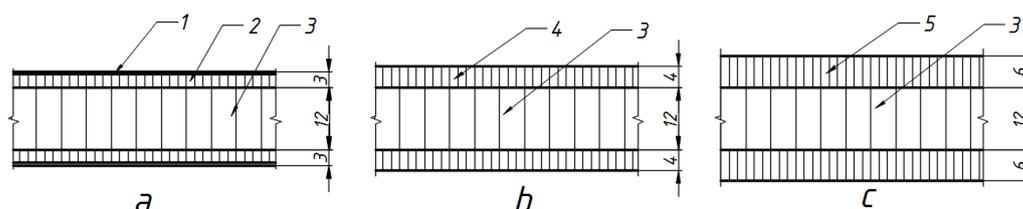


Figure 2. Type and structure of 3-ply wood-based panels:

- a - 3-ply panel with PB and 2 layers laminated HDF (3PI-LHDF); b - 3-ply panel with PB and 2 layers MDF (3PI-MDF-20); c - 3-ply panel with PB and 2 layers of MDF (3PI—MDF-24)
 1 - laminate over layer; 2 – HDF-3 mm; 3 – PB-12 mm; 4 – MDF-4 mm; 5 – MDF-6 mm.

Table 1. Thickness and density of wood-based materials

№	Type of panel	Nominal thickness t_n , mm	Measured thickness t_m , mm	Mean ρ , kg/m^3	SD , kg/m^3	CoV , %
1	Laminated particleboard (LPB)	18	18.10	697.93	3.33	0.48
2	Poplar plywood (PoPIW)	18	18.22	408.15	7.21	1.77
3	Birch-faced lightweight plywood (BiPIW)	18	17.59	478.37	16.76	3.50
4	Medium density fiberboard (MDF)	18	18.03	681.10	4.40	0.65
5	Cherry veneered-faced MDF (ChrVMDF)	19	18.80	750.59	3.99	0.53
6	3-ply panel with laminated HDF (3PI-PB-LHDF)	18	17.34	668.54	9.32	1.39
7	3-ply panel with MDF 4 mm (3PI-PB-MDF-20)	20	20.72	692.33	8.37	1.21
8	3-ply panel with MDF 6 mm (3PI-PB-MDF-24)	24	23.29	736.80	5.84	0.79
9	Oriented strand board (OSB)	18	17.55	654.88	14.59	2.23
10	Beech plywood (BePW)	20	19.32	755.08	13,36	1,75

SCREWS

Two types of screws were used. The first one was universal, galvanized, rolled cut, metal, fully threaded screw for wood and particleboards, with nominal size of $\text{Ø}4 \times 40$ mm and the second was one-piece connector Confirmat with nominal size of $\text{Ø}7 \times 50$ mm for drill hole of $\text{Ø}5$ mm. Both screws were with countersunk head and PZ cross slot. The shape and the parameters of the screw and Confirmat are shown on Figure 2 and the dimensions are given in Table 2.

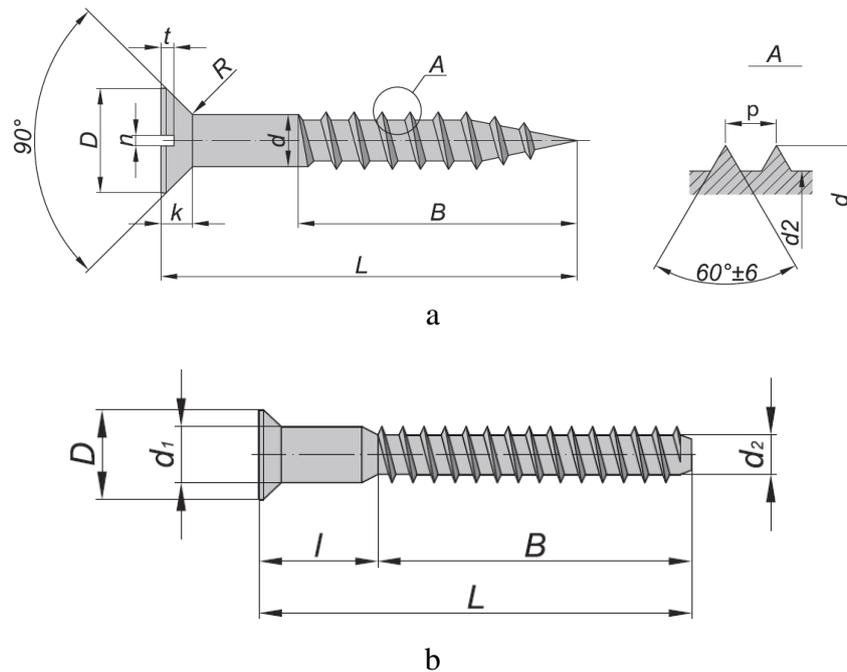


Figure 2. Type of screw:
a – universal screw, b – Confirmat screw

Table 2. Dimensions of the screw and Confirmat

№	Type of screw	Nominal size, mm	d , mm	D , mm	L , mm	B , mm	p , mm	d_1 , mm	d_2 , mm
1	Universal screw	Ø4 x 40	3.79	7.71	39.57	34.51	2.33	-	-
2	Confirmat	Ø7 x 50	6.81	9.99	49.53	37.19	3.69	6.85	4.05

TEST SPECIMENS

Test specimens were prepared according to BDS EN 13466:2003 with the nominal dimension of $50 \times 50 \times t$, where t is the thickness of the sample. From each type of panel between 20 and 27 test specimens were cut for each serial of screw withdrawal testing. The pilot holes of Ø2.8 mm for the screw and Ø5 mm for Confirmat were drilled through the panel in each specimen perpendicular to the plain of the board (Kyuchukov, G. and Kyuchukov, B. 2016). One screw or one Confirmat were driven to each specimen perpendicular to the plain of the board (face direction) according to the principles of BDS EN 13466. All test specimens were conditioned at 20 ± 2 °C and at $65 \pm 3\%$ humidity for 1 week.

TEST METHOD

Universal testing machine Zwick 250, equipped with jigs (fig. 3) to hold the specimens was used in the test. The loading speed was set to 10 mm/min. Specific withdrawal capacity (SWC) of screw perpendicular to the face of the board was determined using the following equation

$$f = \frac{F_{\max}}{d \cdot l_p} \quad (1)$$

where:

f is specific withdrawal capacity of screw, N/mm^2

F_{max} – ultimate load, required to withdraw the screw from the specimen, N
 d – diameter of the screw, mm
 l_p – depth of penetration of the screw (thickness of the board), mm

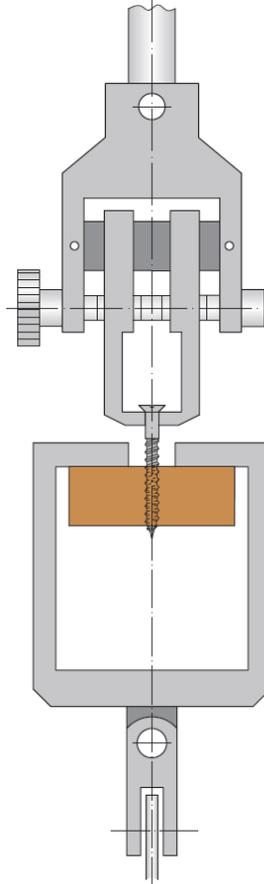


Figure 3. Loading scheme and test jigs

The data obtained from the test were statistically analysed. One-way ANOVA was used to determine the difference between the withdrawal capacity of screw into different wood-based materials and Tukey HSD test was used to determine whether the differences within groups have a significant level with a confidence interval of 95%.

3. RESULTS AND DISCUSSION

SCREW WITHDRAWAL CAPACITY OF UNIVERSAL SCREW

In Table 3 are given the results from the test carried out to determine the withdrawal capacity of universal screw $\varnothing 4 \times 40$ mm into different wood-based material. Statistical data for the mean values of ultimate load (F_{max}) in Newtons, calculated specific withdrawal capacity (f) followed by descriptive statistic included minimal (f_{min} , N/mm²) and maximal (f_{max} , N/mm²) values, standard deviation (SD , N/mm²) and coefficient of variation (CoV , %) are shown in the Table 3. In Figure 4 the results are displayed graphically.

Table 3. Ultimate load and specific withdrawal capacity of screw $\varnothing 4 \times 40$ mm

Name of series	Type of the board	t , mm	N $^{\circ}$ of samples	Mean, F_{max} , N	Mean f , N/mm 2	f_{min} , N/mm 2	f_{max} , N/mm 2	SD , N/mm 2	CoV, %
1-S	Laminated PB (LPB)	18	20	920.32	12.78	11.35	14.26	1.05	8.22
2-S	Poplar Plywood (PoPIW)	18	22	1336.86	18.56	13.78	27.40	3.69	20.03
3-S	Birch-faced Plywood (BiPIW)	18	20	1709.71	23.75	20.96	26.97	1.85	7.79
4-S	Medium Density Fiberboard (MDF)	18	20	1117.80	15.52	10.62	19.76	2.08	13.38
5-S	MDF, Cherry Veneered (ChrVMDF)	19	21	1690.52	22.24	17.55	25.43	2.15	9.67
6-S	3-ply board with lam. HDF (3PI-PB-LHDF)	18	24	1104.25	15.34	12.19	17.56	1.68	10.92
7-S	3-ply board with MDF 4 mm (3PI-PB-MDF-20)	20	21	1578.49	19.73	16.78	23.22	1.48	7.48
8-S	3-ply board with MDF 6 mm (3PI-PB-MDF-24)	24	22	1845.08	19.22	16.42	23.15	1.58	8.23
9-S	Oriented strand board (OSB)	12	20	1376.76	28.68	14.01	44.63	10.85	37.83
10-S	Beech plywood (BePW)	19	21	4066.29	53.50	43.55	59.55	4.54	8.48

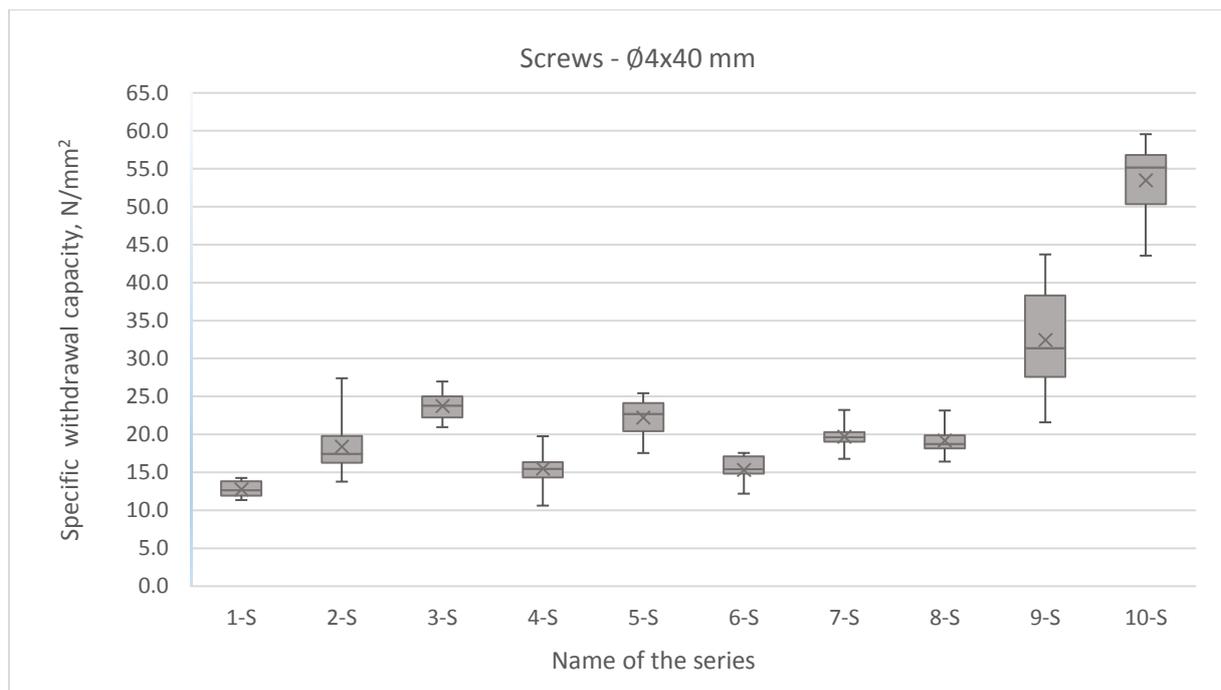


Figure 4. Specific withdrawal capacity of universal screw $\varnothing 4 \times 40$ mm into wood-based materials

According to the results the lowest SWC was shown from laminated particleboard (12.78 N/mm 2) following with 15.34 N/mm 2 by 3-ply panel with particleboard and laminated with 3mm HDF (3PI-PB-LHDF) and MDF with 15.52 N/mm 2 . Similar ultimate load from laminated particleboard were obtained by Joscak et al. (2014). The highest SWC was shown from beech

plywood (53.50 N/mm²). The result which were obtained by Simeonova (2015) for screw Ø 5x50 mm in beech plywood (45.10 N/mm²) is slightly differ from this study but in calculation method according BDS EN 13466:2003 the screw diameter is influenced on this result. Second higher SWC was shown by OSB (28.68 N/mm²) but with higher normal distributions of the values which could be explained with specific structure of the OSB. Best performance of the beech plywood and OSB according to the SWC of universal screw is also an explanation, why these materials are one of the main products used in building constructions. The difference between highest (53.50 N/mm²) and lowest (12.78 N/mm²) SWC of universal screw is 4.2 times.

According to the one-way ANOVA and pairwise comparison conducted by Tukey HSD test a significant difference of $\alpha=0.05$ and level of confidence of 95% was found between the obtained withdrawal capacity of universal screw Ø4x40 mm from different wood-based materials (Table 4). The results of SWC are divided in 6 homogeneous groups, which confirms the thesis that the material is of main importance for withdrawal capacity of screw from wood-based materials. In 4 groups (C, D, E, F) were not find a significant difference between 2 (C, D) or 3 types of material (E, F). The new composed 3-ply wood-based materials according to the achieved SWC are in group D, E and F, where they compete together with laminated particleboard, MDF with and without veneer and poplar plywood.

Table 4. Tukey HSD analysis of the differences between the group of panels with a confidence interval of 95% of withdrawal capacity of screw Ø4x40 mm of all pairwise comparisons

Name of series	Type of panel	Groups of homogeneities ($\alpha=0.05$)					
		A	B	C	D	E	F
		Mean of specific withdrawal capacity of universal screw, N/mm ²					
10-S	BePIW	53.50					
9-S	OSB		32.64				
3-S	BiPIW			23.75			
5-S	ChrVMDF			22.24	22.24		
7-S	3PI-MDF-20				19.73	19.73	
8-S	3PI-MDF-24					19.22	
2-S	PoPIW					18.56	
4-S	MDF						15.52
6-S	3PI-LHDF						15.34
1-S	LPB						12.78

SCREW WITHDRAWAL CAPACITY OF CONFIRMAT SCREW

In Table 5 are given the results from the test carried out to determine the withdrawal capacity of Confirmat screw Ø 7x50 mm into different wood-based material. Statistical data for the mean values of ultimate load (F_{max}) in Newtons and calculated specific withdrawal capacity (f) followed by descriptive statistic are shown in the Table 5 and graphically in Figure 5. Results in the segment of lower capacity show similar classification as with universal screw. The lowest capacity was obtained again by laminated particleboard (12.09 N/mm²), following by 3-ply panel with particleboard and laminated with 3mm HDF (3PI-PB-LHDF) with capacity of 13.92 N/mm² and 3-ply panel with particleboard and MDF 4 mm (3PI-PB-MDF-20) with capacity of 14.34 N/mm². Similar ultimate load from laminated particleboard were obtained by Joscak et al. (2014). The highest SWC was shown from beech plywood (45.36 N/mm²). Second higher

SWC was shown by OSB (33.45 N/mm²) but in comparison with universal screw the normal distribution of the values within the group is lower and this is due to different size of the threats pitch. The difference between highest (45.36 N/mm²) and lowest (12.09 N/mm²) withdrawal capacity of Conformat screw is 3.75 times.

Table 5. Ultimate force and specific withdrawal capacity of Conformat screw $\varnothing 7 \times 50$ mm

Name of series	Type of the panel	<i>t</i> , mm	№ of samples	Mean, <i>F</i> _{max} , N	Mean <i>f</i> , N/mm ²	<i>f</i> _{min} , N/mm ²	<i>f</i> _{max} , N/mm ²	<i>SD</i> , N/mm ²	<i>CoV</i> , %
1-C	Laminated PB (LPB)	18	21	1523.38	12.09	10.89	13.49	0.70	5.78
2-C	Poplar plywood (PoPIW)	18	21	2169.65	17.20	13.86	23.47	2.26	13,12
3-C	Birch plywood (BiPIW)	18	21	2382.21	18.89	15.79	22.10	1.74	8.96
4-C	MDF (MDF)	18	21	2036.34	16.16	13.58	18.37	1.21	7.46
5-C	MDF, Cherry Veneered, (ChrVMDF)	19	21	2715.95	20.42	17.81	22.64	1.33	6.50
6-C	3-ply panel with lam. HDF (3PI-PB-LHDF)	18	24	1689.50	13.92	19.36	27.89	2.66	10.92
7-C	3-ply panel with MDF 4 mm (3PI-PB-MDF-20)	20	27	2091.32	14.94	12.96	17.34	1.33	8.91
8-C	3-ply panel with MDF 6 mm (3PI-PB-MDF-24)	24	26	2807.43	16.71	15.30	17.79	0.70	4.22
9-C	Oriented strand board (OSB)	12	19	2118.41	33.45	31.08	35.57	1.33	27.82
10-C	Beech plywood (BePW)	19	18	6032.70	45.36	35.67	49.51	3.96	8.72

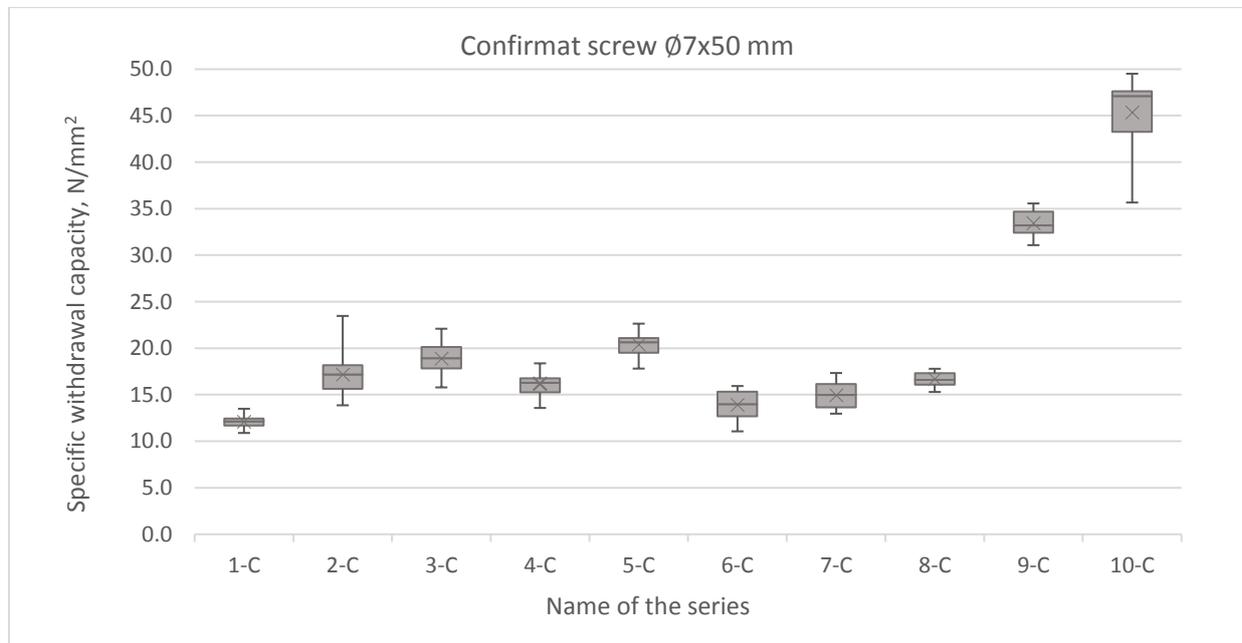


Figure 5. Specific withdrawal capacity of Conformat screw $\varnothing 7 \times 50$ mm into wood-based materials

According to the one-way ANOVA and pairwise comparison conducted by Tukey HSD test a significant difference of $\alpha=0.05$ and level of confidence of 95% was found between the obtained withdrawal capacity of Confirmat screw $\varnothing 7 \times 50$ mm from different wood-based materials (Table 6). The results of SWC are divided in 8 homogeneous groups. In 5 groups (C, D, E, F, G) were not found a significant difference between 2 (C, D, F, G) or 3 types of material (E). The new composed 3-ply wood-based materials are in the second half of the ranking according to their withdrawal capacity.

Table 6. Tukey HSD analysis of the differences between the group with a confidence interval of 95% of withdrawal capacity of Confirmat screw $\varnothing 7 \times 50$ mm of all pairwise comparisons

Name of series	Type of panel	Groups of homogeneities ($\alpha=0.05$)							
		A	B	C	D	E	F	G	H
		Mean of specific withdrawal capacity of Confirmat, N/mm ²							
10-C	BePIW	45.36							
9-C	OSB		33.45						
5-C	ChrVMDF			20.31					
3-C	BiPIW			18.91	18.91				
2-C	PoPIW				17.22	17.22			
8-C	3PI-MDF-24					16.71			
4-C	MDF					16.16	16.16		
7-C	3PI-MDF-20						14.94	14.94	
6-C	3PI-LHDF							13.92	
1-C	LPB								12.09

It is obvious from the results given in this study that the type of material is a main factor affecting on specific withdrawal capacity of universal screw and Confirmat screw. This is confirmed by the very high correlation ($r=0.98$) between withdrawal capacity of the screws and different materials. Very less correlation was found between the density of materials and SWC for universal screw ($r=0.23$) and for the Confirmat ($r=0.22$) which is opposite to the results obtained by some other authors (Josca et al. 2014; Vassiliou and Barraboutis 2005).

COMPARISON OF SCREW WITHDRAWAL LOADING CAPACITY BETWEEN UNIVERSAL SCREW AND CONFIRMAT SCREW

It is clear from the comparison of all the data for each screw type, including 10 wood-based materials, that screw withdrawal capacity of universal screw in comparison to Confirmat screw has a little difference which is statistically significant. Higher SWC is shown by universal screw (23.30 N/mm^2) compare to Confirmat (20.90 N/mm^2). That is why additionally, Tukey test was conducted for evaluation the statistical differences between the screws and material's group at $\alpha=0.05$ and level of confidence of 95% for each type of material. It was shown that only in 3 out of 10 pairwise groups have significant difference of SWC between 2 types of screws. These are the following groups of materials: birch-faced lightweight plywood (23.75 vs 18.91 N/mm^2), 3-ply wood-based panel made from particleboard and MDF with thickness of 20 mm (19.73 vs 14.94 N/mm^2) and beech plywood (53.50 vs 45.36 N/mm^2). In all three of them higher SWC show universal screw. This fact is due to the finest thread and smaller pitch of universal screw which allow better resistance of the screw in the material.

For practical use and direct understanding about the loading capacity of the screws, a graphic with mean values of ultimate loads (F_{max}) under withdrawal force in Newton is presented in Figure 6. This graphic clearly shows that Confirmat screw has higher loading capacity in

absolute value in each type of material. The difference varies between 32% for 3-ply wood-based panel made of particleboard and MDF 4 mm (3PI-MDF-20) to 82% for MDF and 66% for particleboard. This is the reason Confirmat screw to be preferable fastener for furniture made of MDF and particleboard.

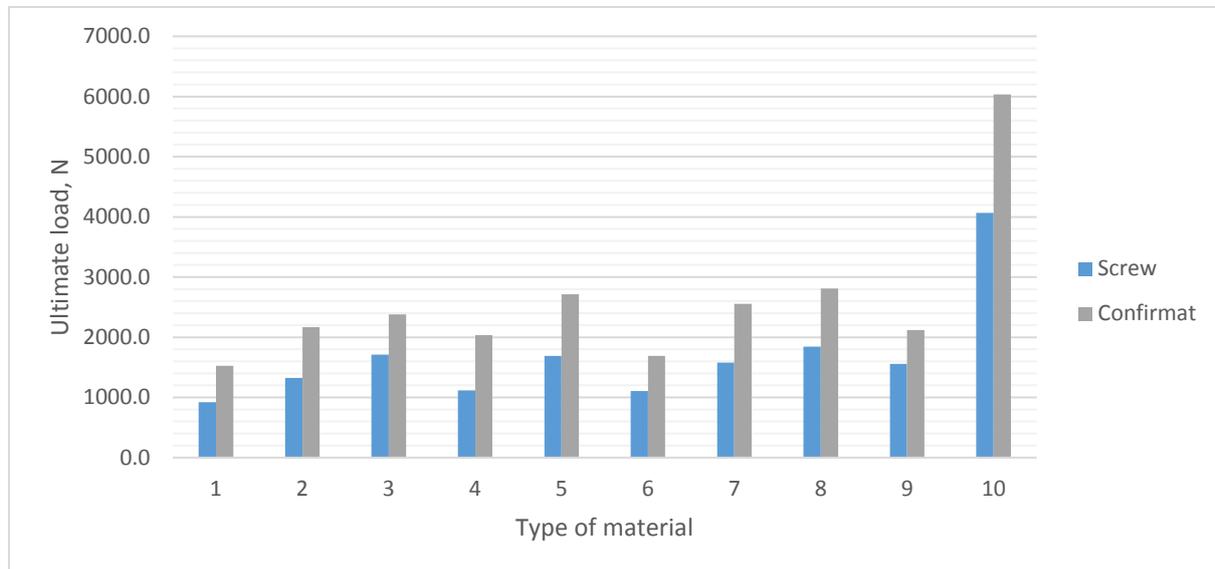


Figure 6. Ultimate loading capacity (F_{max}) of universal screw and Confirmat screw into different wood-based materials

4. CONCLUSIONS

Based on this study conducted with 10 types of wood-based materials and 2 type of screws the withdrawal capacity in the direction perpendicular to the plain were evaluated. The following conclusions can be drawn from the results:

- The type of the wood-based materials has significant influence on the specific withdrawal capacity of the universal screw and Confirmat screw.
- There is no significant difference between the results for specific withdrawal capacity calculated according BDS EN 14366 and type of screw for most of the materials. Only for 3 wood-based materials the difference was statistically proven – beech plywood, birch-faced lightweight plywood and 3-ply panel made from particleboard and MDF with total thickness of 20 mm. The difference is in a favour of universal screw.
- There is no correlation between density of materials and specific withdrawal capacity of the screws.
- Highest specific withdrawal capacity and ultimate loading capacity for both type of screws was performed into beech plywood, OSB, cherry veneered MDF and birch-faced lightweight plywood.
- Lowest specific withdrawal capacity and ultimate loading capacity for both type of screws was performed into laminated particleboard, 3-ply board made of particleboard and laminated HDF with total thickness of 18 mm and MDF.
- The wood-based panels developed for the purpose of this study as a sandwich composite of particleboard and different outer layers performed good withdrawal resistance. The highest value was obtained by 3-ply composite of particleboard and MDF with 4 and 6

mm. Lowest capacity was achieved by the combination of particleboard and laminated HDF.

- For better understanding of the loading capacity of the screws it is recommendable not only the calculative values according to EN 14366 to be announce but the values of ultimate loads as well.
- Highest ultimate loading capacity were achieved by Confirmat into beech plywood (6032 N) and by universal screw into beech plywood (4066 N) and lowest capacity was for universal screw into particleboard (920 N).
- All the tested wood-based materials as well the universal screws and Confirmat meet the requirements for furniture structure design and the results can be used for predicting withdrawal capacity of similar materials and screws.

ACKNOWLEDGMENTS

The research project has been carried out with the financial support of Scientific Research Centre (NIS) at the University of Forestry, Sofia, Bulgaria within the framework of Contract № 29 / 21.01.2016.

References

- Bal, B. (2017): Screw and nail holding properties of plywood panels reinforced with glass fiber fabric. *CERNE*, 23(1), 11-18.
- Bal, B., Akçakaya, E., Gündeş, Z. (2016): Screw-Holding Capacity of Melamine-Faced Fiberboard and Particleboard Used in Furniture Production. *International Furniture Congress*. 13-15 October. Mugla.
- Bal, B., Orhan, H., Bostan, T. (2016): Screw and Nail-Holding Capacities of Combi Plywood Produced from Eucalyptus, Beech and Poplar Veneer. *International Furniture Congress*. 13-15 October. Mugla.
- BDS EN 13446:2003. Wood-based panels - Determination of withdrawal capacity of fasteners.
- Celebi, G., Kilic, M. (2007): Nail and Screw Withdrawal Strength of Laminated Veneer Lumber Made Up Hardwood and Softwood Layers. *Materials and Design*. 21: 894-900.
- Chen, Y., Guo, Z., Liu, S., Tu, D., Fan, H. (2016): Investigation on Withdrawal Resistance of Screws in Reconstituted Bamboo Lumber. *Wood Research*. 61 (5): 799-810.
- Çolakoğlu, M. (2009): Determination of Bending Strength Elongation in Bending Screw Withdrawal Strength and Swelling in Thickness of Some Panels. *Journal of Applied Sciences* 9(22): 4061-4065. ISSN 1812-5654.
- Eckelman, C. (1975): Screwholding Performance In Hardwoods and Particleboards. *Forest Products Journal*. 25 (6): 30-35.
- Eckelman, C. (1988): The Withdrawal Strength of Screws from a Commercially Available Medium Density Fiberboard. *Forest Products Journal*. 38 (5): 21-24.
- EN 1382. Timber structures - Test methods - Withdrawal capacity of timber fasteners.
- EN 320. Fibreboards - Determination of resistance to axial withdrawal of screws.
- Erdil, Y., Zhang, J., Eckelman, C. (2002): Holding Strength of Screws in Plywood and Oriented Strandboard. *Forest Products Journal*. 52 (6): 55-62.
- Haftkhani, A., Ebrahimi, G., Tajvidi, M., Layeghi, M. (2011): Investigation on Withdrawal Resistance of Various Screws in Face and Edge of Wood-Plastic Composite Panel. *Materials and Design*. 32: 4100-4106.

- Jivkov, V. (2002a): Bending strength and stiffness of some end corner joints from 25 mm particleboard. Symposium "Furniture 2002", Technical University-Zvolen, 24-25 October.
- Jivkov, V. (2002b): Influence of edge banding on bending strength of end corner joints from 18 mm particleboard. Symposium "Furniture 2002", Technical University-Zvolen, 24-25 October.
- Jivkov, V., Grbac, I. (2011): Influence of the cyclic loading on bending strength of different end corner joints made of MDF. In International Conference, Wood is good–EU challenges of the sector. Innovawood, University of Zagreb, Faculty of Forestry, Croatia, 21st October, 59-66.
- Jivkov, V., Marinova, A. (2005): Investigation on ultimate bending strength and stiffness under compression of corner joints from particleboard with connectors for DIY furniture. Proceeding International Scientific Conference Interior and Furniture Design. 17-18 October, 2005. 155-165.
- Jivkov, V., Marinova, A. (2009): Influence of the type and shape of the eccentric connectors on ultimate bending strength and stiffness of corner joints from particleboard. 20th International Scientific Conference Wood is good-new materials, quality and design of products. Ambienta, Zagreb, 16 October, ISBN 953292013-7, 91-99.
- Jivkov, V., Marinova, A. (2003): Ultimate bending moment of some corner type joints of structural element made by OSB. DPM, No.1, p. 12-14.
- Joščák, P., N. Langová, N., Tvrdošský M. (2014): Withdrawal Resistance of Wood Screw in Wood-Based Materials. Forestry and Wood Technology. 87: 90-96.
- Kasal, A., Yuksel, M., Fathollahzadeh, A., Erdil, Y., Yildirim, N. (2011): Ultimate Failure Load and Stiffness of Screw Jointed Furniture Cabinets Constructed of Particleboard and Medium-Density Fiberboard. Forest Products Journal. 61 (2): 155-160.
- Kiliç, M , Burdurlu, E , Usta, İ , Özgür Berker, U , Oduncu, P . (2006): Comparative Analysis of the Nail and Screw Withdrawal Resistances of Fir (Abies Mill.), Cherry (Prunus Avium L.), Walnut (Juglans Regia L.) and Oak (Quercus L.) Wood. Düzce Üniversitesi Ormancılık Dergisi, 2 (2), 61-75. Retrieved from <http://dergipark.gov.tr/http-ordergi-duzce-edu-tr-2279-sayfa-anasayfa/issue/4832/291061>
- Kjučukov, G., Enčev, E. (1977a): Der Einfluß der Schraubenabmessungen auf den Ausziewiderstand bei Tannenholz. – Holztechnologie, 18, No 1, 26-29.
- Kjučukov, G., Enčev, E. (1977b): Der Einfluß der Schraubenabmessungen auf den Ausziewiderstand bei Rotbuchenholz. – Holztechnologie, 18, No 3, 149-151.
- Kyuchukov, G., Jivkov, V. (2016): Furniture construction. Structural elements and furniture joints. ISBN: 978-954-91648-6-2, "Bismar", Sofia, 452 p.
- Kyuchukov, G., Kyuchukov, B., Jivkov, V., Marinova, A. (2011): Physical and mechanical and technological properties of wood of some valuable tree species in Bulgaria, ISBN 978-954-323-901-6, „Avangard Prima”, Sofia.
- Kyuchukov, G., Yosifov, N. (1968): Influence of the structure and density of the particle board on the screw resistance. DMP, 11, vol. 3, 13-20.
- Kyuchukov, G., Yosifov, N. (1971): Influence of thread parameters on screws on the resistance of their removal from particle board. DMP, 14, , vol. 8-9, 23-25.
- Kyuchukov, G., Yosifov, N. (1979): Application of particleboards in furniture constructions, Tehnika, Sofia, 355p.
- Kyuchukov, G., Kyuchukov, B. (2016): Wood boards. Determination of the resistance to the removal of connecting elements according to the European standards.DMT, 6, 60-63.

- Marinova, A. (2010): Study on strength and stiffness behaviour of corner joints made of pine wood one layer wood-based panels. Habilitation thesis, University of Forestry, Sofia.
- Özçifçi, A. (2009): The effects of pilot hole, screw types and layer thickness on the withdrawal strength of screws in laminated veneer lumber. *Materials and Design*. 30: 2355-2358.
- Rajak, Z. I. B. H. A., and Eckelman, C. A. (1993): Edge and face withdrawal strength of large screws in particleboard and medium density fiberboard. *Forest products journal*, 43(4), 25-30.
- Semple, K., Smith, G. (2006): Prediction of Internal Bond Strength in Particleboard from Screw Withdrawal Resistance Model. *Wood and Fiber Science*. 38 (2): 256-267.
- Simeonova, R. (2015): "Strength and deformation characteristics of corner joints of structural elements made of plywood". PhD thesis. University of Forestry. Sofia. 166 p.
- Sydor, M., Wołpiuk, M. (2016): Analysis of resistance to axial withdrawal of screws embedded in locally reinforced MDF. *Drewno: prace naukowe, doniesienia, komunikaty*, vol. 59, 173-182.
- Sydor, M., Zmysłony, G., Pinkowski, G., Szymański, W. (2015): The Influence of Pitch on the Holding Power of Screws in Scots Pine Wood. *Forestry and Wood Technology*. 90: 193-197.
- Taj, M., Najjafi, S., Ebrahimi, Gh. (2009): Withdrawal and Lateral Resistance of Wood Screw in Beech, Hornbeam and Poplar. *Wood Products*. 67: 135-140.
- Vassiliou, V., Barboutis, I. (2005): Screw Withdrawal Capacity in the Eccentric Joints of Cabinet Furniture Connectors in Particleboard and MDF. *Wood Science*. 51: 572-576.
- White, C. (2005): Observations on the Development of Wood Screws in North America. Unpublished presentation, Furniture and frame conservation lab., Boston Museum of Fine Arts.
- Yuksel, M., Kasal, A., Erdil, Y. Z., Acar, M., & Kuşkun, T. (2015). Effects of the panel and fastener type on bending moment capacity of L-type joints for furniture cases. *Pro Ligno*, 11(4), 426-443.
- Zhang, J., Efe, H., Erdil, Y., Kasal, A., Han, N. (2005): Moment Resistance of Multiscrew L-type Corner Joints. *Forest Products Journal*. 55 (10): 56-63.

Corresponding author:

V. Jivkov
 University of Forestry, Faculty of Forest Industry, Department Interior and Furniture Design,
 Sofia / Bulgaria
v_jivkov@ltu.bg

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

SPLITTING RESISTANCE OF PLYWOOD IN THE AREA OF COUNTERSUNK HOLES

Vassil JIVKOV¹, Ralitsa SIMEONOVA¹

¹ University of Forestry, Faculty of Forest Industry, Department of Interior and Furniture Design, Sofia / Bulgaria

Key words

*plywood,
split resistance,
countersunk holes,
split resistance test
method.*

Abstract

New method was developed for experimental evaluation of splitting resistance of structural elements made of plywood in the area of countersunk holes. Stress concentration around the countersunk holes is an important problem for any plywood construction. The aim of this study was to establish information about splitting resistance of elements made of plywood in the area of countersunk holes by using a new method of testing. Test specimens, loading devices and method of loading have been described. Plywood with thickness of 20 mm and 3 different widths of the test specimens has been produced – 30, 40 and 50 mm. Test has been made with 3 different jigs for holes with diameters of Ø4, Ø5 and Ø6 mm. Additionally, the influence of the distance between the hole and the end edge of the test specimens has been investigated. Results indicated that within this test the diameter of the hole and countersunk parameters have considerable influence on the split resistance of plywood elements. Distance from the hole to the end edge has effect on resistance as well. Less influence on the splitting resistance shows the width of the elements.

Corresponding author: v_jivkov@ltu.bg, Jivkov V., University of Forestry, Faculty of Forest Industry, Department of Interior and Furniture Design, Sofia / Bulgaria

1. INTRODUCTION

Plywood is well known and widely used material in building and furniture industry. The use of wood-based composites, and in particular plywood, is increasing because of their high strength, high stiffness, dimensional stability, relatively low density and long fatigue life. As the application of plywood has increased, the need of more knowledges for design aspects about the behaviour of the material increased. Despite that plywood has many advantages, it has also disadvantages. One of the main problems with the use of plywood as a construction material for furniture is the risk of its splitting during installation and subsequent functional loading in the area of holes where screws or different fittings are installed. The possibility of splitting is increased when the countersunk hole is done and the conical head of the connecting elements is embedded in the direction parallel to the plies. The countersunk bolts, screws and Conformat are often used in furniture industry and they contribute to creating compressive forces in the area of countersunk and under the effect of stress concentration these zones are potential initiation areas of crack initiation. Tension forces in the direction perpendicular to the thickness

of the panels are trying to split the material. This can occur both on the glue line, destroying the adhesion between the layers and through the layers of veneer (Fig. 1).

The investigation of the effect of countersunk diameters, countersunk angle and depth, plate thickness and width on the stress concentration in the area of the countersunk has been carried out by many authors (Shivakumar et al. 1992; Park and Grandt 2007; Darwish et al. 2013; Zhang et al. 2015). The objective of this studies has been to describe the effect of fastener load transfer on the cracking behaviour at countersunk fastener holes in different composites used in building construction, automotive or aerospace structures. In some, computational model using the finite element analysis were done and in some an experiment. Mostly these studies are concentrated on single lap joints of non-wood materials. All of them show that countersunk hole always results to stress concentration which reflect to load carrying capacity of the countersunk bolt.

Very few data are found in the scientific literature concerning the influence of the countersunk hole on the possible splitting of plywood structural elements jointed with screws and bolts with countersunk head. Simeonova (2015) studied different corner joint made of plywood to evaluate their strength and stiffness characteristics. She reported that in most of the studied dismountable joints made of plywood structural elements where the screws or Confirmat are used, main problem is the split of the material parallel to the layers in the area of the countersunk. This is clearly indicated not only for end type of joints but for T-shape as well (Fig. 1).

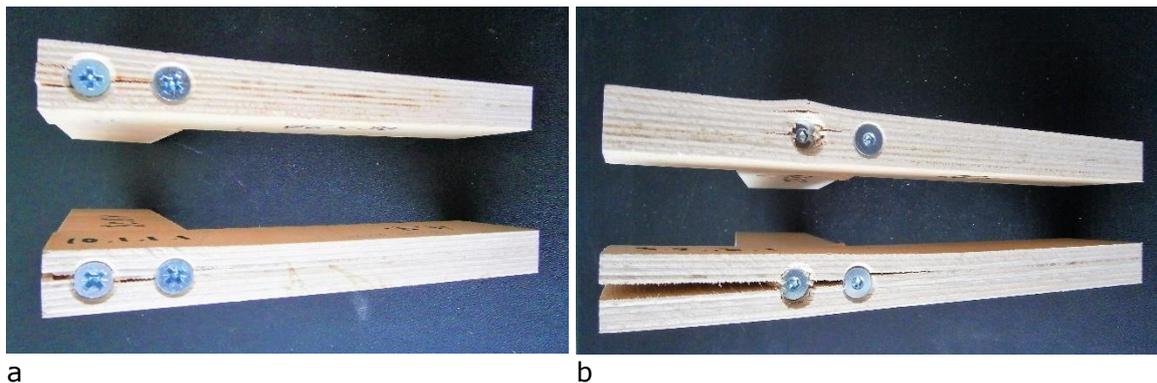


Figure 3. Typical failure of end and T-shape corner joints made of plywood and connected by screws and Confirmat under compression bending load (Simeonova 2015):

a – end corner joint with screw $\text{Ø}6 \times 80$ mm; b – T-shape corner joint with Confirmat $\text{Ø}7 \times 70$ mm.

Smardzewski and Ozarska (2005) were developed mathematical model of a semi-rigid angle joint of the Confirmat type screw loaded in bending and they come to a conclusion that the maximum screw tightening moment did produce breaking stresses in the board compressed by the head of the Confirmat.

No reports or data on the splitting resistance of wood-based materials, in particular of plywood with countersunk holes were found in the literature.

Determination of the ultimate splitting loads in the area of a countersunk hole of veneer plywood elements depending on different parameters of the joints is of particular importance for improving their strength which will make the construction of plywood furniture more reliable and longer service life.

For this reason, a new method has been developed for determining the splitting load in the area of a countersunk hole used for mounting the different type of screws, bolts and furniture fittings into veneered plywood elements. Load has been applied in the direction of the hole axis which is parallel to the plies and simulate the mounting of the connecting elements into countersunk holes as well as their subsequent functional load.

For the purpose of this study, the influence of the following parameters of the countersunk hole on the splitting resistance of plywood is determined: the diameter of the hole, the distance from the end edge to the axis of the hole and the width of the test element.

2. METHODS AND MATERIALS

PRINCIPLE OF THE TEST METHOD

The principle of the test method for evaluation the splitting resistance of plywood is based on a compression force applied by test machine with a special device placed in the countersunk hole located in the edge of the test specimen. During the test, the device transmit the force F from the testing machine to the specimen consisting of vertical and horizontal component. The vertical force creates a compression on the surface of the conical area of the countersunk and the horizontal force a tension in the adhesion line and veneer layers which cause split in the area of the countersunk hole. The ultimate load which indicates the initial split of the plywood is measured.

MATERIALS

For the purpose of this study plywood from rotary-cut beech veneer with quality mark 'A', were manufactured by industrial manufacturer "Nikrom-Veneer" Ltd, Petkovo, Bulgaria. The thickness of the plywood was $\delta=20$ mm. Plywood panels were produced in size of 920 by 500 mm. Two-component urea formaldehyde adhesive manufactured by "DINEA"- Hungary, with adhesive spread quantity of 150 g/m^2 was used. The production of the plywood was carried out on "Vecciato VALTER" multi-storey pressing machine. Hot-press schedule was as follow: hot-press temperature of 110°C , press time of 15 min, and specific pressure of 1.3 N/mm^2 .

The physical and mechanical characteristics of the plywood are as follows (Jivkov et al. 2013):

- Density - $760,1 \text{ kg/m}^3$;
- Bending strength under loading perpendicular to panel layers - $55,58 \text{ N/mm}^2$;
- Bending strength under loading parallel to panel layers - $63,16 \text{ N/mm}^2$;
- Modulus of elasticity in bending under loading perpendicular to the veneer layers- 5286 N/mm^2 ;
- Modulus of elasticity in bending under loading parallel to the veneer layers - 6650 N/mm^2 .

SPECIMEN SHAPE

The shape and dimensions of the test specimen for determining the splitting resistance in the direction parallel to the layers of plywood made of beech veneer are shown in Figure 2. The length of the test specimen is depending of the distance from the end edge to the axis of hole l_1 . The size l_2 has to be at least twice the size l_1 . Totally 36 series have been prepared, each consisted of 10 specimens with length (l) of 150 mm and thickness (δ) of 20 mm. The influence of 3 factors on the splitting resistance have been investigated: the diameter (d_1) of the hole with the relevant parameters of the countersunk, the distance of the axis of the hole to the end of the sample (l_1) and the width of the test specimen (b). Three diameters (d_1) of the hole were chosen as most popular for screws and bolts in the furniture and woodworking industry - $\text{Ø} 4$ mm with

the countersunk dimension of $\text{Ø } 8$ (d_2) x 2.4 mm (h); $\text{Ø } 5$ mm with countersunk dimension of $\text{Ø } 10$ (d_2) x 2,9 mm (h) and $\text{Ø } 6$ mm with countersunk dimension of $\text{Ø } 12$ (d_2) x 3,4 mm (h). All the dimensions of the 3 types of countersunk are given in Table 1. Distance of the axis of the hole to the end edge of the sample (l_1) were 15, 30, 45 and 60 mm. The width of the test specimens was 30, 40 and 50 mm. All combinations in between the factors were done. All test specimens were conditioned at 20 ± 2 °C and at $65\pm 3\%$ humidity for 1 week.

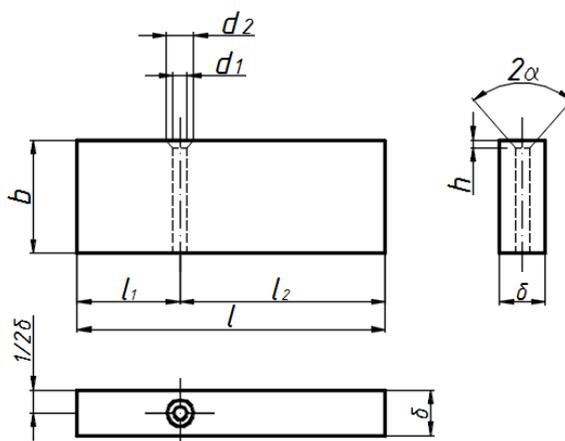


Figure 2. Type and parameters of test specimen made of plywood

Table 1. Dimensions of the countersunk hole

№	d_1 , mm	d_2 , mm	h , mm	α°
1	Ø4	Ø8	2.4	39.8
2	Ø5	Ø10	2.9	40.8
3	Ø6	Ø12	3.4	41.4

LOADING DEVICE

For the purpose of this study 3 type of loading devices were designed and produced. Each of them had the dimensions as described in Table 2 and shown in Figure 3. The material is stainless steel class EN 1.4301.

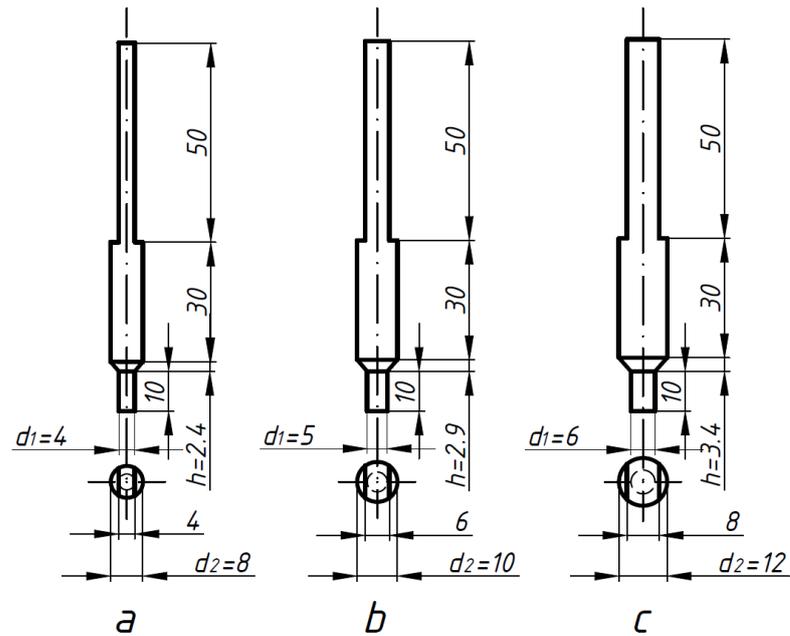


Figure 3. Type and dimensions of loading devices for splitting test in the area of countersunk holes:
 a – Ø4 mm; b – Ø5 mm; c – Ø6 mm

TEST METHOD

Tests were done according to the test method principle describe above. The loading scheme is shown in Figure 4. Universal testing machine was used where the special loading devices were fixed. The loading speed was set to 5 mm/min. The ultimate splitting load F was measure in Newtons.

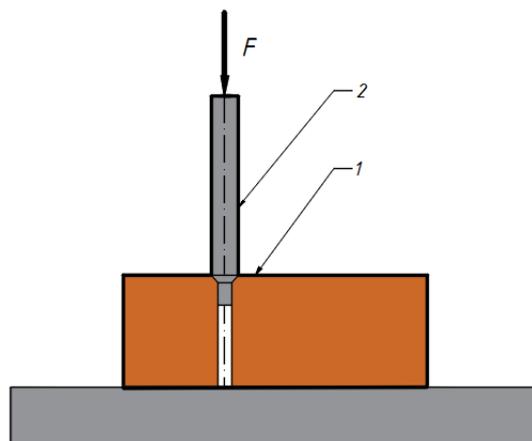


Figure 4. Loading scheme for evaluation of splitting resistance:
 1 - loading device; 2 - test specimen made of plywood

The data obtained from the test were statistically analysed. One-way ANOVA was used to determine whether there is a statistical significant difference between the groups and Duncan test was used to determine between which groups the difference is at significant level with a confidence interval of 95%.

3. RESULTS AND DISCUSSION

The results from the test carried out to determine the splitting resistance of plywood in the area of countersunk holes are given in Table 2. Statistical data for the mean values of ultimate splitting load (F) in Newtons are shown in descending order, from largest to smallest values, according to the investigated factors, followed by descriptive statistic included standard deviation (SD , N) and coefficient of variation (CoV , %). The abbreviation of the factors is based on combination of diameter of the hole (d_l), width of the test specimen (b) and distance from the end edge (l_l). Additionally, are given the group of homogeneity (HG) according to Duncan test at significant difference of $\alpha=0.05$ and level of confidence of 95%.

Among the factors it was found that the diameter of the countersunk hole (d_l) is most important. The highest ultimate splitting load was shown by the group of samples with diameter (d_l) $\varnothing 6$ mm and lowest by the group with diameter (d_l) $\varnothing 4$ mm. The force increased in average with 23% between the groups of $\varnothing 4$ to $\varnothing 5$ and 27% between $\varnothing 5$ and $\varnothing 6$. This is due to the increase of the conical area where the loading device is acting on the surface of the countersunk hole. For diameter of $\varnothing 4$ mm the conical area is 58.4 mm^2 , for $\varnothing 5$ mm – 89.5 mm^2 and $\varnothing 6$ mm – 127.2 mm^2 . No data were obtained for diameter of $\varnothing 4$ and distance from the end edge because in that case the plywood was loaded more in compression than in splitting. The difference between the highest splitting load of 9181 N obtained by test specimens $d_{16-b50-l_160}$ and lowest of 5876 N obtained by $d_{14-b40-l_130}$ is 36%.

Table 2. Statistical data for the splitting load of plywood in the area of countersunk hole

№	Factor	Means, N	SD, N	CoV, %	HG	№	Factor	Means, N	SD, N	CoV, %	HG
1	$d_{16-b50-l_160}$	9181	618.7	6.7	A	18	$d_{15-b30-l_145}$	7317	453.4	6.0	EF
2	$d_{16-b50-l_145}$	9156	634.2	6.9	A	19	$d_{15-b50-l_130}$	7251	889.5	12.6	EF
3	$d_{16-b50-l_130}$	9132	444.0	4.9	A	20	$d_{15-b40-l_130}$	7224	620.4	8.7	EF
4	$d_{16-b40-l_160}$	9116	661.5	7.3	A	21	$d_{15-b30-l_130}$	7210	441.6	5.8	EF
5	$d_{16-b40-l_145}$	9090	544.9	6.0	AB	22	$d_{15-b50-l_115}$	6997	428.2	6.1	FG
6	$d_{16-b30-l_160}$	9053	441.9	4.9	AB	23	$d_{15-b40-l_115}$	6684	766.5	11.6	G
7	$d_{16-b30-l_145}$	9052	735.6	8.1	AB	24	$d_{15-b30-l_115}$	6615	719.9	10.6	G
8	$d_{16-b40-l_130}$	8966	379.2	4.2	ABC	25	$d_{14-b50-l_145}$	6161	128.2	2.1	H
9	$d_{16-b30-l_130}$	8808	456.0	5.2	ABCD	26	$d_{14-b50-l_130}$	6096	484.0	7.9	HI
10	$d_{16-b50-l_115}$	8634	369.8	4.3	BCD	27	$d_{14-b40-l_145}$	5944	323.6	5.4	HIJ
11	$d_{16-b40-l_115}$	8579	503.9	5.9	CD	28	$d_{14-b40-l_130}$	5876	228.8	3.9	HIJ
12	$d_{16-b30-l_115}$	8414	420.4	5.0	D	29	$d_{14-b30-l_145}$	5767	157.2	2.7	HIJ
13	$d_{15-b50-l_160}$	7547	559.3	7.4	E	30	$d_{14-b30-l_130}$	5690	214.8	3.8	IJ
14	$d_{15-b50-l_145}$	7435	422.0	5.7	EF	31	$d_{14-b30-l_115}$	5523	218.4	4.0	J
15	$d_{15-b40-l_160}$	7415	271.3	3.9	EF	32	$d_{14-b50-l_115}$	5513	224.4	4.1	J
16	$d_{15-b40-l_145}$	7375	527.8	7.1	EF	33	$d_{14-b40-l_115}$	5493	570.7	10.4	J
17	$d_{15-b30-l_160}$	7358	212.7	3.0	EF						

The difference in the most critical combination of factors where distance from the end edge (l_1) is 15 mm and width (b) of the test sample is 30 mm for $\varnothing 6$ mm (8414 N) and for $\varnothing 4$ mm (5523 N) is 36.4%.

Typical failure of the test specimens is characterized by initial crack appearance that grows to layer splitting either in the adhesion line or through the layers which is identical to the information given by Simeonova (2015).

According to the one-way ANOVA and pairwise comparison conducted by Duncan test at significance of $\alpha=0.05$ and level of confidence of 95% given in Table 2 was found that the results of ultimate splitting loads are divided in 10 homogeneous groups. These groups confirm the conclusions that the size of the countersunk hole is of main importance for splitting resistance of plywood, following by distance from the end edge (l_1) where differences are significant for 15 and 30 mm, and when it is over 30 mm this factor becomes less important and over 60 mm should be expected that it has no influence. The width of the test specimens in the diapason between 30 and 50 mm has the lowest or no influence on the splitting resistance of plywood. This can be seen at Figure 5 where the influence of the diameter (d_1) and the distance (l_1) to the splitting load is shown with Box & Whisker plot graphic. The height of the boxes depends on the variation of the width of the test specimens.

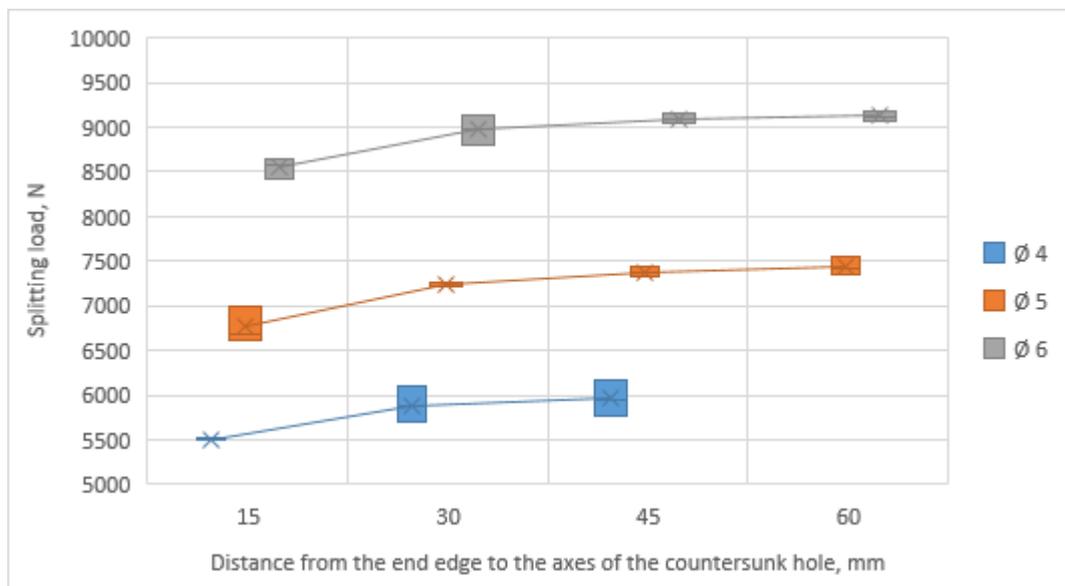


Figure 5. Splitting loads of different hole diameters ($\varnothing 4$, $\varnothing 5$ and $\varnothing 6$) depending on distance from the countersunk hole axes to the end edge of the test specimen

4. CONCLUSIONS

In this study based on a new method developed for evaluation of splitting resistance of plywood in the area of countersunk holes were investigated the influence of hole diameter, distance of hole from the end edge and width of tested specimens to the ultimate splitting load.

The study confirms the thesis that countersunk hole in composites, in particular in plywood in the direction parallel to the layers, creates stress concentration and this increase the danger to reduce the mechanical properties which may lead to split in the plywood and further failure.

Results indicated that splitting resistance of plywood is strongly dependent on the diameter of the countersunk hole. Also, it was determined, that among the other 2 parameters, distance from

the end edge to the axis of the hole has greater influence and the width of the sample in the field of 30-50 mm has less or no influence.

Highest splitting load was achieved by the test specimens with countersunk holes with diameter of Ø6 mm and lowest by diameter of Ø4 mm. The most dangerous zone for failure is the distance from the end edge to the axis of the hole between 15 and 30 mm. Further increase of this distance reduce the risk of material split.

The new method for evaluation of the splitting resistance of plywood in the area of countersunk holes can be used successfully for investigating the other parameters of the countersunk hole or other wood-based materials such as MDF, particleboards and etc.

References

- Darwish, F., Tashtoush, G., Gharaibeh, M. (2013): Stress concentration analysis for countersunk rivet holes in orthotropic plates. *European Journal of Mechanics-A/Solids*, 37, 69-78.
- Jivkov, V., Simeonova, R., Marinova, A. (2013): Influence of the veneer quality and load direction on the strength properties of beech plywood as structural material for furniture. *Innovation in Woodworking Industry and Engineering Design*, 1/2013 (3): 86-92.
- Park, C. Y., Grandt, A. F. (2007): Effect of load transfer on the cracking behavior at a countersunk fastener hole. *International journal of fatigue*, 29(1), 146-157.
- Shivakumar, K. N., & Newman Jr, J. C. (1992): Stress concentrations for straight-shank and countersunk holes in plates subjected to tension, bending, and pin loading. *NASA Technical Paper 3192*, June, pp 34.
- Simeonova, R. (2015): Strength and deformation characteristics of corner joints of structural elements made of plywood. PhD thesis. University of Forestry. Sofia. 166 p.
- Smardzewski, J., Ożarska, B. (2005): Rigidity of cabinet furniture with semi-rigid joints of the Confirmat type. *Electronic Journal of Polish Agricultural Universities, Wood Technology*, 8(2).
- Zhang, Q., Wang, S., Cheng, X., Qi, J., Dong, G. (2015): Effect factors study on the pin load distribution of multi-countersunk bolt composite laminate joints. *20th International Conference on Composite Materials, Copenhagen, 19-24th July*.

Corresponding author:

V. Jivkov
University of Forestry, Faculty of Forest Industry, Department Interior and Furniture Design,
Sofia / Bulgaria
v_jivkov@ltu.bg

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

THE DETERMINATION OF OPTIMAL PROCESS PARAMETERS OF MDF IN THE POCKET MILLING USING CNC MACHINE

Musa KAYA, Hasan Ozgur IMIRZI, Cevdet SOGUTLU¹

¹Gazi University, Technology Faculty, Wood Products Industrial Engineering Department, Ankara / Turkey

Key words	Abstract
MDF, Pocket milling, Tool path, Step over, Depth of cut , CNC.	This study discusses the optimum tool path, step over, and depth of cut for pocket milling in CNC machine for MDF (Medium-density fiberboard) which is widely used in the production of furniture and decoration elements. For this purpose, MDF specimens with 18 mm thickness conforming to TS 64-3 EN 622-3 standard were processed to pocket milling with 3 different tool paths, 2 step over, and 2 depth of cut in the Z1 model wood CNC machine produced by SCM group. Step over distances were 50% and 70% of the bit diameter, cutting depths were 4 mm and 8 mm. A total of 120 test specimens were prepared in the dimensions of 18 x 300 x 300 mm. The surface roughness values of specimens were determined using a stylus-type profilometer Mitutoyo-SJ 301 according to the ISO 4287 standards. The surface roughness was evaluated according to mean roughness value (<i>Ra</i>). The data was evaluated at a 0.99 level of reliability in the MSTAT-C package software. The results showed that smoother surfaces could be obtained in the tool path of counter milling, step over of 50%, and cutting depth of 4 mm.

Corresponding author: cevdet@gazi.edu.tr, Sogutlu, C., Gazi University, Technology Faculty, Wood Products Industrial Engineering Department, Ankara / Turkey

1. INTRODUCTION

Wood and wood-based materials are widely used for interior and exterior decoration applications due to their superior properties, such as the ease to process, low energy consumption requirement during the processing, their availability in variable different colors and patterns, their sound and heat transmission characteristics, and their suitability for surface processes (Kopac and Sali 2003, Aydin and Colakoglu 2005). Medium density fiberboard (MDF) is widely used in the furniture industry and displaced a very high portion of solid wood (Gu *et al.* 2017).

Wood and wood-based material used in the production of furniture and decorative pieces is processed through various steps, including sawing, planing, milling, and sanding (Fujiwara *et al.* 2005, Sogutlu 2010, *et al.* 2016).

The milling of MDF is a very often used in the wood industry, especially in furniture manufacturing, machining process. During manufacturing a high level of cutting performance and long life of cutting tools are the most important from practical point of view. Both above things (cutting performance and tool life) are closely related to cutting speed (Porankiewicz 1993, Stefaniak 1970, Szymanowski and Gorkski 2011). Many researchers have tested the influence of cutting parameters on surface roughness in MDF milling (Davim *et al.* 2009, Sütçü and Karagöz 2012, Aguilera 2000).

Surface roughness is defined as the irregularities, which are rather small and repeated in a periodical manner, and that are excluded from the shape and wave defects formed on the surface of a material processed by various methods (Stumbo 1963, Peters and Cumming 1970).

The surface roughness is an important factor that influences the upper surface finishing and bonding strength of adhesives (Söğütü 2010). On the other hand, the surface roughness of MDF is significant when panels are used as the substrate for overlays such as thin melamine paper or vinyl. Fine irregularities on the board surface resulting from sanding/calibration will show through the overlays, affecting product grade and quality (Hiziroglu 1996, Gurau and Irle 2017, Gurau *et al.* 2017).

Consequently, it is necessary to select correctly the procedure parameters to obtain a high quality surface after processing either in conventional or CNC machines.

In this study, the effects on surface roughness of different processing parameters have been determined for the Medium Density Fiberboard (MDF), which is used extensively today in the furniture and interior decoration sector, by having it undergo pocket milling in a Computer Numerically Controlled (CNC) machine that has the capability of making high speed and sensitive procedures.

2. EXPERIMENTAL

MDF was used in the preparation of the test specimens that was according to the TS 64-3 EN 622-3 standards, with a humidity of 6%, a specific gravity of 0.7 gr/cm³ and a thickness of 18 mm. The specimens underwent pocket milling in the SCM Model Automatic CNC located in the panel processing center at the application laboratories of the Gazi University under the conditions of a 24000-rpm rotation speed, 8000 mm/min. feed speed, 50% and 70% step over and 4 mm and 8 mm depth of cut according to the principles of the outside lines tool path (A), linear lines tool path (B) and spiral tool path (C) (Fig.1a). Two each razor blade cutters (turnblade knife) with a diameter of 16 mm from the NETMAK Company were used (Fig. 1b).

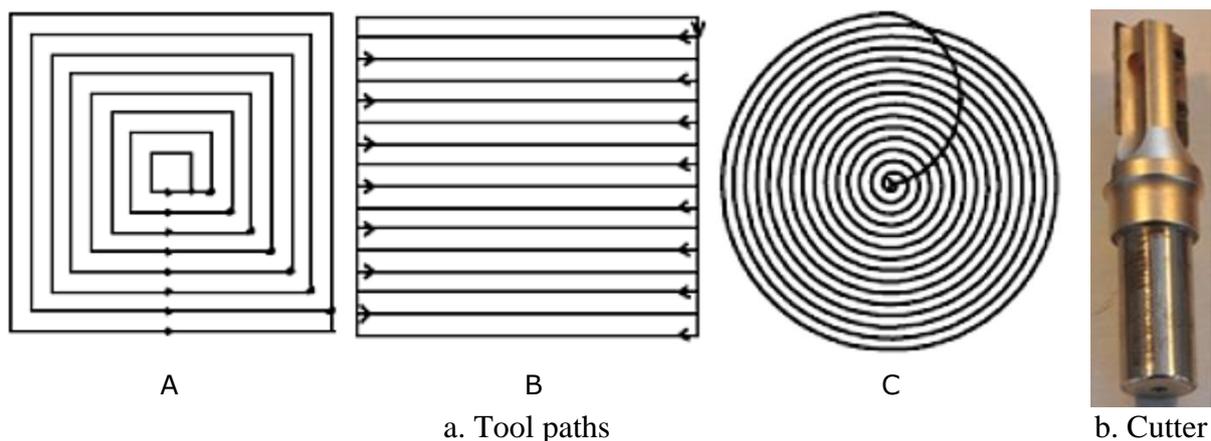


Figure 1. Tool paths and cutter used in the experiments

The test specimens that would provide for the operation of the roughness measurement machine in an easy manner on the MDF surface that was processed for determining the roughness values, were drawn with the CAD-CAM program as shown in Fig. 1 in a square geometry in the measurements of 30 cm x 30 cm and in a circular geometry with a 30-cm diameter and were processed by determining the codes at the CNC processing center.

In this study, the surface roughness was evaluated according to the principle of average surface roughness (Ra) by complying with the ISO 4287 and TS 2495 EN ISO 3274 standards (Fig. 2). The Mitutoyo Surftest SJ 301 Model Surface Roughness Analyzer, which can measure the consecutive profile change for determining the surface roughness, was used. The equipment has a 10 mm/min. measuring speed, 5 μm stylus tip radius and a 90° pivot angle. The measuring process was made in a perpendicular direction to the fibers according to the principle of a 2.5 mm specimen length and 5 cut-offs.

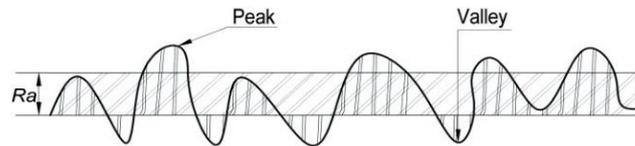


Figure 2. Surface roughness (Ra) (Sogutlu *et al.* 2016)

Tool path, step over, and depth and the dual interactions with these factors and the effect on surface roughness in MDF was determined with the “Multiple Analysis of Variance” and in case it emerged statistically different, according to a 95% level of reliability, then the LSD (Least Significant Difference) test was used for the importance among groups of these differences. Thus, the tool path geometry, amount of step over and depth of cut from the factors taken into the experiment and the enumerating of success among these with each other were determined by separating them into homogeneity groups.

3. RESULTS AND DISCUSSION

The statistical data on average surface roughness (Ra) are given in Table 1.

Table 1. Surface roughness values (Ra)

Tool path geometry	Step over	Depth of cut (mm)	Surface Roughness (Ra) – (μm)			
			\bar{X}	Min.	Max.	CV (%)
Outside lines tool path (A)	50% (8 mm)	4	15.17	11.11	18.44	15.3
		8	12.17	9.26	14.23	11.1
	70% (11,2 mm)	4	14.66	11.55	17.76	16.4
		8	12.53	10.54	14.72	10.5
Linear tool path (B)	50% (8 mm)	4	16.07	11.18	20.96	17.4
		8	14.97	11.60	19.25	15.9
	70% (11,2 mm)	4	13.57	11.31	17.45	15.0
		8	15.36	13.04	18.90	11.4
Spiral tool path (C)	50% (8 mm)	4	16.56	13.26	20.67	17.3
		8	13.32	11.04	17.16	13.1
	70% (11,2 mm)	4	14.37	12.17	16.42	10.2
		8	13.87	11.21	19.27	16.8

The analysis of variance result was to determine whether the effect on surface roughness (Ra) in terms of tool path geometry, step over, and depth of cut are given in Table 2.

Table 2. Analysis of Variance

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
Tool Path Geometry (A)	2	38,130	19,065	4,2168	0,0172
Step Over (B)	1	12,708	12,708	2,8106	0,0965*
Interaction (A*B)	2	5,170	2,585	0,5717	NS
Depth of Cut (C)	1	55,665	55,665	12,3120	0,0007
Interaction (A*C)	2	46,098	23,049	5,0979	0,0077
Interaction (B*C)	1	35,154	35,154	7,7754	0,0063
Interaction (A*B*C)	2	6,355	3,177	0,7028	NS
Error	108	488,291	4,521		
Total	119	687,570			

Note: *: Significant at 95% confidence level, NS: No significance

The tool path geometry (A), amount of step over (B), depth of cut (C), interaction A*C and interaction B*C for surface roughness (Ra) were found to be statistically significant, whereas, the amount of step over (B) and interaction A*B and interaction A*B*C were found to be statistically insignificant.

The Duncan test comparison results at the level of tool path geometry and depth of cut have been given in Table 3.

Table 3. Comparison results of the Duncan tests for tool path geometry and depth of cut

Surface Roughness (Ra) - (µm)									
Tool Path Geometry (LSD ±0.9414)						Depth of Cut (LSD ±0.7687)			
A		B		C		4 mm		8 mm	
\bar{X}	HG	\bar{X}	HG	\bar{X}	HG	\bar{X}	HG	\bar{X}	HG
3.63 ¹	B	4.99 ¹	A	4.53 ¹	A	5.06 ¹	A	3.70 ¹	B
\bar{X} : Mean, HG: Homogeneity Groups									

Note: Number followed by the same letter indicates no statistical significant differences (Least-Significant-Difference Test with 0.95 confidence).

According to Table 3, the highest surface roughness value (Ra) at the tool path geometry was obtained in the linear. The difference between the linear and spiral was insignificant. To make a process at a depth of 4 mm at the level of depth of cut produced a rougher surface compared to making the process at a depth of 8 mm. The reason for a decrease in surface roughness with an increase in depth of cut can be stemming from the fact that thanks to the cavity parts being fewer in the sections close to the surface of the MDF, it has a more homogeneous structure and that in the stylus scan measuring method, the cavities of materials are also perceived to be roughness.

The Duncan test comparison results of the tool path geometry-depth of cut interaction have been given in Table 4.

Table 4. Comparison results of the Duncan tests for tool path geometry-depth of cut

Tool Path Geometry	Surface Roughness (R_a) - (μm)			
	Depth of Cut - 4 mm		Depth of Cut - 8 mm	
	\bar{X}	HG	\bar{X}	HG
Outside lines tool path (A)	14.91	AB	12.35	C
Linear tool path (B)	14.82	AB	15.16	A
Spiral tool path (C)	15.46	A	13.59	BC
LSD ± 1.331 , \bar{X} : Mean, HG: Homogeneity Groups				

Note: Number followed by the same letter indicates no statistical significant differences (Least-Significant-Difference Test with 0.95 confidence).

When the average surface roughness (R_a) dual interaction of the factors of tool path and depth of wood shavings were considered according to Table 4, then the highest R_a value was obtained in the pocket milling process that was realized at a 4-mm depth of cut of the spiral tool path.

The Duncan test comparison results of the step over-depth of cut interaction have been given in Table 5.

Table 5. Comparison results of the Duncan tests for step over-depth of cut

Step Over	Surface Roughness (R_a) - (μm)			
	Depth of Cut - 4 mm		Depth of Cut - 8 mm	
	\bar{X}	HG	\bar{X}	HG
50%	15.93	A	14.49	B
70%	14.20	B	13.92	B
LSD ± 1.087 , \bar{X} : Mean, HG: Homogeneity Groups				

Note: Number followed by the same letter indicates no statistical significant differences (Least-Significant-Difference Test with 0.95 confidence).

When the average surface roughness (R_a) dual interactions of the factors of step over and depth of wood shavings were considered according to Table 5, then the lowest R_a value appeared at an 8-mm depth of wood shavings for the 50% step over.

4. CONCLUSIONS

Many furniture components have been used in furniture production, from the past to the present, both veneered and painted. Consequently, one of the most important factors in the surface being of high quality prior to these types of operations is the definition with digital data of the processes made for being able to obtain surface roughness at low values and it is necessary to be able to control the situations of influence by the variables on the surface quality.

The results obtained in this study show that when MDF underwent the pocket milling operation in the CNC machine, then it affected the tool path geometry, depth of cut and step over factors. The lowest surface roughness (R_a) value was obtained with the outside lines tool path. On the other hand, it was observed that to make a process at an 8-mm cutting depth did not increase the surface roughness (R_a), on the contrary, it decreased. A similar situation, by also determining the step over, it was produced at a lower level of surface roughness (R_a) at 70% compared to 50%. It was reported in the literature that for surface roughness to be at lower

levels an important role was played in the success of the processes that would be made later to the surface and in increasing the quality of the product (Söğütlü 2010, Hizirolu 1996, Gurau and Irle 2017, Gurau *et al.* 2017).

Just as there would be a decrease in the surface roughness and that it can increase the economic value of the product, a decrease in the amount of wastage in materials, can also provide for a decrease in the cost of products by directly affecting it. This is observed to be a positive production behavior from the aspect of competition. Consequently, it can be proposed that studies are made for determining the optimal parameters in the processing of different materials with the CNC machines, for which the area of use has gradually broadened.

References

- Aguilera, A., Meausoone, P.J., Martin, P., (2000), "Wood material influence in routing operations: The MDF case", *Holz als Roh- und Werkstoff* 58(4): 278-283.
- Aydin, I., Colakoğlu, G., (2005), "Effects of Surface Inactivation, High Temperature Drying and Preservative Treatment on Surface Roughness and Color of Alder and Beech Wood", *Applied Surface Science*, 252: 430-440.
- Davim, J.P., Clemente, V.C., Silva, S., (2009), "Surface roughness aspects in milling MDF (Medium Density Fibreboard)", *Int. J. Adv. Manuf. Technol.* 40(1-2): 49–55.
- Fujiwara, Y., Fujii, Y., Okumura, SH., (2005), "Relationship between Roughness Parameters Based on Material Ratio Curve and Tactile Roughness for Sanded Surfaces of Two Hardwoods", *Journal of Wood Science*, 51:274–277.
- Gu, J., Hu, C., Zhong, R., Tu, D., Yun, H., Zhang, W., & Leu, S. Y., (2017), "Isolation of cellulose nanocrystals from medium density fiberboards", *Carbohydrate Polymers*, 167, 70-78.
- Gurau, L., & Irle, M., (2017), "Surface Roughness Evaluation Methods for Wood Products: a Review", *Current Forestry Reports*, 3(2), 119-131.
- Gurau, L., Ayrilmis, N., Benthien, J. T., Ohlmeyer, M., Kuzman, M. K., & Racasan, S., (2017), "Effect of species and grinding disc distance on the surface roughness parameters of medium density fiberboard", *European Journal of Wood and Wood Products*, 75(3), 335-346.
- Hizirolu, S., (1996), "Surface roughness analysis of wood composites: a stylus method", *Forest Prod Journal*, 46(7/8):67–72.
- ISO 4287, (1997), "Geometrical product specifications surface texture profile method terms, definitions and surface texture parameters", International Organization for Standardization.
- Kopac, J., Sali, S., (2003), "Wood: an Important Material in Manufacturing Technology", *Journal of Materials Processing Technology*, 133: 134-142.
- Peters, C., Cumming, D.S., (1970), "Measuring wood surface smoothness: A Review". *Forest Products Journal*, 20(12): 40-43.
- Porankiewicz B., (1985), "Wybrane problemy z narzedzi skrawajacych do obróbki drewna", Wydawnictwo Akademii Rolniczej w Poznaniu.
- Söğütlü, C., (2010), "The effect of some factors on surface roughness at planing process of cedar wood," *Gazi University, Journal of Polytechnic*, 13(3), 177-181.

- Söğütlü, C., Nzokou, P., Koc, I., Tutgun, R., and Döngel, N., (2016), "The effects of surface roughness on varnish adhesion strength of wood materials," *Journal of Coatings Technology and Research*, 13(5), 863-870.
- Stefaniak W.,(1970), "Wpływ szybkości skrawania na tępienie się ostrzy pil tarczowych znakładkami z węglików spiekanych przy pilowaniu płyt wiórowych", *Folia For. Pol. B*, 9:66-7.
- Stumbo, D.A., (1963), "Surface texture measurement methods". *Forest Products J.*, 13: 299-304.
- Sütçü A., Karagöz Ü., (2012), "Effect of machining parameters on surface quality after face milling of MDF", *Wood Research*, 57 (2): 231-240.
- Szymanowski K., Górski J., (2011), "Relationship between cutting speed and tool life observed for MDF milling process", *Annals of Warsaw University of Life Sciences – SGGW, Forestry and Wood Technology No 76*, 116-119, (Ann. WULS-SGGW, Forestry and Wood Technology 76.).
- TS 2495 EN ISO 3274, (2005). Geometrical product specifications (GPS) - surface texture: profile method - nominal characteristics of contact (stylus) instruments, Turkish Standard Institute.
- TS 64-3 EN 622-3, (2005), "Fiberboards - Specifications-Part 3: Requirements for medium boards, Turkish Standard Institute.

Corresponding author:

Cevdet Sogutlu

Department of Wood Products Industrial Engineering, Technology Faculty, Gazi University
06500 Ankara, Turkey

E-mail: cevdet@gazi.edu.tr

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

COMPUTER AIDED ERGONOMICS IN FURNITURE DESIGN: BABY CRIB CASE STUDY

Halil KILIÇ¹, Can ÖZCAN², Hasan EFE³, Ali KASAL¹

¹ Muğla Sıtkı Koçman University, Faculty of Technology, Department of Woodworking and Industrial Engineering, Muğla / Turkey

² Akro Mühendislik, GOSB Teknopark – Kemal Nehrazoğlu Cad. High Tech Building, Kocaeli / Turkey

³ Gazi University, Faculty of Technology, Department of Woodworking and Industrial Engineering, Ankara / Turkey

Key words	Abstract
<i>Baby Crib, Ergonomics, Furniture Ergonomics, Computer Aided Ergonomics, AnyBody Modelling System</i>	66% percent of the care giving parents experience musculoskeletal pain during the first 4 years of their children (Sanders & Morse, 2005). Lifting child in and out of a crib was reported to be one of the over-average stressful activities (Vincent & Hocking, 2013). Thus, design of baby cribs should not only concentrate around babies but also include study of care givers ergonomics. In this study, ergonomics of mothers was analyzed during reaching out and lifting the baby from the baby crib. AnyBody Modeling System (AMS) (“AnyBody Modeling System,” 2016) simulation software was utilized to calculate the joint reaction forces in lumbar region and muscle activations of the female human model. Average crib bed height was taken as 55 cm according to common applications in Turkish furniture industrial products. Alternative bed heights (75 and 95 cm) were simulated in terms of peak load and effort during the lifting and compared to aforementioned average. According to the results of analyses, lower bed heights gave significant increase in both joint loads in lumbar region and muscular activity. In conclusion, it could be suggested that the bed height should be higher than the current industry practice. However, the designs which will increase the bed height should be implemented by considering ASTM safety standards (ASTM-F406-15).

Corresponding author: *halilkilic@mu.edu.tr Kılıç H., Muğla Sıtkı Koçman University, Faculty of Technology, Department of Woodworking and Industrial Engineering, Muğla / Turkey*

1. INTRODUCTION

Lifting is a very complex process involving a number of different body mechanisms and a decision-making system to orchestrate the mechanisms. Movement involves both 'hardware' or functional anatomy and 'software' which may be said to consist of the involuntary (e.g., motor programs) and voluntary (volitional strategy) control mechanisms (Schmidt, 1982; Winters and Woo, 1990).

The lifting movement is one of the main causes to low back injury. Thus for many years many researchers investigated biomechanics of lifting activity and attempted to find the reasons which might give rise to musculoskeletal disorders. Various methods such as pressure transducer

needle, surveys (RULA, REBA, OWAS etc.) motion capture systems, electromyography (EMG), biomechanical simulations etc. have been used to understand the reason of Low Back Pain (LBP). Records also show that LBP is one of the most expensive medical problems in industry (Klein et al., 1984; Vojtecky et al., 1987). Despite improved working conditions (including progress due to automation), many objects in industry are still handled manually (Hsiang et al. 1997). Among basic manual material handling activities, lifting has most frequently been associated with LBP (Snook et al., 1978; Cady et al., 1979; U.S. Bureau of Labor Statistics, 1982).

Lifting activity generally have been considered as an occupational issue. But human being have always been lifting objects from birth till death. Mothers routinely lift children in and out of car seats, tubs, cribs, strollers and highchairs. Some experience musculoskeletal disorders (MSDs) that affect their lower back, neck, shoulders, wrists and knees (Vincent and Hocking, 2013). 66% percent of the care giving parents experience musculoskeletal pain during the first 4 years of their children (Sanders & Morse, 2005). Lifting child in and out of a crib was reported to be one of the over-average stressful activities (Vincent and Hocking, 2013).

The report (The percentage of main diseases/health problems declared by individuals in the last 12 months in 2016) shows that 57.4% of females have low back disorders (32.8%) (lumbago, back hernia, other back defections) and neck disorders (24.6%) (neck pain, neck hernia, other neck defections) (Web-1).

Accordingly, design of baby cribs should not only concentrate around babies but also include study of care givers ergonomics. In this study, ergonomics of mothers was analyzed during reaching out and lifting the baby from the baby crib.

2. METHODS AND MATERIALS

ANYBODY MODELING SYSTEM

AnyBody Modeling System (AMS) is computer software designed for constructing detailed models of the musculoskeletal system. The mathematical and mechanical methods of the system were described in detail in (Damsgaard et al. 2006). The system is based on inverse dynamics. It presumes that muscles are recruited according to a minimum fatigue criterion and is capable of simulating the force in every muscle and reactions in every joint and external support condition for prescribed movements and external loads. The system is fully dynamic in the sense that body forces from accelerations and gravity are included in the analysis (Wagner et al. 2007). In the AMS, the user creates the model of the problem to be investigated. Such a model is termed an application. Unlike traditional digital manikins the human model is not an integrated part of the system. However, a public-domain repository of human body models is available and eliminates the need to build the human anatomy over again for each application. The human model is scaleable, so essentially the same human model in different scaled forms is used in multiple applications (Wagner et al. 2007).

APPLICATION

In this application AMS (AnyBody version 6.0.5. 64-bit version) simulation software was employed to calculate the joint reaction forces in lumbar region (L1-L2, L2-L3, L3-L4, L4-L5 and L5-Sacrum intervertebral discs) and muscle activations. Model was obtained from AnyBody Managed Model Repository (AMMR v.1.6.4.).

The anthropometric scaling of the AnyBody manikin used for analysis was derived from the AnyBody repository function Scaling Uniform. It was utilized from Turkish female (25-34

years old) average height and weight for scaling the human model. Average height (162.8 cm) and weight (64.5 kg) was obtained from Turkish Statistical Institute database (Table 1.).

Table 1. Average heights and weights by sex last accessed group, 2016

[15+age]	(Cm)			(Kg)		
Age group	Total	Male	Female	Total	Male	Female
Total	167,2	173,2	161,4	72,8	77,4	68,4
15-24	168,4	173,9	162,7	63,6	68,9	58,2
25-34	169,1	175,5	162,8	71,1	77,7	64,5
35-44	168,1	173,9	162,2	76,2	81,4	71,0
45-54	166,5	172,2	160,7	78,2	81,3	74,9
55-64	165,5	171,2	160,0	78,4	80,6	76,2
65-74	164,1	170,1	158,9	75,3	77,2	73,7
75+	161,3	168,3	156,7	69,6	72,8	67,5

(Web 1)

This age group was evaluated because of births statistics by age group of mother (Web 1). Mothers 25-34 years old are 55.33 % of total births by age group of mother in 2015 (Table 2.).

Table 2. Births by age group of mother, 2015

Year	Age group of mother									
	Total	18-19	20-24	25-29	30-34	35-39	40-44	45-49	50+	Unknown
2015	1 325 783	60 893	313 345	412 331	321 302	151 591	34 954	2 465	431	10 438

(Web 1)

The baby crib was modeled in AutoCad 2017 (Windows 64-bit version) and STL files used in AMS for simulations. The bed height was described for 55 cm. An experimental model was recorded while the model was lifting baby from the crib (55 cm bed height). The lifting activity duration was determined for 3 seconds from the experimental model and AMS model activity was defined for 3 seconds. Besides, each angle of the segments was determined from the experimental model by using uMED Ergonomi software (v.1.3.3.0.).

Lifting activity simulations were repeated seven times in terms of 50 percentile of male baby body weight (Table 3.). Applied force (representative baby weigh) to the hands was varied from birth weight to 3rd, 6th, 9th, 12th, 15th and 18th month weight.

Table 3. Percentile values for weight in Turkish children (kg)

Male Baby Weight Percentile (kg)							
Percentile	3	10	25	50	75	90	97
Birth	2,58	2,85	3,13	3,43	3,73	4	4,27
3rd month	4,75	5,26	5,79	6,38	6,99	7,54	8,1
6th month	6,21	6,79	7,41	8,12	8,85	9,54	10,25
9th month	7,27	7,87	8,51	9,26	10,06	10,81	11,58
12th month	7,96	8,61	9,32	10,16	11,05	11,92	12,82
15th month	8,61	9,28	10,01	10,89	11,83	12,75	13,72
18th month	9,13	9,82	10,58	11,49	12,48	13,46	14,49

(Neyzi et al. 2015)

Initially, 1.715 kg force represented half of baby birth weight was applied to the each hand and scaled model was then applied the lifting task from bed height of the crib (55 cm). This analysis was repeated for each month and for each bed height (75 and 95cm). 95 cm bed height was determined because of the elbow joint height from the ground was measured from the scaled mannequin in terms of average Turkish women (Figure 1).

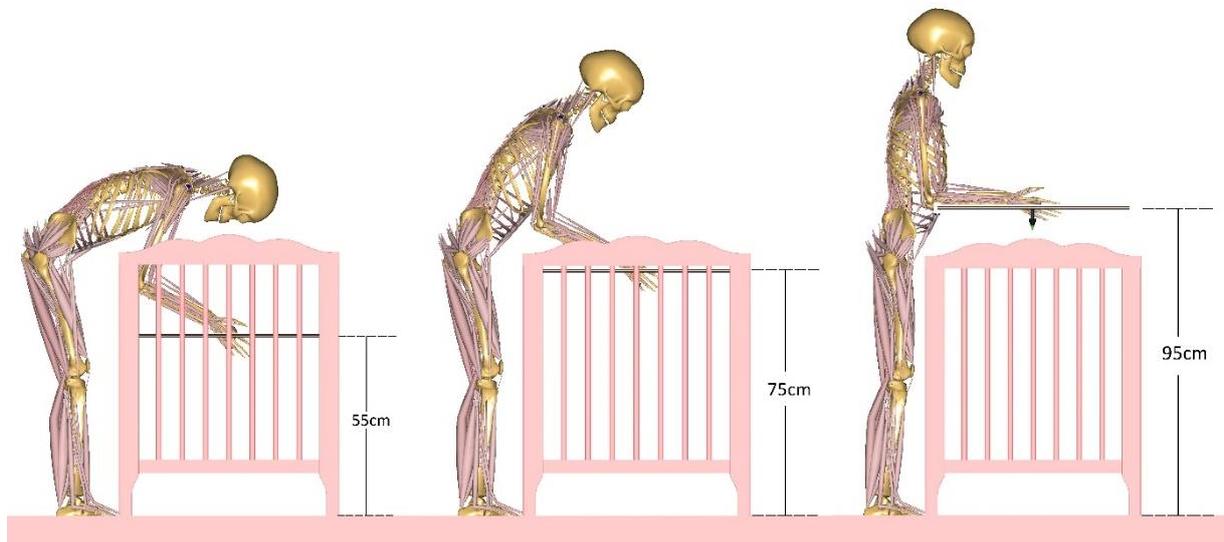


Figure 1. Lifting activity simulations from three different bed heights

Forces (N) occurring in lower back (L1-L2, L2-L3, L3-L4, L4-L5 and L5-Sacrum intervertebral discs) and maximum muscle activity (%) was obtain from the simulations and results was compared according to tested three bed heights for each time period.

3. RESULTS AND DISCUSSION

Results was obtained from the simulations for three bed heights. Lumbar region joint force values were calculated by the AMS and given in the Figures. Force values was taken at the beginning of lifting activity. L5-Sacrum force value was calculated as the highest for each simulations. Then it was focused on the L5-Sacrum joint reaction force (N) and maximum muscle activity (%) was calculated for each bed heights and results was shown in the Figure 5. Comparing the lifting activity results among the three bed height, highest joint reaction force

and muscle activity values was obtained from the 55 cm bed height while the lowest values was calculated for 95 cm bed height.

Joint reaction force results in the lumbar region of lifting the baby from 55 cm bed height from birth till 18th month are shown in Figure 2.

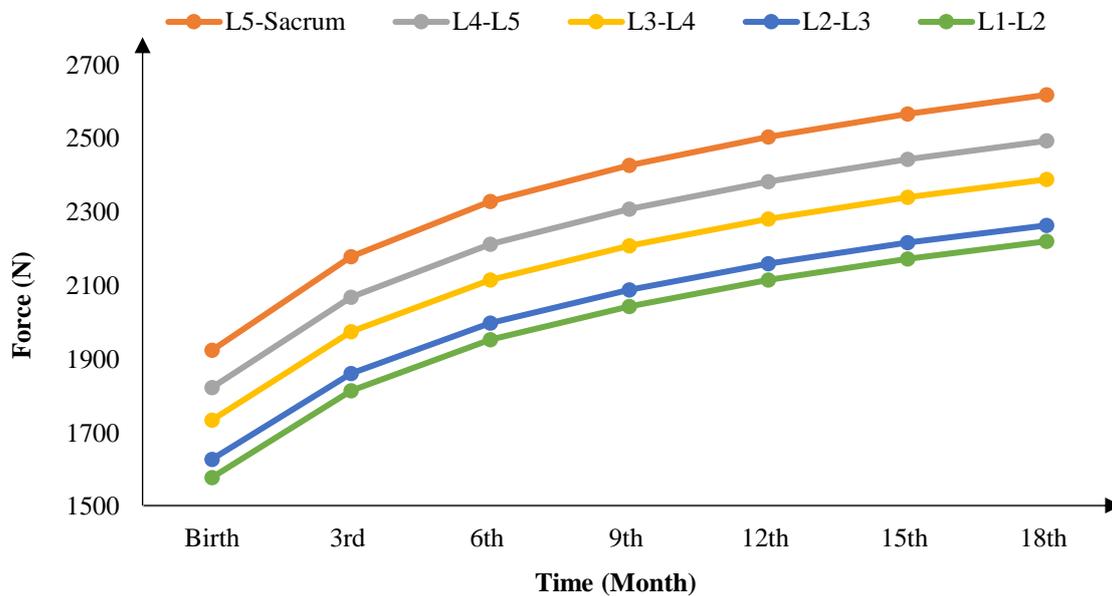


Figure 2. Joint reaction force in lumbar region while lifting the baby from 55 cm bed height

Lifting the baby from 55cm bed height caused high forces in the lumbar region from birth till 18th month. Results showed that highest joint reaction was occurred at L5-Sacrum. It can be clearly seen that there were very similar joint reaction forces between the L2-L3 and L1-L2 joint reaction forces for each months. Calculations showed that the average joint reaction forces at lumbar region was increased about 36% while lifting the baby from the age of birth to 18th month. High joint loads can cause pressure on muscle groups and time-dependent stretch on intervertebral discs. Pressure on muscle groups can cause pain in the back region. High muscle activation cause early fatigue; thus it could cause discomfort.

Joint reaction force results in the lumbar region of lifting the baby from 75 cm bed height from birth till 18th month are shown in Figure 3.

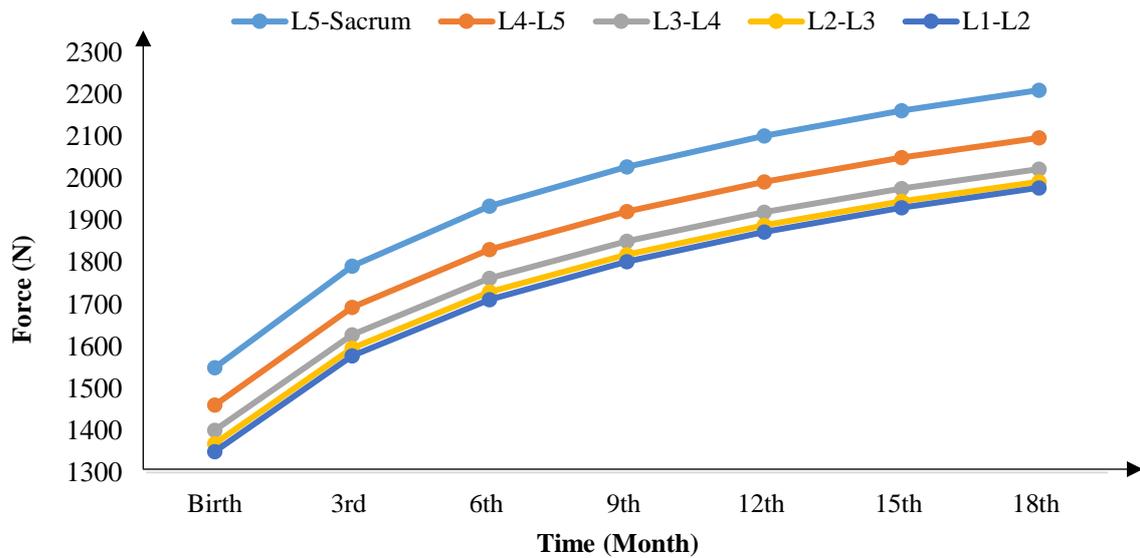


Figure 3. Joint reaction force in lumbar region while lifting the baby from 75 cm bed height

Lifting activity results from 75 cm bed height showed lower joint reaction forces comparing 55 cm bed height. Highest joint reaction force was occurred at L5-Sacrum just as values from 55 cm. Calculations showed that joint reaction forces at lumbar region was increased about 43% while lifting the baby from the age of birth to 18th month. Results showed that joint reaction forces at L1-L2, L2-L3 and L3-L4 were considerably similar for each months.

Joint reaction force results in the lumbar region of lifting the baby from 95 cm bed height from birth till 18th month are shown in Figure 4.

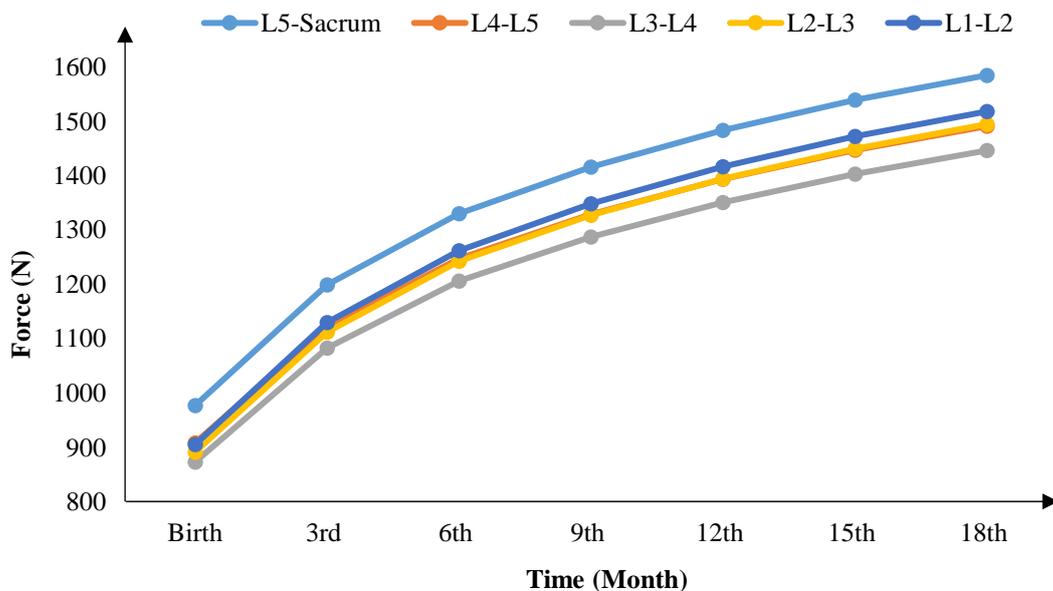


Figure 4. Joint reaction force in lumbar region while lifting the baby from 95 cm bed height

Results of the lifting activity from 95 cm showed that joint reaction forces occurred in lumbar region was given the lowest values comparing with the 75 cm and 55 cm bed height results. Highest joint reaction force was occurred at L5-Sacrum just as values from 55 cm and 75 cm. L2-L3 and L4-L5 joint reaction forces was resulted almost at the same level. Calculations showed that in time, when the baby weight increase (from birth to 18th month), joint reactions in lumbar increase about 62% while lifting the baby from 95 cm bed height.

Comparative joint reaction force results in L5-Sacrum (a) and maximum muscle activity percentiles (b) while lifting the baby from the three different bed heights from birth till 18th month are shown in Figure 5.

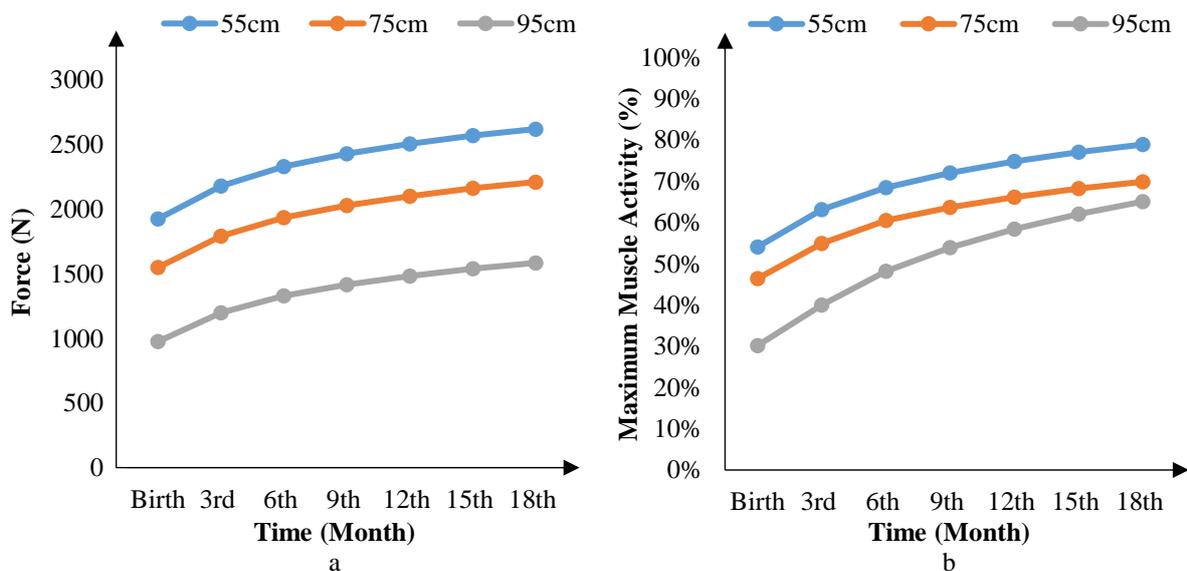


Figure 5. Joint reaction force in L5-Sacrum (a) and maximum muscle activity percentiles (b) while lifting the baby from three different bed heights

Figure 5. Enables to make a general interpretation for each case. There was considerable amount of differences between joint reactions in L5-Sacrum obtained from the simulations for three bed heights.

Calculations showed that highest joint reaction force was occurred in L5-Sacrum while lifting the baby from 55 cm and lowest joint reaction force was occurred in L5-Sacrum while lifting the baby from 95 cm bed height at each time periods. At birth weight, increasing bed height from; 55 cm to 75 cm result in 19.4%, 55 cm to 95 cm result in 49.2%, and 75 cm to 95 cm result in 36% decrease in L5-sacrum joint reactions. At 18th month weight, increasing bed height from; 55 cm to 75 cm result in 15.6% 55 cm to 95 cm result in 39.4%, and 75 cm to 95 cm result in 18% decrease in L5-sacrum joint reactions (Figure 5a).

Results showed that highest muscle activity was occurred while lifting the baby from 55cm and lowest activity was occurred in L5-Sacrum while lifting the baby from 95cm bed height at each time periods. At birth weight, increasing bed height from; 55cm to 75cm result in 14.8%, 55cm to 95cm result in 44.4% and 75cm to 95cm result in 34.7% decrease in muscle activity. At 18th month weight, increasing bed height from; 55cm to 75cm result in 11.3% 55cm to 95cm result in 17.7%, and 75cm to 95cm result in 7.1% decrease in muscle activity (Figure 5b).

4. CONCLUSIONS

In this study it was analyzed the joint reaction forces at lumbar region and muscle activations of mothers while they are lifting their babies from the baby cribs designed with different bed heights. Further, the main objective of this study was to show the advantage of the AnyBody Modeling System for designing and manufacturing ergonomic furniture for a specific person or people group. The conclusions are shortly specified below;

- Highest joint reaction force was occurred at L5-Sacrum for each bed height,
- Highest values was obtained from 55 cm bed height with regard to L5-sacrum joint reaction force and muscle activity,
- Lowest values was obtained from 95 cm bed height with regard to L5-sacrum joint reaction force and muscle activity,
- It can be concluded that decreased bed heights of the cribs cause higher joint reaction force and muscle activity,
- When baby weight increase, lumbar region exposes higher joint reaction forces and increased baby weight leads to more muscle strength.

As a crucial component of furniture design, ergonomics always should be considered. Thus, computer aided ergonomics (CAE) methods could be utilized in furniture design. In this regard, this case study could be an example for further studies about utilizing the CAE methods in furniture design.

References

- ASTM F406-15, Standard Consumer Safety Specification for Non-Full-Size Baby Cribs/Play Yards, ASTM International, West Conshohocken, PA, 2015, www.astm.org
- Klein, B.P., Jensen, R.C. and Sanderson, L.M. (1984): Assessment of workers' compensation claims for back strain/sprains. *Journal of Occupation Medicine* 26(6): 443-448.
- Cady, LD., Bischoff, D.P., O'Connell, E.R., Thomas, P.C. and Allan, J.H. (1979): Strength and fitness and subsequent injuries in firefighters. Letter to the editor. *JOM* 21: 724-725.
- Damsgaard, M., Rasmussen, J., Christensen, S. T., Surma, E., and De Zee, M. (2006): Analysis of musculoskeletal systems in the AnyBody Modeling System. *Simulation Modelling Practice and Theory* 14(8): 1100-1111.
- Hsiang, S. M., Brogmus, G. E., and Courtney, T. K. (1997): Low back pain (LBP) and lifting technique a review. *International Journal of Industrial Ergonomics* 19(1): 59-74.
- Neyzi, O., Bundak, R., Gökçay, G., Günöz, H., Furman, A., Darendeliler, F., and Baş, F. (2015): Reference values for weight, height, head circumference, and body mass index in Turkish children. *Journal of clinical research in pediatric endocrinology* 7(4): 280.
- Sanders, M. J., and Morse, T. (2005): The ergonomics of caring for children: an exploratory study. *American Journal of Occupational Therapy* 59(3): 285-295.
- Schmidt, R.A. (1982): *Motor Control and Learning - A Behavioral Emphasis*. Human Kinetics, Champaign, IL, 185-235.
- Snook, S.H., Campanelli, R.A. and Hart, J.W. (1978): A study of three preventive approaches to low back injury. *Journal of Occupational Medicine* 20: 478-481.

- U.S. Bureau of Labor Statistics. (1982): Back injuries associated with lifting. Bulletin 2144. Author, Washington, DC.
- Vincent, R., & Hocking, C. (2013): Factors that might give rise to musculoskeletal disorders when mothers lift children in the home. *Physiotherapy Research International* 18(2): 81-90.
- Vojtecky, M.A., Harber, P., Sayre, J.W., Billet, E. and Shimozaki, S. (1987): The use of assistance while lifting. *Journal of Safety Research* 18(2): 49-56.
- Wagner, D. W., Reed, M. P., and Rasmussen, J. (2007): Assessing the importance of motion dynamics for ergonomic analysis of manual materials handling tasks using the AnyBody modeling system (No. 2007-01-2504). SAE Technical Paper.
- Web 1: <http://www.turkstat.gov.tr/Start.do> Last access: 30.08.2017
- Winters, J.M. and Woo, S.L.-Y. (1990): *Multiple Muscle Systems - Biomechanics and Movement Organization*. Springer Verlag, New York.

Corresponding author :

H. Kılıç
Muğla Sıtkı Koçman University, Faculty of Technology, Department Woodworking Industrial Engineering, Muğla / Turkey
halilkilic@mu.edu.tr

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

ELICITING PRODUCT EXPERIENCES: A STUDY OF OLDER PEOPLE'S INTERACTION AND SATISFACTION WITH CHAIRS

Oskar JONSSON¹, Elisabeth DALHOLM HORNYÁNSZKY², Britt ÖSTLUND³, Anders WARELL²,
& Lena SPERLING²

¹ Lund University, Faculty of Medicine, Department of Health Sciences & Centre for Ageing and Supportive Environments, Lund / Sweden

² Lund University, Faculty of Engineering, Department of Design Sciences, Lund / Sweden

³ KTH Royal Institute of Technology, STH, School of Technology and Health, Health Systems Engineering, Stockholm / Sweden

Key words	Abstract
<i>Ageing, Design, Furniture, Human-product Interaction, Usability, User experience.</i>	Today, older people have difficulties to find furniture that meet their needs. Older people's own experiences may be a valuable resource in the design of totally new or improved products. In the present study, 10 chairs were evaluated with 30 people. The method used was structured interviews with a user satisfaction scale as a tool for elicitation. The study shows that the participants have diverse needs and wishes, but that they all value product features that enable fit to their body, home and aspired identity. The study participants agreed on the importance of easy egress of a chair. Recognized chairs were considered to best fit the participants' homes. Various product features influenced the overall as well as individual experiences of the investigated chairs in the test. Our recommendation is that design practitioners should strive to understand older people holistically and the role furniture play in their lives.

Corresponding author: *oskar.jonsson@med.lu.se, Jonsson O., Lund University, Faculty of Medicine, Department of Health Sciences & Centre for Ageing and Supportive Environments, Lund / Sweden.*

1. INTRODUCTION

The present study concerns the challenges and possibilities in meeting demographic shifts and the presumed expectations of today's and tomorrow's older generations. The background is the lack of furniture that responds to the demands of older people and the lack of knowledge about how older people experience furniture. Generalizations made regarding old people's needs have proved to be too limited in scope to meet needs and wishes (Daunfeldt, 2008). The purpose is to improve knowledge and awareness concerning the ways in which old people act on, are influenced by, reflect on and appreciate furniture. The problem was initially addressed by furniture manufacturers and retailers in the *PLUS-project (Development of Swedish Wood and Furniture Industry for Consumer Oriented and Competitive PLUS-products)*, which was funded by VINNOVA from 2008 to 2010 (Jonsson, 2013). Older people's potential contribution to early phases of design is often underestimated (Essén and Östlund, 2011). Due to older peoples' life experience, one can expect that they are more discerning about potential issues

resulting from interaction with product and better able at judging and predicting such issues (Stephens et al., 2006). Therefore, much effort was put in the *PLUS-project*, a project for small and medium sized furniture manufacturers in Sweden, to provide a detailed understanding of the unmet needs and wishes of older people.

The need for furniture that meets the demands of older people is expected to grow in the near future. Increased average life expectancy, more people living longer periods of their lives with disabilities and reduced functional capacity (Newman and Cauley, 2012), an increasing number of older people remaining and receiving care in mainstream housing and access to economic resources are factors expected to contribute to a development where more people will continue to buy furniture for their own homes at higher ages.

Design for older people is typically associated with the act of understanding and responding to the needs of the user's physical changes. The physical effects of ageing are a natural part of ageing and often regarded as one of the unifying factors. So far, most of existing knowledge about furniture design for older people take their starting points in instrumental interaction which for example includes operational task-related use, safety and physical comfort (Engdahl, 1968; William-Olsson and Svanborg, 1984; Holden et al., 1988; Pirkl, 1994; De Looze et al., 2003; Moes, 2005; Mills, 2007; Vink, 2008; Vink and Brauer, 2011; Farage et al., 2012; Franz et al., 2012; Zenk et al., 2012). Despite increased demand for human-centered design and healthcare, older people's views are still missing. In the present study the interest is in people-furniture relationships as seen from an end-user perspective. The research is based on the vision that it is important that incremental or radical furniture design are based on knowledge about the entire product experience. In the present study, product experience refer to all possible subjective experiences resulting from people's interaction with chairs. According to Desmet and Hekkert (2007), human-product interaction can be divided into:

- Instrumental interaction (operational use of the product)
- Non-instrumental interaction (perceiving sensory experiences that do not directly serve a function in operating the product)
- Non-physical interaction (fantasizing, remembering, or anticipating usage of the product)

The notion of product experience includes the role products play in people's lives, which makes a holistic view on people increasingly important (Jordan, 2000). According to Forlizzi (2007), a product experience is specific to each person and dependent on:

- Personal factors (e.g. personality, personal history, life stage, gender and motives)
- Product related factors (e.g. properties and characteristics)
- Factors in the physical environment (e.g. architecture, styling, scale and technology)
- Factors in the social environment (e.g. culture and economy)

The purpose of the present study is to develop a deeper understanding of the value older people attribute to the different product related factors, referred to as product features in this paper. The research questions were: What types of chairs do older people prefer? What are the properties and characteristics that satisfy older people? Which properties and characteristics are

the most important for older people? Which properties and characteristics are the most relevant for design practitioners to focus on?

2. METHODS AND MATERIALS

This chapter describes the methods and procedure used for evaluating chairs through structured interviews in a usability laboratory.

PRODUCTS

In the present study, ten chairs that were considered to have *PLUS-values* were jointly selected by the seven furniture manufacturers participating as partners in the *PLUS-project* and the researchers to be evaluated with older people. For the present study, products with *PLUS-values* are defined as a conceptual category of products designed for a wide range of diverse potential users which, in addition, remain desirable and usable for as long as possible during the lifetime of an individual. The choice to study chairs was motivated by, among other things, the fact that it was the type of furniture most frequently mentioned in previous human-centered studies within the *PLUS-project* (Jonsson, 2013). Also, chairs are the most frequently used furniture type and the most common purchase for assisted living/nursing homes. The choice was made to represent a variation within the product types (see Fig. 1-10). Both Swedish furniture classics from the twentieth century and contemporary chairs produced by the seven furniture manufacturers were included. The chairs were categorized in three groups: (A) easy chairs with headrests, (B) easy chairs without headrests, and (C) armchairs and rocking chairs that were merged into one group. Three of the easy chairs with headrests also had separate footstools and one had an automatically adjustable leg support that was integrated into the seat.



Figure 4. Easy chair (no. 1, group A) Farmor (Grandma) from OH Sjögren. Designed in 1956 by Carl Malmsten, a major Swedish furniture designer. The chair and designer are familiar to many Swedish citizens. The test chair was upholstered in a black wool fabric.



Figure 2. Easy chair (no. 2, group A) Mistral from Nelo AB. This reclining chair has an adjustable headrest. The reclined back can be fixed in any chosen position by means of a lever on the inside of the armrest. The integrated footrest extends automatically when the back is reclined. A chair upholstered with white leather was used in the test. Design: Okamura and Marquardsen.



Figure 3. Easy chair (no. 3, group A) Newtom from Nelo AB. The chair has a glider, a swinging seat that reclines the chair and has a motion similar to a rocking chair, and an adjustable headrest. Design: Okamura and Marquardsen.



Figure. 4. Easy chair (no. 4, group A) Lamino from Swedese designed by Yngve Ekström in 1956. The test chair was upholstered in sand colored sheepskin. This chair is familiar to many Swedes and was in 1999 accorded “The Swedish Furniture of the 20th Century” award by readers of Sköna Hem, the largest design magazine in Sweden.



Figure. 5. Easy chair (no. 5, group A) Select designed by Roger Persson for Swedese. The back can be reclined by pulling on a leather ear on the inside of the armrest and leaning backward. The back can be fixed in any chosen angle by releasing the leather ear.



Figure. 6. Easy chair (no. 6, group B) Nude designed by Nirvan Richter for Scandiform. The test chair was made of oak, had a grey seat cushion and a green back cushion that was unfastened.



Figure. 7. Easy chair (no. 7, group B) Sahara Wood designed by Gunilla Allard for Lammhults möbler.



Figure. 8. Armchair (no. 8, group C) Sandö designed by Marit Stigsdotter for Stolab. The test chair was upholstered in a green patterned fabric.



Figure. 9. The rocking chair (no. 9, group C) Lilla Åland was originally designed by Carl Malmsten in 1941. In 2008, production was resumed by Stolab.



Figure. 10. Rocking chair (no. 10, group C) Curt designed by Björn Dahlström for NC Nordic Care. The test chair had a black and grey striped cushion on the seat.

PARTICIPANTS

Participants were recruited through the voluntary network of older people organized by the Aging and Design Research and Development Program at the Department of Design Sciences at Lund University. Some participants were also recruited from older employees within the university, which had no connection to the *PLUS-project* and no past professional experience of furniture design. The outcome was 30 people, 18 females and 12 males, aged 57-87 (Table 1), with a variation in height, weight, functional ability and current or previous occupation. All participants lived in ordinary/mainstream housing available on the regular housing market, ten of which in senior housing. Senior housing is a collective term for a category of adapted housing characterized by good accessibility and access to shared rooms/spaces. There is a minimum age requirements to become a resident in a senior housing.

Table 2. Participants (N=30)

<i>Characteristics</i>	<i>n (%)</i>
Gender	
Females	18 (60%)
Males	12 (40%)
Age	
56-67 years	13 (43%)
68-77 years	11 (37%)
78-87 years	6 (20%)
Self-reported inconvenience with ingress	
Females (n=18)	2 (11%)
Males (n=12)	2 (11%)
All	4 (13%)
Self-reported inconvenience with egress	
Females (n=18)	3 (17%)
Males (n=12)	5 (42%)
All	8 (27%)

EVALUATION METHOD

At the chair test sessions, a modified version of the VOICE (Volvo Index of Car Experience) customer satisfaction form (Volvo Car Corporation, 1984) was used. It was originally used in surveys directed to statistically selected owners of Volvo Cars to find out what they were satisfied or dissatisfied with, in order to enhance the company's ability to produce competitive cars (Englund, 1986). In the original questionnaire a user satisfaction scale (Table 2) was used for rating of more than 100 product related factors, from total satisfaction with the car, to satisfaction with the car interior and various accessories. Later the user satisfaction scale was used at direct interviews with car assembly workers about their work-tools (Sperling, 1990) and truck drivers about surface materials (Sperling and Eriksson, 2006). As the time for interviews is limited in production environments, the structured interview made it possible to carry out the study in an efficient way. When analyzing the results in these studies, the focus was on qualitative comments instead of proper numerical ratings. However, the numerical ratings of the user satisfaction scale facilitated identification of desirable and less desirable product related factors. In the present study, the numerical ratings were primarily used for elicitation of verbal statements from the participants and to start a conversation.

Table 2. The user satisfaction scale

<i>Very satisfied</i>		<i>Rather satisfied</i>		<i>Neither nor</i>		<i>Rather dissatisfied</i>		<i>Very dissatisfied</i>	
10	9	8	7	6	5	4	3	2	1

PROCEDURE

The chair test sessions began in November 2009 and were completed in December 2009. The tests were carried out in a usability laboratory of Lund University in on-to-one sessions (Figure 11). In each session, one test moderator instructed the participant and carried out the interview. The ten chairs were placed in a circular arrangement and grouped according to the three categories. Each of the participants individually tested all ten chairs in one session. The chairs were tested in an order that was changed each day, both in terms of the three groups and within each group of chairs. A maximum of three sessions were carried out each day. The test included to try out the chairs in everyday interactions such as looking at, ingressing, sitting in, egressing and moving the chair. Footstools were tested solely if the participant utilized these or if the test moderator thought that they would improve the product experience significantly for people who expressed dissatisfaction with the interaction.



Figure. 11. The tests was carried out in one-to-one sessions between the participant and the test moderator in the usability laboratory at the Department of Design Sciences at Lund University.

The test moderator used a structured interview guide in each test that included a response form. The response form was directly filled in by the test moderator. Each session was conducted in a series of steps. First, each participant was informed, in a uniform manner, of the objectives of the study and the confidentiality of the results. Each participant signed a consent form to participate in the study before the test started. Second, the participant was asked if he/she was familiar with any of the chairs, and if so, in what way. Third, the test of each chair started with the participant's description of his/her first impression of the chair. Fourth, the user satisfaction scale (Table 2) was administered. The participants' ratings and statements of satisfaction/dissatisfaction were elicited with the user satisfaction scale (Table 2) in combination with the test moderators' questions and instructions in a systematic sequence of human-product interaction (Table 3). The first item in the test sequence was always the visual appearance of the chair. According to Schifferstein and Spence (2008), this interaction often comes first and has to the role to give product related information that has a profound effect upon the way products are interpreted, approached and used. The test moderator went through each item in the test sequence and asked the participant to physically encounter and rate his or her level of satisfaction on the item regarding each chair in the circular arrangement. The test moderator encouraged the participant to verbally justify his/her satisfaction ratings, asked follow-up questions and made sure that both ratings and statements were well-founded. All the participant's ratings and statements were noted by the test moderator in the response form. After the bodily encounter with each chair, the participants were asked to describe their most positive and the most negative product features. Each participant was also given the opportunity to add additional comments.

Table 3. The test sequence of human-product interaction

1	Visual appearance
2	Ingress (after two ingresses)
3	Adjustments (if applicable)
4	Appearances and usability of adjustments levers (if applicable)
5	Seat comfort (after properly seated)
6	Seat comfort while reading (after browsing in a book)
7	Egress (after two egresses)
8	Movability

When all the chairs in one of the three groups in the circular arrangement were tested, the participant was asked which products would fit, or not fit, in his/her home and explain why. After all ten chairs were tested, questions were asked about the participant's age, height, weight, occupation and if they had any inconvenience with ingress or egress of chairs (i.e. sitting down and getting up from chairs in their everyday life). All the tests were conducted in the same way. Each participant's test of all the chairs took between 70 to 120 minutes.

When all the tests were carried out and a preliminary analysis was completed, all study participants and partners in the *PLUS-project* were invited to a consultation meeting at Lund University where the study and preliminary results were presented. The purpose was to seek input from the participants and enable them to express their opinion to ensure that we understood and included all test participants' views in the analysis and that the representatives from the furniture manufacturers could meet the study participants and improve their end-user understanding.

DATA ANALYSIS

The data analysis was based on the test moderators' notes in the response forms. The notes consisted of the numerical values corresponding to the user satisfaction scale for each item in the test sequence for each chair and the participants' verbal statements, which had either been generated by the questions in the interview guide or elicited by follow-up questions. Statements noted in the response forms at each step of the interviews and on each item in the test sequence were codes for analysis concerning all possible product features. The procedure was exploratory in order to identify aspects that emerged from the kind of descriptions that people gave in physical encounters with furniture. Similar trends of product related descriptions were merged to reveal patterns. User feedback, regarded as important for design practitioners to know and reflect on when considering older people's needs and wishes, were kept as a basis for the attention and selection of statements. The approach was qualitative and searched for the meanings participants gave to the human-product interactions, with the aim to capture as much as possible of the content. The numerical ratings of the user satisfaction scale facilitated the identification of strong and weak product features.

2. RESULTS AND DISCUSSION

In this chapter results are presented according to the items evaluated in the test sequence: visual appearance, ingress of, adjustability, sitting comfort, sitting comfort while reading, egress of and movability. Numbers reported (n=) relates to how many of the participants described the specific product feature regarding any of the evaluated chairs. This chapter also includes discussions on the results, the methods and the practical implications.

The numerical ratings showed a wide range of assessments scores of each chair. A wide variability in opinions was also found among the statements, when participants were asked to describe their first impressions and the most positive and the most negative product feature of each chair. Apart from the wide range of opinions, some common views were also observed. For example, chairs that were recognized by the majority of participants (chair no/ Fig. 1, n=22 and no/ Fig. 4, n=25) did not receive low scores on visual appearance. Recognisability, thus, had a huge impact on the participants' overall satisfaction. In a Swedish context, these two chairs (no/Figs. 1 and 4) can be viewed as belonging to the category of "modern furniture classics"; a complex phenomenon that has a strong normative influence (Wahlöö, 2017). The participants also agreed on the importance of comfort and easy egress of a chair.

VISUAL APPEARANCE

Generally, the participants based their statements about the visual appearance on whether the chairs could fit into their home or not. A suitable fit were motivated with coherence between and composition of furniture in their home and the chairs' relations to the home interiors scale, size and styling. A high degree of satisfaction with a chair's visual appearance was motivated in terms such as "dainty/not bulky" (n=23), "simple/not ostentatious" (n=22), "elegant" (n=16), "timeless" (n=13) and "inviting" (n=11). Desirable aesthetic product features mentioned were that the form of the chair had "materials and workmanship of good quality" (n=22), "nice colorings and materials that harmonies" (n=20), "well/not poorly balanced proportions" (n=17), "elegant shapes" (n=13) and "beautiful lines" (n=8). Dissatisfaction arose when chairs generated associations to "public environment" (n=9), "office" (n=3), and "ageing" (n=3). Distinctive product characteristics were appreciated (n=6), while chairs perceived as having no character (n=10) were considered boring.

INGRESS OF A CHAIR

Several product features facilitate ingress of a chair. The chair's stability and knowing the position in space of the chair's armrests contribute to a sense of security (n=12). Rocking chairs were considered by some (n=9) to be unsafe. The sooner a chair meets the human body and the haptic senses, the easier it was for the participants to get in. Lessons learnt are in line with Holden et al. (1988) who state that ease of ingress is dependent on the dimensions of chairs such as seat height, position of armrests and angle of the seat and back. Chairs that early contact the human body in ingress, so that the user was able to find a suitable position directly were satisfying (n=16). Dissatisfaction arose when the participants' feet did not reach the floor after getting seated (n=7) or if the angle of the back of the chair was too upright so he/she bounced back during ingress (n=3). If a chair has a lack of support during ingress due to low seat pan (n=4), due to reclined back (n=2) or by too low armrests (n=1), participants perceived this as not smooth enough. High positioned and stable armrests with rounded and curved forms, having soft, not too cold materials were mentioned to contribute to having sufficient support and grip during ingress. A pleasant firmness of the seat was appreciated so that the user did not sink into the chair during ingress.

ADJUSTABILITY

Generally, the ability to recline or adjust the chair's seat angles was appreciated. The motivation often was that it improved comfort and allowed for different activities such as socializing and reading, watching TV, resting or sleeping. Adjustability also makes it easier to change the sitting position. Adjustments for the height and depth of the headrest were appreciated as well, due to various body sizes and shapes. Most of the participants (n=22) complained about the headrest of chair no/ Fig 1, which was too low positioned and unfastened, some (n=4) chose or preferred to use it as a lumbar support instead of a neck support. Footstools were needed for

seats with adjustable seat angles, otherwise the participants' feet ended up in the air. Several of the participants (n=13) appreciated easy chair no/ Fig. 3 that had a glider, a function that changed the seat angle according to how the user changed his/her sitting position and did not require a control such as a lever (easy chair no/ Fig. 2) or a leather ear (easy chair no/ Fig. 5). Other participants (n=10) saw the fact that the seat angles changed as unsafe and preferred being able to lock the back into one position. Those who were dissatisfied with the glide function also justified their dissatisfaction in other items in the test sequence with the fact that parts of the chair were not fixed and thus unsafe. The controls of the seat angles should not require arm or finger force (n=12), and they should respond quickly and distinctly (n=3). Controls that were perceived as discrete, with interfaces that were intuitive, gentle, pleasant and easy accessible received a high degree of satisfaction (n=12), even for the people who are overweight or left-handed (n=3). To be perceived as an attractive feature, some participants (n=7) stated that the ability to adjust the chair should have had controls and functionalities with technically durable constructions, and also give the impression of having that. The adjustability function was by some participants (n=4) considered to be unnecessary.

SEAT COMFORT

Generally, participants motivated high seat comfort with statements about fit to their body size (n=16), head/neck support (n=13), lumbar support (n=10) and their feet reaching the floor (n=3). The importance of head/neck support goes in line with Franz et al. (2012), who argue that headrests contribute to the experience of comfort. Other common statements related to comfort were that the seat should be stiff in such a way that the body does not sink into the chair and be firm in a comfortable way and soft in a nice way. These results agree with other studies. For example, Mills (2007) states: "A foam seat must be thick enough not to bottom out..." (p. 230), and its compression should be similar to the human tissue. Zenk et al. (2012) give suggestions per body region for optimal load distribution. Figure 12 provides an overview, showing the proportion of the participants who reported that they were satisfied, dissatisfied or neither nor with seat comfort per chair. The fact that for each of the chairs there was at least one participant who was dissatisfied with the seat comfort shows that personal preference differs much. Easy chair no/ Fig. 5 is the chair that was rated as having the highest average satisfaction score with the seat comfort due to the fact that low scores are relatively less low. The highest satisfaction scores are found in every chair. High satisfaction with the seat comfort on chair no/ Fig. 5 were motivated with comments on a comfortable headrest (n=11), an elbow support (n=8), a stiff seat pan that prevented sinking into the seat (n=7) and the possibility to change positions and sit for a long time (n=3).

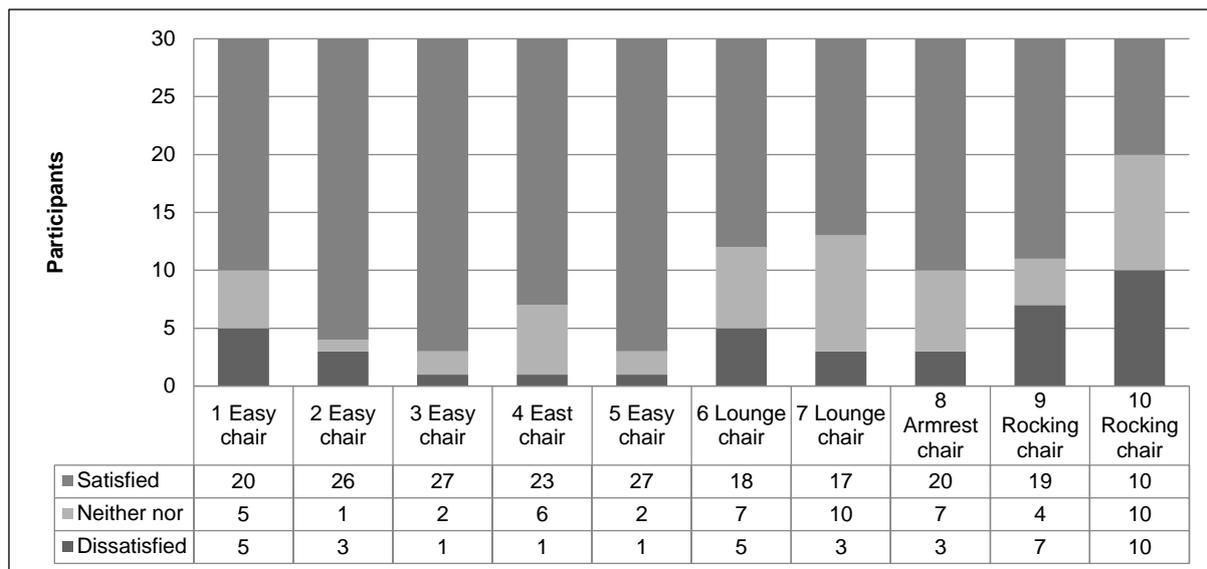


Figure. 12. Proportion of the 30 participants who rated that they were satisfied, dissatisfied or neither nor with the sitting comfort of all 10 chairs.

The participants' degree of satisfaction with the sitting comfort was sometimes motivated by subjective experiences such as: "Makes me feel welcome and/or cared for" (n=3) and "I do not feel trapped" (n=1). Some participants (n=9) mentioned that the chair's seat pan, especially the edge at the front pressed on thighs leading to discomfort. Three participants stated that they sometimes wanted to fall asleep and were in need of a supportive headrest. Some participants appreciated chairs that allowed sitting in several positions (n=9) and made it possible to have the feet in the chair (n=3). These comments are in line with Rosmalen et al. (2009), who argue that a seat that stimulates movement enables prolonged sitting and also decrease the chance of back problem. The sheepskin on chair no/ Fig. 4 received two positive comments because the "warmth" it generated. Old people are more sensitive to the cold (Farage et al., 2012). Materials that become "slippery", "sticky", "prickly", "too warm" or "too cold" received negative comments (n=6). Materials that emit sounds, such as air hissing out of cushions or neck pads, were perceived as negative (n=4). Three participants mentioned that they preferred low armrests that allowed for the practice of handicrafts such as knitting. Positive statements about seat comfort of the evaluated rocking chairs were that they were considered "nice" or "cozy" (n=4) and "restful" or "relaxing" (n=3). These statements, are in line with the results of a study by Snyder et al. (2001), indicating that the effects of a glider swing significantly improved emotions and relaxation in a group of nursing home residents with dementia.

SEAT COMFORT WHILE READING

Several (n=10) participants preferred an upright sitting position for reading to be able to stay alert. One participant stated that he/she preferred a reclined position. Eight participants commented that the seats were too hard for prolonged sitting. For satisfying seat comfort while reading, it is important to be able to sit in the chair for a long time. It seems plausible that soft and wide upholstered headrests are desirable as well as armrests without sharp edges and cold materials. When reading, support for the book was an important issue. All of the participants mentioned the impact of support from the armrest, with comments about their height, form and material. Ideas on how this support could be achieved were: a cushion on your lap (n=1) or a floor stand (n=1). Seats that were too wide meant that thin people could only use one armrest at a time. Some of the participants (n=6) stated that chairs that moved disturbed their reading; they preferred chairs that were stationary to be able to concentrate and relax. For them, the rocking chairs (no/Figs. 9 and 10) or chair no/ Fig. 3 that had a glider did not provide satisfying

seat comfort while reading. However, three participants stated that it was pleasant to move when reading.

EGRESS OF A CHAIR

Most of the participants (n=27) mentioned that a high seat and an upright position facilitated egress. The assumption that a high seat fits to older people's needs is commonly spread, but as Holden et al. (1988) argue, and the results of the present study indicate, if short persons cannot get their feet on the ground there will be unwanted increase in pressure on their front thighs. Three participants wanted seat fronts that were "curved" or "soft". According to Holden et al. (1988), an important feature that facilitates egress is that the user can get his/her feet under the seat. This was stated by several participants (n=11). Seat properties that facilitated egress were: short seat depth that allows flexed knees and lumbar support (n=15), firm (n=7) and springy seat cushion (n=3). The easy chair no/ Fig. 6 had a springy seat cushion, which supported egress. Many of the participants (n=19) mentioned that stable and sturdy chairs increased their stability and reduced uncertainty. Armrests that provide support until the user stand up and have found the balance facilitate egress. Motivations included product features such as, provide a proper grip (n=17), long enough (n=14), high enough (n=12), rounded front edges that are not too hard for the hands (n=11) and not too wide (n=2). Most of the participants (n=23) stated that they needed strength to egress of the chair. Having enough arm strength (n=6) and prepare to get up (n=4) were mentioned. Some participants (n=5) stated that rocking chairs provided a boost and facilitated egress. However, several participants (n=10) mentioned that rocking chairs are too uncertain; they did not stand firmly before the participant started to egress. Three participants mentioned problems with footstools when they reach and grip them to move away before starting to egress.

MOVABILITY

Product features that made the participants satisfied with the movability of the chairs, were lightweight (n=30) and not too big and bulky (n=11). They appreciated when it was easy to get a grip on the chair (n=23) from different angles (n=8), and were able to position the chair close to the body when lifting (n=5). Many participants (n=16) expressed satisfaction with chairs they could shuffle over the floor that had such contact surfaces with the floor that could slide well without scratching the floor. Rocking chair no/ Fig. 9 was considered by four participants to have too projecting and bulky rocker runners. The need to move a chair is required, for example, when cleaning the house. Some of the participants (n=8) made positive statements about chairs that facilitate cleaning. This included few and small contact areas on the floor or legs that make it easy to reach when cleaning, which eliminate the need to move a chair.

DISCUSSION OF RESULTS

The present study draws attention to questions related to user needs by exploring properties and characteristics of chairs that contribute to older people's satisfaction. As could be expected, various product features were perceived and valued differently by different individuals. Possible explanations for this are that older people are a heterogeneous group, that the human body has various sizes, shapes and abilities to move, and that each individual perceives and values different properties and characteristics of chairs differently depending on their past experience, resources and expectations. Usage and preferences of pieces of furniture are regionally and culturally determined and depend on the individual's background. Eriksson (2010) states that viewing older people as a homogeneous group with similar interests, common attitudes and ways of living contributes to age discrimination and that such a preconceived and uniform understanding has become increasingly erroneous. In other words, the fit between the chair and the individual user and his/her identity and body jointly influences the product

experience. In line with Hekkert and Schifferstein (2008) human-product interaction is not necessarily restricted to instrumental interaction (operational use of the product) or non-instrumental interaction (perceiving sensory experiences that do not directly serve a function in operating the product) but may also consist of non-physical interaction (fantasizing, remembering, or anticipating usage of the product). The chairs were not just evaluated as technical tools to serve an operational task-related purpose. They were also seen as expressions of values and expressions of one's self. This was shown when the participants were asked which products would fit, or not fit, in their home and explain why. Product experiences perceived as meaningful went beyond goal fulfillment and accessibility. Lessons learnt are that chairs that fit with other interior products in the user's home, elicit recognition, and reflect the identity the user strives for, are perceived as valuable product features.

It is important to point out, however, that the participants shared their opinions about some product features. Possible explanations for that would be chairs that were perceived as comfortable, elegant, inviting, flexible, pleasant for all senses, ageing with grace as well as easy to use, handle, move and clean were ranked high on the satisfaction scale. Chairs that met all aspects and were perceived as well-balanced, where no product features dominated at the expense of others, appears also to be highly appreciated. The results showed that the individual participants' ratings and statements about satisfaction on the items in the test sequence were intertwined and had a tendency to follow each other. Different properties and characteristics are likely to co-affect the totality of what is perceived. It seems plausible that the perceived experiences do more than simply determine the user's preference as a result of the interaction. The experience affects the interaction since it accompanies and guides the interaction (Hekkert and Schifferstein, 2008). According to Norman (2004), every human-product interaction has an affective component. A positive affect can "...broaden the brain processing, the muscles can relax, and the brain attends to the opportunities offered by the positive affect" (Norman, 2004, p. 26). A relaxed feeling is the core of the comfort experience. A possible explanation for why the ratings and statements about satisfaction followed each other, could, for example, be that product features that convey messages of attention and consideration of the user, also influence the experience of comfort and usability. "Welcome" and "care" were among other words used to justify a high degree of satisfaction with ingress. These lessons learnt are in line with Desmet et al. (2008) who state that all emotions carry a specific behavioral component, also called action tendency. In this case the positive action tendency might have been "accept" and/or "care for". That is, for example, if you are happy with the visual appearance of a chair it affects your ratings and statements of how satisfied you are with the comfort and usability. On the other hand, this phenomenon probably works inversely: expected satisfaction with comfort and usability affects the degree of satisfaction with the visual appearance. Similarly, if you are satisfied with the comfort, it might affect how satisfied you are with the visual appearance and usability of the chair.

DISCUSSION OF METHODS

Limitations of the present study include that the evaluation was carried out on short-term experiences in an artificial environment; a usability laboratory. This means that long-term effects on experience and use in authentic environments could not be studied. Short-term usage could be experienced differently from long-term use. It is important to understand that an everyday experience in an authentic environment is more complex than an experience in a usability laboratory, which prevents one from arriving at a complete understanding of the significance of the furniture. Natural positions humans take while seated may not be supported in a usability laboratory (Vink and Brauer, 2011). Still, more research is needed to determine the importance of the differences in the context of use and its influence on product experiences.

More studies on long-term effects of human-product interaction in end-users' homes are needed to verify if the laboratory results also are found in situated contexts of use. On the other hand, a usability laboratory enables performing controlled tests in which it is possible to focus on particular aspects of use. In the present study, the chairs were tested in a uniform way and in varying order, and the results for the chairs are valid in reference to each other. Issues about older people's experience of chairs require constant revisiting, as user preferences, sensory perceptions and technology are likely to change over time, involving changes in past experiences, expectations, abilities, home environments and usage or tasks.

Many steps of the test sequence contained qualitative dimensions of movement. Johnson (2008) states that, "...learning about the possibilities for different types of experience and action that comes from moving within various environments occurs mostly beneath the level of consciousness" (p. 21). This fact causes difficulties to improving our understanding of bodily encounters and may have had an impact and limited the results since the analysis is based on the participants' verbal responses, and also probed and interpreted by the researchers. However, the method used elicited some tacit user needs that were hard for the participants to express in words. The majority of the participants really tried to express their movements in the test sequence in words, movements they carry out on a daily basis, but in some cases had never reflected on before. This is why the participants were confronted with tests of everyday interactions in a controlled environment, conducted in a similar manner for all participants. The present study aimed to elicit tacit knowledge about actual bodily experiences of instrumental interaction in direct encounters with chairs. The idea was that proximity to the chairs and actual bodily experiences would assist the users in expressing their experiences, opinions and ideas and in stating reasons for their actions, e.g., why some participants chose to perform their egress of the chairs in several steps or why they gripped or held on to the chair in a particular way.

PRACTICAL IMPLICATIONS

A vast number of chairs are designed and introduced on the consumer market every year, but these are rarely evaluated with end-users to generate new knowledge for the design of totally new or iteratively refined products. The present study highlights the importance of recognizing the many attributes of humans that have various impacts on product experiences, and stresses the importance of considering various properties and characteristics of furniture. Examples of such product features include how the chair fits the user's body and body movements, whether it is easy to handle and use, whether it suits the individual, whether it is easy to furnish with, and whether it goes well with the intended home environment. Importantly, the present study indicates that the lack of attention to one product feature seems to negatively influence the user's satisfaction with other product features. These results are valuable for design practitioners because they can be used to facilitate structured attempts to design for usability and well-being in later life. However, in the practice of design there are several other perspectives to consider and balance, not at least ecological, economical and commercial as well as production related factors. When investigating what being a partner meant to the participating furniture manufacturers of the *PLUS-project*, the present study was described as particularly valuable by several of their representatives (Jonsson et al, 2013).

3. CONCLUSIONS

The present study contributes to knowledge about various product features that affect and co-shape the perceived experience of older people interacting with chairs. The results show that participants displayed different needs and wishes. Therefore, a conclusion is that various chairs

are needed to satisfy the diverse group of users. The participants shared an appreciation for chairs with properties and characteristics suiting their bodies, homes and desired identities. The participants agreed on the importance of comfort and easy egress of a chair. Properties and characteristics of furniture that from different perspectives satisfy, pay attention and show consideration to the users' needs and the contexts of use were appreciated. Chairs that were recognized and familiar to participants because they were viewed as "modern furniture classics" were considered to best fit participants' homes. The results also point to the fact that various properties and characteristics of furniture influences the overall experience as well as experiences of each everyday interaction in the test sequence of the investigated chairs in the test. One possible explanation may be that previous experiences together with the first impression of a chair elicit expectations, which in turn affect the product experience. This knowledge is valuable to design practitioners in order to understand what to focus on, what is in the users' best interests, and to be able to respond to the needs and wishes of older people. The fulfillment of these needs and wishes can lead to design solutions that are competitive, perceived as appealing earlier during people's life, avoid the needs of future changes, and leads to sustained health and psychological well-being in later life. Because the meanings of furniture are constructed by its user/users, the present study suggests the best way to make sure that pieces of furniture meet older people's needs and wishes is to assume a holistic perspective on older people and involve them as potential users in the design process.

ACKNOWLEDGEMENTS

The present study was carried out in the framework of the *PLUS-project (Development of the Swedish Wood and Furniture Industry for Consumer Oriented and Competitive PLUS-products)*. The *PLUS-project* was supported by VINNOVA (The Swedish Governmental Agency for Innovation Systems). This support is gratefully acknowledge. Many thanks to the persons participating in the study.

References

- Daunfeldt, S-O., Gustafsson, N., Hortlund, P., & Rosén, E. (2008). *Äldres konsumtionsmönster och preferenser [Consumption patterns and preferences of old consumers]*105 (Report No. S118). Stockholm, Sweden: HUI Research (The Swedish Retail Institute). Retrieved 1 September 2017 <http://docplayer.se/1429861-Aldres-konsumtionsmonster-och-preferenser.html>
- De Looze, M. P., Kuijt-Evers, L. F. M., & Van Dieën, J. G. M. (2003). Sitting comfort and discomfort and the relationship with objective measures. *Ergonomics*, 46(10), 985-997.
- Desmet, P. M. A., & Hekkert, P. (2007). Framework of product experience. *International Journal of Design*, 1(1), 57- 66.
- Desmet, P., van Erp, J., Hu, C., & van der Veen, L. (Eds.) (2008). *Enriching. Enrich the passengers' airport experience by designing interventions with an intended emotional effect* (pp. 36-41). Rotterdam: Veenman Publishers.
- Engdahl, S. (1968). *Möbler för äldre: Sammanställning av praktiska krav [Furniture for elderly: Compilation of practical demands]* (Report no. 11). Stockholm, Sweden: The Swedish Furniture Institute.
- Englund, A. (1986). *Ett öra mot kunden [An ear to the customer]*. Volvo Monitor, September 1986. Volvo Car Corporation, Torslanda, Sweden.
- Eriksson, B. G. (2010). *Studying Ageing: Experiences, description, variation, prediction and explanation*. Göteborg Studies in Sociology No. 41 (Doctoral dissertation, Dept. of Sociology, University of Gothenburg, Göteborg, Sweden). Retrieved September 5, 2013, from https://gupea.ub.gu.se/bitstream/2077/21906/6/gupea_2077_21906_6.pdf

- Essén, A., & Östlund, B. (2011). Laggards as innovators? Old users as designers of new services & service systems. *International Journal of Design*, 5(3), 89-98.
- Farage, M. A., Miller, K. W., Ajayi, F., & Hutchins, D. (2012). Design principles to accommodate older adults. *Global journal of health science*, 4(2), 2-25.
- Forlizzi, J. (2008). The product ecology: Understanding social product use and supporting design culture. *International Journal of Design*, 2(1), 11-20.
- Franz, M., Durt, A., Zenk, R., & Desmet, P. M. A. (2012). Comfort effects of a new car headrest with neck support. *Applied Ergonomics*, 43(2), 336-343.
- Hekkert, P., & Schifferstein H. N. J. (2008). Introducing product experience. In H. N. J. Schifferstein, & P. Hekkert (Eds.), *Product experiences* (pp. 1-8). Oxford: Elsevier.
- Holden, J. M., Fernie, G., & Lunau, K. (1988). Chairs for the elderly - design considerations. *Applied Ergonomics*, 19(4), 281-288.
- Johnson, M. (2008). *The meaning of the body. Aesthetics of human understanding*. Chicago: The University of Chicago Press.
- Jonsson, O. (2013). *Furniture for later life: Design based on older people's experiences of furniture in three housing forms* (Doctoral dissertation, Lund University, Lund, Sweden). <http://www.lu.se/forskning/avhandlingar-och-publikationer/avhandlingar/>.
- Jonsson, O., Östlund, B., Warell, A. & Dalholm Hornyánszky, E. (2013). Experiences of a User-Centred Research Approach involving Old People in Early Phases of Design; Reflections from Furniture Manufacturers. *Proceedings of the 10th European academy of design conference - crafting the future*, Gothenburg, April 17-19, 2013.
- Jordan, P. W. (2000). *Designing of pleasurable products: An introduction to the new human factors*. London: Taylor & Francis.
- Newman, A. B., & Cauley, J. A. (Eds.) (2012). *The epidemiology of ageing*. Dordrecht, Germany: Springer.
- Norman, D. A. (2004). *Emotional design. Why we love (or hate) everyday things*. New York: Basic Books.
- Mills, N. J. (2007). *Polymer foams handbook – Engineering and biomechanics applications and design guide*. Oxford: Butterworth Heinemann.
- Moes, N. C. C. M. (2005). Analysis of sitting discomfort, a review. In P. D. Bust, & P. T. McCabe (Eds.), *Contemporary Ergonomics 2005* (pp. 200-204). London: Taylor & Francis, London.
- Pirkkl, J. J. (1994). *Transgenerational design: Products for an aging population*. New York: Van Nostrand, Reinhold.
- Rosmalen, D. van, Groenesteijn, L., Boess, S., & Vink, P. (2009). Using both qualitative and quantitative types of research to design a comfortable television chair. *Journal of Design Research*, 8(1), 87-100.
- Schifferstein, H. N. J., & Spence, C. (2008). Multisensory product experience. In H. N. J. Schifferstein, & P. Hekkert (Eds.), *Product experiences* (pp. 133-161). Oxford: Elsevier.
- Snyder, M., Tseng, Y. -H., Brandt, C., Croghan, C., Hanson, S., Constantine, R., & Kirby, L. (2001). A glider swing intervention for people with dementia. *Geriatric Nursing*, 22(2), 86-90.
- Sperling, L. (1990). *Ergonomics of the female hand*. (Tech. Rep.). Ergoma AB, Volvo Group, Torslanda, Sweden.
- Sperling, L., & Eriksson, P. (2006). Drivers' experiences of material qualities in present and future interiors of cars and trucks. In P. D. Bust (Ed.), *Contemporary Ergonomics 2006* (pp. 179-183). London: Taylor & Francis.

- Stephens, E. C., Carswell C. M., & Schumacher, M. M. (2006). Evidence for an elders' advantage in the naive product usability judgments of older and younger adults. *Human Factors*, 48(3), 422-433.
- William-Olsson, M., & Svanborg, A. (1984). *Gammal eller ung på äldre dar [Old or young in later life]*. Malmö, Sweden: Utbildningsproduktion AB.
- Vink, P. (2008). Crucial elements of designing for comfort. In H. N. J. Schifferstein, & P. Hekkert (Eds.), *Product experiences* (pp. 441-460). Oxford: Elsevier.
- Vink, P., & Brauer, K. (2011). *Aircraft interior comfort and design*. Boca Raton, FL, USA: CRC Press.
- Volvo Car Corporation (1984). *Some questions to you as a Volvo driver*. Quality Staff, Volvo Car Corporation, Torslanda, Sweden.
- Wahlöö, A. (2017). *Att göra en klassiker: En studie av fenomenet moderna möbelklassiker i en samtida svensk kontext [To make a classic: A study of the phenonomen of modern furniture classics in the context of contemporary Sweden]*. (Doctoral dissertation, Lund University, Lund, Sweden). Höör, Sweden: Brutus Östlings Bokförlag Symposium.
- Zenk, R., Franz, M., Bubb, H., & Vink, P. (2012). Technical note: Spine loading in automotive seating. *Applied ergonomics*, 43(2), 290-295.

Corresponding author:

O. Jonsson

Lund University, Faculty of Medicine, Department of Health Sciences & Centre for Ageing and Supportive Environments (CASE), Lund / Sweden
oskar.jonsson@med.lu.se

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

THE ROLE OF USER IN THE DESIGN PROCESS. CREATING ADDITIVE EXPERIENCE.

mgr Joanna Lisiecka

University of Arts in Poznań, Faculty of Architecture and Design, Furniture Department, Poznań

Key words	Abstract
<i>Research, Design process, User experience, Ergonomics, Communication, 65+ users</i>	<p>The Approach towards product design and furniture for people 65+ has changed lately.</p> <p>We can easily distinguish two main groups of potential users, with extremely different needs and ways of using our products. “New young” and people who need help in everyday routine will need different stimulus. This fact creates a wide space for design processes and us, designers. I would like to present the theory of design process, an established, step-by step journey from the idea to the production, filled with data connected directly to these two groups. On these examples, I wish to show to the audience how user-centric experience can be created with good communication.</p>

Corresponding author: *joannalisieckadesign@gmail.com, University of Arts in Poznań, Faculty of Architecture and Design, Furniture Department, Poznań/ Poland*

1. TWO FACES OF 65+ GROUP

BENEFITS AND RISKS IN THE NEW STAGE OF LIFE

Design process allows us to develop better ideas. As designers, we create visions that have not existed in the past. Methods and processes should be S.M.A.R.T., just like the value. Understanding the needs of people in their late 60's is essential for developing products and furniture. Many of western countries have ageing societies. This fact creates a new reality with a new group of specific consumers. Looking at them as two groups “new young” and “living with help” allows us to create concepts in an early stage of design process. Differences in making decisions, fields of interests and kinds of plans for future in these groups creates potential market for new designs. Mind maps, moodboards, research, all of them focused on each group, can help in creating new value and solve important problems.

ROLE OF DESIGNER, S.M.A.R.T. PROJECTS

In every new design, problem understanding and creativity ads into the solution. Today we can observe many design specializations. Many industries are benefiting from the Design approach. We can see it in technology, artistic projects, user and customer experience, services, food, furniture & products. S.M.A.R.T. is a strategy of creation meaning: Specific (we know who, why, when, where, witch, what) for designer it means to start with a BRIEF of the project, meeting with a client, getting to know their expectations and how work will be Measured (KPIs). By getting to know more about technology which is going to be used in the project and by making proper research (client, product, competition, trends), the goal becomes more

Achievable & Realistic. Good team work and a lot of hard work provides Time-bound effects. It is important to start with basic information because even “obvious knowledge” can shape the design. Organizations ask designers to think out of the box and to write down the vision for their companies. They always seek for something they can’t achieve by their own.

DESIGN PROCESS – WHY IT IS IMPORTANT & STAGES OF ESTABLISHING THE PROCESS

In every cooperation there is a different problem to be solved, needs to be fulfilled, and unique prioritisation to be looked at. Also looking at the client’s needs, we need to look at a wider horizon. The Client is not only the company which will pay you for the product, the client is every person who will touch the new design in the future. People who will produce it, people who will sell it and those who will use it for years. Even people who will deal the product when it reaches the end of its’ live. This gives designers more aspects to think about on the beginning of design process.

Creators have to address problems, do research, generate ideas, select them, develop & redefine, explore possible options, define and make final product.

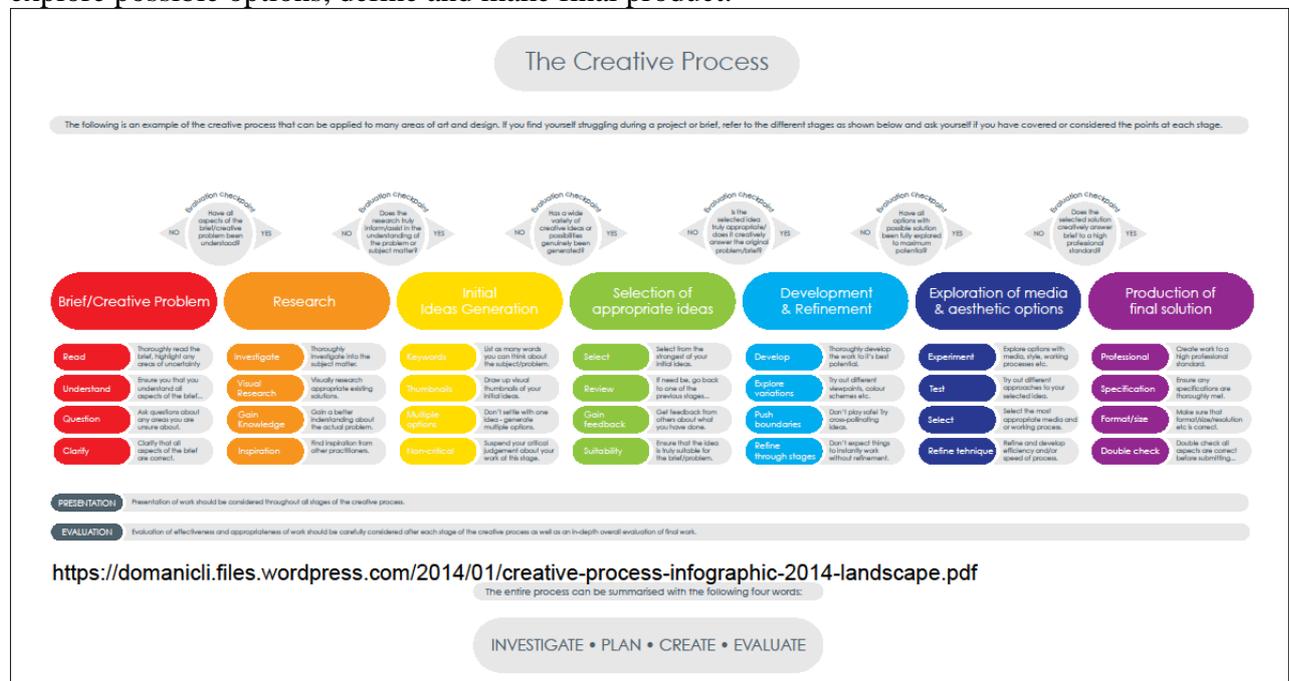


Figure 1. Design proces, source: <https://domanicli.files.wordpress.com/2014/01/creative-process-infographic-2014-landscape.pdf>

“NEW YOUNG” OR “LIVING WITH HELP” UNDERSTANDING DIFFERENT NEEDS.

Three years ago Joanna Lisiecka had an opportunity to create a new design for Marmite company. They are a big manufacturer of conglomerate basins and baths. The material which they use give designers a possibility to produce unique, beautiful and powerful designs. Their products stays pricey comparing to clay which leaves polish customers out of the main target group. The need for proper research has emerged. The search for potential client had to target richer European countries. By watching trends connected with a lifestyle and demographic data, designers realized that populations of many European countries are ageing.

Needs of every person in the World are in general pretty much the same – as A. H. Maslow said: physiological, safety, membership& love, respect, self-realization. Followed by another two higher needs which are not in the pyramid but are just as well important, esthetic needs and

will of possessing the knowledge. The deeper meaning of these needs is changing depending on personal motivations, life deficiencies, human will and development.

These differences influence formation of two Persona types in the 65+ age group: 'New young'- and "Living with help". New young are usually self-motivated, driven and open to new experiences. These people after age of 65 want to remain active. They spend their time on fruition of their life's passions and dreams¹. They have a great consumer potential for the market. They are not hesitating from spending money, they socialize and they like fashionable ads. Depending on what is more important for them, they can fulfill their ambitions at home, but also by expressing their personal style's flare in clothes, food, holidays. The meaning of style is important to them, they want to emphasize that they are unique.

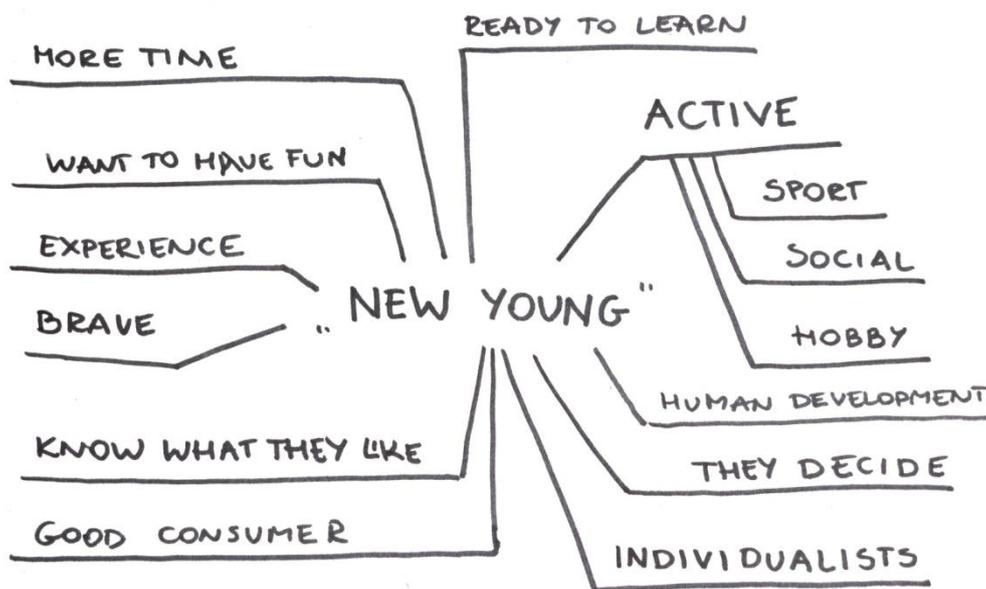


Figure 2. Mind map "new young", own elaboration

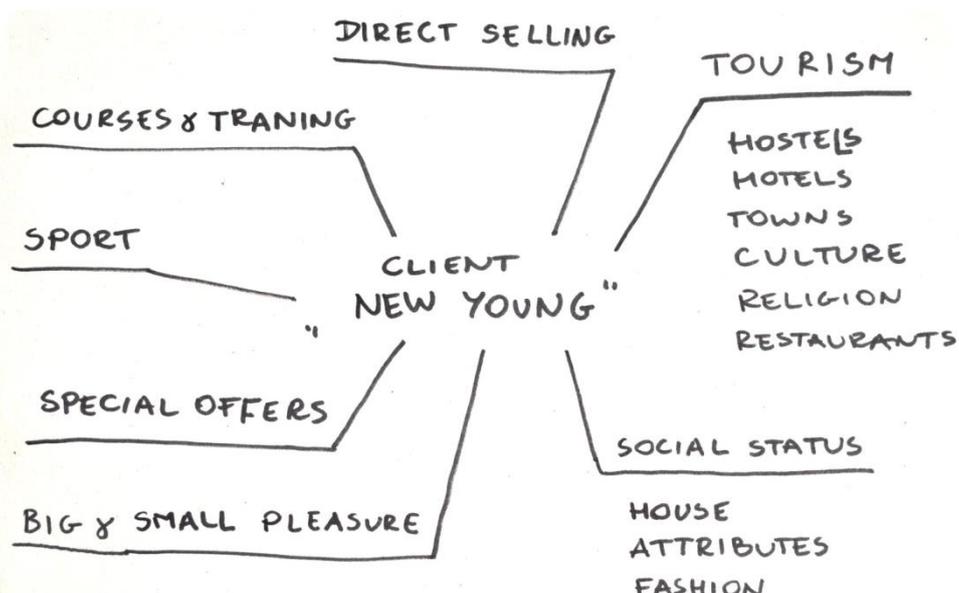


Figure 3. Mind map "client- new young ", own elaboration

¹ Dąbrowska, M. i Rey, T. (2008). Kosztowne ignorowanie segmentu 55+. Marketing w Praktyce, 123, 20-23.

'Living with help' group needs a help of a carrier to fully enjoy their life's. The intensity and frequency of that help might vary creating smaller units within this team. Two most common subjects of interest for the carriers are helping out with daily routine of an elderly person and/or helping with their health treatments. These people more than others depend on social help from structural organizations and communities. It means that designs needs to answer slightly different problems, for example Ergonomics is going to be more important than style as it might create an easier way to do perform daily tasks independently. Another issue demanding another approach pricing model. "Living with help" depend on others with most of their purchases. Therefore, people engaged in shopping for products might include families, aid organizations, caregivers, hospitals and institutions.

Businesses dedicating their offer to people 65+ will benefit from keeping both groups in mind. Providing customers with accessible information will help buyers to make the right choices. Enriching product's family ranges might strengthen the connection with the brand.

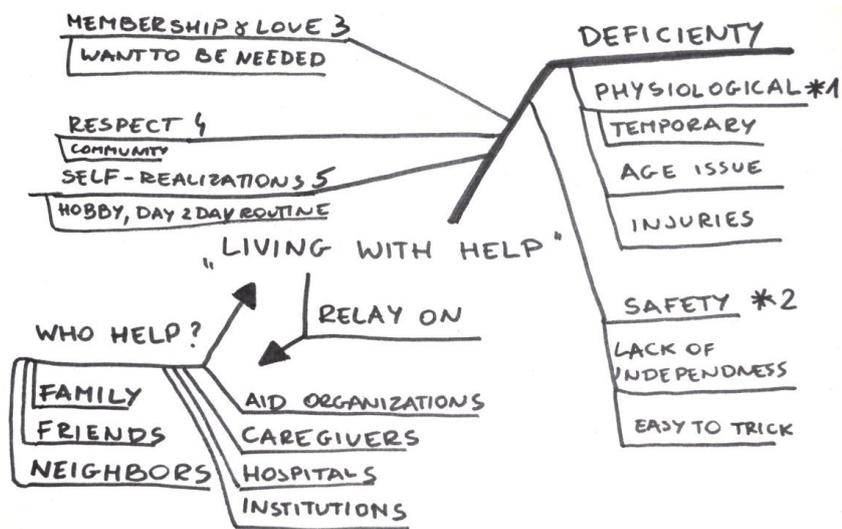


Figure 4. Mind map "living with help ", own elaboration

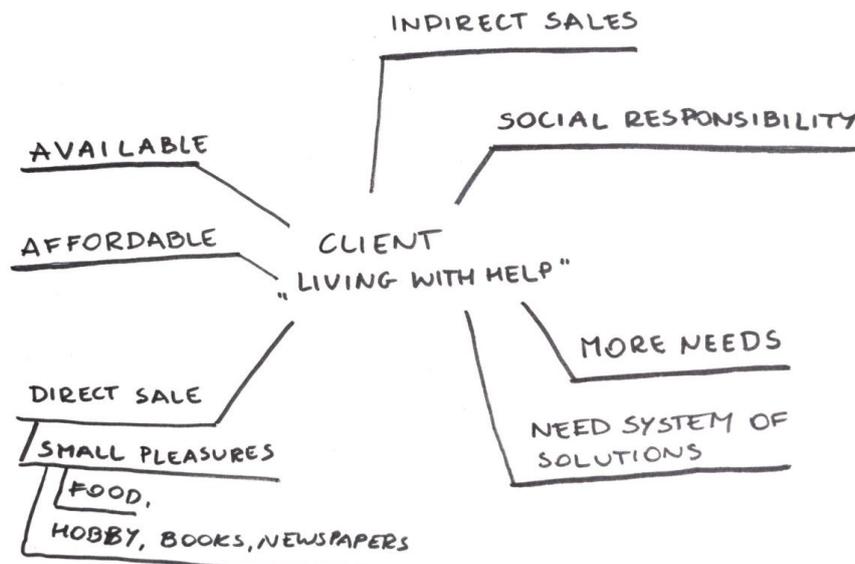


Figure 5. Mind map "client- living with help", own elaboration

2. METHODS AND MATERIALS

USER ROLE IN DESIGN PROCESS: PERSONA BUILDING, RESEARCH, MOODBOARDS, PROBLEM SOLVING.

As Opaschowski said ‘human being doesn’t have to spend Money to feel happiness’.²

Happiness is not a lack of unhappiness either. We need emotional stimulations to feel good. In our culture of consumer goods there is expansion of fashion and ownership in its’ symbolic and emotional meaning, which increases diversity of products, with the same value of usability, and causes faster replacement of older products by new ones.³

To create a suitable product, our consumer needs to be properly examined. One of the very first subjects is User value. Design thinking methodology gives us tools like value mapping and pyramid of needs allowing us to create persona hypothesis. Best practice is to invite Potential clients and compare them with our personas and conduct some research. It can be done in a form of interviews, focus groups or simple interactions observation. In result Designer can alter personas and get better results down the process. Starting design process from the user guarantees not just fulfilment of user’s needs – therefore happier costumers, but also understanding of the user’s behavior. It means that product can be better fitted for purpose. Use cases for the knowledge gained are broad, from material colors to marketing channels.

Design process is today more than one of the best practices followed by industry leaders, It’s key part of a product strategy.

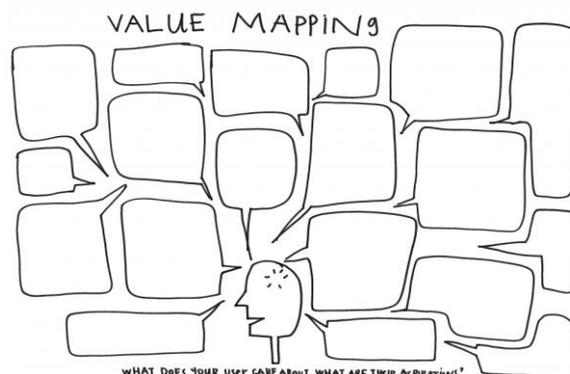


Figure 6. <http://www.legaltechdesign.com/LegalDesignToolbox/develop-a-new-project/>



Figure 7. <http://www.legaltechdesign.com/LegalDesignToolbox/develop-a-new-project/>

² Opaschowski, W.H. (1992). Konsum 2000 – Szenarien über die Zukunft von Konsum und Freizeit. W: G. Rosenberger (red.), Konsum 2000. Veränderung im Verbraucheralltag (s. 208–225). Frankfurt nad Menem: Verlag Campus

³ Schneider, N.F. (2000). Konsum und Gesellschaft. W: D. Rosenkranz (red.), Konsum: soziologische, ökonomische und psychologische Perspektiven (s. 9–22). Opladen: Verlag Leske+Budrich.



Figure 8. Photos of real surrounding of persona

Figure 8 show real photos from persona to designs for Marmite company. Healthy life style, full of active sports and business challenges. Danuta has time for her family and for realization her hobbies. She was a great inspiration to create five propositions of basins design.



Figure 9. Moodboard and project TRIANGLE, design Joanna Lisiecka, owner of product: Marmite company



Figure 10. Moodboard and project FLOW, design Joanna Lisiecka, owner of product: Marmite company



Figure 11. Moodboard and project STONE, design Joanna Lisiecka, owner of product: Marmite company

Figures 9 to 11 present 3 from 5 designs which presents different options for New Young group. Triangle has a big shelf zone which is most practical and simple in shape. It is a good product for bigger spaces and it's intended either as a hanging basin, or with a locker. It is symmetrical and gives impression of harmony. Simple and dynamic for people who exactly know what they need. Flow (picture 10) presents functionality dedicated to guest bathrooms, where aesthetic values are most important. Basin can be use as the overtop, or a nice decoration of bathroom cabinet. Delicate, feminine form, could also be used in luxury spaces presenting status of the owner. Mix of needs of individuality and functionality is Stone basin. Simple in external shape with interesting inside. It is a safe choice for modern spaces and fresh accent in conservative bathrooms.



Figure 12. Basin UNO⁴, 10PE-P, design Anna Dull, manufacturer: Marmorin

Uni is a basin, also a Master Degree design from Academy of Arts in Poznań produced in cooperation with Marmorin. Anna Dull created a symmetrical, shallow basin with extra handles which could be use by as well as young and strong as disabled people. It also resolve problems such as using basin during wash hair routine. Shape of Uni is a natural answer for research in social care home.

3. RESULTS AND DISCUSSION

There is a space for all kinds of products. People should have possibilities to dream and decide what they want in every moment of their life. manufactures are responsible for creating new categories of functionalities and life of products. Could we create a space which would be comfortable for children, adults and seniors?

Splitting people into groups, new young and living with help, is good start for designing process for designers. It is also important business decision and good strategy in marketing communication. Good channels of advertising products will decide on success of the product. Most important is to educate our users about life changing circle. If we educate 30 years old people who have close contact with their parents, we will get better social relations which may bring better life changing decisions.

4. CONCLUSIONS

There is a lot of to design for each group of 65+. By creating for them, we create our future possibilities. Raising comfort and safety of seniors living space depends on designers' and manufactures' decisions.

⁴ Catalog 10 PE-P, ISBN:978-83-88400-75-9

References:

- Dąbrowska, M. i Rey, T. (2008). Kosztowne ignorowanie segmentu 55+. Marketing w Praktyce, 123, 20–23.
- Opaschowski, W.H. (1992). Konsum 2000 – Szenarien über die Zukunft von Konsum und Freizeit. W: G. Rosenberger (red.), Konsum 2000. Veränderung im Verbraucheralltag (s. 208–225). Frankfurt nad Menem: Verlag Campus
- Schneider, N.F. (2000). Konsum und Gesellschaft. W: D. Rosenkranz (red.), Konsum: soziologische, ökonomische und psychologische Perspektiven (s. 9–22). Opladen: Verlag Leske+Budrich.
- Catalog 10 PE-P, ISBN:978-83-88400-75-9

Web references :

<http://www.helpage.org/>

<https://domanicli.files.wordpress.com/2014/01/creative-process-infographic-2014-landscape.pdf>

<http://www.legaltechdesign.com/LegalDesignToolbox/develop-a-new-project/>

Author name J.Lisiecka

University of Arts in Poznań, Architecture and Design Faculty, Furniture Department, Poznań / Poland

joannalisieckadesign@gmail.com

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

INFORMATION SYSTEM FOR FURNITURE INDUSTRY KNOWLEDGE BASE TRANSFER

Milan ŠIMEK¹, Boris HÁLA¹, Petr BRUNECKÝ¹

¹ Mendel University in Brno, Faculty of Forestry and Wood Technology,
Department of Furniture, Design and Habitation, Brno / Czech Republic

Key words	Abstract
<i>Furniture, Industry support, Information system, Quality, Database.</i>	The main goal of this contribution is the presentation of new web based information system developed in Czech Republic to support research, development, innovation and higher quality of furniture industry and its products. Furniture Information System (Nábytkový Informační Systém - NIS) is an open information system on the basis of a structured database of furniture requirements and standards to support the creation of products, especially for small and medium enterprises sector. Basic description of the content and structure of the system is the main content of this contribution. As a conclusion, there are the special benefits described, which are supposed to bring users an advantages over their less informed competitors. This new furniture information system (NIS) is available for all possible users on the internet (www.n-i-s.cz), in Czech language so far, but it is projected to be extended to other language mutations.

Corresponding author: simek@mendelu.cz Šimek M., Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Furniture, Design and Habitation, Brno / Czech Republic

1. INTRODUCTION

Whoever is into furniture sector in areas such as design, development, manufacturing and trade will sooner or later face a problem that seems to have no solution. One guesses that the problem has been solved in previous times or the solution is part of some standards or regulations or it is just generally known. But no one knows where the needed information is hidden. Looking for the information can take hours or days that could be used in much better way. Good information at the right time is very valuable and it is being valued more and more. That is the reason why there is a project that has been developed in the Czech Republic. It is called Furniture information system, which is also the name of this article. The shortcut for this project is „NIS“ and we would like to inform you about our solution in this article.

2. BASIC SYSTEM INFORMATION

Project of the system was made by experienced workers of Mendel University in Brno, within the framework of the Department of Furniture, Design and Habitation and under the guidance of associate professor Petr Brunecky. The Ministry of Industry and Trade of the Czech Republic has announced that the project supports research and development in its category (TIP). The project has been supported by The Association of Czech Furniture Manufacturers (Asociace českých nábytkářů - AČN) and by the Cluster of Czech Furniture Makers (Klastr českých nábytkářů – KČN). The results of the project are available online: www.n-i-s.cz

Participants and co-solvers:

- Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Furniture, Design and Habitation
- Wiesner-Hager Bohemia s.r.o. Humpolec
- NADOP furniture manufacturing Ořechov
- INT,s.r.o. Brno

3. GOALS AND CRITERIA

The goal of our project was the development of a unique open information system based on a structured database of requests concerning about the furniture and by that supporting production of small and medium- sized enterprises.

The database consists mainly from safety criteria of products, ergonomics and anthropometric demands, technical quality – product testing, qualitative characters of the furniture construction including criteria for application of products and its design.

It contains also approximated EU requirements in the field of obligatory legal regulations demanded in the furniture industry. The database consists of conditions specification for products certification and it is in perspective to extend the system and imply also demands from countries in the EU and export destinations in the furniture industry. The database is structured by typological groups and one can find here complex information by inputting a wanted concept.

Part of the project goals is fulfilling these criteria:

FUTURE ORIENTATION

Active orientation on research, innovations/development potential of universities and outputs usable by the industry especially for needs of small and middle-sized enterprises.

ECONOMIC VALUE

Improving of Czech industry competitiveness on the European field. Increasing efficiency of manufacturing companies, especially small and middle-sized enterprises. Furthermore the capacity and time for finding new solutions and product development.

USABILITY OF THE SOLUTION

Interdisciplinary solutions are also available in other fields such as building or wood industry. The system can be used not only for development, but also for trading of furniture and entering European and other markets. Various kinds of usage support different needs, new design, modern manufacturing, distribution, customer's usage and production control.

There has been a clear urge of the Association of Czech Furniture Manufacturers to the goal of offering the project results to all companies not only in the furniture business, but also in manufacturing of other furnishing products for interiors, including architects and designers. The system is also great help for companies dealing with export of interior equipment and realization of interiors in homeland and abroad.

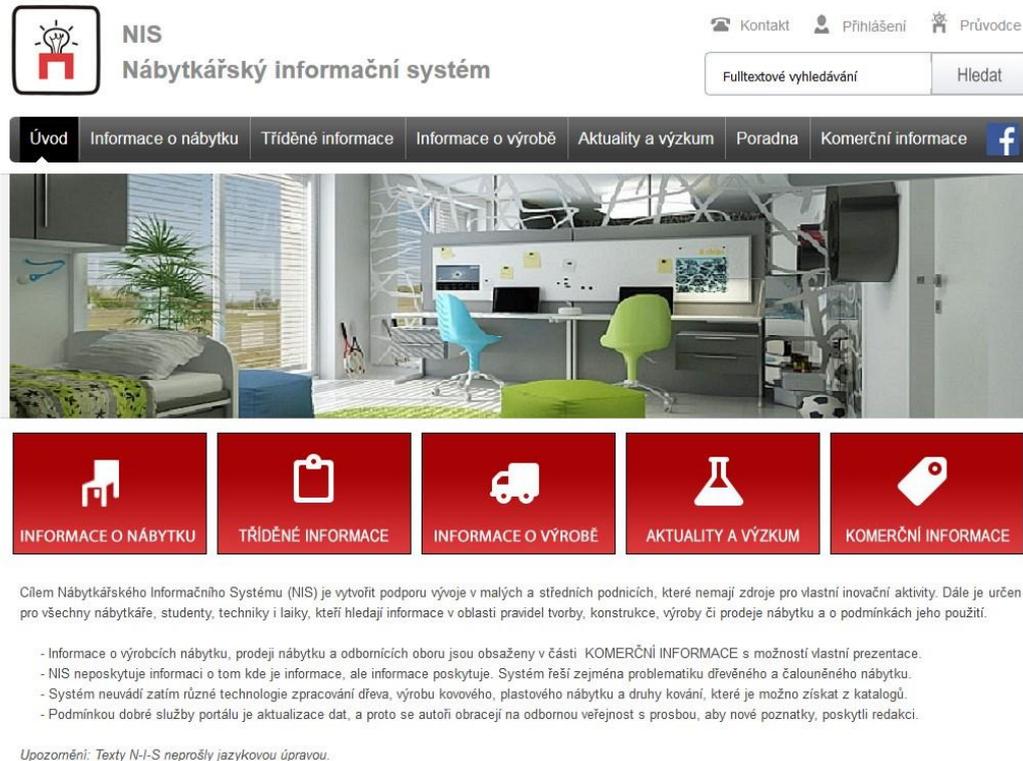


Figure 5. NIS database/webpage overview

4. SYSTEM BENEFITS AND POTENTIAL

The system is a unique solution. It generously supports competitiveness of the Czech furniture industry within the European field but also the field of world export. The system has started and has been giving significant support for innovations and development of small and mid-size enterprises. These companies has usually very limited sources for their own development and innovation activities. The system allows development of technological proceedings that cares about the environment. The secondary effect of the system causes a production of higher quality products and specific comparative advantages for furniture companies on the market. It vicariously creates new job vacancies. It allows faster and quality of innovation process compared to a competition abroad. There is no such system abroad so it brings more attention to the Czech research and development in furniture industry on the European field.

5. CONTENT OF THE SYSTEM

Analysis of all options has become the basic task for realization of developing information system. The analysis was based for setting basic parameters, demands and needs for its evolution and construction and for finding means that are used or developed for the intent of the system.

Putting the chosen parts together has created a real version of the current solution. A system and functional proposal of the portal content has been processed and its attributes were characterized, than database system content has been specified. Due to the few analysis, it was possible to define and try graphical form of architecture on the graphic system interface in which the content and structure has been defined (Figure 1.). There are also defined attributes for the basic menu in the „searching“ part of the system.

Nowadays the system has four basic parts. It contains and offers following information:

- General information about furniture
- Categorized information about furniture
- Information concerning manufacturing process
- Research and Commercial part of the portal

Generally speaking, the system consists of information about legislatively demanded properties of furniture products in a way to satisfy the conditions of standard accreditation and testing necessary for placing the products on the market.

The system also contains criteria for developing products that are not legislatively demanded, but are made by general conditions, technical and technological ways of actual manufacturing, attributes of material use and other parameters that are generally expected to be accomplished. It contains also the parameters to place products on the market such as safety criteria of products, ergonomic and anthropometric demands, technical quality – examining of products, qualitative characters of construction and construction of the furniture including criteria for application of products and design.

The system contains not only demands on standard furniture but also furniture demands for public interior – built-in furniture, furniture specifications for children and information about marketing methods and control of the furniture market. The database is structured by typological groups and we can look up complex information by inputting a demanded concept. It contains also new anthropometric data and parameters. A new anthropometric research with the actual population has been made for this part of the system within the project. Its results were processed and integrated into a structure in the system during the final phase of the project.

From the short introduction to the system's content, we can see that there is a database with great amount of data. It was necessary to create a system with searching tool for the data and arrange it in a way to be able to offer a logical setting and the right data for the right question asked by a user.

The most effective way in present time, is to create a portal which is a graphical interface of this database system. This web is accessible easily and its rules are known to most of the potential users without having to learn something new. The user does not have to invest to technical equipment of his workplace, because it has already been equipped. The problem was just to find the right graphics and the right way of sorting the information that are supposed to be user friendly, understandable and in such extent, so it is not too overloaded for users.

The result of this work can be presented on following example: If a user wants to know specifics about a armchair for using in an office with a metallic base and wheels for export to European Union countries, he will get logically sorted information about demanded specifics containing safety requirements, requested anthropometric and ergonomic characteristics, requested quality signs of the construction and performance of the surface, criteria for tests and as a bonus also a

requests and customs concerning application in space. If the user is not able to specify the product in such detail, the system will lead him through and make him choose the specifications. It is important because a clearly specified answer can be given to a clearly specified question only.

In this way it is possible to ask about all categories within the furniture products including atypical products for arranging public interiors. It is also possible to ask about specific products and place them into categories according to aspects that has been chosen.

Conditions for furniture manufacturing are specified in that part of the system that is dealing with manufacturing information. This part of the portal is designed especially for production company workers but it also contains information about basic materials and technologies used. It also contains information that are necessary to set up the manufacturing process right way. The aspects are environment and its quality in relation with the manufacturing process, information about protection employee's health during work process, waste management and also important valid information from the field of legal relations.

The last part of the system is called "commercial", it has commercial conditions and it is available for registered users only. The commercial part is supposed to make a way how to find resources for managing and updating the portal. It contains updated information about companies manufacturing furniture and furniture components with residency in the Czech Republic, companies that are focused on selling furniture and its accessories and it also contains information about the people, companies and firms developing new technologies and production proceedings or developing marketing and business methods for sales and new markets. Therefore the research section is also present.

6. CONCLUSIONS

As we can see in the content description, the main demand that must be accomplished in the system is persistent validity of the information. Advantage of web portal, which has been chosen for processing the data, is the possibility of systematic editing which is happening on every day basis. The unitary database of the system prevents from twinning and developing various versions of data. The right setting of the system should offer long term tool significantly facilitating professional life to all users. Fast orientation in information is important advantage in all Europe. It is a huge time saving tool for our manufacturers, merchandisers and development workers. Thus an informational system has been made; it is helping to avoid problems with gaining basic information about expected and demanded properties of certain products on the furniture field and offering valid data about the products. It is simple, clear and available from any place. Furniture makers, constructors and traders can use this tool, which is time saving, because they can look up professional, technical information in the field of manufacturing and trade of furniture and it also facilitate education of new professionals. The new professionals will assure the current professionals about validity of their knowledge in the world of fast development of new products, technologies and rules for usage. The intent of this article is to inform you, professionals from the field, about system that has been created and about the intentions of the creators who would like to start building second phase of the system on an international level. It will enable comparing data of various countries. It would be in area of creating process and also technical parameters and international trade in the countries of European Union and countries outside of the European Union. The third phase will enable perfect analysis and successive unification of conditions in participating countries that will take a part of the project. For being part of these phases it is necessary to create a high level

international team. You can contact the creators of the current phase; the contact is included in this article.

Acknowledgement: This article was kindly supported by the Ministry of Industry and Trade of the Czech Republic – project ID MPO ČR FR-TI1/050.

References

The basic literature used for this project was ČSN EN and ČSN P ENV standards valid for furniture and other fields. The list of the standards would be longer than the article itself. The website provides the list.

Web references

NIS, <http://www.n-i-s.cz>, August 30, 2017

Corresponding author:

Milan Šimek

Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Furniture, Design and Habitation, Brno / Czech Republic
simek@mendelu.cz

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

LATVIAN FURNITURE INDUSTRY'S COMPETITIVENESS POTENTIAL IN THE BALTIC STATES

Sigita LIŠE¹, Andrejs DOMKINS²

¹ Latvia University of Agriculture, Forest Faculty, Wood processing Department, Jelgava / Latvia

² Forest and Wood Product Research and Development Institute, Jelgava, Latvia

Key words	Abstract
<i>Furniture industry, Competitiveness, Baltic States, Latvia</i>	Latvian furniture market value, numbers of employees and enterprises in the sector has decreased from 2008 to 2015. There are the serious challenges to be met and increase their competitiveness in domestic and export markets. The strong tradition of furniture production, abundance of timber resources, cheaper access to timber resources and human resources, and favourable geographical location create equal strengths for all the three Baltic States. The evaluation in the context of the Baltic States leads to the conclusion that national strategic support and creation of favourable business environment for entering of foreign capital companies have made a significant contribution to the furniture industry of Lithuania. Whereas, the successful development of Estonia's furniture industry has been achieved by national strategic support that was oriented to increasing the capacity and benchmarking approach of furniture manufacturing enterprises. It is difficult to find one common basis that would promote exactly the furniture manufacturing industry of Latvia, because national strategic support for attracting investors or, on the contrary, increasing of capacity of local enterprises manufacturing furniture practically does not exist. The regular monitoring of wooden furniture manufacturing could significantly contribute to the overall growth of the industry and the development of wood products.

Corresponding author: *sigita.lise@llu.lv, Liše S., Latvia University of Agriculture, Forest Faculty, Wood processing Department, Jelgava / Latvia*

1. INTRODUCTION

Competitiveness is crucial to the success of a highly competitive market (Fedotovs un Pavloviča, 2000). The market is changing and continues to change, which makes it difficult for companies to position themselves and find ways to differentiate themselves from their competitors (Fikss, 2009). Furniture production should foster the emergence of companies, prioritizing production opportunities before entering the export markets, identifying the company's overall capacity, continuously improving operational competence, being flexible and constantly looking for opportunities to enter new markets (Vidal, 2006). The contemporary EU furniture industry is characterized by a high level of production in terms of technical, aesthetic, design and fashion, and has a steady and stable position all over the world (Europe ..., 2011). The furniture industry is an innovative industry that produces high added value products and its turnover is several billions of euros in Europe. Nowadays competitiveness is

an essential factor for both a country and its enterprises in the process of dealing with changing market conditions.

ESTONIA

Researching the Estonian furniture industry leads to the conclusion that in general it has developed an action plan aimed at increasing competitiveness, and includes the following activities:

- increase in export turnover - support for participation in international exhibitions, involvement of foreign marketing experts for 12 months, website development "Marketing opportunities";
- product development - promotion of furniture design;
- increase in production efficiency - support for the rational production in the furniture industry", raising qualifications to the subcontractors of equipment suppliers partners, and mid-level managers;
- reducing the cost of purchasing raw materials - support for subcontracting specialized in furniture manufacturing as well as joint procurement of raw materials from Asia;
- renewal of training programs - vocational and higher education programs contribute to the development of the sector.

The author emphasizes that Estonia, in the long run, has developed a competitive vocational education system that provides for growth opportunities for young skilled workers. Estonia, in comparison with Latvia, has managed to maintain and further develop the growth of the furniture industry. The development of the Estonian furniture industry among the EU member states is noted as the most successful, largely due to the positive influence and experience of the Scandinavian countries, in particular the use of outsourcing in production and supply. Regardless of the product brand, it has been able to preserve a special place in the domestic market by offering outbuildings, built-in furniture, office and hotel furniture to builders and other companies, outsourcing. However, in recent years there was a tendency for strong foreign brands to move to Estonia, because is a liberal economic environment and geographical proximity, as well as relatively low labor and raw material costs, are served by the arrival of these producers. The Estonian furniture industry is generally difficult to compete with major furniture industry countries such as Poland, Russia and Lithuania without close cooperation between enterprises and state support. The international competitiveness of the Estonian furniture industry has improved, despite the increase in raw material and energy prices, which is offset by increased efficiency in business, in marketing area and lowering the prices of materials in order to reduce the risks for exporters of products. Due to the fact that the companies operating in the furniture sector are small, it is very important to promote their cooperation. To achieve this, one quick and effective solution is to build a business enterprise (b2b) network. Estonian furniture manufacturers should try to increase their competitiveness each year through cooperation. Innovations in the furniture industry, especially in product development (design, new materials, etc.), promote the transnational knowledge transfer in local markets for fast and efficient production. Therefore, a skilled workforce is an essential element of development. The development of professional education and policy, as well as support for exporting companies, is important for the growth of the country, which can increase the competitiveness of the sector. Research and higher education institutions with competences on new opportunities and materials for furniture production should be significantly and rapidly increased. Therefore, working in this direction requires close cooperation between entrepreneurs, designers, research institutions and educational institutions in the future, which should be integrated into national development programs.

LATVIA

European, as well as Latvian furniture manufacturers have some advantages over imported furniture from non-EU countries. As the demand for furniture and, consequently, sales prices

go down, the costs of transporting these furniture and the speed of delivery play an increasingly important role. Particular shipping costs are significant for manufacturers in Asia and South America who sell their products on the EU market. Therefore, the author, as the key factor of Latvian furniture manufacturers, mentions the advantageous geographic position and the small distance to the large furniture-footed markets, which allows the fast production and delivery of furniture requisitioned by customers in small lots. Local furniture manufacturers have found their niche in the Latvian market, as well as trying to successfully develop furniture exports. According to the author's research, it is concluded that at present, Latvia and the rest of the Baltic countries are seriously concerned about the economic crisis in Greece, the United Kingdom and elsewhere in Southern Europe, which still requires caution in purchasing prices in many European countries. In the Latvian market, the most competitive domestic producers are Lithuanian and Polish companies that offer products at a lower price. According to the author, the main reason why Polish and Lithuanian furniture can be bought at lower prices is both the selected materials and the fact that these countries are likely to have lower production costs, mainly due to lower taxes, as well as the company's high production capacity. The buyer should choose who would prefer the cheapest particle board or the most expensive solid wood furniture, which is traditionally considered a more durable investment

LITHUANIA

According to the author's research, the growth and development of the Lithuanian furniture industry depends on the strategy implemented by the world-class IKEA, and from the activity's specialization to traditional products or the production of high added value products. The furniture industry in Lithuania can benefit a lot from such big manufacturers as IKEA, especially in the years of the economic and financial crisis. Among the 30 largest suppliers from the Baltic countries, the majority of IKEA companies are Lithuanian furniture manufacturers and almost none of Estonia. The main reason why Lithuania has entered IKEA is lower costs and the country came with a better strategic approach to attracting new investors. The role of IKEA in the production of Lithuanian furniture is enormous, for example, before the emergence of the economical and finance crisis, Lithuanian furniture manufacturers earned two-thirds of their export earnings using IKEA. This trend continued in the years to come. Furniture exports are a key factor in helping producers cope with losses in the domestic market, and during the crisis, it has been confirmed that cheap and high-quality furniture is particularly attractive and demanded in Europe and North America. Long-term cooperation between IKEA and Lithuanian furniture manufacturers has allowed the group to open one of its stores directly in Lithuania, not Estonia or Latvia.

Analyzing publicly available statistical information, the author concludes that the overall indicators of the furniture industry in Estonia and Lithuania are significantly better than in Latvia. For example, in terms of number of registered companies (Fig. 1) and employees (Fig. 2), as well as in terms of production (Fig. 3), exports and imports (Fig. 4), value added of the industry (Fig. 5)

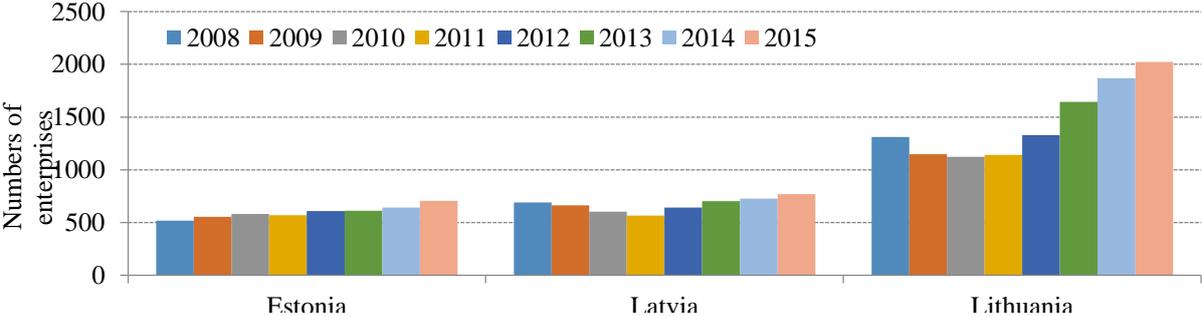


Figure 6. Number of enterprises in the Baltic States (created by the author)

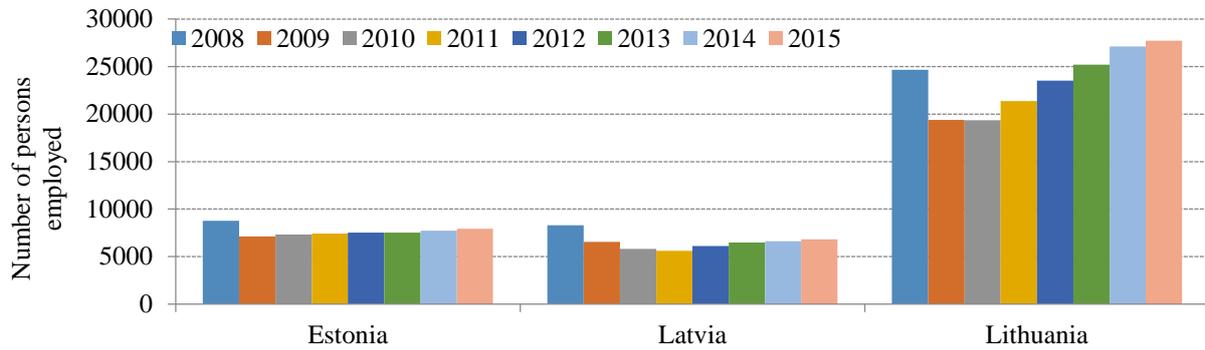


Figure 2. Number of persons employed in the Baltic States (created by the author)

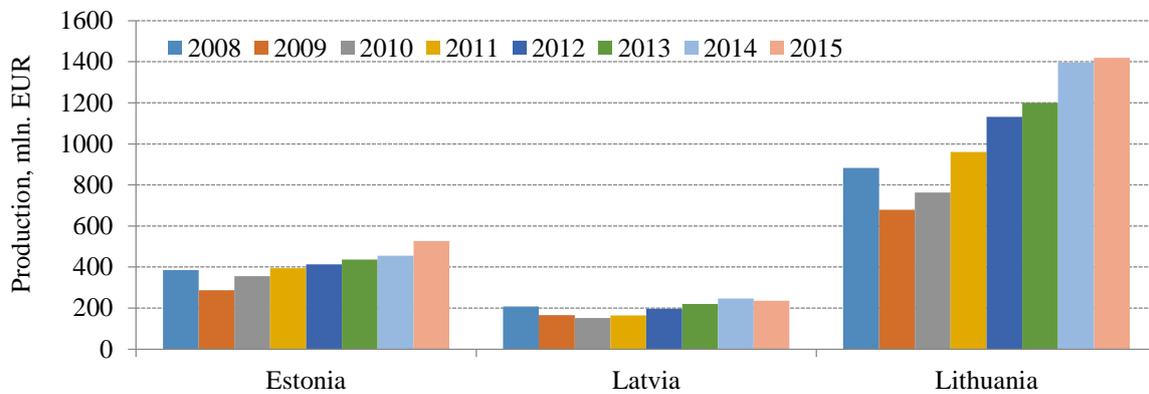


Figure 3. Production in the Baltic States (created by the author)

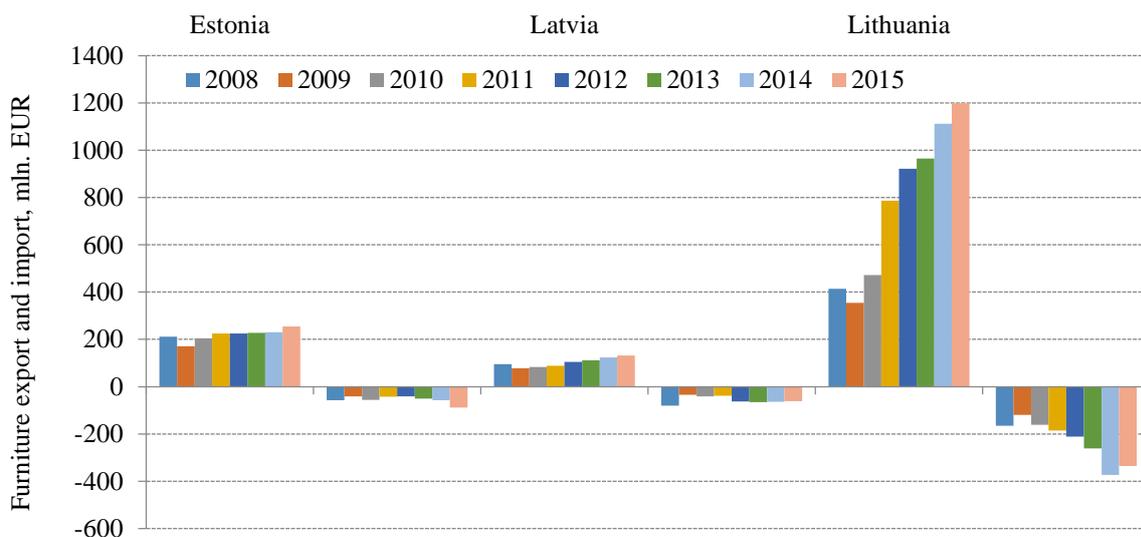


Figure 4. Exports and imports of the furniture industry in the Baltic States (created by the author)

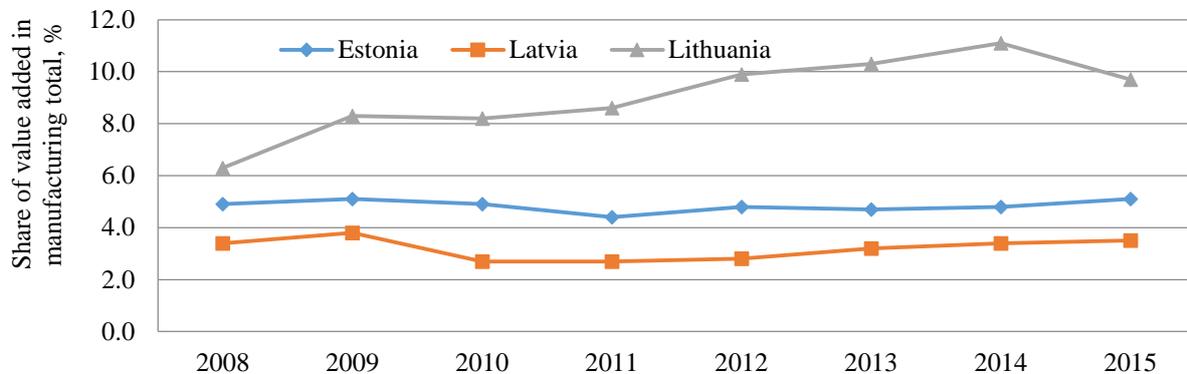


Figure 5. Share of value added of furniture industry in the Baltic States (created by the author)

In recent years, the Latvian furniture industry has displayed the worst indicators in the context of the Baltic States, which prompts the author to assert that the furniture sector monitoring government and sectoral institutions and organizations should immediately create a strategic support mechanism (solution) so that in the longer term the Latvian furniture industry becomes significantly competitive compared to the other Baltic States. Of course, there are and there will be separate furniture manufacturing or trade companies in Latvia, however, according to the author, they will mostly be medium or large enterprises that would be of sufficiently good or high competitiveness compared to Estonian and Lithuanian companies, but the overall tendency for the competitiveness of furniture manufacturing companies could stay medium or low.

2. METHODS AND MATERIALS

According to the pre-defined tasks, the author used the following generally recognized research methods to obtain the results: the logically constructive method, data grouping method, monographic descriptive method, a graphical method, and synthesis method. The scientific research methods were also used: a sociological study (document analysis), interpretation (comparison of systematic, historical) methods of experts and survey of enterprises.

In order to achieve the objectives, a number of complementary research methods are used:

- Analysis of secondary sources of information; within the framework of the research it is planned to analyze the existing databases and evaluate the results of research carried out so far;
- The analysis of statistical data will be carried out on the project task by compiling the necessary data in the reference national statistics.
- Experts methods used to there are trends in both the furniture industry and related industries, which can only be understood by industry specialists, therefore specialists of related sectors will be involved in the development of separate sections of the study;
- Entrepreneurs - Expert's focus group to gather conclusions about the information obtained as a result of the research, as well as to formulate recommendations for the development of the industry.

CONFIDENCE LEVEL FOR CURRENT STATISTICS

When assessing the accumulated data, the level of confidence was currently determined on the basis of the assessment of the level of credibility of each country's statistical data. In each country's relevant statistics office, the level of credibility in almost all cases is considered to be high, with an average representativeness of about 90%. In addition, the cases in which one of the respondents does not submit reports or questionnaires are taken into account, in most cases the data is dumped (replacing the missing data with counted data) or the weight of the respondents in the sample was recalculated in a particular sector, thus ensuring that in any case, the unanswered respondents data is included in the calculation of total data, except when confidentiality is to be respected for non-reflection, thus maintaining a high level of confidence. In order to have better visibility of the data in the graphical representation, the value scale report in most cases does start from zero.

3. RESULTS AND DISCUSSION

The author analyzes the statistical data and literature of the furniture industry in the Baltics using one of the methods of comparing competitiveness, in other words: SWOT analysis that can adequately capture the main regularities in the context of the competitiveness of the furniture industry, which is characteristic of each of the reference countries, i.e., Estonia, Latvia and Lithuania. The created SWOT matrix can serve as an informative material for the previous analysis of documents on the importance of competitiveness in the comparison of industries and enterprises, and as a basis for the author's allegations in the following sections. The sub-chapter will examine the competitiveness of the furniture industry in the context of the Baltic States, which can directly help Latvian furniture manufacturing companies to understand their strengths and weaknesses in order to choose in future a development strategy that would stimulate the growth of the sector. SWOT analysis is a method by which a national benchmarking exercise can be made and its application helps to focus more on critical issues. Internal factors are usually divided into the following: Strengths (S) and Weaknesses (V), Out-of-business factors are divided into: Opportunities (I) and Threat (D). In English, this analysis is called SWOT analysis - Strengths, Weaknesses, Opportunities, and Threats. In order to identify the determinants of the external and internal environment, SWOT analysis of the Latvian furniture industry in the context of the Baltic States was carried out (Table 1-3).

Table 3. Determining the strengths of the furniture industry in the context of the Baltic States.

STRENGTHS. (INTERNAL ENVIRONMENT)		
Estonia	Latvia	Lithuania
<ul style="list-style-type: none"> – Profitable geographical location, facilitating short distances to major outlet markets and shorter delivery times. – Available local wood resources and cheaper available wood raw materials (indirectly cheap timber resources) – Lower available labor costs compared to EU countries in its western and northern regions. 		
<ul style="list-style-type: none"> – State support for increasing the production capacity of local producers in export markets. – Positive impact from the experience of the Scandinavian countries, contributing to a greater contribution to the improvement of vocational education and competences, as well as the adoption of the cooperation model. 	<ul style="list-style-type: none"> – The ability of individual companies or their groups to improve their performance effectively in both domestic and external product exports markets. – Strategic approach at the level of sectoral management to implement cooperation 	<ul style="list-style-type: none"> – National strategic support (implemented state policy) and the creation of a favorable environment for attraction of foreign capital, as well as strategic competence of leaders of key sectors – State support (support programs), allowing to accelerate faster export growth during and after the economic crisis, thus covering losses from activities in the local market

STRENGTHS. (INTERNAL ENVIRONMENT)		
Estonia	Latvia	Lithuania
<ul style="list-style-type: none"> – Strategic competence of high-level leaders in improving the overall competitiveness of the industry. – A liberal economic environment for attracting foreign investors, as well as the openness and ability of state institutions to cooperate. – Increasing industry productivity indicators, using functionally oriented marketing opportunities and experience in export markets. 	<p>principles in increasing the turnover of the sector and improving efficiency.</p> <ul style="list-style-type: none"> – Production of wood furniture is strongly developed in relation to the total furniture turnover. 	<ul style="list-style-type: none"> – Stable international company IKEA's orders and investment flows in the industry, also promoting mass production of furniture products – Furniture manufacturing companies are showing significant technological progress, helping to lower operating costs of production, as well as the ability to handle orders in smaller lots more flexibly.

Data source: created by the author

Analyzing the available literature and research on the furniture sector in the Baltic States, the author has to conclude that in Estonia and Lithuania the furniture industry and its competitiveness have been much studied, thus emphasizing the role of this sector in national economies and reducing social problems at both sectoral and national level.

Following Table No. 1 summarized by the strengths of the key furniture industry in each country, the author comes to the following conclusions:

- the strengths of the Baltic States are their geographical location, the strong tradition of furniture production, the wealth of local resources, the cheaper available wood raw materials and human resources compared to other EU countries, which places Estonia, Latvia and Lithuania in a similar position in this regard, thus giving each country the furniture industry needs to create and develop its own prominent strengths that can make it more competitive compared to the other Baltic states.
- the success of the Lithuanian furniture industry has been greatly enhanced by the country's strategic support and the creation of a favorable business environment directly for the entry of a foreign capital company, thereby, of course, contributing more to the business model where local furniture manufacturing companies operate in order to execute orders from large foreign companies. There are different opinions among the industry and companies about whether the existence of such a business model is useful in ensuring the overall competitiveness of the Lithuanian furniture industry, but we must not forget the important aspect that it was precisely the foreign companies in Lithuania that were able to provide local furniture companies with a much easier way to overcome the financial and economic crisis in the world and many faster to restore their performance indicators, even to increase them compared to the other Baltic states.
- In turn, the successful development of the Estonian furniture industry has been provided by the state strategic support, which is more oriented towards increasing the capacity of local furniture manufacturing companies with the potential to increase it more directly in foreign markets. In the strategic direction of the Estonian furniture industry, the application of business access in Scandinavia, in particular Finland is felt in areas such as the creation of vocational education and the development of competences in line with the needs of the industry, operating both in local and export markets. In turn, the second best practice approach from the Scandinavian countries relates to the establishment of collaborative models between local furniture manufacturing, trade and research institutions, in order to start more successfully in various foreign market acquisition activities, and to purchase, by joint collaboration, raw materials for optimizing the costs of raw materials and create New or refine existing products to meet consumer preferences and needs, including fashion trends in the furniture industry.

– It was difficult for the author to find one common ground for promoting the furniture industry in Latvia, because unfortunately, the state strategic support for attracting foreign investors or vice versa, that is, the increase of capacity of local furniture manufacturing enterprises, practically does not exist in comparison with other Baltic states, such position was expressed by furniture manufacturing companies . At present there is a situation where furniture production is neglected and it is given the opportunity to fight for itself and look for possible operational solutions in order to be successful in the future. Although there are various support mechanisms at the national level for co-financing EU funds, modernization of production technologies, the acquisition of foreign markets through exhibitions, the creation of higher value added products or technologies, these support mechanisms are for all industries operating in the country and there is a direct effect on the implementation of the project for furniture manufacturing companies excessive the bureaucratic burden.

Table 2. Determining the weaknesses of the furniture industry in the context of the Baltic States.

WEAKNESSES (INTERNAL ENVIRONMENT)		
Estonia	Latvia	Lithuania
<ul style="list-style-type: none"> – When introducing new outlets, Estonian furniture manufacturers are small, unable to execute / sell furniture orders in larger volumes – The poorly developed products of local enterprises and their brands influenced by the dependence on products produced by large foreign furniture companies – The creation of local brand names does not involve enough professional professionals – Existing lack of cooperation between companies creates a low level of efficiency in the overall furniture industry, without creating a unified marketing approach, generates sufficient production capacity – Transferring of limited intermediate competencies (knowledge and skills) on the process and trends of modern furniture production 	<ul style="list-style-type: none"> – When introducing new outlets, furniture manufacturers in Latvia are small, unable to execute / sell furniture orders in larger volumes – The growth of furniture production in the domestic market is influenced by Lithuanian and Polish companies operating in Latvia – There is no involvement of professional specialists in the creation of local brand products – Transferring of limited intermediate competencies (knowledge and skills) on the process and trends of modern furniture production – Inadequate cooperation between companies, research and education institutions, the circulation of sales in the markets, as well as the transfer of practical and theoretical competences 	<ul style="list-style-type: none"> – High dependence on the business decisions of large furniture manufacturing companies and even on one of the main furniture manufacturers, i.e. IKEA – The poorly developed products of local enterprises and their brands influenced by the strong dependence on products produced by large foreign furniture companies – Transferring of limited intermediate competencies (knowledge and skills) on the process and trends of modern furniture production – Inadequate cooperation between enterprises and research and education institutions, resulting in fierce competition in the low-cost group of products, as well as in the implementation of innovations for SMEs

Data source: created by the author

Table No. 2, which summarizes the main weaknesses of each national furniture industry, follows the following author's conclusions:

– The main weakness of the Lithuanian furniture industry is its strong dependence on large foreign furniture companies, thus not promoting the development of its local furniture brand, product development, local business marketing experience, operating in the foreign markets itself, as well as cooperation between local furniture manufacturing and trading companies. Due to the globalization of the last years and the disappearance of transnational borders in the strict control of product movements, the institutions and companies in the Lithuanian furniture industry are beginning to discuss more and more about this weakness and possible solutions in the context of its reduction, but there is currently no obvious solution.

- In turn, the main weakness of the Estonian furniture industry is related to the weak capacity of the company itself, especially of small and medium-sized enterprises, which results in low production new pressures and weak management competencies for the successful implementation of the furniture marketing concept by acquiring export markets. The use of collaborative models from different companies can successfully help to reduce this gap. Therefore, in recent years various clusters of industry, research and education institutions have been created, and a separate cluster of the furniture industry has been created, where the successful realization of these models and the main benefits can be judged over the next few years.
- The weak part of Latvian furniture industry is the lack of state support for the implementation of certain strategic directions, which at the same time poses problems to implement and choose an appropriate strategy for the development of production companies. As a result, companies from other countries in this sector become more competitive, operating both in export markets and in Latvia. With state support, Latvian furniture manufacturers could more successfully locate and maintain appropriate management and production competences and facilitate the implementation of cooperation opportunities between companies, in particular small and medium-sized furniture manufacturing companies. Particularly effective optimization requires professional and theoretical competences that can contribute to the activities of every SME in Latvia (Tunkele, 2009).

One of the components of the SWOT matrix is the solution to identify potential opportunities and threats that each national furniture industry is able to see in order to increase its competitiveness in the future. According to the literature and research analysis, the production opportunities and threats of furniture production in the Baltic States are summarized in Table 3.

Table 3. Determining the opportunities and threats of the furniture industry in the context of the Baltic States.

OPPORTUNITIES (EXTERNAL ENVIRONMENT)		
Estonia	Latvia	Lithuania
<ul style="list-style-type: none"> – Ability to offer lower shipping costs and faster delivery times – Enhanced cooperation between enterprises and public administration in strengthening competitiveness by exchanging good practice approaches through projects of common interest – Enhanced cooperation between enterprises in the field of high technology integration, education and innovation, developing their own furniture products – Raising Enterprise Productivity and Business Specialization – Financial support for entry into new markets as well as long-term investment in raising productivity – Consumer orientation towards the use of environmentally friendly materials and energy 	<ul style="list-style-type: none"> – Ability to offer lower shipping costs and faster delivery times – Collaboration between enterprises and research institutions, creating a strong cluster of the furniture industry, boosting the export market – Strategic support at national level for attracting foreign capital, also by promoting good practice and transfer of relevant competences – To promote the transfer of professional competences by developing their products and their brands – Avoiding competition in traditional market outlets, changing strategic availability in favor of investment in technology, product development and the introduction of innovative business models, effectively using EU support instruments – Consumer orientation towards the use of environmentally friendly 	<ul style="list-style-type: none"> – Ability to offer lower shipping costs and faster delivery times – Create strong product lines and brands (national design schools), gradually reducing the dependence on the impact of products from foreign companies – Avoiding competition in traditional product markets, changing strategies for investment in technology, product development and the introduction of an innovative business model, which can be assisted by analysis of IKEA's business and business experience – Make effective use of EU support for strengthening business, production modernization and management competences – Consumer orientation towards the use of environmentally friendly materials and energy saving

OPPORTUNITIES (EXTERNAL ENVIRONMENT)		
Estonia	Latvia	Lithuania
saving creates a prerequisite for wider use of wood.	materials and energy saving creates favorable preconditions for wider use of wood	creates favorable preconditions for wider use of wood
THREATS (EXTERNAL ENVIRONMENT)		
<ul style="list-style-type: none"> – Increasing competition from producers in Poland, Lithuania and Russia, i.e. the pressure of "cheap" furniture supply from the East – Rising raw material prices and labor cost increases, resulting in shortages – Stagnation in the banking and financial sector, increasing tax burden, facilitating a slow recovery of the market 	<ul style="list-style-type: none"> – Rising raw material prices and labor cost increases, resulting in shortages – Low productivity of production and a small proportion of innovative technologies and new products in industry, attracting EU co-financing – Weak and inadequately coordinated forest sector development cooperation with related sectors in the context of the overall national sustainable development – Stagnation in the banking and financial sector, increasing tax burden, facilitating a slow recovery of the market 	<ul style="list-style-type: none"> – Rising raw material prices and labor cost increases, resulting in shortages – Stagnation in the banking and financial sector, increasing tax burden, facilitating a slow recovery of the market – The deterioration of business conditions in the country may reduce the interest of foreign investors, as well as IKEA to stop its activities – The shortage of skilled labor in the long-term emigration of skilled labor, especially in engineering and technology

Data source: created by the author

According to the available literature and studies on the furniture sector in the Baltic States, the author has formulated the following options:

- At present, the strategy of the Estonian furniture industry is oriented towards the elimination of already identified weaknesses, ie increasing labor productivity and production capacity, promoting closer cooperation between companies and state institutions, developing competences in accordance with the needs of existing industries, acquiring new products market with existing and new products , which could be positively promoted by the acquisition of positive business experience by Scandinavian and other foreign furniture manufacturers. There are a number of threats to the competitiveness of the Estonian furniture industry, which can seriously undermine the overall growth of the industry, i.e. Increasing competition from cheaper products from Polish, Lithuanian and Russian producers, including rising raw material prices and labor costs, while creating a shortage of skilled labor. The author hopes that currently the strategy of promoting co-operation, education and competencies development, as well as export promotion, implemented in Estonia will not make any negative impact on the threats identified by the industry in the future.

- The main future opportunities of the Lithuanian furniture industry are related to the creation of local furniture manufacturing brands, thus reducing the strong dependence on the incoming large foreign furniture manufacturers. To successfully implement it, serious work is needed on the creation of its Lithuanian furniture brands, it is necessary to promote the implementation of cooperation models between companies, research and educational institutions, to create the long-term strategy of the Lithuanian furniture industry with state support, to modernize existing production technologies in line with market demand, as well To launch products themselves on the markets. A lot has to be done in the elimination of the weaknesses of the Lithuanian furniture industry, and at the moment, according to the author, neither the creation of its own brand creation and cooperation models, nor the emergence of new markets, effective and strategic action can be seen. The most significant threat to the Lithuanian furniture industry is the possible decision of the large furniture manufacturers to leave Lithuania, because such a decision would have a very negative impact on the joint activities of many local furniture manufacturers and the competitiveness of the overall

furniture production in the long term, as Lithuania has poorly developed local furniture production, is not strong the tradition of own brand, product creation, and weak experience in developing competences, creating and developing a concept for your furniture industry.

- There is a lot of possibilities to improve the competitiveness of the Latvian furniture industry, but at the beginning it should be understood or determined by a common strategic direction at the national level, so that each company does not realize its strategy, thus creating a lot of patterns and possibly even the opposite effect.

The author believes that Latvian furniture industry should gain positive experience from Estonia by implementing effective cooperation models between companies and state, research and educational institutions and from Lithuania, attracting and providing strategic support at the state level for the arrival of foreign furniture manufacturing companies in Latvia. With the implementation of such a strategy, the Latvian furniture industry could stimulate domestic furniture manufacturers and activate their business experience by mastering foreign markets, thereby improving the competitiveness of the forest sector, which has been recognized as one of the most important sectors in the national economy in the long term. The long-term increase in the competitiveness of the Latvian furniture industry is threatened if no decision or position is taken in the country and the sector in favor of the implementation of the strategy for promoting cooperation and attracting foreign capital. Thanks to the country's strategic vision, there is a well-developed primary wood processing sector, but weak support is for the further processing of wood, i.e. the furniture manufacturing sector. The author believes that creating only support mechanisms with EU co-financing, in which the furniture industry companies can start, without the position of certain state and sectoral institutions, a strategic view of the potential for further wood processing, incl. Namely the furniture industry, competitiveness, the situation is to be regarded as critical, and in the future, except in some cases, the successful growth of this sector in general is not expected.

The analysis of the competitiveness of this furniture industry in the Baltic States helped the author to understand the strengths and weaknesses of the furniture industry in Latvia, including the existing industry, as well as to see potential opportunities and reduce external threats in order to be able to make the right strategic decisions and operating principles in order to raise the future. the overall furniture and forestry industry. Timely identification of the positive and negative factors affecting each industry can improve its competitiveness in local and foreign markets (Tunkele, 2010). In this context, the author emphasizes the importance of state support for increasing the competitiveness of the sectors and also of individual enterprises.

4. CONCLUSIONS

The development of the furniture industry in Lithuania and Estonia was influenced by the economic processes and decisions taken, which is related to the entry of serious foreign investors into the local furniture industry. In Latvia foreign investors mainly sought opportunities to work at a lower cost, based not only on lower wages, but also on the difference on occupational safety and environmental requirements from the western countries.

Given the export market role in the furniture industry in all three countries, individual companies or groups of companies are not direct competitors and joint marketing activities in the global market are possible.

In the local market, the main competition is in public procurement and in this market, with the exception of some big companies, intermediaries dominate and, after accession to the EU, there are no criteria for supporting producers in this sector.

A substantial increase in the volume of furniture in Latvia in order to reach the level of neighboring countries is possible only with the help of foreign investments and this investor must have its own sales channels.

The growth of the local furniture industry is possible mainly due to the development of design and added value. However, no growth in this market is expected in the near future.

The main challenge in the Latvian furniture industry is the increase in labor and production costs, which is needed to overcome:

To attract investments for modernization of technologies;

To develop the competence of designing an industrial design in the design and manufacture of furniture;

To develop the cooperation between companies to reduce the cost of product development, production and marketing;

To develop cooperation with state support institutions for joint marketing activities, jointly attracting EU funds.

To motivate young people to choose the professions necessary for the furniture industry and to continuously improve vocational education.

To develop Latvian furniture design.

References

- Eiropas Ekonomikas un sociālo lietu komitejas informatīvs paziņojums par Eiropas kokapstrādes un mēbeļu ražošanas nozari (2011) Brisele: Eiropas Ekonomikas un sociālo lietu komisija. CCM/088. 2.lpp.
- Fedotovs A., Pavloviča A. (2000): Tālmācības kurss „Ekonomikas pamati”. Rīga: SIA „Latvijas uzņēmējdarbības un menedžmenta akadēmija”. 69. lpp.
- Fisks P. (2009): Mārketinga ģenijs. Rīga: Jāņa Rozes apgāds. 392. lpp.
- Tunkele S. (2009): Production cost analysis of carpentry and joinery wood products in Latvia. Proceedings of the 5th Meeting The Nordic-Baltic Network in Wood Material Science and Engineering (WSE), Copenhagen. p. 183-185.
- Tunkele S., Mārciņš J. (2010): The Competitiveness analysis of Latvian forest industry. Международная научно-практическая конференция " Актуальные проблемы экономики и права", Барановичи. стр. 252 – 254.
- Vidal V. (2006) US Market Environment for Tropical Timber and Opportunities for added value for Small and Medium Forest Enterprises. Report “International Conference on Small and Medium forest enterprises development for poverty reduction: opportunities and challenges in globalizing markets”, Costa Rica. May 23-25. p. 15.

Corresponding author:

S.Liše

Latvia University of Agriculture, Forest Faculty, Wood processing Department, Jelgava/Latvia
e-mail: sigita.lise@llu.lv

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

MODELING OF DENSITY OF PERIODIC STRUCTURES CORES OF HONEYCOMB PANELS

Krzysztof PELIŃSKI¹, Marlena WOJNOWSKA¹, Michał MASLEJ¹, Michał SŁONINA¹,
Jerzy SMARDZEWSKI¹

¹ Poznan University of Life Sciences, Faculty of Wood Technology, Department of Furniture Design,
Poznań, Poland

Key words

*Honeycomb,
auxetic,
density.*

Abstract

Light, layered cell panels are commonly used in the aerospace, automotive and maritime industries. Some leading furniture factories use them to manufacture case furniture. The stiffness and strength of the structural components of the furniture depends on the thickness and structure of the cellular panels made of wood based materials. Particularly important is the stiffness of the shelves and the horizontal partitions. It depends on the type of facings and the type of paper core cells. At present in furniture industry, the most common form are sandwich panels with hexagonal core cells. The novelty could be cores made of paper or wood composites having auxetic properties.

The aim of the study was to model optimum shapes of auxetic cells characterized by the lowest relative density. In particular, it was decided to design different models of auxetic cells for use in layered furniture panels.

Mathematical models have been developed to describe the relationship between the relative density of an elementary cell and the length and thickness of a cell wall and the inclination angle of a wall.

It has been shown that auxetic cells are characterized by strong orthotropy. They will be very useful for designing bent shelves and partitions. Particularly during the production of custom made furniture for individual orders. Cells with isotropic properties will be useful in the mass production of furniture. Especially for the reason of optimization the cutting process of large-sized furniture boards.

Corresponding author: *pelinski@up.poznan.pl, K.Peliński, Poznan University of Life Sciences, Faculty of Wood Technology, Department of Furniture Design, Wojska Polskiego 28, 60-637 Poznań, Poland.*

1. INTRODUCTION

Basic mechanical properties of the cellular boards core are influenced by the length and the angle of the cell arm inclination, the cell wall thickness, the relative density and type of the core material (Chang and Ebcioğlu 1961, Alqassim 2011, Balawi and Abot 2008, Chi et al.2010; Chen and Pugno, 2012; He and Hu 2008; Hu et al., 2013; Jeyakrishnan et al., 2013;Schultz et al., 2012; Sha Yin et al., 2012; Smardzewski 2013). The relative density of the cells is determined as ratio of density of the core to the density of the structure-forming substance. In the following paper, authors made an analytical approach to relative density of hexagonal cells and selected auxetic cells. The aim of the study was to model optimum shapes of auxetic cells

characterized by the lowest relative density. In particular, it was decided to design different models of auxetic cells for use in layered furniture panels.

2. METHODS AND MATERIALS

HEXAGONAL CELL

Figure 1 shows an elementary unit of a cellular cell core with a hexagonal shape. The shape of the cells determine the dimensions: l length of the free side, h length of the ribbon (common cell wall), t wall thickness, L_x cell length, S_y width of the cell, φ angle of inclination of the wall.

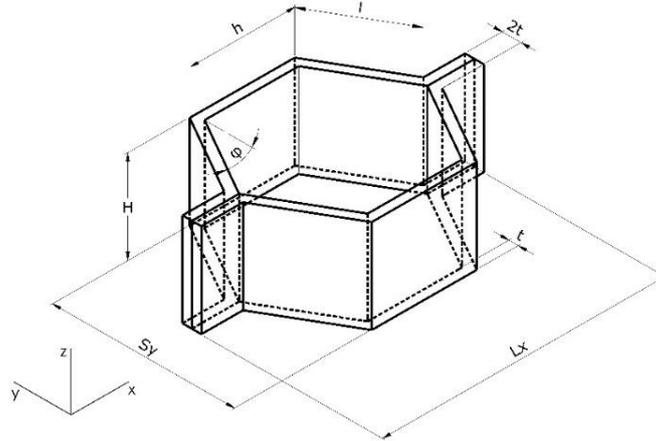


Figure 1. Elementary unit of a cellular cell core with a hexagonal shape

The relative density ρ of the analyzed structure can be written as the quotient of the core density ρ^* and the density of the substance forming the framework of the structure ρ_s :

$$\rho = \frac{\rho^*}{\rho_s} \quad (1)$$

therefore:

$$\rho^* = \frac{m^*}{V^*} = \frac{m^*}{HF^*} \quad (2)$$

$$\rho_s = \frac{m_s}{V_s} = \frac{m_s}{HF_s} \quad (3)$$

where: $m^* = m_s$ means the mass of the cell and the mass of the substance forming its skeleton, H the height of the core, F^* the surface of the elementary core section, F_s the surface of the substance forming the skeleton of the structure. Therefore, the relative density should be written as:

$$\rho = \frac{F_s}{F^*} \quad (4)$$

According to Figure 1, the surface of the elementary section of the core is expressed by equation:

$$F^* = 4(l\sin(\varphi) + h - tctg(\varepsilon))(t + l\cos(\varphi)) \quad (5)$$

while the surface of the substance forming the framework of the structure:

$$F_s = 4(t + l\cos(\varphi))(l\sin(\varphi) + h - tctg(\varepsilon)) - 2l\cos(\varphi)(\sin(\varphi)(2l - tctg(\varepsilon)) + 2h - 4tctg(\varepsilon)) \quad (6)$$

hence:

$$\rho = 1 - \frac{l \cos(\varphi) (\sin(\varphi) (2l - t \operatorname{ctg}(\varepsilon)) + 2h - 4t \operatorname{ctg}(\varepsilon))}{2(l \sin(\varphi) + h - t \operatorname{ctg}(\varepsilon))(t + l \cos(\varphi))} \quad (7)$$

where:

$$\varepsilon = \frac{90^\circ + \varphi}{2}$$

Relative density of the reference hexagonal cell as shown on figure 1 is:

$$\rho_{REF} = 0,02493.$$

RIBBON SHAPE AUXETIC CELL

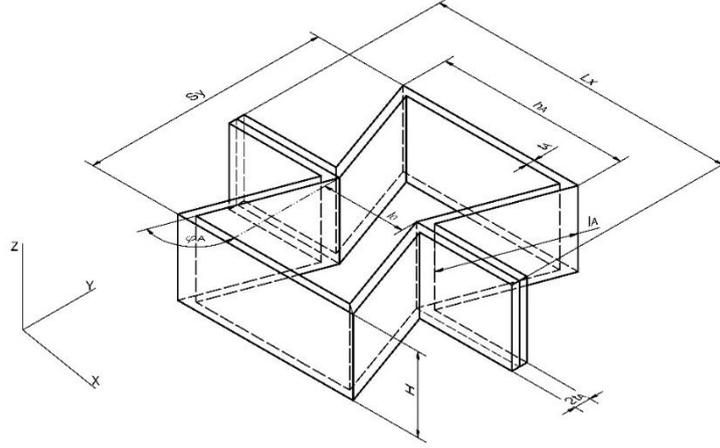


Figure 2. Elementary unit of a cellular cell core with a ribbon shape

The relative density ρ_A of the analyzed structure can be written as the quotient of the core density ρ_A^* and the density of the substance forming the framework of the structure ρ_{SA} :

$$\rho_A = \frac{\rho_A^*}{\rho_{SA}} \quad (8)$$

Assuming the same assumptions as above (for hexagonal cells) the relative density should be written as:

$$\rho_A = \frac{F_{SA}}{F_A^*} \quad (9)$$

According to figure 2, the surface of the elementary section of the core is expressed by equation:

$$F_A^* = 4(t_A + l_A \cos(\varphi_A))(h_A - t_A \operatorname{ctg}(\varepsilon_A) - l_A \sin(\varphi_A)) \quad (10)$$

while the surface of the substance forming the skeleton of the structure:

$$F_{SA} = 4(t_A + l_A \cos(\varphi_A))(h_A - t_A \operatorname{ctg}(\varepsilon_A) - l_A \sin(\varphi_A)) - 4l_A \cos(\varphi_A)(h_A - 2t_A \operatorname{ctg}(\varepsilon_A) - l_A \sin(\varphi_A)) \quad (11)$$

hence:

$$\rho_A = 1 - \frac{l_A \cos(\varphi_A)(h_A - 2t_A \operatorname{ctg}(\varepsilon_A) - l_A \sin(\varphi_A))}{(t_A + l_A \cos(\varphi_A))(h_A - t_A \operatorname{ctg}(\varepsilon_A) - l_A \sin(\varphi_A))} \quad (12)$$

where:

$$\varepsilon_A = \frac{90^\circ - \varphi_A}{2}$$

Critical condition of the existence of an auxetic cell with the presented geometry is:

$$l_0 > 0.$$

where:

$$l_0 = 2 \left(\frac{hA}{2} - lA \sin(\varphi A) - tA \cos(\varepsilon A) \right) \quad (13)$$

AUXETIC CYLINDRICAL CELL

Analysis of the geometry of the section of the auxetic cellular core structure (figure 3), shows that it is composed of: cylindrical cells with outer radius R_1 , inner radius R_2 and wall thickness equal to $d=R_1-R_2$.

Between the cylinders, tangent to their outer surface, a tape of thickness t is shown. The shape of the tape allows to impart auxetic properties to the structure of the core. The width of the elementary core L_x is equal to:

$$L_x = 2(2R_1 + t - m) \quad (14)$$

height S_y is equal to:

$$S_y = 2(R_1 + n) \quad (15)$$

where: m – horizontal distance between the peripheral surfaces of the cylindrical cells (horizontal module), n - vertical distance between the peripheral surface and the axis of the next cell (vertical module).

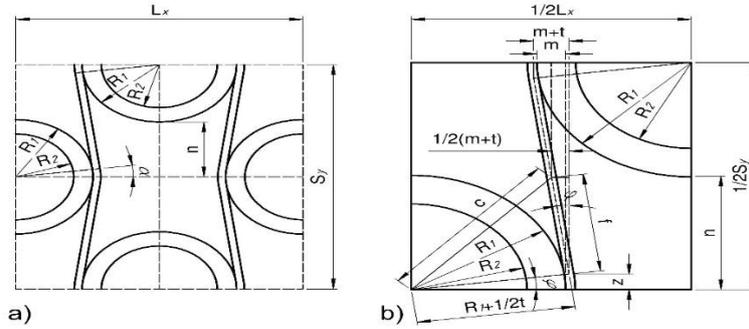


Figure 3. Auxetic core with cylindrical cells: a) elementary unit of the core, b) periodic structure

Changing the values of R_1 , R_2 , m i n have a major influence on the geometry of the core structure and its auxetic properties. According to Figure 3b:

$$\sin(\varphi) = \frac{z}{R_1 + \frac{1}{2}t} = \frac{2z}{2R_1 + t} \quad (16)$$

and

$$\sin(\varphi) = \frac{\frac{1}{2}(m+t)}{f} = \frac{m+t}{2f} \quad (17)$$

therefore:

$$z = \frac{(m+t)(2R_1+t)}{4f} \quad (18)$$

In addition, Figure 3b shows another regularity:

$$\begin{cases} c^2 = \left(\frac{1}{2} \left(\frac{1}{2} L_x \right) \right)^2 + \left(\frac{1}{2} \left(\frac{1}{2} S_y \right) \right)^2 \\ f^2 = c^2 - \left(R_1 + \frac{1}{2} t \right)^2 \end{cases} \quad (19)$$

whence:

$$f = \frac{1}{2} \left((2R_1 + t - m)^2 + (R_1 + n)^2 - (2R_1 + t)^2 \right)^{0.5} \quad (20)$$

Following successive equations:

$$\begin{cases} f = \frac{1}{2}((2R_1 + t - m)^2 + (R_1 + n)^2 - (2R_1 + t)^2)^{0.5} \\ z = \frac{(m+t)(2R_1+t)}{4f} \end{cases} \quad (21)$$

and

$$\begin{cases} \sin(\varphi) = \frac{2z}{2R_1+t} \\ z = \frac{(m+t)(2R_1+t)}{4f} \end{cases} \quad (22)$$

result:

$$z = \frac{(m+t)(2R_1+t)}{2((2R_1+t-m)^2+(R_1+n)^2-(2R_1+t)^2)^{0.5}} \quad (23)$$

$$\sin(\varphi) = \frac{m+t}{((2R_1+t-m)^2+(R_1+n)^2-(2R_1+t)^2)^{0.5}} \quad (24)$$

The structure has some geometrical constraints making it possible to physically produce it. The first one occurs when the core structure has the highest density and the cylindrical cells adhere to each other (Figure 4). In this case for $n=0$ and $f=30^\circ$:

$$\sin(30^\circ) = \frac{m+t}{((2R_1+t-m)^2+(R_1)^2-(2R_1+t)^2)^{0.5}} = \frac{1}{2} \quad (25)$$

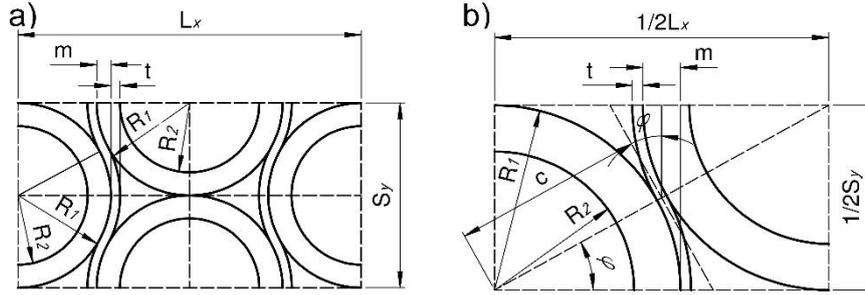


Figure 4. Auxetic core with a minimum spacing of cells: a) elementary unit of the core, b) periodic structure

After necessary transformations, we will get a square equation:

$$3m^2 + (4R_1 + 10t)m - ((R_1 + n)^2 - 4t^2) = 0 \quad (26)$$

whence:

$$\Delta = (4R_1 + 10t)^2 + 12((R_1 + n)^2 - 4t^2) \quad (27)$$

$$m_{1,2} = \frac{1}{6}(- (4R_1 + 10t) \pm \sqrt{\Delta}) \quad (28)$$

The value of one of the roots of the equation is the maximum horizontal module m_1 for the core structure, where:

$$\begin{aligned} L_x &= 2(2R_1 t - m) \\ S_y &= 2R_1 \\ f &= 30^\circ \end{aligned} \quad (29)$$

For $n=0$ and $(-t) \leq m \leq m_1$:

$$\begin{aligned}
L_x &= 2(2R_1 t - m) \\
S_y &= 2R_1 \\
f &= \text{asin} \left(\frac{m+t}{((2R_1+t-m)^2 + (R_1)^2 - (2R_1+t)^2)^{0.5}} \right)
\end{aligned} \tag{30}$$

For $0 < n$ and $(-t) \leq m \leq R_1$:

$$\begin{aligned}
L_x &= 2(2R_1 + t - m) \\
S_y &= 2(R_1 + n) \\
f &= \text{asin} \left(\frac{m+t}{((2R_1+t-m)^2 + (2R_1+n)^2 - (2R_1+t)^2)^{0.5}} \right)
\end{aligned} \tag{31}$$

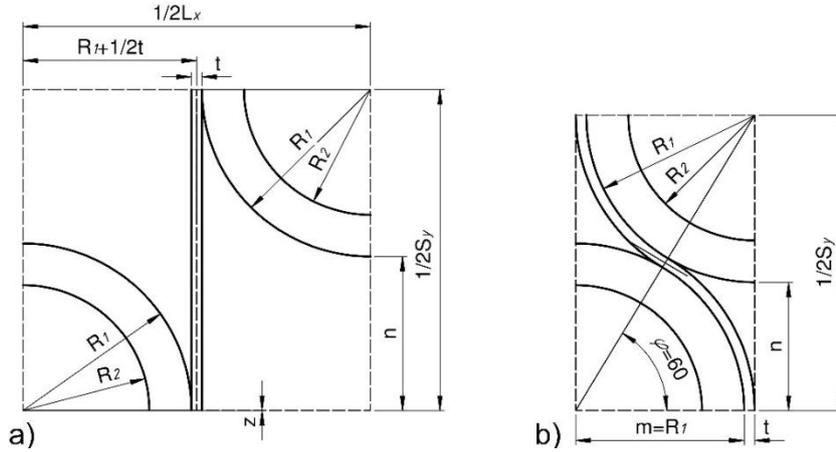


Figure 6. Auxetic core with extreme cell spacing: a) maximal spacing $m = 0$, b) minimum spacing $m = R_1$.

The relative density ρ of the analyzed structure can be written as the quotient of the core density ρ^* and the density of the substance forming the skeleton of the structure ρ_s :

$$\rho = \frac{\rho^*}{\rho_s} \tag{32}$$

therefore:

$$\rho^* = \frac{w}{V^*} = \frac{w}{HF^*} \tag{33}$$

$$\rho = \frac{w}{V_s} = \frac{w}{HF_s} \tag{34}$$

where: w - means the mass of the cell and the mass of the substance forming its skeleton, H the height of the core, F^* the surface of the elementary core section, F_s the surface of the substance forming the skeleton of the structure. Therefore, the relative density should be written as:

$$\rho = \frac{F_s}{F^*} \tag{35}$$

According to figure 4. surface of the elementary core section follows the equation:

$$F^* = 4(2R_1 + t - m)(R_1 + n) \tag{36}$$

Surface of the substance forming the skeleton of the structure follows the equation:

$$F_s = 4 \left(\frac{1}{2} \pi (R_2^2 - R_1^2) + \frac{\varphi \pi}{180} ((R_1 + t)^2 - R_1^2) + 2tf \right) \tag{37}$$

hence:

$$\rho = \frac{\frac{1}{2} \pi (R_2^2 - R_1^2) + \frac{\varphi \pi}{180} ((R_1 + t)^2 - R_1^2) + 2tf}{(2R_2 + t - m)(R_1 + n)} \tag{38}$$

RIB SHAPE CELL

Geometry of the elementary section of the rib shape core structure of the cellular panel (Figure 5), it worth noticing that it is composed of two orthogonal arms of the dimensions as shown in Figure 6. Where: the height of the core h , the angle of inclination of the ribs in the plane ZX and ZY respectively φ_x, φ_y , the width of the rib base a , rib width s , rib thickness t .

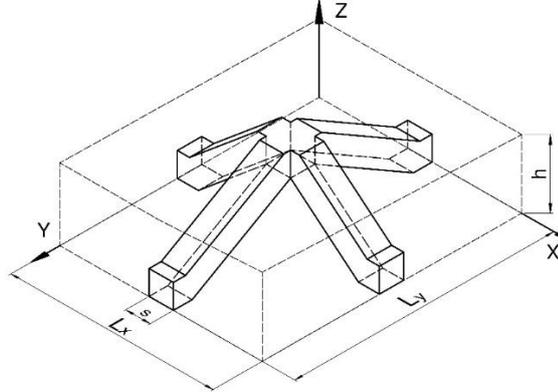


Figure 5. Elementary unit of the structure of the rib shape core of the cellular panel

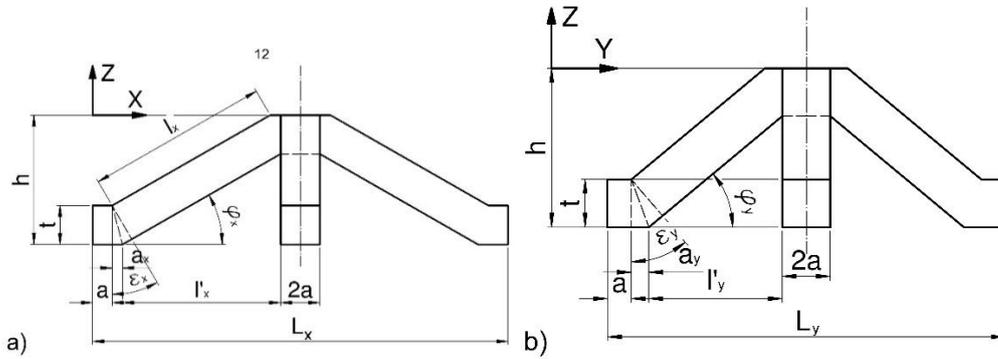


Figure 6. Geometry of the rib for plane: a) ZX, b) ZY

Because:

$$\varepsilon_x = \varphi_x \text{ and } \varepsilon_y = \varphi_y$$

lengths L_x, L_y of elementary section are equal to:

$$L_x = 2 \left(2a + t \cdot \operatorname{tg} \left(\frac{\varphi_x}{2} \right) + (h - t) \operatorname{ctg}(\varphi_x) \right) \quad (39)$$

$$L_y = 2 \left(2a + t \cdot \operatorname{tg} \left(\frac{\varphi_y}{2} \right) + (h - t) \operatorname{ctg}(\varphi_y) \right) \quad (40)$$

where:

$$\operatorname{tg} \left(\frac{\varphi_x}{2} \right) = \operatorname{tg} \left(\frac{\varepsilon_x}{2} \right) = \frac{a_x}{t} \quad (41)$$

$$\operatorname{tg} \left(\frac{\varphi_y}{2} \right) = \operatorname{tg} \left(\frac{\varepsilon_y}{2} \right) = \frac{a_y}{t} \quad (42)$$

$$l'_x = \frac{h-t}{\sin(\varphi_x)}, l'_y = \frac{h-t}{\sin(\varphi_y)} \quad (43)$$

$$l'_x = (h - t) \operatorname{ctg}(\varphi_x) \quad (44)$$

$$l'_y = (h - t)ctg(\varphi_y) \quad (45)$$

The relative density ρ of the analyzed structure can be written as the quotient of the core density ρ^* and the density of the substance forming the skeleton of the structure ρ_s :

$$\rho = \frac{\rho^*}{\rho_s} \quad (46)$$

Therefore:

$$\rho^* = \frac{w}{V^*} \quad (47)$$

$$\rho = \frac{w}{V_s} \quad (48)$$

where: w - means the mass of the cell and the mass of the substance forming its skeleton, H the height of the core, V_s - the volume of the elementary core section, V_s - the volume of the substance forming the skeleton of the structure. Therefore, the relative density should be written as:

$$\rho = \frac{V_s}{V^*} \quad (49)$$

According to figure 6, volume of the arms of the elementary core section follows the equations:

$$V_{s(ZX)} = s \left(hL_x - 4(h - t) \left(a + \frac{1}{2}l'_x \right) \right) \quad (50)$$

$$V_{s(ZY)} = s \left(hL_y - 4(h - t) \left(a + \frac{1}{2}l'_y \right) \right) - a^2t \quad (51)$$

Therefore volume of elementary core section:

$$V^* = L_xL_yh \quad (52)$$

Surface of the substance forming the skeleton of the structure follows the equation:

$$F_s = 4 \left(\frac{1}{2}\pi(R_1^2 - R_1^2) + \frac{\varphi\pi}{180} ((R_1 + t)^2 - R_1^2) + 2tf \right) \quad (53)$$

hence:

$$\rho = \frac{V_{s(ZX)} + V_{s(ZY)}}{L_xL_yh} \quad (54)$$

AUXETIC RIB SHAPE CELL

To maintain symmetrical structure, auxetic cell with the spatial structure (Figure 7) should exhibit uniform elastic properties in all directions of the rectangular spatial coordinate system. Nominal thickness of these cells should be considered in case of use in thin sandwich panels. In the furniture industry standard thickness is 18 mm. The outer facing of such boards are usually 2 mm or 3 mm thick. Thus, the core of the auxetic cells should have a thickness of 12 mm or 14 mm (Figure 8).

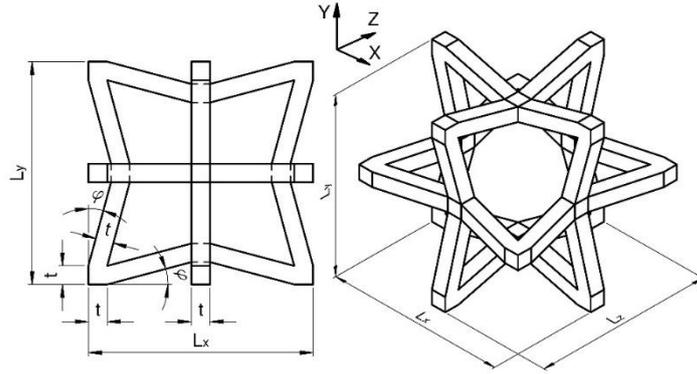


Figure 7. Auxetic cell with the spatial structure

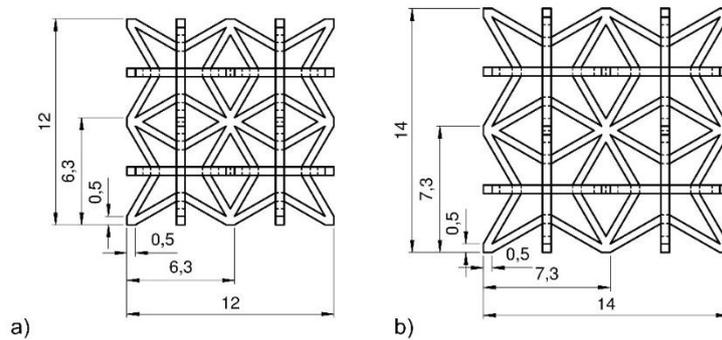


Figure 8. Compilation of cells to panel core: a) 12 mm, b) 14 mm

Spatial geometry of the spatial structure of the rib shape core of the cellular plate (Figures 7,8), it should be noted that it is composed of twelve equal pairs of arms inclined to the axis of the coordinate system at an angle φ where: L the length of the elemental cell section, l' length of the projection of cell arm, l length of the cell arm, t thickness of the node connecting the arms of the cell. For technical feasibility, the angle φ should be between $0^\circ < \varphi < 40^\circ$.

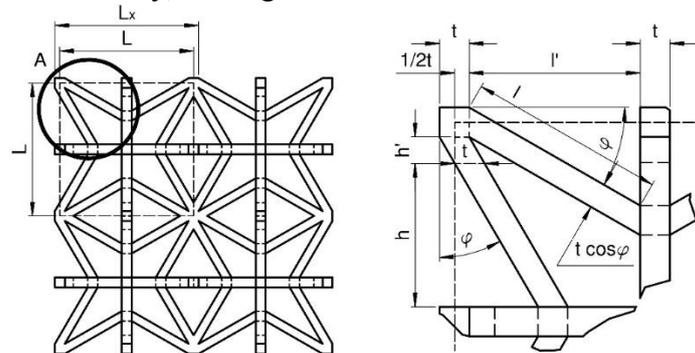


Figure 9. Elementary unit of the rib shape cor structure of cell panel

Lengths of single cell arms are equal $L_x=L_y=L_z$, therefore:

$$l' = \frac{L_x - 3t}{2} \quad (55)$$

$$h' = \frac{t}{2tg(\varphi)} \quad (56)$$

For equal masses of cells substance, the relative density ρ of the analyzed structure can be written as the quotient V_s of the volume of the structure-forming substance and V^* of the volume of the core section:

$$\rho = \frac{V_s}{V^*} \quad (57)$$

According to figure 9 volume of arms of elementary section of the core follows the equation:

$$V_s = 6t \left(t(L_x - 3t)tg(\varphi) + t \left(\frac{1}{2}t + x \right) + t^2 \right) \quad (58)$$

where:

for $h' \leq l' x=0$,

for $h' > l' x=(Lx-3t)tg(f)$,

while, volume of the elementary core follows the equation:

$$V^* = (L_x - t)^3 \quad (59)$$

3. RESULTS AND DISCUSSION

EFFECT OF RIBBON SHAPE CELL PARAMETERS ON ITS RELATIVE DENSITY

Figure 10 shows the results of an analytical calculations for an auxetic ribbon shape cell, showing the effect the angular deviation of the arms f , the length of the free side of the cell l , the length of the common cell wall (ribbon) h , the thickness of the cell wall t on the relative cell density.

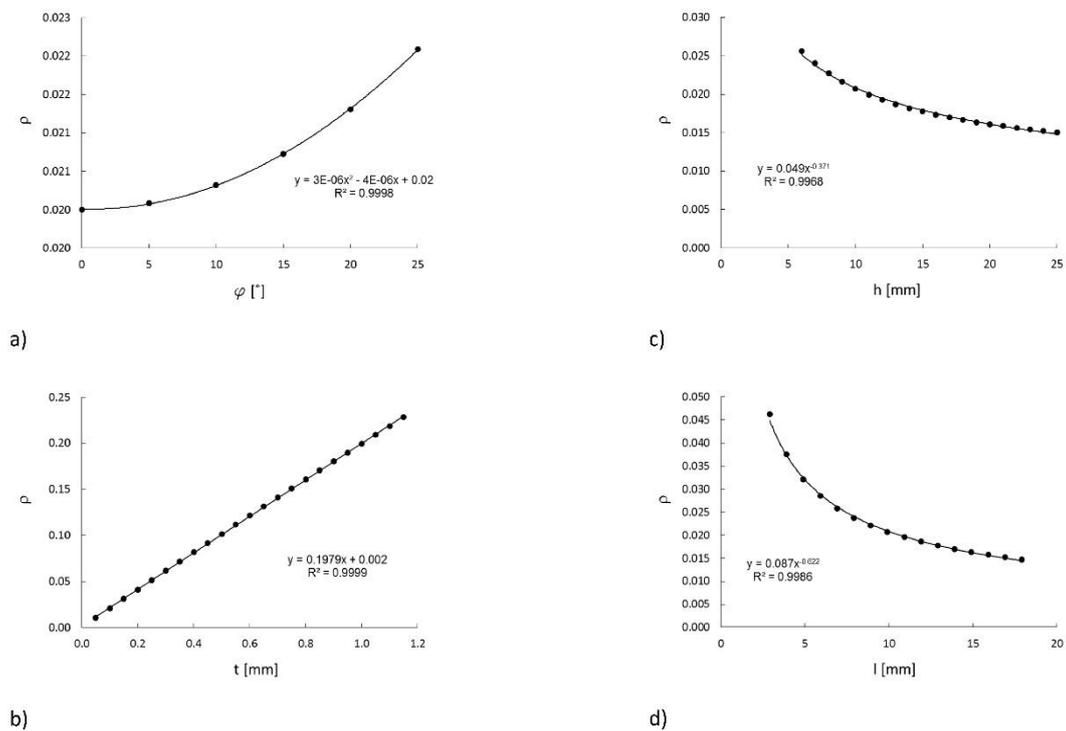


Figure 10. Relative density ρ as function of: a) cell wall angle f ;
b) cell wall thickness t ; c) length of common side of cell h ; d) length of free side of cell l

With increase of cell wall thickness and the cell wall angle inclination, the relative cell density increases. It decreases with increasing parameters h and l . The determination coefficient above 0.9 also indicates a very good fit of the regression model. For further analysis, several auxetic cells with identical apparent density were identified (Figure 11). The reference cell is a cell with isotropic properties. Figure 12 shows the effect of the cell type on its linear dimensions.

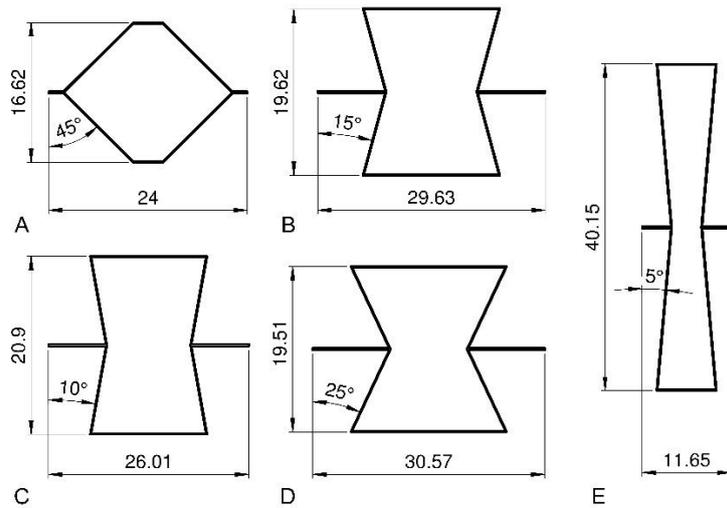


Figure 11. Geometry of selected core cells

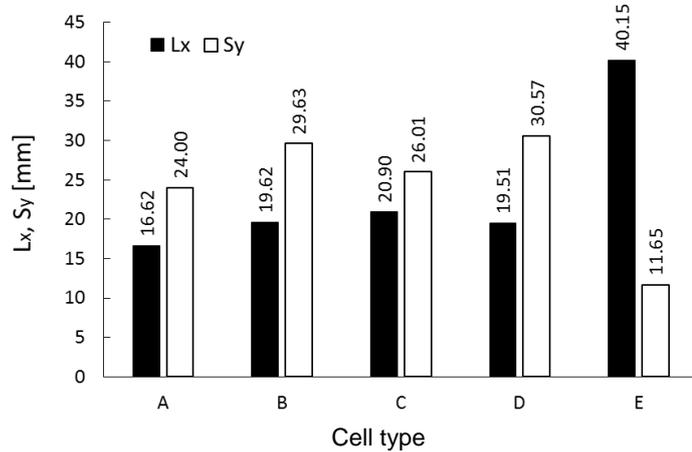


Figure 12. Effect of cell type on its linear dimensions

Cell E exhibits most ortotropic character therefore its linear dimensions show notable disproportion between length and width, also length dimension has the highest value among all selected cells. Cells A-D are slightly smaller and also values of their linear dimensions show tendency to form more regular cell shape.

EFFECT OF CYLINDRICAL CELL PARAMETERS ON ITS RELATIVE DENSITY

Figure 13 shows the effect of variable parameters on cylindrical cell properties.

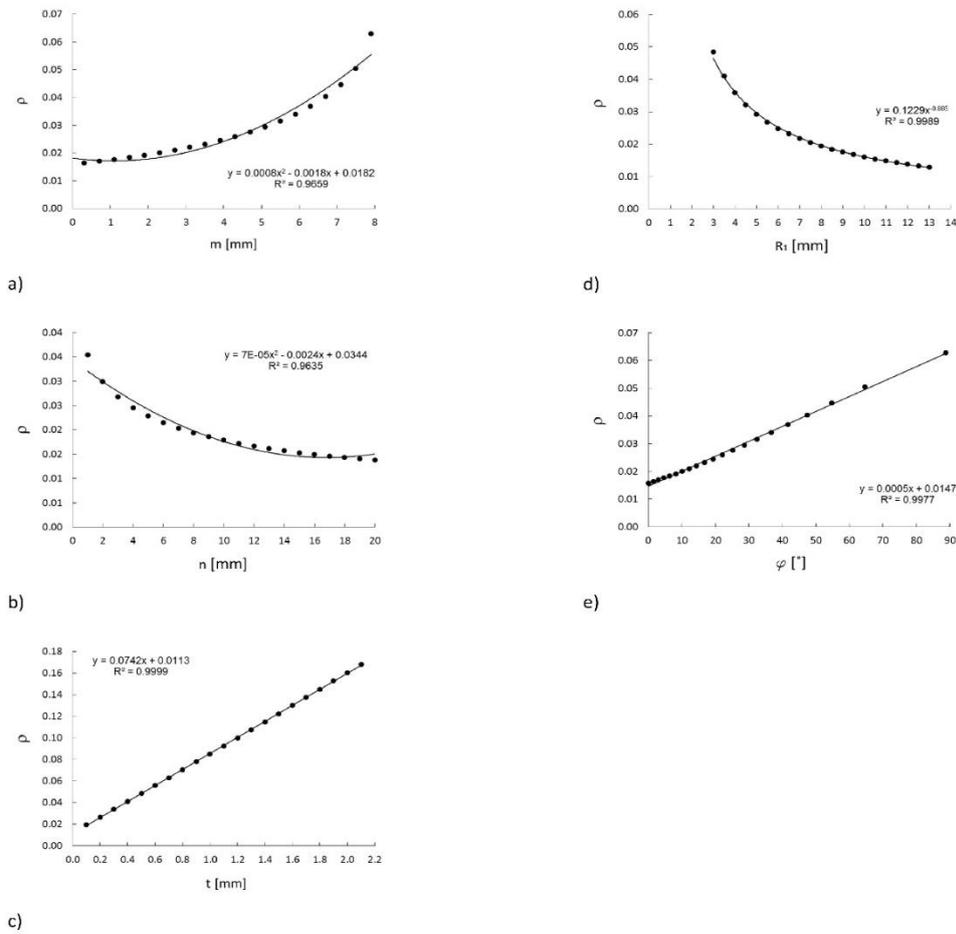


Figure 13. Relative density ρ as function of: a) horizontal module m
 b) vertical module n c) tape thickness t d) outer radius R_1
 e) cell wall angle φ

Increase of vertical distance between the peripheral surface and the axis of the next cell results in a decrease of relative cell density. Increase of thickness t of the tape connecting the cylinders and increasing the tilt angle of the cell wall φ increases the apparent density of cell. As the outer radius of the cylindrical cell increases, relative density of cell decreases. A coefficient of determination close to 1 indicates a very good fit of regression models.

For further analyzes, several cylindrical auxetic cells with identical relative densities were selected (Figure 14).

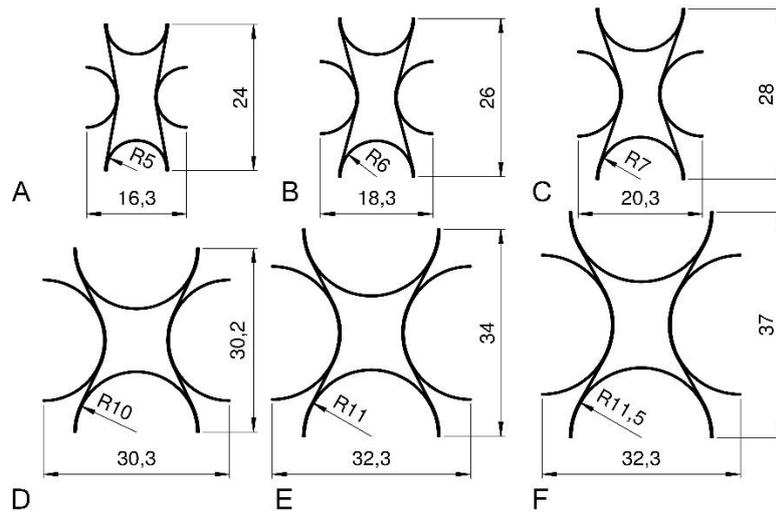


Figure 14. Geometry of selected core cells

Figure 15 shows the effect of cell type on its linear dimensions.

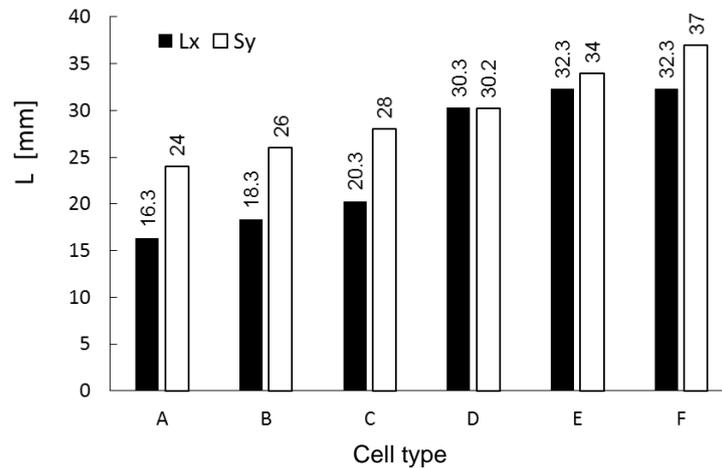


Figure 15. Effect of cell type on its linear dimensions

To maintain same or similar relative density, cylindrical cell dimensions exhibit tendency to grow in both directions. Therefore cell F has the highest values of width and length dimensions, among all other cells. It's due to the filling of the space by the cylindrical cell and also necessary spacing to maintain the technical feasibility of the core.

EFFECT OF RIB SHAPE CELL PARAMETERES ON ITS RELATIVE DENSITY

Figure 16 shows the effect of variable parameters on rib shape cell properties.

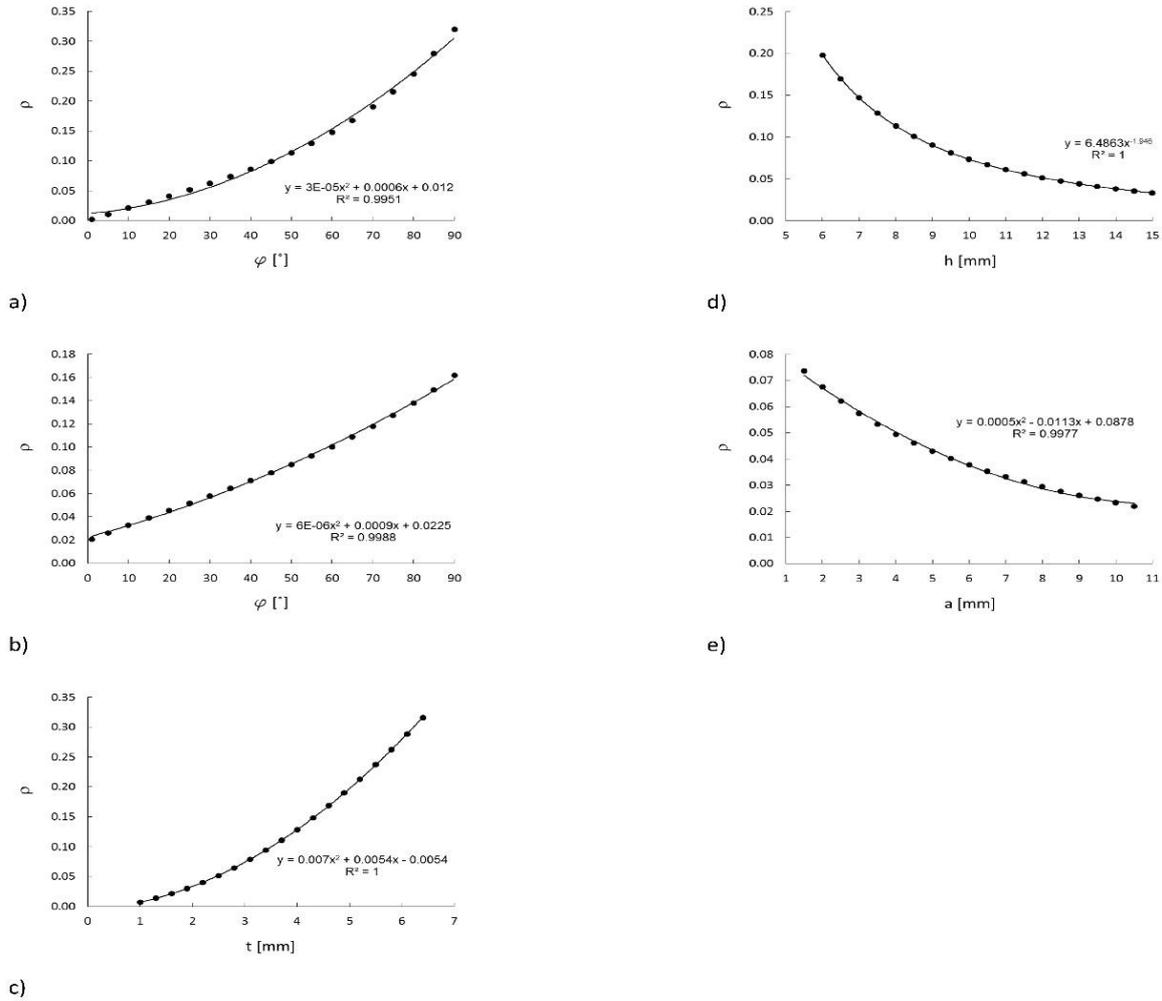


Figure 16. Relative density ρ as function of: a) cell rib angle inclination $f_x=f_y$
 b) cell rib angle inclination $f_x \neq f_y$ c) rib thickness t d) core height h
 e) base width a

Increase of rib inclination angle, both the $f_x=f_y$ and the $f_x \neq f_y$ increases relative density of cell. The same effect for increasing rib thickness. With increase of core height h or base width a , the relative density decreases. Below are the results of analytical calculations showing the effect of the angle of inclination of the cell arms, length of the side of the cell L_x , the thickness of the node connecting the arms of the cell t and the modulus of elasticity of the cell material on its relative density.

For further analyzes, several rib shape cells with identical relative densities were selected (Figure 17).

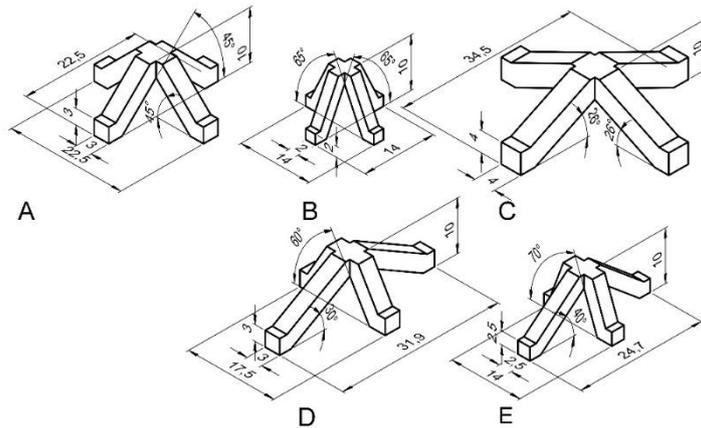


Figure 17. Geometry of selected core cells

Figure 18 shows the effect of cell type on its linear dimensions.

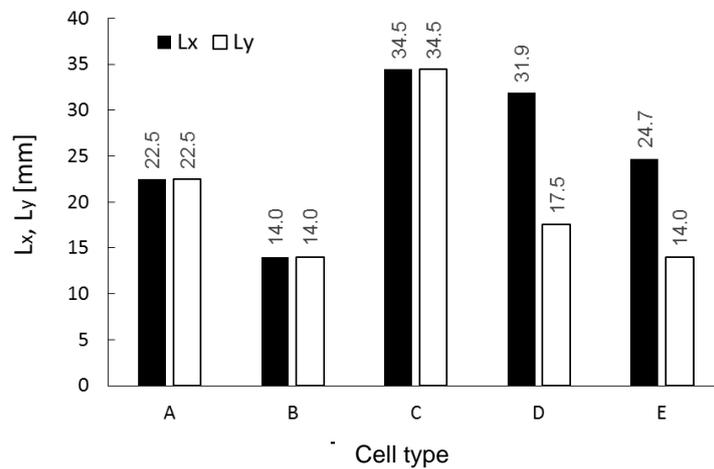
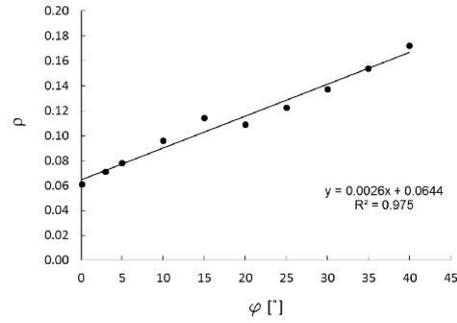


Figure 18. Effect of cell type on its linear dimensions

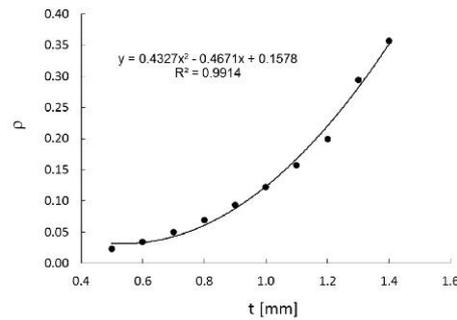
Cell C exhibits highest values of linear dimensions, it's connected to the smallest value of cell rib angle inclination. It shows strong isotropic character. It's possible to achieve smaller cells with iso- or ortotropic character, however in order to maintain similar or same relative density their geometry must exhibit wide diversity.

EFFECT AUXETIC RIB SHAPE CELL PARAMETERS ON ITS RELATIVE DENSITY

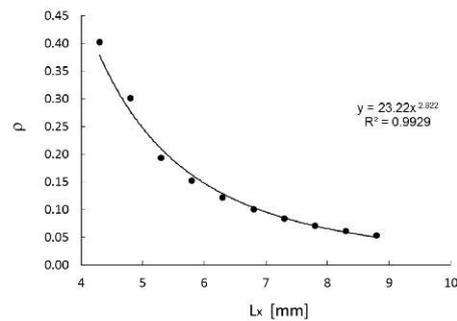
Figure 19 shows the effect of variable parameters on rib shape auxetic cell properties.



a)



b)



c)

Figure 19. Relative density ρ as function of: a) cell wall angle φ ;
b) cell wall thickness t ; c) length of cell L_x

Increase of angle inclination of the arms of the cell and the thickness of cell wall results in increase of relative density of auxetic cell. Increase of length of the cell results in a decrease in the relative density value.

For further analyzes, several rib shape auxetic cells with identical relative densities were selected (Figure 20).

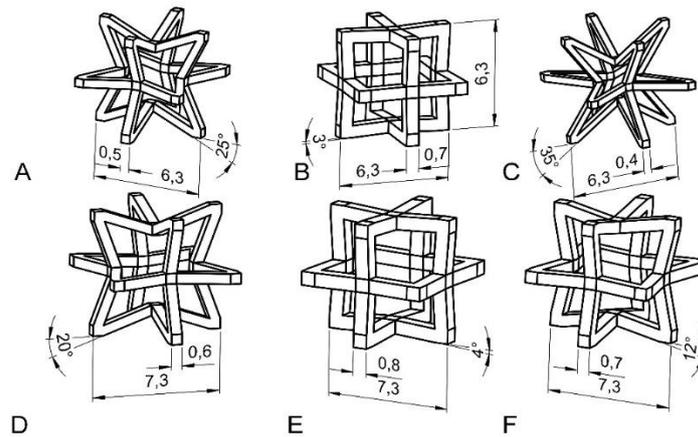


Figure 20. Geometry of selected core cells

Figure 21 shows the effect of cell type on its linear dimensions

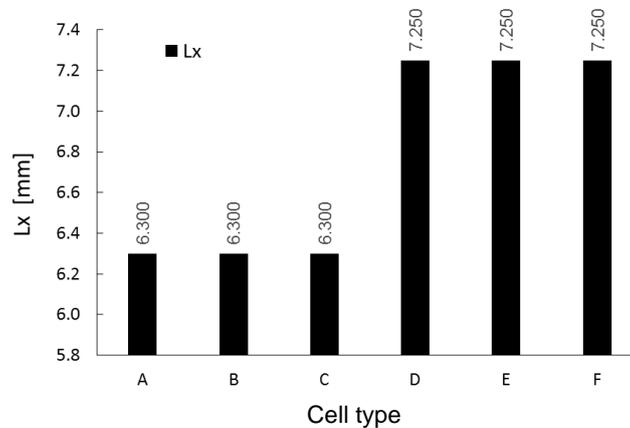


Figure 21. Effect of cell type on its linear dimensions

Cells A-C and D-F have same length dimension. Change of other cell dimensions, while maintaining same or similar relative density, don't strongly affect its overall dimensions but exhibits in geometrical shape of obtained cell.

4. CONCLUSIONS

The obtained results on novel cell constructions made it possible to draw the following conclusions:

1. It is possible to search for cells of different geometry and the like or the same relative density within one cell type, while striving to obtain the optimum lowest relative density.
2. There is a close correlation between the variable cell dimensions and its relative density.
3. It is possible to create cells with designed properties like relative density, by changing their linear dimensions. In order to maintain technical feasibility, cells may exhibit regular or quite disproportional shape, which leads to iso- or ortotropic character.

ACKNOWLEDGEMENTS

Work supported by National Science Center (NCN) project OPUS 11 within research grant “Modeling of the properties of new lightweight wood-based honeycomb panels with auxetic cores”

References

- Alqassim G. (2011): Mechanical properties of hierarchical honeycomb structures. Mechanical Engineering Master's Theses. Paper 42.
- Balawi S., Abot J.L. (2008): The effect of honeycomb relative density on its effective in-plane elastic moduli: An experimental study. *Composite Structures* (84): 293 – 299.
- Chang C. C., Ebcioğlu I. K. (1961): Effect of cell geometry on the shear modulus and on density of sandwich panel cores. *Series D*, 83: 513–518
- Chi Y., Langdon G.S., Nurick G.N. (2010): The influence of core height and face plate thickness on the response of honeycomb sandwich panels subjected to blast loading. *Materials and Design* (31): 1887 – 1899.
- Chen Q., Pugno N.M. (2012): In - plane elastic buckling of hierarchical honeycomb materials. *European Journal of Mechanics A/Solids* (34): 120 - 129.
- He M., Hu W. (2008): A study on composite honeycomb sandwich panel structure. *Materials and Design* (29): 709 – 713.
- Hu L., You F., Yu T. (2013): Effect of cell - wall angle on the in - plane crushing behaviour of hexagonal honeycombs. *Materials and Design* (46): 511 – 523.
- Jeyakrishnan P.R., Chockalingam S.K., Narayanasamy R. (2013): Studies on buckling behavior of honeycomb sandwich panel. *The International Journal of Advanced Manufacturing Technology* Vol. 65: Issue 5 - 8: 803 - 815.
- Schultz J., Griese D., Ju J., Shankar P., Summers J.D., Thompson L. (2012): Design of Honeycomb Mesostructures for Crushing Energy Absorption. *Journal of Mechanical Design* (134): 071004-1 - 071004-9.
- Smardzewski J. (2013): Elastic properties of cellular wood panels with hexagonal and auxetic cores. *Holzforschung* (67:1), p. 87 – 92.
- Sha Yin, Linzhi Wu, Steven Nutt. (2012): Stretch-bend-hybrid hierarchical composite pyramidal lattice cores. *Composite structures* (98): 153-159

Corresponding author:

Krzysztof Peliński

Department of Furniture Design, Poznań University of Life Sciences,

Wojska Polskiego 28, 60-637 Poznań, Poland

pelinski@up.poznan.pl

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license

WITHDRAWAL CAPACITY OF GLUED-IN RODS IN BIRCH PLYWOOD

Karlis PUGOVICS¹, Uldis SPULLE¹

¹ Latvia University of Agriculture, Jelgava, Latvia

Key words	Abstract
<i>Glued-in rods, Plywood, Pull-out, Threaded bar, Joints</i>	<p>Timber connections with glued-in rods are primarily used within timber construction field, however, smaller diameter rods with solid timber panel materials can be used in producing furniture joints with high strength.</p> <p>The aim of this study was to determine the effect of plywood panel thickness and rod embedment length to the withdrawal force.</p> <p>Testing was conducted for a single threaded rod (steel grade – 4.8), embedded using two component epoxy adhesive, within 30, 40 and 50 mm thick plywood panel, embedment lengths were 10 d (d – diameter of the rod), 12 d and 14 d.</p> <p>Results show no substantial effect to withdrawal force when increasing aforementioned parameters, however, increasing embedment length does affect the failure mode; ductile failure being achieved in 100% specimens with embedment length of 14 d. Data also suggests that plywood allows for a smaller rod axis to edge distance than glued or solid timber.</p>

Corresponding author: karlis.pugovics@e-koks.lv Pugovics K., Latvia University of Agriculture, Jelgava, Latvia

1. INTRODUCTION

Contrary to popular belief - timber connections with glued-in rods (GIR) being a new and innovative timber joinery type – joining timber elements using GIR has been known since 1960's, where joints using GIR were used in Sweden (Wiktor, 1990). More widespread research on joints with GIR has been going on since 1980's. Although, traditionally used in timber structures and with glulam or LVL as the timber host, joints using GIR can be used in furniture industry as part of a heavy duty, disassemblable fixing system if necessary.

Overall concept of a joint with GIR is relatively simple: a borehole is made into a timber host in which, by means of an adhesive, a metal or polymer rod is embedded (see Fig. 1). However, as more comprehensive studies have shown, there are many factors and properties to be considered, such as: diameter of the rod, rod's embedment length, glue line thickness, distance from rod's axis to timber host's edge, different materials for the rod, timber host and different adhesives etc. These and many more parameters make an impact on the performance of joints with GIR, on top of that, albeit extensive research, no internationally accepted calculation standards are currently in place and significant problems with quality control exist.

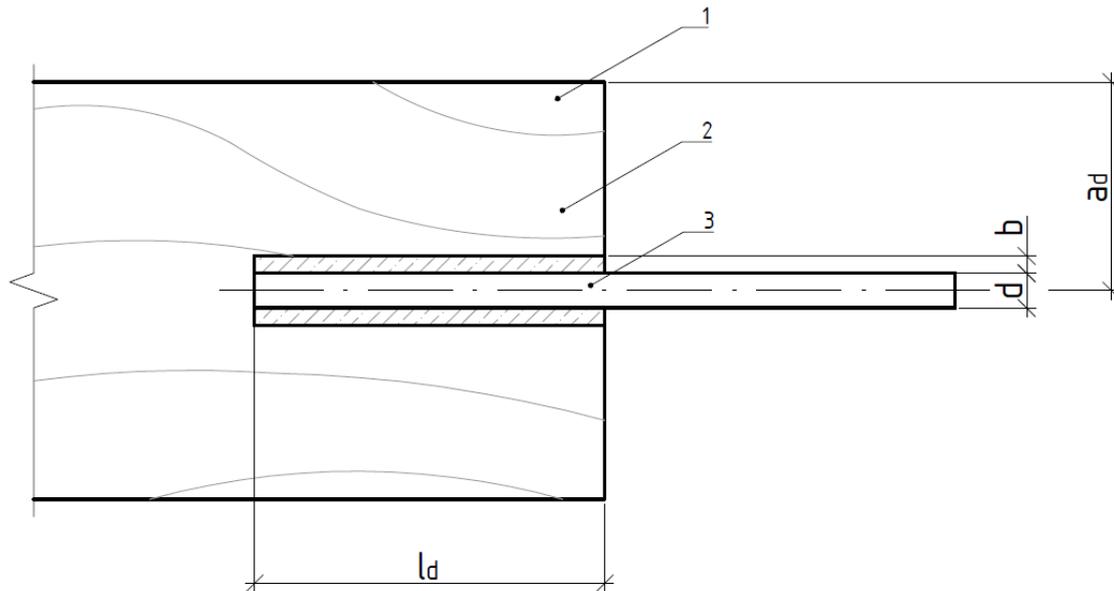


Figure 1. Basic scheme of a GIR. 1 – timber host, 2 – adhesive (not to scale), 3 – rod, d – diameter of rod, b – adhesive line thickness, a_d – rod axis to timber edge distance, l_d – rod embedment length.

Since no serious studies of behavior of GIR with birch plywood as the timber host have been made, this study focuses on basics: influence of altering two basic variables – rod embedment length (l_d) and rod axis to timber edge distance (a_d) – on the performance of the joint.

2. METHODS AND MATERIALS

VARIABLES

Since ductile failure mode is favourable, rod embedment length was chosen with this particular property in mind. According to literature, ductile failure mode in glulam is generally achieved at rod embedment length approximately $12 d$ (d being the diameter of the rod), however, some sources claim to achieve ductile failure mode at $10 d$ (Barillas, 2016). With this and the possible problems regarding plywood – glue adhesion problems in mind, the embedment lengths were chosen $10 d$, $12 d$ and $14 d$.

The second variable – rod axis to timber edge distance, a_d – is directly conditional upon the thickness of the plywood panel. According to literature rod axis to timber edge distance should be chosen at least $2,5 d$ to prevent cracking of the timber host (Steiger, 2015). Since this is crucial, for this study a smaller diameter rod was chosen (see “Fixed values”) in order to achieve values that fall short and surpass this limitation; a 30 mm, 40 mm and 50 mm thick plywood panels were used to achieve rod axis to timber edge distance of $1,8 d$; $2,5 d$ and $3,1 d$ respectively.

FIXED VALUES

The diameter of the rod, as mentioned, was chosen M8 in order to satisfy possible limitations regarding rod axis to timber edge distance. In order to achieve ductile failure mode more easily, steel class 4.8 in accordance with EN 1993-1-8.

Plywood quality grades were chosen BB/WG in accordance with “Latvijas Finieris” JSC. Quality grades, BB being equivalent of grade III for SFS 2413 and EN 635-2, WG – respectively – IV.

Settling upon an adhesive can be a problematic task. Normally, one of three types of adhesives are used: epoxy-based (EPX), polyurethane-based (PUR) or phenol-resorcinol (PRF). Studies have shown that EPX based adhesives show the highest axial capacity, which determined the choice of adhesive type.

Commonly overlooked concern is the possibility of a chemical reaction between polyamines in chemical composition of hardener and zinc plating of the steel rod. Although the probability of this occurrence can generally be judged as insignificant, this also was taken into account and an adhesive specifically designed for steel and timber connections – “Xepox 235.4” was used for sample manufacturing.

Adhesive line thickness can vary considerably and manufacturer’s recommendations should be followed at this point. For this study, adhesive line thickness of 1 mm was chosen according to manufacturer’s recommendation for greatest adhesive line capacity, which calculates in a borehole with diameter of 10 mm.

Other physical dimensions of the sample were chosen in accordance with EN 1382:2016 and are given in Figure 2.

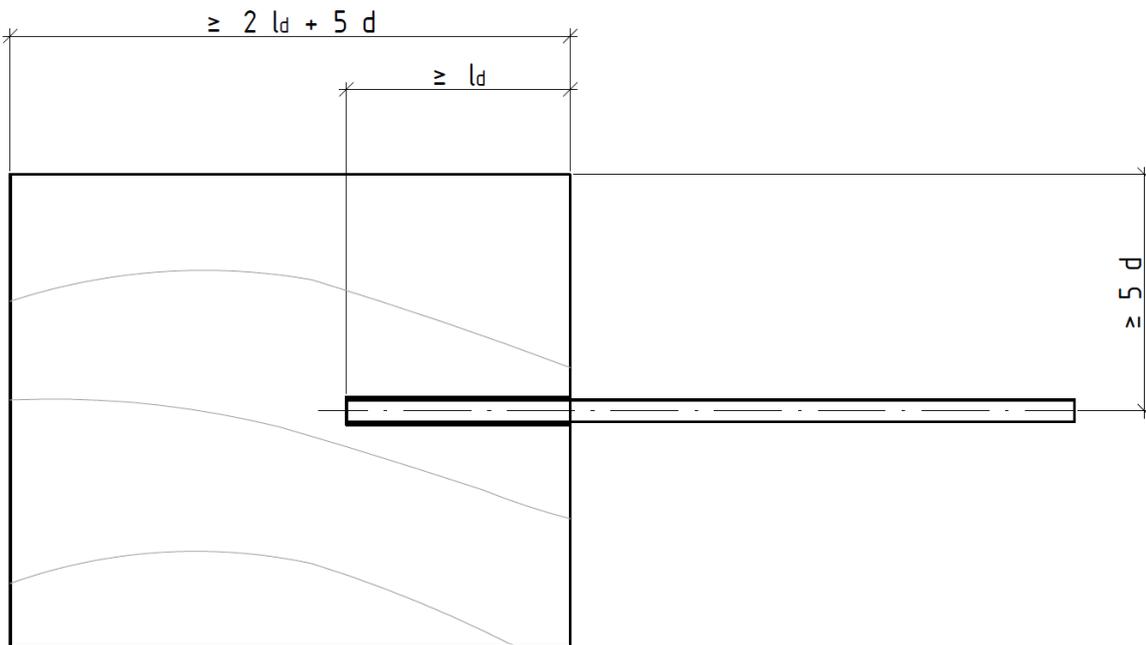


Figure 2. Dimensions of test specimen in accordance with EN 1382:2016.

EXPERIMENTAL SETUP

For the purposes of this study, 9 sample populations were set up with 12 test specimens in each group in order to ensure all possible rod embedment lengths and rod axis to timber host edge distances combinations and provide sufficient number of samples for successful statistical analysis. Sample populations were given designated titles consisting of plywood panel thickness, rod embedment length and number of individual sample, for example code “30 mm

– 12 d - 2” would be the second sample in sample group with plywood panel thickness 30 mm and rod embedment length 12 d.

After cutting and drilling the samples were stored in a climate – controlled chamber in order to achieve equilibrium moisture content and reduce the impact of variations in moisture content on the performance of the sample. After this, rods were embedded in the sample by means of an adhesive.

For testing purposes, the samples were loaded in pull – compression setup conditions as shown in figure 3.

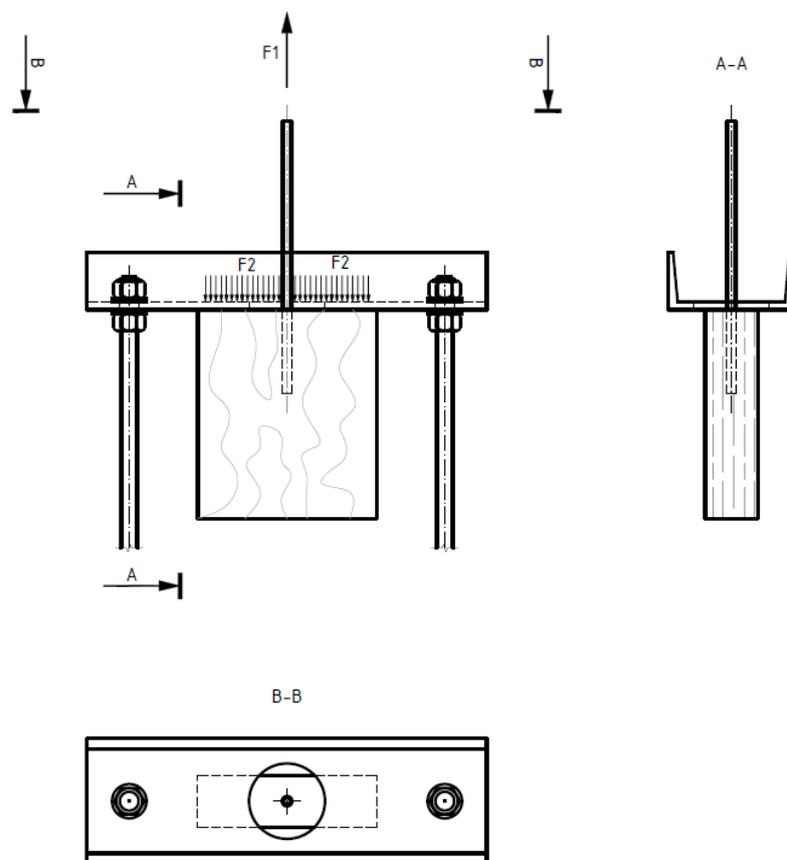


Figure 3. Pull – compression test setup used for the study.

3. RESULTS AND DISCUSSION

During sample testing, it was clearly visible and later on backed by statistical data analysis, that neither rod embedment length, nor plywood panel thickness present significant influence on the sample withdrawal capacity within the scope of this study. For rod embedment length, this was consistent with other studies using glulam, where no significant impact of rod embedment length to sample withdrawal capacity were observed where rod embedment length is greater than 10 d. Changes in rod axis to timber host distance also presents no significant impact on sample withdrawal capacity and suggests that, while using plywood, this distance can be smaller than that recommended for glulam while still maintaining consistent failure modes and avoiding sample failure due to cracking of the timber host.

During sample testing, 2 samples were rejected due to incomplete curing of the adhesive, which illustrates the aforementioned problem regarding the quality control during manufacturing process.

In figure 4, the complete summary of withdrawal capacity is given.

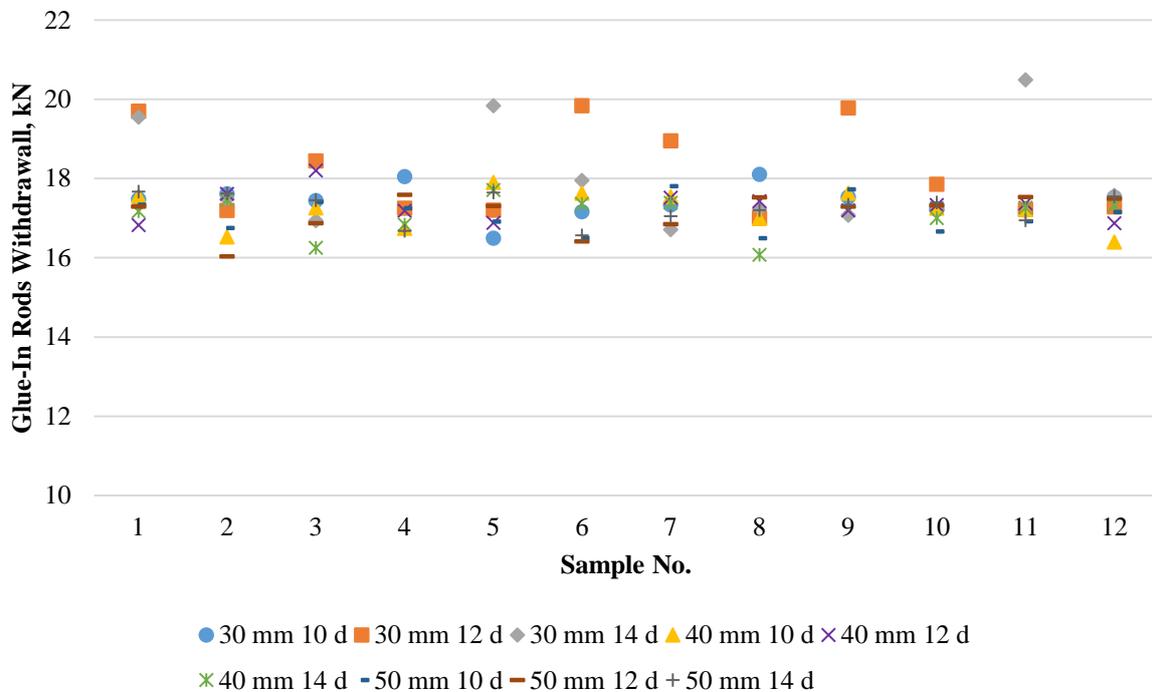


Figure 4. Comparison of withdrawal capacity for all sample groups.

4. CONCLUSIONS

Within the scope of this study, the effect of rod embedment length upon the withdrawal capacity of sample specimen is not statistically significant ($p \geq 0.05$).

Within the scope of this study, the effect of rod axis to timber host edge distance (plywood panel thickness) upon the withdrawal capacity of sample specimen is not statistically significant ($p \geq 0.05$).

Ductile failure mode has been achieved to for 100% of the samples with rod embedment length 14 d.

Ductile failure mode can be achieved for samples with rod axis to timber host edge distance as little as 1,9 d.

References

- Barillas E., (2015): Performance of timber connections with single and multiple glued-in rods. Master's thesis. Vancouver. University of British Columbia.
- EN 635-2 (1995): Plywood - Classification by surface appearance - Part 2: Hardwood.
- EN 1382 (2016): Timber Structures. Test Methods. Withdrawal capacity of Timber Fasteners.
- EN 1993-1-8 (2007): Eurocode 3: Design of steel structures - Part 1-8: Design of joints

SFS 2413 Quality requirements for appearance of plywood with outer plies of birch
Steiger et. al. (2015): Strengthening of timber structures with glued-in rods. *Construction and Building Materials* 97: 90-105.
Wiktor, R. (1990): Glulam connections using glued-in rebars. Masters thesis. Vancouver, University of British Columbia.

Corresponding author:
Karlis Pugovics
Latvia University of Agriculture, Jelgava / Latvia
karlis.pugovics@e-koks.lv

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

CURRENT CONCEPTS FOR TECHNOLOGY ALLOWING INDEPENDENT AND ACTIVE LIVING FOR ELDERLY PEOPLE

Jörg GÜTTLER¹, Katharina LANGOSCH¹, Thomas BOCK¹

¹ Technical University of Munich, Faculty of Architecture, Chair for Building Realization and Robotics, Munich / Germany

Key words

*Ambient assisted living,
modularization,
personalization,
smart home,
seamless integration*

Abstract

In an ageing society, there is a huge need for ways to allow elderly people an independent yet active life. Fewer people have time to care for their relatives and the nursing staff available is on a decrease as well. In face of the demographic changes, this challenge is certain to increase in the future. This paper aims at describing several concepts for seamless integration of ambient assisted living (AAL) technologies, ranging from unobtrusive detection of vital parameters to active service robots. The principal idea is to develop solutions in a modular manner for personalised yet cost-effective installation. Depending on the specific needs, these solutions are combined to a smart home environment for the elderly. The usability and acceptance of several concepts tested on female and male subjects are also discussed in the paper.

Corresponding author: *katharina.langosch@br2.ar.tum.de, Langosch K., Technical University of Munich, Faculty of Architecture, Munich / Germany*

1. INTRODUCTION

The effects of the demographic changes are well-known. Thanks to the remarkable evolution of medicine and medical technology innovations, and increased wealth among European citizens, the life expectancy has significantly increased over the last century. Furthermore, the living conditions of both the younger and older generations have also changed. While previously all generations lived together and supported each other, nowadays the elderly are increasingly living alone, away from their children and other family members. Not least because the young people are forced to move further away in search of suitable employment. Also, the share of the working population is continuously decreasing, such that there will be no enough nursing staff to take care of the elderly at home or in a care home. All these factors present various challenges for our society currently and in the future.

To enable the ageing population to live in dignity, support the relatives and ease the burden of the caregivers, the development of affordable, innovative, supportive and intelligent systems, which can be integrated into the living environment of the elderly, need to be advanced. Elderly people often have reduced cognitive abilities that makes it difficult to manage the complexity of social and sociotechnical interactions. This creates worries and stress. On one hand, the absence of family members is often a concern and likewise on the other hand, the desire to be independent and to live in one's own home, causes further concerns. For this purpose, age appropriate furniture and environments, in which information and communication technologies (ICT) are decently integrated (mainly sensors and robotic systems), offer the elderly the required support in their daily lives and provide a feeling of security and safety. These kinds of

ICT based solution systems, which are modular and expandable, can be adapted to the individual needs of seniors without giving the impression that it is a senior housing. In this paper, a selection of concepts of such embedded ambient assisted living (AAL) technologies developed at the Chair for Building Realization and Robotics at the Technical University of Munich (TUM) for different applications in various rooms (bathroom, wardrobe, kitchen, living room and workspace) for common daily needs of seniors are presented. Each of the presented AAL solutions have been evaluated by elderly persons of both genders. The results of the evaluation are also discussed in this paper. Finally, based on the already achieved results, further planned developments are introduced.

2. METHODS

The development of age-appropriate living environments with integrated sensing and robotic systems is an iterative process, which can be described as follows: (1) analysis of user needs, (2) definition of requirements, (3) identification of required technologies, (4) building of initial concepts or prototypes, (5) evaluation of the concepts through test with test persons, (6) improvement of the concepts according to the results of the tests, (7) further tests in real environment and (8) development of the final concepts.

In the first stage of the development, a detailed analysis of the needs of the affected groups, e.g. the elderly, the nursing staff, relatives and, if necessary, care home providers and operators, is required. Within the projects LISA (“Living Independently in Südtirol Alto Adige”) and LISA HABITEC (“Habitat, Bits and Technology in an Ageing Society”), which have been recently concluded at the Technical University of Munich, interviews and discussions with several stakeholders (elderly, relatives, caregivers, etc.) were conducted to receive a representative overview of the user’s needs. After an analysis of the survey, it became clear that the idea to support elderly by age-appropriate assistance systems with integrated ICT technologies for an independent life (AAL) in their own living environment has a high relevance and confirmed the necessity of such developments for the whole society. Based on these findings as well as further systematic literature research, the requirements and functions for age-appropriate AAL systems could be summarised, defined and evaluated. Furthermore the required technologies (sensors and robotic technologies) could be identified.

This analysis was carried out in a so-called functional matrix and its results formed the basis for the development of the initial concepts and prototypes taking into account the technical feasibility. The concepts are therefore oriented towards the needs of the target group members as well as their technical feasibility. These concepts represent supportive solutions for various rooms, e.g. bathroom, wardrobe, kitchen, living room and workspace, which are also presented here. In order to meet the individual needs of the users, various modular assistive systems (hereinafter referred to as terminals) have been developed, which serve as a platform for the assistance functions or prototypes. The main characteristic of an age-appropriate home terminal is that it can be modularly integrated into any existing residence (also in an old building). The shape of the terminal is irrelevant and can take any form from a piece of furniture to a ceiling or wall element.

WARDROBE

In the first generation of the terminal for the wardrobe or entrance area of an age-appropriate apartment, the basic configuration consists of four functions: A robotic seat to assist the elderly when sitting down and standing up, a module for the vital data collection, a control interface and a module for the storage of a TurtleBot, which assists the elderly to carry the purchases. Any further functions, e.g. reminder function, light, weather information, etc., can be easily attached using plug and play connectors to upgrade and customise the assistive capability even over time, see Figure 1.



Figure 1. First generation of the terminal for the wardrobe with integrated functions

The first function focuses on the difficulty of the elderly when standing up and sitting down. For this purpose, a robotic seat, which is unobtrusively implemented in the sitting area in front of the mirror, is equipped with a mechanism consisting of a worm gear and an actuator. A switch next to the sitting surface activates the robotic seat, which pushes carefully a person in a position that facilitates standing up and sitting down activities.

The integration of BioComfort products in the wardrobe terminal for the blood pressure, pulse, blood sugar, and body scale measurements enables the recording of vital data from the elderly. Using a wireless connection, the vital data can then be transmitted directly from the BioComfort devices to a health server in the local network and accessed by the control interface. In this context, the control interface, see Figure 1, consists of three touch screens: two of them are directly embedded into the mirror, whereas one is implemented next to the mirror and serves as remote controller. The touch screens are also used to control additional functions such as light, the mobile platform and the remind function.

Since increased age is coupled with memory loss, a reminding function has been developed and installed hidden in the shelves using the plug and play connection system, Figure 1. The reminding function is composed of a RFID antenna connected to an RFID reader, which is able to read out tags mounted on objects of interest, e.g. keys, glasses, umbrella, etc., and to forward the information to a computer using USB. For instance, when leaving the house, an alarm sounds and reminds the elderly to take the forgotten object of interest (Güttler, et al., 2014).

In the second generation, further developments on this wardrobe terminal focuses on assistance in the set of activities related to sitting down, dressing, putting on shoes, and standing up. For the assistive functions sit down and in particular stand up, the “Uplift Premium Power Lifting Seat” from the company Uplift Technologies Inc. has been mounted in the seat place of the

wardrobe and facilitates the elderly to get up using a spindle mechanism. Additionally, a belt lifting system, which is implemented as a mock-up, allows dragging the user into the standing position, see Figure 2.

The activity putting on shoes has also been improved in the second generation of the wardrobe terminal. On one hand, the shoehorn has been optimised; on the other hand, a moveable plate has been integrated into the ground on a sliding system. Using a mechanical lifting up system, the plate is able to lift up into a higher position and thus bring the foot closer to the person's hands. In this position, it is more comfortable and safe for the elderly to put on the shoes. An optimal reaching area of the shoes could be achieved using a rotatable shoe shelf, which has been implemented as a mock-up, see Figure 2. This special construction of the shoe shelf, which has been installed directly next to the person's lifting seat, allows an easy and ergonomic access to the shoes without getting up. Thanks to the rotating function of the shoe shelf, the shoes can always be brought into an upper position, in which taking the shoes is facilitated.



Figure 2. Further developments of the terminal for the wardrobe with integrated functions related to sitting down, standing up and putting on the shoes

BATHROOM

In the bathroom, there is often the danger that a person can slip or fall. A fall of the person may be as a result of many reasons, e.g. dizziness, unwariness, or heart attack, etc. In most cases, this situation is the most common cause of anxiety among elderly living alone at home and relatives, living far away from their family members. Here, the so-called fall detection systems is a remedy which can help reduce the fear and anxiety.

Most of the fall detections that are currently available on the market focus on wearables e.g. integrated into smartwatches (Dai, et al., 2010; Sposaro & Tyson, 2009), or apps running on a smartphone. Better alternatives, for example such as the Sensfloor, are integrated directly into the floor of an apartment (Steinhage & Lauterbach, 2008), but these systems are on the other hand very complex in terms of installation. For this reason, the fall detection developed at TUM is aimed at providing a cost-effective solution compared to the already existing systems, which can be easily installed and is suitable for the conditions of an existing bathroom.

The TUM version of the fall detection consists of two lasers spatially separated from each other with a combination of several other photosensors. The photosensors are responsible for generating a light barrier and enable the estimation of the size of an object or a person thereby distinguishing between a standing and a fallen (lying on the ground floor) person. The line lasers as well as the photosensors are implemented in a frame system, which can be installed in the area of the baseboard and thus represent the area of application, see Figure 3. The integration of the fall detection in the height of the baseboard allows an application in a bathroom, where

it cannot be ruled out that there the ground can be quite wet and affect the measurement and the system.

The fall detection operates according to the light-barrier principle. The photosensors are illuminated by the line lasers, which are located at the two right-angled arranged sides, whereby a larger area can be covered by the fall detection. If a person is in the room, some photosensors are obscured by this person, but the remaining photosensors are still able to receive the laser light. Depending on the constellation and the number of blocked photosensors, the implemented microcontroller board Arduino Uno decides whether an "-OK-" signal is transmitted via a XBee antenna (the XBee antenna is connected to the Arduino via the SparkFun Shield "RF development tools XBee Shield" (Sparkfun, n.d.)) or a "-FALL-" signal, where "-FALL-" is the keyword (or key signal) to trigger a fall alarm and an alert rings out.



Figure 3. Fall detection system developed at TUM

KITCHEN / LIVING ROOM

The idea behind the autonomously navigating platform, here designed as a mobile table, is that a modular and mobile piece of furniture can serve as a butler and is able to bring e.g. a glass of water, food, etc., to the elderly, see Figure 4. The main component of the mobile platform consists of the pioneer LX Research platform provided by Omron Adept (Omron Adept, n.d.), which is integrated into a table with wheels. The robot itself is able to carry up to 60 kg and is also suitable to push a piece of furniture, here the table (Adept MobileRobts LLC, 2013). For the controlling of the robot, a BeagleBone Black (Coley, 2014) connected with an LCD touch screen was used as remote controller. The movement sequence of the robots was pre-programmed as an application on the remote controller using the integrated C++ with QT5. The appropriate programs for the movement of the robot could be run in a Wi-Fi- network over a SSH connection to the Ubuntu 12.04 PC unit on the mobile robot.

For an intuitive operation of the mobile platform by the elderly, a graphical user interface (GUI) developed with QT4 (QT, n.d.) on a single-board computer BeagleBone Black (BBB) with an LCD touch screen was created (Bealgeboard.org, n.d.; 4D Systems, n.d.). On the LCD touch screen only three buttons (one button for the command "robot come on", another button for the command "robot leave again", and the other button for "exit") with a sufficient size stretched over the entire available screen width were provided, which ensures that the elderly people could easily operate the robot.



Figure 4. Autonomously navigating platform and the controlling LCD touch screen

An age-appropriate handling of the monitoring and measurement of one's own blood pressure led to the development of the capacitive Electrodes module, which can be attached at the armrest of a chair, see Figure 5. In this context, the cuff-free blood pressure measurement or rather the estimation of the blood pressure via the pulse transit time (PTT) or the pulse wave velocity is in foreground. Although the approaches of such developments can be found in the literature (Smith, et al., 1999; Geddes, et al., 1981; Yahagi & Yamada, 2012), it shows here that the predominantly used adhesive electrodes for these capacitive Electrocardiogram (ECG) are skin-irritating and impractical for the users (Betts & Brown, 1976). On the other hand, capacitive (or active) electrodes are also being introduced and may offer new possibilities.

The capacitive electrodes developed at the TUM focus on the approach that using the capacitive sensors Plessey (Plessey Semiconductors a, n.d.; Plessey Semiconductors b, n.d.) these electrodes serve as dry electrodes, where no glue or other liquids are needed. This kind of measurement leads to the advantage that the elderly are easily and without any great effort able to monitor the blood pressure and thus incorporate this activity into their daily life. Furthermore, this approach allows to measure through clothes, as long as the layers are not too thick and the application is properly shielded (Komensky, et al., 2012).

The ECG measurement is operated via a user-friendly GUI located on a single-board computer BeagleBone Black (BBB), which is connected with an LCD touch screen. On the display of the touch screen, three buttons in an age-appropriate size are available, start, stop and close. The operation of the ECG measurement provides that the old person only sits down on the chair, starts the measuring program via “start” button on the GUI, touches the two electrodes attached on both armrests and waits until the measured value is displayed on the touch screen, see Figure 5. Furthermore, the measured data could be sent to a health server via Wi-Fi, where relatives, medical staff, etc., could access them, if required.

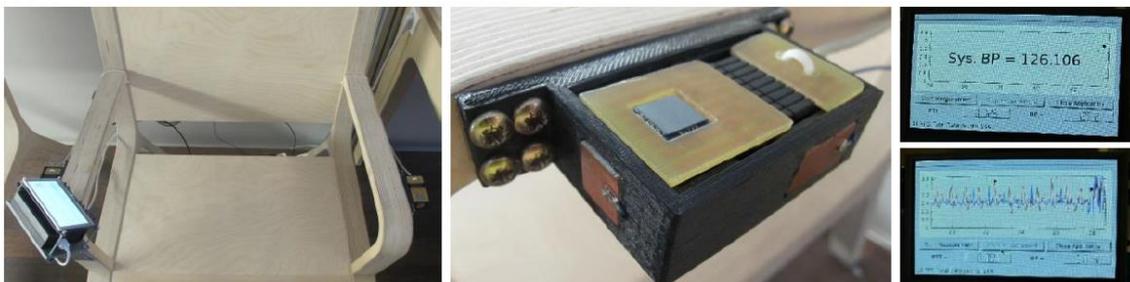


Figure 5. Chair with the attached capacitive Electrodes and the ECG measurement

BEDROOM

In the bedroom, elderly often do not face the challenge of getting in but rather getting up from the bed. To facilitate these everyday activities, handles have been decent integrated on both sites in the back wall of the bed module. Furthermore, an additional assistive facility in form of

folded handle mounted on the moveable table has been provided, see Figure 6. If required, both handles can be pulled out and thereby brought into the appropriate position and the elderly can easily and safely leave the bed. When the handles are not in use, they can be hidden in the furniture.

A further feature of the bed module is the moveable table mounted on a sliding rail. The table can be moved electronically to any position along the bed length using a remote control. In addition, a folded table integrated in the middle of the table system offers a comfortable reading position of a book or a tablet, see Figure 6.



Figure 6. Bed module with integrated handle and sliding table

WORKSPACE

Another aspect of elderly people is their ability to work in their advanced age. Within the framework of the project USA² (“Ubiquitous and Self-determined work in old Age”), a closer examination was conducted of how elderly people staying active in the working world using technical assistance and decentralised workstations e.g. in their own homes (home office). This approach is based on the idea that older people, for example in the age of retirement, still want to and can continue to participate in the working world. The productivity of the “young” elderly as well as the transfer of their knowledge can have a positive impact on companies. On the other hand, old people benefit from the social participation and individual value, which can influence positively the respective life and health situation of the elderly.

The workspace developed for elderly is oriented to the ergonomic design of a cockpit in an airplane, where all necessary equipment is within reach, see Figure 7. A steel frame allows a modular adaption in terms of size, task or extension of the system with further components / subsystems. The system of the workspace consists of (1) a logistic system with a mobile robotic platform for transportation of items, (2) 3D scanner for complex customised CAD models using a depth camera or a laser scanner, (3) telepresence for online participation at meetings (through a correspondingly large screen, an almost life size transmission is possible), (4) 3D printer for competitive production of the customized CAD models and (5) cooperative assembly station for robot supportive assembly of products using a robot arm controlled semi-automated, manually or through gesture, see Figure 7.

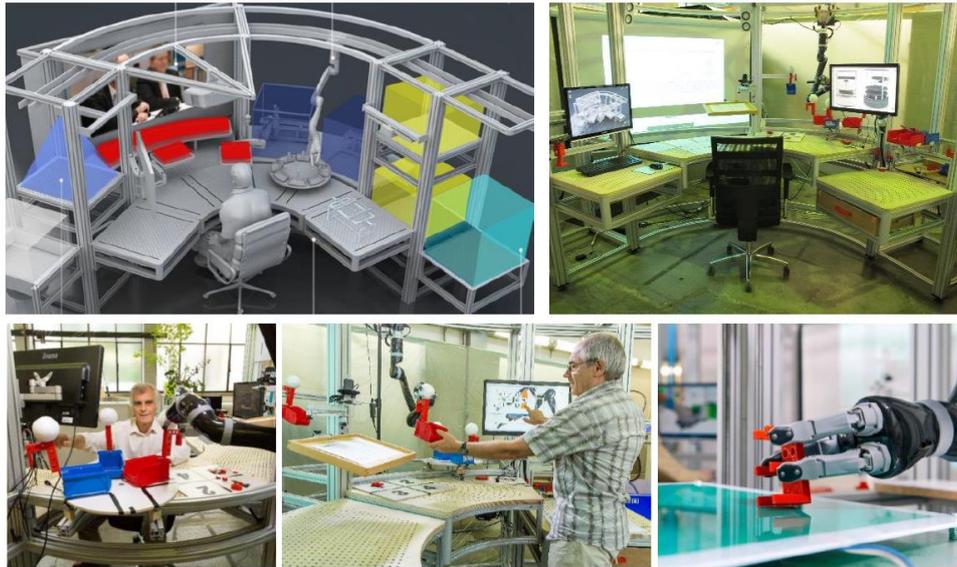


Figure 7. System architecture of the workspace

3. RESULTS AND DISCUSSION

The terminals for old people with their various functionalities have been evaluated by subjects in the laboratory of the Chair for Building Realization and Robotics at TUM. Depending on the prototype, nine up to 32 elderly with an age span of 63 to 96 years, tested the several functions of the terminals (Anne & Eva, 2016; Anne & Eva, 2017). Only elderly with dementia or heavy gait disorder (e.g. wheelchair driver) were excluded from the tests. Among the test persons, mainly female subjects above 65 years evaluated the prototypes. In case a prototype needed elderly with technical background (e.g. for the workstation), the technical background was an important factor for a subject invitation (Zirk & Schulze, 2014).

The general approach for all tests, regardless of the prototype, can be summarised as follows: First, the elderly received an introduction in form of a demonstration of all service functions implemented into the specific terminal. The demonstration included a possible user scenario to ensure that the subject could better imagine the simulated situation. Furthermore, during the demonstration phase all remaining questions could be answered. In the second step of the evaluation process, the subject replayed the presented scenario and tested all the service functions within the terminal. The third phase included a pre-prepared questionnaire for a quantitative analysis, which the subject needed to fill out after the test. In the fourth step, a guided interview was performed by an expert, which allowed investigating qualitatively the impression of the subject. All the four steps were carried out for each prototype.

To ensure the objectivity of the evaluation, an independent institute (Berliner Institut für Sozialforschung - BIS) was responsible for the preparation of the questionnaire and the interview as well as for their conduction in the laboratory and their evaluation afterwards.

The evaluation results of the tests show that all the terminals presented in this paper are useful to the elderly. The various prototypes were classified as more or less important depending on the personal interests, technical affinity and personal experience of the subject, which were recorded in the questionnaire.

In particular, the fall detection awakened the most interest among the subjects, who could imagine implementing this in their own environment. Regarding the prototypes, which aim to track health related data, the opinion was divided. On one hand, some subjects were looking forward to such a technology being soon available in the market and their private homes. Other subjects, in turn, were scared due to the risk of observation, data protection as well as technical

overtaxing. However, all subjects stated that if someone is in need and is living alone without any relatives, then the implementation and usage of these prototypes is a better option than moving to a retirement home or being a burden to others.

The evaluation results form a basis for further improvement of the concepts and terminals, which have been done within the projects. Furthermore, the laboratory tests showed also, that both the technology and the user have started to mature. Nevertheless, in the future, still more research work on user acceptance as well as technical implementation possibilities is needed, before these prototypes can successfully enter the public markets.

4. CONCLUSIONS

The increasingly ageing population and its impact in the future, e.g. increasing number of single-living elderly, low number of nurses, and no relatives in the immediate vicinity, etc., lead to new challenges, which the society face. There are suitable solutions for elderly required, which enable the old people to remain in their familiar surroundings and lead dignified independent lives.

In this paper, a selection of assistive and intelligent systems to support the elderly in their daily lives were presented. The systems, which consist of age-appropriate furniture terminals with integrated information and communication technologies, focus on assistive functions using sensors and robotics. The terminals have been developed for various areas of an apartment, whereby here in particular the application in the floor area, bathroom, kitchen / living room, bedroom and workspace were in foreground. It could be shown in the individual living areas, which difficulties the elderly face every day and how the sensor and robotic technology can support their daily activities. The benefit of the ICT technology has been evaluated by elderly subjects in laboratory tests, and their feedback formed a valuable basis for further improvements. Although the evaluation of the elderly has been introduced in further improvement, it has become clear that further developments and tests are required before the furniture with the integrated ICT technology can be launched.

In addition, the laboratory test with the subjects made it clear that the fall detection system is the most worthwhile system for elderly. This system offers the most promising possibilities to support people in a way that it helps them feel a little more safe when living alone in old age. However, this system also needs further improvements, which could be implemented in the framework of the Interreg Baltic Sea Region program project BaltSe@nioR (“Innovative solutions to support enterprises in the Baltic Sea Region in product development aimed at raising comfort and safety of seniors home living”) funded by the European Union's Regional Development Fund. Further development could follow the approach of considering other technologies instead of lasers, as well as installing the sensors directly in the baseboard. The first improvements in this area also include the use of robots as a mobile platform, which have already been presented in this publication in the context of the kitchen and living room, which is capable to communicate with the fall detection and to assist the fallen person in case of emergency. The first tests are currently being run at the TUM. Further developments may consider the use of camera for personal identification, an auxiliary tool for reaching objects (such as the robotic arm JACO in the workspace) or a telepresence for communication with relatives or caregivers. Thus, a combination of the prototypes presented here could be used for further innovative applications.

References

4D Systems, n.d. 4DCAPE-43 4D 4.3" LCD CAPE for beaglebone black. [Online] Available at: http://www.4dsystems.com.au/product/4DCAPE_43/ [Accessed 26 08 2016].

- Adept MobileRobts LLC, 2013. Datasheet: Pioneer LX Mobile Research Platform. s.l.:s.n.
- Anne, E. & Eva, S., 2016. LISA habitec, Ergebnisse der Usability Tests, Berlin: s.n.
- Anne, E. & Eva, S., 2017. LISA habitec, Ergebnisse des Feldtests, Berlin: s.n.
- Beagleboard.org, n.d. BeagleBoard.org Latest Firmware Images. [Online] Available at: <http://beagleboard.org/latest-images> [Accessed 08 03 2017].
- Betts, R. & Brown, B. H., 1976. Method for recording electrocardiograms with dry electrodes applied to unprepared skin. *Medical and biological engineering*, 14(3), pp. 313-315.
- Coley, G., 2014. BeagleBone Black System Reference Manual-Revision C.1. s.l.:s.n.
- Dai, J. et al., 2010. Mobile phone-based pervasive fall detection. *Personal and ubiquitous computing*, 14(7), pp. 633-643.
- Geddes, L. A. et al., 1981. Pulse transit time as an indicator of arterial blood pressure.. *Psychophysiology*, 18(1), pp. 71-74.
- Güttler, J., Georgoulas, C., Linner, T. & Bock, T., 2014. Unabhängiges Wohnen durch modulare und mit Assistenzfunktionen individualisierbare Mikro-Roboterräume. Berlin, s.n.
- Komensky, T., Jurcisin, M., Ruman, K. & Kovac, O., 2012. Ultra-wearable capacitive coupled and common electrode-free. San Diego, s.n.
- Omron Adept, n.d. Pioneer LX Research Platform. [Online] Available at: <http://www.mobilerobots.com/ResearchRobots/PioneerLX.aspx> [Accessed 12 07 2017].
- Plessey Semiconductors a, n.d. PS25201B EPIC Ultra High Impedance ECG Sensor Advance Information, Data Sheet 291497 issue 3. s.l.:s.n.
- Plessey Semiconductors b, n.d. PS25203B EPIC Ultra High Impedance ECG Sensor Advance Information, Data Sheet 291499 issue 3. s.l.:s.n.
- QT, n.d. Qt Documentation - Qt 4.8. [Online] Available at: <http://doc.qt.io/qt-4.8/> [Accessed 12 07 2017].
- Smith, R. P., Argod, J., Pépin, J.-L. & Lévy, P. A., 1999. Pulse transit time: an appraisal of potential clinical applications. *Thorax*, 54(5), pp. 452-457.
- Sparkfun, n.d. XBee Shield Hookup Guide. [Online] Available at: <https://learn.sparkfun.com/tutorials/xbee-shield-hookup-guide> [Accessed 27 04 2017].
- Sposaro, F. & Tyson, G., 2009. iFall: An Adroid Application for Fall Monitoring and Response. Minneapolis, Minnesota, USA, s.n.
- Steinhage, A. & Lauterbach, C., 2008. Ein aal sensorsystem für sicherheit, homecare und komfort. Berlin, Germany, s.n.
- Yahagi, N. & Yamada, I., 2012. Relation Between Blood Pressure Estimated by Pulse Wave Velocity and Directly Measured Arterial Pressure. *Journal of Robotics and Mechatronics*, 24(5), pp. 811-819.
- Zirk, A. & Schulze, E., 2014. Evaluation des Prototyps, s.l.: s.n.

Corresponding author:

K. Langosch

Technical University of Munich, Faculty of Architecture, Chair for Building Realization and Robotics, Munich / Germany

katharina.langosch@br2.ar.tum.de

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

THE ELDERLY AND DISABLED IN NURSING HOMES COMPLIANCE WITH HARDWARE FURNITURE IN MERSIN

Cevdet SAÇLI¹, Osman PERÇİN², Mustafa ALTINOK³

¹ Mersin University, Mersin University, Technical Sciences Vocational School, Program of Furniture and Decoration

² Necmettin Erbakan University, Faculty of Fine Arts Department of Interior Architecture and Environmental Design

³ Gazi University, Faculty of Technology Department of Woodworking Industrial Engineering

Key words

*Aging,
Safety in space,
Ergonomic furniture.*

Abstract

8% of the Turkish population consists of people over 65 years of age. Individuals, who are considered elderly, even if they have no physical disabilities, face obstacles in their daily lives due to health problems brought by their elderly age. In the relevant articles of the Constitution of the Republic of Turkey, there are provisions concerning the protection of disabilities and the taking of measures to provide adaptation to society's life.

In this study, it was aimed to determine the problems faced by 65 physically handicapped and elderly individuals living in 3 different nursing homes in Mersin province and to suggest suggestions for solution of these problems. In the direction of this aim, firstly the questionnaires and observations were made and the problems were identified and the analyses were included in the evaluation.

Corresponding author: cevdetsacli@mersin.edu.tr Mersin University, Technical Sciences Vocational School, Program of Furniture and Decoration

1. INTRODUCTION

Turkey has a similar process to demographic developments in many countries around the world. After the establishment of the Republic of Turkey in 1927, the population of Turkey, which was 13.6 million in the first census, promoted fertility after nearly 30 years, by the influence of the activist pronatalist policies. From 1965 onwards, anti natalist policies to control fertility have tended to decline in nature through the implementation of population policies. Changes in the level of mortality are also an important factor in determining the numerical size of the elderly population. The migration of the migratory movements from the sea to the land in Turkey in the 1950s and the acceleration in the last thirty years, improvement in the level of education, participation of women in working life, especially after the 1980s fertility declined rapidly and as a consequence total fertility declined to 2.2 children from five children. The increase in the age of death, as well as the increase in population, means the decrease in fertility as well as the decrease in the young population.

Table:1. Turkey Population Distribution by Age Groups 2016

Year	2016						Total
	65-69	70-74	75-79	80-84	85-89	90+	
Population	2.412.537	1.680.492	1.202.050	809.325	401.758	145.341	6.651.503
Percentages	% 3,02	% 2,11	% 1,51	% 1,01	% 0,50	% 0,18	% 8,33

TURKEY POPULATION DISTRIBUTION BY AGE GROUPS 2016

Traditionally, in Turkey, the care of elderly ancestors is taken care of by their own family members. It is considered embarrassing to send their ancestors to nursing homes for young family members. World Health Organization (WHO) chronological description for the old age and accepts this period as "over 65 years of age". The use of different age criteria, for example, the United Nations is based on 60 years of age and above in its work in this area. www.nufusu.com/turkiye-nufusu-yas-gruplari However, the definition of WHO is generally based on national and international aging studies. The elderly population is also divided into subcategories. The 65-74 age groups are defined as "Young old", the 74-84 age group is defined as "Old", and the age group 85+ is defined as "the Oldest old". 2016 yılına göre Türkiye nüfusunun yaş gruplarına göre nüfus dağılımı ve nüfus yüzdesi. <http://transgenerational.org/aging/demographics.htm>

The Nursing homes are institution providing nursing care all day, assistance with activities of daily living and mobility, psychosocial and personal care, paramedical care, such as physiotherapy and occupational therapy.

According to the General Directorate of Disabled and Elderly Services under the Ministry of Family and Social Policies, the number of nursing homes in Turkey seems to be down.

In addition to these nursing homes, there is 5 branches of the General Directorate and 1 day care center belonging to the private sector. Thus, the number of institutions providing elderly care services in Turkey is 297 in total. The total numbers of elderly people are 19,596.

<http://www.dogrulukpayi.com/beyanat/542cfd997153f>

Table 2. Number of nursing homes in Turkey

	Number of NH	Capacity	Number of Elderly
NH attached to the Ministry	107	11.717	10.692
NH attached to other Ministries	2	566	566
NH for the municipalities	20	2.013	1.409
NH belonging to Association and foundations	31	2.556	1.789
NH belonging to minorities	7	920	644
NH Private	130	6.422	4.495
Total	297	24.194	19.596

*Nursing Homes(NH)

While the elderly population (65 and over) was 5 million 682 thousand 3 persons in 2012, it increased by 17.1% in the last five years and became 6 million 651 thousand 503 persons in 2016. The proportion of the elderly population in the total population is 7.5% in 2012 and rose to 8.3% in 2016. 43.9% of the elderly population constituted the male population and 56.1% the female population. The world population constituted 8.7% of the elderly population in 2016. The top three countries with the highest elderly population were Monaco with 31.3%, Japan with 27.3% and Germany with 21.8%. Turkey ranks 66th out of 167 countries in this ranking. A Life table, according to the results of the year 2015, life expectancy at birth was 78 years, for men 75.3 years for men and 80.7 years for women. Generally, women are living longer than men and the life expectancy at birth is 5.4 years. The average life span of a person who is 65 years old in Turkey was 17,8 years. For males, it was observed that this was 16.1 years and 19.4 years for females. In other words, it is estimated that women reaching 65 years will live an average 3.3 years longer than men. The elderly dependency ratio, which indicates the number of elderly people per person in the study period, increased from 11.1% in 2012 to 12.3% in 2016.

The number of elderly people aged over 100, which constitutes 0.1% of the elderly population, was 5 thousand 232 in 2016. According to the results of the family structure survey, 40.2% of elderly people wanting to live with their children, 38.6% of those who want to get home care services, and 7.7% of those who want to go to nursing homes are in need of living with their children. It was seen that the proportion of elderly non-fictional individuals was 12.9%. The most important reason to stay in the nursing home was not to be a burden on the children. In 2016, the most important reason for wanting to stay in a nursing home when elderly people were too old to look after them was that they did not want to be a burden on their children with 48.9%. The second most important reason was 20.2% more opportunities in rest homes, and the third most important reason was 11.2% in which children had to live with themselves. <http://www.tuik.gov.tr/PreHaberBultenleri.do?id=24644> Issue: 24644, March 16, 2017, Time: 10:00, Stats by Ages, 2016

Table 2. Reasons for the elderly to consider the nursing home as a life choice in the future, 2016

Inability to burden their children	% 48,9
The possibilities of nursing homes are more comfortable	% 20,2
Children do not want to live with themselves	% 11,2
Thinking about who will not be interested	% 9,5
Living alone, living with their own peers	% 6,4
Their bride/groom wants to live with them	% 3,8

Source: TÜİK, Aile Yapısı Araştırması, 2016

According to the results of the life satisfaction survey, the proportion of elderly individuals who declared they were happy was 56.8% in 2015, while it rose to 64.5% in 2016. When the general level of happiness is examined on a gender-based basis, 66.2% of elderly men and 63.2% of elderly women are happy in 2016.

According to the results of the life satisfaction survey, the elderly individuals became the most important source of happiness in 2016 with 64.2%. The second happiness source was children with 18.1%. <http://www.tuik.gov.tr/PreHaberBultenleri.do?id=24644>

2. METHODS AND MATERIALS

The survey aimed to find out the effects of social life on the living and working of the physically handicapped and elderly people living in and living in nursing homes by realizing the vital actions of the internal and external places inside the nursing home boundaries. Tarsus, Erdemli and Silifke districts of Mersin province were selected as the research area for the Elderly Care and Rehabilitation Center for the Elderly. First, in order to conduct research and observation in the selected institutions, written permission has been obtained by passing to Mersin Family and Social Policy Directorate. Following the receipt of the research permit, the selected institutions were visited separately and a questionnaire was applied to elderly and disabled people. According to observation and interview results, pre-survey study and frequency evaluation were done. As a result of the evaluation, questionnaires and questionnaires were determined. The survey data were collected between June and July 2017.

SAMPLING RESIDENTS ARE NON-DISABLED AND WHEELCHAIR USERS WHO CAN COMMUNICATE WITHIN THOSE INSTITUTIONS.

Table 2.1. Demographic characteristics of survey participants

County	f	%
Tarsus	8	12,3
Erdemli	43	66,2
Silifke	14	21,5
Total	65	100,0
Gender	f	%
Male	43	66,2
Female	22	33,8
Total	65	100,0
Age	f	%
- 60	1	1,5
60-64	1	1,5
65-69	14	21,5
70-74	13	20,0
75-79	15	23,1
80 +	21	32,3
Total	65	100,0
Marital Status	f	%
Married	9	13,8
Single	10	15,4
Widow	46	70,8
Total	65	100,0
Number of Child	f	%
None	17	26,2
1	7	10,8
2	14	21,5
3	11	16,9
4	4	6,2
5 +	12	18,5
Total	65	100,0
Illiteracy	f	%
Literate	47	72,3
Illiterate	18	27,7
Total	65	100,0
Educational Status	f	%
No education	16	24,6
Primary school	32	49,2
Secondary school	9	13,8
High school	7	10,8
University	1	1,5
Total	65	100,0
Income Level	f	%
Low	41	63,1
Middle	24	36,9
Total	65	100,0
Duration of stay	f	%
Less than a year	23	35,4
Up to 2 years	5	7,7
Up to 3 years	11	16,9
More than 3 years	26	40,0
Total	65	100,0
Self-sufficiency	f	%
Physical and social assistance requirement	37	56,9
Social assistance requirement	11	16,9

Table 2.1. Demographic characteristics of survey participants – cont

County	f	%
Physical assistance requirement	2	3,1
Self sufficient	15	23,1
Total	65	100,0
Auxiliary Tools	f	%
Wheelchair	9	13,8
Walker	4	6,2
Walking stick	21	32,3
None	31	47,7
Total	65	100,0
Room type	f	%
Block single room	16	24,6
Block double room	40	61,5
Block triple room	1	1,5
House single room	5	7,7
House double room	3	4,6
Total	65	100,0

Table 2.3. Ease of Use of Furniture

	Very Difficult		Difficult		Middle		Easy		Very Easy	
	f	%	f	%	f	%	f	%	f	%
Bed	0	0	1	1,5	3	4,6	14	21,5	47	72,3
Wardrobe	0	0	0	0	6	9,2	14	21,5	45	69,2
Armchair	1	1,5	1	1,5	3	4,6	18	27,7	42	64,6
Commode	0	0	1	1,5	0	0	22	33,9	42	64,6
Dinning table and chairs	1	1,5	0	0	4	6,2	15	23,1	45	69,2
Kitchen cupboard	0	0	0	0	29	40,6	16	24,6	20	30,8

When the demographic characteristics of the participants were evaluated, it was determined that individuals living in all age, sex and marital status in the nursing homes of Mersin Provincial Directorate of Family and Social Policy Department. In this condition it can be said that the individuals have different needs and that these differences must be taken into account in the designs.

OBSERVATION

The daily activities of the residents of the nursing home were observed in the observations and the physical dimensions of the service areas were tried to be determined not to affect the social dimensions. In addition, all the service areas of the institution were visited by the researcher one by one and tried to understand the obstacles encountered by the residents of the nursing home.

EVALUATION OF DATA

The data, which were considered to be independent and different from each other after being collected again, were tried to be edited in such a way as to form a meaningful unity. In the research process, the sources that are not directly related to the topics were separated and the content was rearranged according to the information that was not previously thought but considered to contribute to the research.

3. RESULTS AND DISCUSSION

1. The most preferred home for the elderly is erdemli
2. Men prefer 66% of their nursing homes
3. Nursing homes are the most preferred by 80% of the population (32.3%).
4. 70.8% of the people living in nursing homes are widows.
5. Men's death age is lower than women.
6. 21% of the people living in nursing homes have 2 children.
7. The education level of nursing home residents is 49.2% literate
8. Those who have low income status in the nursing home are 63,1%
9. Self-sufficiency rate is 56.9%
10. Those who need physical help 3.1%
11. Income Level %63,1
12. Duration of stay more than 3 years (%40)
13. Ease of Use of Furniture

References

- Meifeng H., Wenbin H. (2008): A study on composite honeycomb sandwich panel structure. *Materials and Design* 29: 709-713.
- Voth C., Yamada V. (2010): Sustainable Lightweight Wood-Strand Panels for Bulding Construction. *Proceedings of the International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe –Timber Committee*. October 11-14, Geneva, Switzerland 1-7.
- Smardzewski J. (2015): *Furniture design*. Springer International Publishing, Heidelberg, New York, Dordrecht, London.

Corresponding author

Author name (e.g. M. Derikvand)

University, Faculty, Department, City / Country (Times New Roman, 12 pt)

address@email.eu

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

TOWARDS A GENERIC DESIGN FRAME FOR AGEING-FRIENDLY DEVELOPMENT FOR SENIORS

Andrew Sirkka¹, Sari Merilampi¹, Sirpa Sandelin¹

¹ Satakunta University of Applied Sciences, Pori, Finland

Key words

Ageing-friendly design, changes in ageing, welfare technology, service design, productisation.

Abstract

Aim: The aim of the paper is to create a generic frame for age-friendly product and service design. The frame is based on a descriptive literature review on age-related changes in human life. The frame emerged from the literature forms a basis for our approach and preliminary ideas of alleviating the effects of aging in a person's daily life by bringing customer-centeredness in the design processes of age-friendly furniture, housing and technology.

Method: This paper is a descriptive literature review of the data gathered from EBSCO and CINAHL databases. The research questions were: "What are the ageing changes in a human being?" and "What solutions to meet the ageing challenges are presented in the literature?". The data was gathered by search terms of "changes in ageing" and "changes of ageing", and published in English between 2010-2017. The search resulted the total of 73 full text articles with references available, of which amount 62 articles passed the selection criteria to be utilised as the data. The selected articles were analysed by a qualitative contents analysis method.

Results: The following main themes regarding changes in/of ageing emerged from the data: sensory changes, changes in functioning and mobility, changes in cognition, behaviour and social activities, mental changes, nutritional changes, and changes in quality of life. Based on the change categories and main causes identified in the literature, some preliminary ideas were drawn as a tentative frame for how to improve age-friendly design in products and services, and what sort of solutions could be useful in designing housing, furniture, other products or services for older people.

Conclusion: The descriptive literature review assisted in identifying main changes caused by and experienced in ageing progress. Already identification of the most common and generic changes in ageing provide a wide range of characteristics and useful elements to be utilised as a generic frame to improve age-friendly design. This tentative frame assists designers of various commodities and/or service providers to pay better attention in the modifiability of products and services relevant to progressive ageing processes. As conclusion, some preliminary examples of products could be presented to concretise the use of the generated frame.

Corresponding author: sirpa.sandelin@samk.fi, Sandelin S., Satakunta University of Applied Sciences, Pori, Finland

1. INTRODUCTION

As to modern service or technology development, service design and design thinking in general have provided fascinating new perspectives and tools in person-centred thinking and individualised services. The atmosphere is changing from conventional industrial productisation and target group focused commerce towards tailor-made production and individually modifiable products and services (Baruth et al 2011; Classon et al 2016; Crundall-Goode et al. 2017; Fristedt et al 2014; Ibrahima & Davies 2012; Lörincz et al. 2010; Muhammad et al. 2017; Warda et al. 2015).

Service design methodology is approved useful to identify personal needs and attaining deeper comprehension of people's life situation, real life needs and daily activities, where any assistive technologies or redesign of facilities would make a difference in quality of life, self-reliance and functioning (Enninga et al. 2013; Ibrahima & Davies 2012). Seeing everyone as a person with one's own priceless life history and other personal resources is a huge force and driver to change professionals' role and use of expertise in comprehensive service delivery systems. That is why e.g. mapping customer journeys or collecting and analysing other personal narratives have become very powerful tools of change agency in modern services let alone commercial productisation (Kelly 2017; Lemon & Verhoef 2016; Weldon et al. 2015).

Design for all (DfA) and other ideologies to individualise products and services have pioneered among making "normalcies" in life accessible, available and feasible for everyone by redesigning environment, products and services applicable for anyone (Blanck 2014; Joines 2009). However, accessibility is a far wider concept than ramps or door widths in constructions and housing environments (Patomella et al. 2011; Preston & Rajé 2007.). In conventional industry and commerce those people are often seen as marginal minor groups that are not so interesting to invest in. Fortunately, the transition from this conventional thinking towards user-oriented productisation and service design is an ongoing process.

There are so many different avenues to improve accessibility and user experiences. Design for Somebody (DfS) is one of those willing to challenge conventional productisation models by setting modifiability as a corner stone in productisation from the beginning. The ideology in DfS is quite identical to that in Design for All; only the approach is different involving the user as an active party throughout the development process. The reason for developing a new approach is related to very specific needs of small target groups. If a solution is designed for all, the same solution is to serve everybody despite limitations. However, when dealing with very specific needs, it may not be possible to make the "Design for All" solution without losing functionality and usability of the solution from other user groups' point of view. Instead, modular structure facilitates tailor-made solutions on generic structure with specified modifiable modules that make the product or service useable even for persons with severe limitations or special needs. In these cases, Design for Somebody seems to work better as a design approach. DfS ideology in technology and service design is approved very applicable also in developing variety of solutions regarding aged population – or in fact all population without need for distinctions. (Finn & Sloane 2016; Koivisto 2016; Sirkka et al. 2017.)

User-friendly design is after all what matters, not how the design ideology or process is called. That is why this paper discusses some ideas and needs for a generic frame usable in whatever aged-friendly designing.

2. METHODS AND MATERIALS

This paper is a integrated literature review of the data gathered from EBSCO and CINAHL databases. A literature review can be conducted in different ways, like as: 1) Narrative Review (to review the literature by verbally describing the past studies, focusing on theories and frameworks, elementary factors and their research outcomes, with regard to a hypothesized

relationship without any standardised procedure for the review), 2) Descriptive Review (focusing on revealing an interpretable pattern from the existing literature producing some quantification, such as publication time, research methodology, and research outcomes), 3) Vote Counting (used to draw inferences about focal relationships by combining individual research findings by a tally of the frequency with which existing research findings to generate insights from a series of experiments), 4) Meta-Analysis (most systematic and profound approach aims at statistically providing support for a research topic by synthesising and analysing the quantitative results of many empirical studies or specifically examining the relationships between certain Independent Variables (IVs) and Dependent Variables (DVs) derived from existing research findings) or 5) Integrated Literature Review (King & He 2005; Wittemore & Knafl 2005).

Integrative reviews are conducted with a systematic procedure including searching, filtering, and classifying processes. The process consists of several stages: problem identification, literature search, data evaluation, analysis, and presentation. Integrated reviews have the potential to present a comprehensive understanding of problems by inclusion of diverse data sources related to the topic of interest. Integrative reviews are the broadest type of research review methods allowing for the simultaneous inclusion of experimental and non-experimental research to more fully understand a phenomenon of concern. Integrative reviews may also combine data from the theoretical as well as empirical literature. (Wittemore & Knafl 2005.)

The key problem identified for this study is presented as the following research questions: “What are the ageing changes in a human being?” and “What solutions to meet the ageing challenges are presented in the literature?”.

The data consisted scientific and professional articles published in English between 2000-2017. The articles were searched using EBSCO and CINAHL database with search terms of “changes in ageing” and “changes of ageing”, and. The search resulted the total of 1948 full text articles. Based on the abstracts, 1882 articles were eliminated not providing answers to the research questions. 66 full texts articles were read through, of which amount 23 finally passed the relevance test, and were analysed by a qualitative contents analysis method.

3. RESULTS AND DISCUSSION

Based on the conducted literature search, main categories regarding changes in/of ageing were identified: functional changes in body, senses, mobility, nutrition; changes in quality of life, social aspects and general life satisfaction; psychological changes, depression; changes in cognition, patterns in functioning, memory, decision-making. All these lead to need of assistance in certain level - at least necessity to pay additional attention to modification in utilities, functional patterns, mobility, additional support services and technologies, or to prevention of excessive difficulties, disabilities, or accidents. In most cases, the enablement of optimal functioning could be done by redesign and modification alone providing right knowledge of causes and consequences of ageing as “normal” parts of human life, and put that knowledge together with skills provided by design thinking.

Culture and community-thinking is one of human characteristics. Socio-cultural environment defines our world view, values, ways to perceive and behave. That is why solutions and their applicability in human challenges differ between various socio-cultural environments. Rather seldom can even good ideas be transplanted as such without any modification into another environment or situation (as is the case in organisations). To understand older persons' current situation, emotions, ways of thinking and daily challenges, the reasons and causes can be found by going through the person's life history, previous living conditions and experienced social support, and assessing the level of limitations.

Health situation among older people varies a lot from good functioning or lack of disability to multi-morbidity and severe disabilities. Each older person is an individual, and thinking that bundles all people based on age as one entity should be discarded. Naturally there are common characteristics and regularities in certain level but our concern in this paper was to focus on age-friendly ways and solutions which as such require any human being seen as an individual with one's own background as moulding factors.

As answers to our research question, the literature research provided certain approaches and tools. Too often in the literature factors and topics are discussed in rather discerning and superficial level. Factors are identified but tougher is to find any propositions how to deal with them. Some ideas also applicable in designing, however, were found in the data. Cultural and community aspects and elements are important to make the activities and environment home-like and enjoyable. Too neutral and impersonal décor passivates by promoting the feeling of being alienated from one's "normal" life. That goes also as far as nutrition is concerned: properly prepared, portioned and designed meals in beautiful and enjoyable environment improves appetite and thus nutritional status of older people.

Keeping up with the daily activities are mentioned frequently as therapeutics in the literature. Participation in daily activities provide physical activation, cognitive stimulation and challenges in a meaningful way. However, in many cases modifications are required as to facilities like furniture, kitchen, bathroom, lighting, but also some other "small scale" arrangements to improve or maintain mobility, ergonomics and safety. Easy to manage, but still often neglected, facilities like surfaces, colouring, design, additional handles, textures could make enormous difference in enabling independence and good quality of life even due to impaired vision, touch, lack of mobility and other normal changes in ageing. Even if this is widely known, most residential care facilities or support systems are regulated the way that still passivates the residents.

In older age, people may lose the ability to socialise – depending on the cultural background. Impaired vision and hearing inhibit meaningful communication. Therefore, the research calls for renewal in care professionals' skills and competences. The aged are too easily left alone to their apartments without actively involving them in normal life activities adopted according to their abilities. Also, the focus should be set on providing and assessing outcomes of care services instead of performing jobs in conventional way. Activity trainers and facilitators in daily activities are needed to train, maintain and support the use of new tools and services that might assist in the daily life.

EXAMPLES OF MODULAR AGEING-FRIENDLY SOLUTIONS LIGHTING

Modern technology enables inexpensive modifiable and tailor-made lighting solutions as part of décor and furniture design. The key is, many potential problems due to sensory or functional changes of ageing can be solved with right kind of lighting, adjusting contrasts and removing adverse reflections. Also, the tone of the light can be adjusted to compensate some changes caused by ageing (like removal of yellow component). Why not to develop a solution to help a person to see objects on table, to detect stairs, threshold etc. by adding lighting the same way as e.g. backlight or other solutions are used in machine vision systems to make camera "see" the object. (National Instruments 2017; Bhardwaj et al. 2011.)

The lighting is an important element in adding quality of life by changing the appearance of the room according to resident's wishes and mood, to create safer and more comfortable home-like environment or to arrange some activities, like a virtual trip with a strong a sensory stimulus by mixing sound and lighting.

Lighting can also help in memory problems since light catches the attention very easily. Time-dependent lighting systems may help to keep up with the daily routines indicating meal and bed

times (like timed fridge door light to indicate meal time, or light indicated bathroom doors to prevent opening wrong door in the middle of the night).

GAMIFICATION

Games provide a way to motivate and activate people, which could be used more effectively even in decor and furniture designs. Games do not have to be video games. Many a hobby, like collecting stamps, have several game-like elements in it: task completion, reward earning, competing against other collectors etc. The baseline approach is to try to gamify everyday life by for example adding some collectables in normal activities. Virtual coins could be earned by a meal prepared in time, photographed and shared with someone. Rewarding outcomes could be that by certain amount of earned virtual coins one could get some extra services, allow participation in certain social activities, or simply by keeping diary to get evidence on how many times you succeeded to do something this week based on the set activity goal.

People are easily motivated to do monitored activities. Technology assist by automated data collection to count steps, activity-sleep balance and many other daily functions. The data should be visually presented to the person, and used in meaningful way in motivational purposes. In BaltSe@nioR project we are developing a customized smart mirror which can identify the user and show custom-made content such as activity graphs while combing hair in front of the mirror (Meine 2003).

Any furniture or the entire apartment could be made full of triggers to be socially, physically or cognitively more activating. There could be interactive surfaces or walls, or just an appealing corner with customizable health games. Health games could also be implemented into furniture with help of mobile technology and sensors. The armchair could have sensors communicating with a tablet game that can be played by changed postures, movements or standing up from the chair. The game can be played alone or ask others to join the game. The armchair could be programmed to remind you of activity need after sitting too long at the time.

Games are good at adding social interaction and provide new topics to talk about. In group home living rooms and other common areas, the games and gamified furniture could be used to add social interaction in group home living rooms and other common areas. Games can be adjusted to individual needs. Huge variety of rehabilitative activities and functions from memory training to physical activation can be implemented into the games. Especially as health games are concerned, alternative ways to deliver them requires service design. Games should be embedded into a service or product concept rather expecting older persons to download them from mobile stores.

To conclude, gamification and games possess huge potential which is not utilized fully. Clever decorative and furniture designs could however be developed to meet many individual needs of aging population.

LIFE STORY IN DECOR AND FUNCTIONAL FURNITURE

The memories play important role in everybody's life. This should not be forgotten in designing decor and furniture especially targeted for aged people. Putting photos on the walls is another thing, but many other elements can remind of the life story of the person (important people, places, professional career, significant life events etc.). There are many ways of implementing these into the décor including curtains or dishes with printed pictures of your summer cottage near the lake, or pillows with your favourite flowers. The decorative elements could also be modifiable according to season or national holidays which help in keeping track on the year rhythm. With the help of technology, these memories could easily be awakened to life. The photos on your electronic photo frame could be remotely changed according to visiting schedules. Therapeutic videoclips and audio could boost the memory experiences. In general,

these hints in decoration could also help care personnel to understand the person deeper and to see a person with character and history instead of just a client.

Selecting material is of crucial importance in terms of memorising the past by smell, touch, sound and visual appearance. Furniture solutions should be modular and easily adjustable according to the customer's needs, history and taste. Neutral, impersonal spaces and long white corridors could be turned to more home-like environment by using large stickers. Residential care homes marking each resident's door with a replica (a sticker) from their former house door would help the residents feel better at home and memory impaired residents to find their rooms. (Grasyte 2016.)

The design of utilities has a huge effect on a person's life. Persons with special needs are often provided with impersonal hospital furniture unnecessarily enforcing the reference to special needs without even considering any other options. Furniture with customized assistive functions could look like any regular furniture only added with required functional modification. Hospital type functional bed could be modified with an embedded convertible bed for a temporary overnight visitor (spouse/parent/other relative) to sleep next to the patient. Small additional element but would make a huge difference in care.

Evolving technologies – not to forget robotics - provide more and more opportunities in the furniture design and industry. Smart designing is much about multidisciplinary development, combining the expertise to deliver need-based innovations.

Based on the findings presented in this study, the individualised and modifiable design frame requires the focus been set on four main categories: standardisation, putting design thinking into practice, modular adaptability of furniture, technology and service development, and improved implementation of personal autonomy and value in support systems. As to standards and regulations, the focus needs to be reset from protecting industrial rights in productisation to protect users' rights to obtain products and services that are affordable and modifiable to meet ever-changing real-life needs. Design thinking is a mindset that should be put into practice in all services and support systems. Basic competence for each professional today is to constantly assess and evaluate one's working patterns and evidence of outcomes in order to serve customers in a purposeful manner. Technology industry is challenged to move from commerce-centred production line thinking towards user-friendly and enabling modular technologies that support user's autonomy and meet the user's needs. Technology commerce should pay attention to provision of user support services alongside with the devices as a product package. In general, older people or people with special needs should not be seen as marginal groups but rather as an emerging resource with individual human value, life history and capital in the society (fig.1).

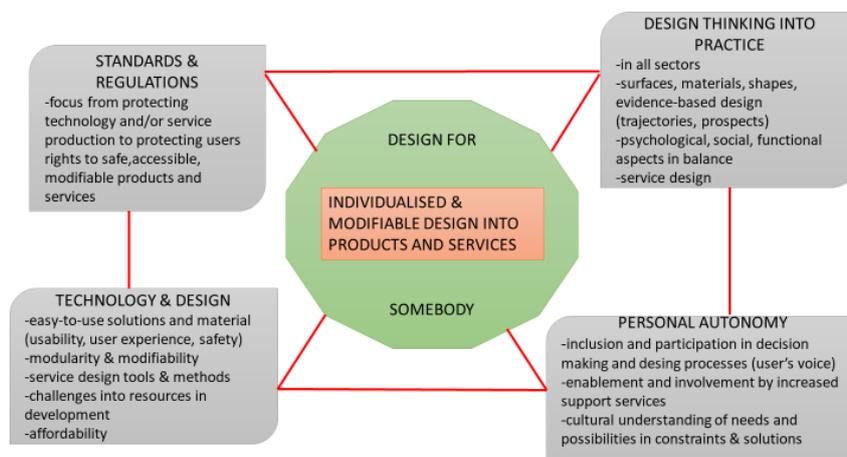


Figure 1. Proposal for a generic frame in age-friendly design

The goal in ageing/aged-friendly concept and environment design is to support and maintain health and wellbeing. Functionality aspects in environmental design include, among other things, architectural design, building layouts and zoning, wayfinding and access to nature and healing gardens. Facilities should be designed in such a manner that they are accessible and well usable by seniors or individuals with limitations. Customers provided with the right to participate in planning processes from the very beginning have better possibilities to achieve independence and reach solutions that pleases them and supports therapeutic wellbeing. The basic ageing-friendly planning principles should be applied, specified, and designed according to the needs of the persons living in the elderly homes, own houses or apartments. The ageing is a continuous process, and housing lay-out should be easily modifiable to fulfil the new requirements ageing brings up. (Sievänen et al. 2007; ARA 2015; ADA 2010; WBDG 2017). Planning room space should start from analysing the seniors' daily routines, what activities they have during day and what kind of walking routes they prefer. Needs for accessibility, reaching, colours, contrasts, lightning, materials and furniture should be assessed separately in each space and room. Colour and contrast will help to identify different rooms and features or objects in the structures and improve safety by contrasting possible hazardous zones. Colours that contrasts with the background application can be used in walls, floors, steps, doors, railings, edges, sockets, cabinetry, and furniture. The homely atmosphere, distinctness and easy orientation help seniors to find their way through the whole apartment or nursing home and its' surroundings. (Sievänen et al. 2007; ARA 2015; ADA 2010; WBDG 2017). Nature connections are important aspects in designing aged-friendly environments. Each apartment should have nature connection either through windows or through balcony, terrace or green spaces. Ways to outdoor areas must have clear, safe routes and paths. Furnishing used should be durable, stable, easily maintained, adjustable and movable. Meaningful outdoor places with possibility to gardening activities enable deeper spiritual communication with the nature and give pleasant feelings. Several research reports indicate the positive benefits, like better life and health status, increased physical functioning and reduction of pain achieved in green environments. When designing the pathways to the outdoor spaces and furniture locations, need for wheelchairs or other devices, extra assistance and/or need to sit down to rest over walking must be taken into consideration. Glazing of the balcony or terrace increases the comfort of living by reducing noise and keeping rain, snow, wind, dust and animals away from the balcony. Rooms reserved for sleeping should be peaceful places and locate separate from other living areas. Great window view from the adjustable bed helps the healing process, especially if the elderly has to spend many hours each day in bed. (ARA 2015; Sievänen et al. 2007; Lumon 2017; KWALU 2017).

References

- ADA. 2010. Information and Technical Assistance on the American's with Disabilities Act. Available https://www.ada.gov/2010ADASTandards_index.htm. Accessed 30.8.2017
- ARA. 2015. Suunnitteluopas: Keskeisiä tavoitteita valtion tukemien asuntojen suunnittelulle. Available http://www.ara.fi/download/Suunnitteluopas_2013/2d274119-2a14-44b7-a758-38acb26cab95/22532. Accessed 28.8.2017
- Bhardwaj, S., Syed, A.A., Ozcelebi, T. & Lukkien, J. (2011). "Power-managed smart lighting using a semantic interoperability architecture", *Consumer Electronics IEEE Transactions on*, vol. 57, pp. 420-427, 2011, ISSN 0098-3063.
- Blanck, P. (2014). The struggle for web eQuality by persons with cognitive disabilities. *Behavioral Sciences and the Law*. DOI: 10.1002/bsl.2101.
- Crundall-Goode, A., Goode, K. M., & Clark, A. L. (2017). What impact do anxiety, depression, perceived control and technology capability have on whether patients with chronic heart failure take-up or continue to use home tele-monitoring services? Study design of

- ADaPT-HF. *European Journal Of Cardiovascular Nursing*, 16(4), 283-289. doi:10.1177/1474515116657465
- Enninga, T., Manschot, M., van Gessel, C., Gijbels, J., van der Lugt, R., Sleeswijk Visser, F., Verhoeven, F., Godfroij, B. (2013). Service design insights from nine case studies. HU University of Applied Sciences Utrecht.
- Finn, E. and Loane, J. (2016). Approaches to Smart Technology Deployment in Care. In Merilampi, S. & Sirkka, A. (eds.) *Introduction to Smart eHealth and eCare Technologies*. CRC Press, Boca Raton. pp. 31-61.
- Grasyte, R. (2016). Company Recreates Doors Of Dementia Patients' Houses To Help Them Find Rooms And Feel At Home. Online document, available at: <http://www.boredpanda.com/nursing-homes-dementia-patients-personalised-true-doors-stickers/> . Accessed 09 Sept 2017.
- Ibrahima, N. I. & Davies, S. 2012. Aging: physical difficulties and safety in cooking tasks. *Work* 41 (2012), 5152-5159.
- Joines, S. (2009). Enhancing quality of life through Universal Design. *Neurorehabilitation*, 25(3), 155-167. doi:10.3233/NRE-2009-0513
- Kelly, J. (2017). Indigenous Health Focus. Using Mapping Tools to Improve Aboriginal Patient Journeys. *Australian Nursing & Midwifery Journal*, 24(9), 43.
- Koivisto, A. (2016). Simple Rehabilitation Games for Special User Groups. In Merilampi, S. & Sirkka, A. (eds.) *Introduction to Smart eHealth and eCare Technologies*. CRC Press, Boca Raton. pp. 239-254.
- Koivisto, A., Merilampi, S., Sirkka, A. (2015). Mobile Games Individualise and Motivate Rehabilitation in Different User Groups, *International Journal of Game-Based Learning* 04/2015; 5(2):1-17.
- Kwalu. 2017. Senior Living Gallery. Available <https://www.kwalu.com/senior-living-gallery/>, accessed 30.8.2017
- Lemon, K.N. and Verhoef, P.C. (2016) Understanding Customer Experience Throughout the Customer Journey. *Journal of Marketing: November 2016, Vol. 80, No. 6*, pp. 69-96.
- Lumon. 2017. Balcony glass systems and glass terraces. Available <https://lumon.com/int>, accessed 29.8.2017. Accessed
- Lörincz, B., Tinholt, D., van der Linden, N., Colclough, G., Cave, J., Schindler, R., Cattaneo, G., Lifonti, R., Jacquet, L., Millard, J. (2010). Digitizing Public Services in Europe: Putting ambition into action. Available at: http://ec.europa.eu/information_society/eeurope/i2010/docs/benchmarking/eGovernment_Benchmarking_Method_paper_2010.pdf . Accessed 01 Sept 2017.
- Meine, R.K. (2003). System and method for displaying information on a mirror. Patent application US 6560027 B2. Available at: <https://www.google.com/patents/US6560027> . Accessed 09 Sept 2017.
- Muhammad, A., Kumar Saini, D., Zia, K., & Ali. Fekihal, M. (2017). Educational Aspects of Service Orientation: Smart Home Design issues and Technologies. *TEM Journal*, 6(2), 250-257. doi:10.18421/TEM62-09.
- National Instruments (2017). A Practical Guide to Machine Vision Lighting. [Online document]. Available at: <http://www.ni.com/white-paper/6901/en/>. Accessed 09 Sept 2017.
- Patomella, A-H., Kottorp, A., Malinowsky, C., Nygård, L. (2011). Factors that impact the level of difficulty of everyday technology in a sample of older adults with and without cognitive impairment. *Technology and Disability* 23 (2011), pp. 243–250. DOI 10.3233/TAD-2011-0331

- Preston, J. & Rajé, F. (2007). Accessibility, mobility and transport-related social exclusion. *Journal of Transport Geography* 15 (2007) 151–160.
- Sievänen, L., Sievänen, M., Välikangas, K. and Eloniemi-Sulkava, U. 2007. Opas ikääntyneen muistioireisen kodin muutostöihin. Available http://www.muistiasiantuntijat.fi/media-files/Opas_ikaantyneen_muistioireisen_kodin_muutostoihin.pdf. Accessed 28 Aug 2017.
- Sirkka, A., Merilampi, S., Koivisto, A., Tommiska, J., Saarinen, T-P (2017). “Design for Somebody” -approach enabling mobile technology development. Full paper in the 14th AAATE conference, Sheffield UK, 13-14 September 2017.
- Warda, G., Holliday, N., Awang, D., & Harson, D. (2015). Creative approaches to service design: Using co-creation to develop a consumer focused assistive technology service. *Technology & Disability*, 27(1/2), 5-15. doi:10.3233/TAD-150424
- WBDG. 2017. Therapeutic Environments. Available <https://www.wbdg.org/resources/therapeutic-environments>. Accessed 29 Aug 2017
- Weldon, S., Ralhan, S., Paice, E., Kneebone, R., & Bello, F. (2015). Sequential Simulation (SqS): an innovative approach to educating GP receptionists about integrated care via a patient journey - a mixed methods approach. *BMC Family Practice*, 16(1), 1-7. doi:10.1186/s12875-015-0327-5
- Whittemore R. & Knafl K. (2005). The integrative review: updated methodology. *Journal of Advanced Nursing* 52(5), 546–553.

Corresponding author:

Sandelin S.

Satakunta University of Applied Sciences, Pori, Finland

e-mail: sirpa.sandelin@samk.fi

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

DETERMINING REASONABLE DESIGN VALUES OF RECTANGULAR MORTISE AND TENON JOINTS BY USING PROBABILISTIC APPROACHES

Mesut UYSAL¹, Eva Haviarova¹, Carl A. Eckelman¹

¹ Purdue University, College of Agriculture, Department of Forestry and Natural Resources, West Lafayette, Indiana, USA

Key words

*Statistical lower tolerance limits,
Rectangular mortise and tenon joints,
Static loading test of joint.*

Abstract

In this study, it is proposed to determine reasonable design values of T-shaped rectangular mortise&tenon joints by using lower tolerance limits. Parametric and non-parametric tolerance analysis methods are provided whether data are or are not normally distributed. Furthermore, minimum sample size requirements corresponding to confidence/proportion levels are determined by using Faulkenberry-Week methods. However, the best suitable confidence/proportion level was not defined in this study. The study shows that lower tolerance limit procedure provides a systematic method of determining the implications of the use of specified fractions of the average capacity of a given joint for design purposes.

Corresponding author: *ehaviar@purdue.edu* Haviarova E., Purdue University, College of Agriculture, Department of Forestry and Natural Resources, West Lafayette, Indiana, USA

1. INTRODUCTION

Engineering design practices of furniture includes: i) determination of loads imposed on structure, ii) estimation of the member size, iii) determination of the internal forces acting on member and joint, iv) re-designing structure until no member is over-stressed and v) joints design (Eckelman, 2003). In reliable furniture design, joint has crucial importance, because a failure may occur more often owing too loose or failed joints rather than legs and rails fracture (Eckelman *et al.*, 2003). Therefore, reliable joint results in reliable furniture structure (Smardzewski, 2009).

The rational design of furniture frames dictates that the moment-resisting capacities of the frame members and joints be known so that both can be designed to resist the internal forces imposed on them in service (Eckelman *et al.*, 2016). Although numerous studies have been conducted to determine the strength values of rectangular mortise&tenon (RMT) joints (Pang *et al.*, 2011; Likos *et al.*, 2012; Kasal *et al.*, 2015; Podlena and Boruvka, 2016), reasonable design values have not been well-defined for engineering design of furniture. In literature, some design values were suggested, such as one-third of the ultimate bending stress for front-rail of sofas (Eckelman, 1974) and 20% of the ultimate static load capacity for allowable design capacity of the cyclically loaded RMT (Ratnasingam *et al.*, 2010). Although statistical lower tolerance limits for rectangular mortise and tenon joints was calculated in previous study

(Eckelman *et al.*, 2016), assumptions to make reliable tolerance analysis and definitive answer of sample size in the experiment have not been addressed.

In engineering design, many uncertainties exist, related to loading, material properties, geometry, and material strength. Therefore, these uncertainties are assumed deterministic in determining ultimate strength of materials. However, such values obtained by using deterministic approaches do not satisfy the reliability of materials. Furthermore, deterministic approaches for furniture design are not reliable and cannot estimate warranty time and reliability of the furniture (Smardzewski, 2009). On the other hand, probabilistic approaches are developed to ensure their reliability (Sediva *et al.*, 2010; Papadrakakis *et al.*, 1996). Probabilistic approaches are useful methods to acquire uncertainties of different parameters and are more efficient compared to experimental methods (Fink and Kohler, 2015).

Intermediate procedure that could be used to develop rational values for design purposes is the use of Lower Tolerance Limits (LTL) method, which is one of the probabilistic approaches. LTLs rationally suggest what proportion of the previously sampled data would lie within specified limits with selected confidence level (Silva *et al.*, 2013). One-sided lower tolerance limits are used to determine reliability and safety of products (Ireson *et al.*, 1960).

The main purpose of the study is to determine reasonable design values of rectangular mortise&tenon joints by using lower tolerance limit method. Furthermore, it is proposed that acceptable confidence/proportion level and minimum sample size requirements for such studies are determined.

2. METHODS AND MATERIALS

MATERIALS and CONSTRUCTION

In this study, red oak (*Quercus rubra*) and white oak (*Quercus alba*) wood materials, which are widely used for furniture construction, were selected for experiment. Lumber for components was obtained from local sawmill. Defect-free 22.2 mm thickness by 63.5 mm wide by 305 mm long components were machined. All components for T-shaped RMT joints were randomly selected from resulting pool.

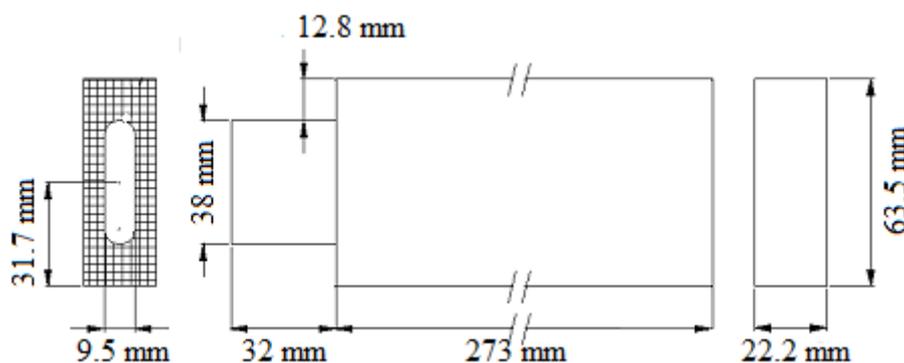


Figure 1: Configuration of rectangular mortise&tenon joint

Tenons were machined in dimension of 9.5 mm thickness by 38 mm wide by 32 mm long. Correspondingly, matching mortises were drilled on multi-chisel router (Figure 1). The rails with tenons and post with mortises were coated with 40% solid content polyvinyl acetate (PVA)

and clamped for 8 hours to cure. Specimens were stored for one week in the conditioning room at 7% moisture content and then tested.

METHODOLOGY

TEST METHOD

Vertical static test loading was applied on the T-shaped RMT joint by using MTS universal testing machine. The rate of loading was 12.7 mm/min on the moment arm of 254 mm from edge of the post. Loading was applied until non-recoverable failure occurs on the specimens (Figure 2) (Erdil *et al.*, 2005).

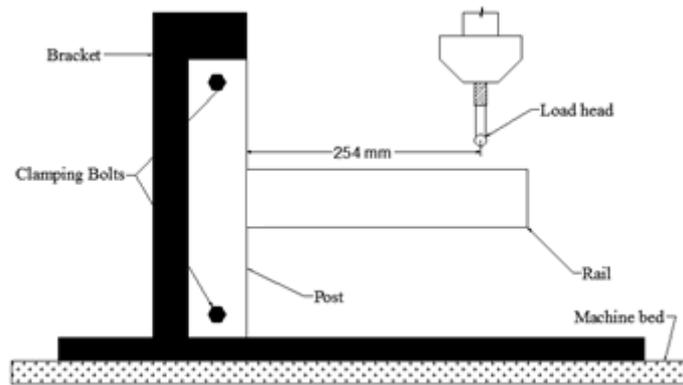


Figure 2: Test set-up

Ultimate bending moment capacities for each specimen were calculated by using following expression;

$$M = F_{max} \times l \quad (1)$$

where, M is the bending moment capacities (N.m), F_{max} is the failure load (N) and l is the moment arm (m).

SAMPLE SIZE

Sample size determination for univariate normal distribution based on specified tolerance intervals was developed by Faulkenberry and Weeks methods (1968). Furthermore, Young *et al.* (2016) proposed method how to determine sample size for normally distributed data set by modifying the Faulkenberry-Weeks methods. In this study, R-statistical software were used to determine minimum sample size requirements by using provided R-codes (Young *et al.*, 2016).

First, 25 T-shaped RMT specimens constructed of red oak and white oak were tested for preliminary study. Then, normality was checked by using Shapiro-Wilks test. Furthermore, minimum sample size requirements corresponding confidence/proportion levels are determined by using following R-codes (Young, 2014);

```
> norm.ss(x = data, alpha = 1-γ, P = β, side = 1, spec = μ-3σ,
+ method = "YGZO", hyper.par = list(mu.0 = X̄, sig2.0 = s)
```

LOWER TOLERANCE LIMITS

Since population parameters, population mean (μ) and population standard deviation (σ), are unknown, normality assumption must be done for sample statistics, because LTL method differs whether data are normally distributed or not. If data are normally distributed, following expression is used to calculate LTL (Ireson *et al.*, 1960).

$$LTL = \bar{X} - (k_{n,\gamma,q} \times s) \quad (2)$$

where, \bar{X} is the sample mean, $k_{n,\gamma,q}$ is the tolerance factor given sample size and confidence/proportion (C/P) levels, and s is the sample standard deviation. On the other hand, binominal probability is used to calculate LTL when normality assumption is violated. The binominal probability expression is (Cai and Wang, 2009; Ayyub and McCuen, 1997);

$$P(X_i < \xi) = \binom{n}{x} \times p^x \times q^{n-x} \quad (3)$$

where, X_i represents the values below LTL, ξ is the LTL value, n is the sample size, x is the number of the samples below LTL, p is significance level and q is one minus proportion level ($1-\beta$). To make simpler LTL calculation for non-normal data set, R-statistical software was used to obtain significance level by using following R-code (R stat package, version of 3.5.0);

```
> pbinom(q, n, 1-prop)
```

where, q is the vector of quantiles, n is the total observation and $prop$ is the proportion level. Significance levels (α) are given in sequence. Desired confidence level ($1-\alpha$) is selected and obtained from this sequence This sequence number will be used to obtain LTL value from the total dataset, which is sorted from lowest to highest values.

3. RESULTS AND DISCUSSION

MINIMUM SAMPLE SIZE REQUIREMENTS

Result of modified Faulkenberry-Weeks methods to determine minimum sample size requirements corresponding confidence/proportion level is shown in Figure 3. According to Shapiro-Wilk normality test, p-value is 0.2448 and 0.3602 for 25 T-shaped RMT joint specimens constructed of red oak and white oak wood, respectively. Data in both sample groups are normally distributed because p-values are greater than 0.05. Minimum sample sizes are 8, 20, 55, 99, 131, 220, 282, 417, 1000 and 1340 corresponding C/P levels which are 75/75, 90/75, 75/90, 90/90, 95/90, 90/95, 95/95, 99/95, 95/99 and 99/99, respectively. It is obvious that increase in the C/P levels makes sample sizes larger. Determination of proper sample sizes is facilitating reliable tolerance analysis, as well as reducing experiment time and production cost.

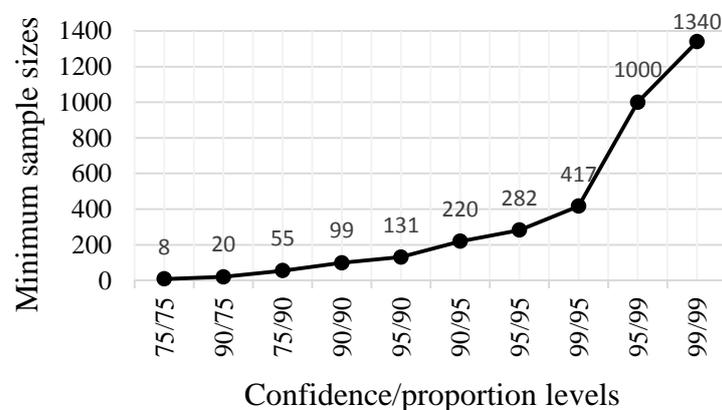


Figure 4: Minimum sample size requirements corresponding C/P levels

In this study, 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels are selected to calculate LTLs so 220 specimens were constructed for vertical static loading test.

BENDING MOMENT CAPACITIES OF THE JOINTS

Results of 220 specimens constructed of red oak are given Figure 5. Average bending moment capacity 350.57 N.m with standard deviation of 50.03 N.m. The highest and lowest bending moment capacities are 464.37 N.m and 137.84 N.m, respectively.

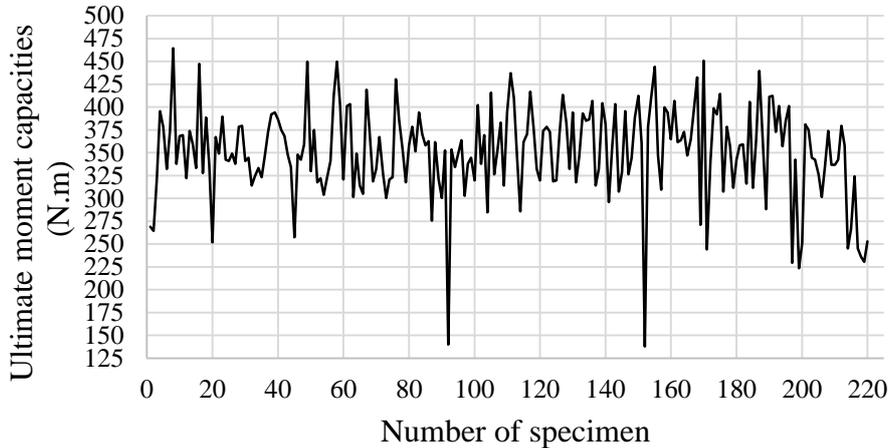


Figure 5: Ultimate bending moment capacities of T-shaped RMT joints constructed of red oak

Results of 220 specimens constructed of white oak are given Figure 6. Average bending moment capacity 341.17 N.m with standard deviation of 60.25 N.m. The highest and lowest bending moment capacities are 475.66 N.m and 151.39 N.m, respectively.

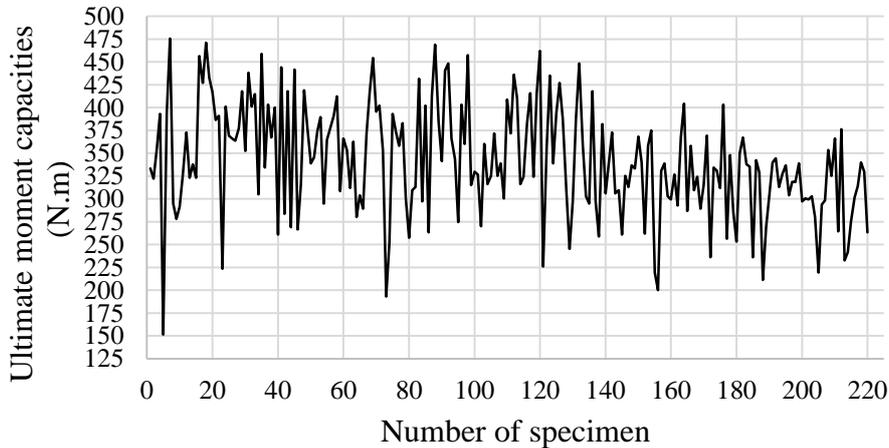


Figure 6: Ultimate bending moment capacities of T-shaped RMT joints constructed of white oak

NORMALITY TEST

Results of Shapiro-Wilk normality test show that data T-shaped RMT joint specimens constructed of red oak ($p\text{-value} = 3.016 \times 10^{-6} < 0.05$) is not normally distributed, whereas those joints constructed of white oak ($p\text{-value} = 0.5172 > 0.05$) are normally distributed (Table 1). In the case of non-normality, non-parametric tolerance analysis must be conducted by using

binominal probability. On the other hand, tolerance analysis for univariate normal distribution must be conducted by using sample statistics and k-tolerance factor.

Table 1. Shapiro-Wilk normality test

Joint	W	p-value	
RMT – Red Oak	0.95632	3.016×10^{-6}	< 0.05
RMT – White Oak	0.99395	0.5172	> 0.05

LOWER TOLERANCE LIMITS

Results of LTLs are given in Table 2.

Table 2. LTLs, ratio of LTLs and mean, ratio of LTLs and highest moment, number of specimen below LTLs and percent of specimens below LTLs

Specimen	C/P Levels	LTLs (N.m)	Ratios of LTLs and mean	Ratios of LTLs and highest moment	No of specimen below LTLs	Percent of specimens below LTLs
Red Oak n = 220 Mean = 350.37 N.m Stdev = 50.03 N.m	75/75	328.79	93.84%	70.80%	64	29.10%
	90/75	320.88	91.58%	69.10%	51	23.18%
	75/90	284.72	81.26%	61.31%	18	8.18%
	90/90	268.90	76.75%	57.91%	15	6.81%
	95/90	266.64	76.10%	57.42%	14	6.36%
	90/95	244.05	69.65%	52.56%	6	3.18%
White Oak n = 220 Mean = 341.17 N.m Stdev = 60.25 N.m	75/75	297.41	87.17%	62.53%	48	21.81%
	90/75	294.55	86.34%	61.92%	41	18.63%
	75/90	260.08	76.23%	54.68%	18	8.18%
	90/90	256.53	75.19%	53.93%	16	7.27%
	95/90	254.34	74.55%	53.47%	15	6.81%
	90/95	233.57	68.46%	49.10%	9	4.09%

According to results, LTLs of T-shaped RMT joints constructed of red oak are 328.79 N.m, 320.88 N.m, 284.72 N.m, 268.90 N.m, 266.64 N.m and 244.05 N.m at the 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels, respectively. It must be expected that number of specimens must not exceed $100(1-\beta)\%$ of total specimens; for example, this percentage must be 5 % at the 90/95 C/P level. Such percentages are 29.10%, 23.18%, 8.18%, 6.81%, 6.36% and 3.18% for red oak specimens at the 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels, respectively. All C/P levels are meeting the expectation but except 75/75 C/P level. This was due to the fact that 29.10% (>25%) of total specimens are below $LTL_{75/75}$. Furthermore, ratios of LTLs and highest moment capacity are 70.80%, 69.10%, 61.31%, 57.91%, 57.42% and 52.56% at the 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels, respectively. Moreover, ratios of LTLs and average moment capacity are 93.84%, 91.58%, 81.26%, 76.75%, 76.10%, and 69.65% at the 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels, respectively.

LTLs of T-shaped RMT joints constructed of white oak are 297.41 N.m, 294.55 N.m, 260.08 N.m, 256.53 N.m, 254.34 N.m and 233.57 N.m at the 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels, respectively. Percentage of number of specimen below LTLs are 21.81%, 18.63%, 8.18%, 7.27%, 6.81% and 4.09% of total specimens for white oak specimens at the 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels, respectively. All C/P levels are meeting the expectation. Furthermore, ratios of LTLs and highest moment capacity are 62.53%, 61.92%, 54.98%, 53.93%, 53.47% and 49.10% at the 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels, respectively. Moreover, ratios of LTLs and mean are 87.17%, 86.34%, 76.23%, 75.19%, 74.55%, and 68.49% at the 75/75, 90/75, 75/90, 90/90, 95/90 and 90/95 C/P levels, respectively

DISCUSSION

In this study, it is proposed to determine design values of RMT by using LTL method which is one of the probabilistic approaches. The results show that LTLs of T-shaped RMT joints would result in determination of those design values. Besides, normality assumption and sample sizes must come into prominence to make reliable tolerance analysis. Therefore, non-parametric tolerance analysis was made for RMT joints constructed of red oak due to non-normality. In this study, determination of appropriate C/P levels is one of the objectives. However, the study could not define a best suitable C/P level. It must be selected depending on reliability of chair frame which one would like to design. Design value at the higher C/P levels, which is lower LTLs, should be selected for load carrying capacity of joint to make more reliable structure.

In order to make reliable tolerance analysis, determination of sample size has crucial importance. In this study, modified Faulkenberry-Weeks method is used to determine sample sizes. The preliminary study show that minimum sample size requirements changes depending on C/P levels (Figure 4). Increase in sample size may result in more reliable analysis. 220 specimens for RMT joints specimen constructed of both red oak and white oak. That's why, tolerance analysis was conducted until 90/95 C/P level. However, sample sizes could be increased to make tolerance analysis at the higher C/P levels.

Homogeneous conditions must be taken into consideration to make reliable tolerance analysis during experiment, as well as samples preparation (Little and Ekvall, 1981). Such design values were obtained in the laboratory conditions and specimen were obtained from local sawmill. Due to morphological properties of wood and growing region of the tree, properties of wood material used may show differences within the same wood species. Therefore, this study is only proposing a methodology to determine design values of joints.

4. CONCLUSIONS

In this study, T-shaped RMT joints were used to determine their reasonable design values by using LTL method. The result shows that LTL method provide a methodology to determine the implications of the use of specified fraction of the average bending moment capacity of given joint for design purposes.

The study could not define appropriate C/P levels but designer must select it based on reliability level for the specific structure; namely, joint must be designed to resist the internal forces imposed on the joints due to reaction forces on structure. On the other hand, minimum sample size requirements corresponding C/P levels could be determined by using modified Faulkenberry-Weeks method so that reliable tolerance analysis could be made.

The given LTLs could be used to determine size of RMT joint in the structure by using expressions in Eckelman (2003).

This study provides a systematic methodology to determine reasonable design values of T-shaped design values by using probabilistic approach rather than deterministic approaches, which does not ensure reliability.

Further study is underway, conducting performance testing of chair frames made of RMT joints designed by using LTLs. Furthermore, LTL study for other joint types (screws and dowels), which are used for frame type of furniture construction, will be conducted.

References

- Ayyub, B.M. and McCuen, H. (1997): Probability, Statistic and Reliability for Enginners and Scientists, 2nd edition. Chapman & Hall/CRC Press LLC, Boca Raton, Florida/USA.
- Cai, T.T. and Wang, H. (2009): tolerance Intervals for Discrete Distributions in Exponential Families. *Statistica Sinica* 19: 905-923
- Eckelman, C.A. (1974): Reasonable Design Stresses for Woods Used in Furniture. *Purdue University Agricultural Experiment Station Research Bulletin* 916: 1–7.
- Eckelman, C.A. (2003): *Textbook of Product Engineering and Strength Design of Furniture*. West Lafayette.
- Eckelman, C.A., Erdil, Y.Z. and Haviarova, E. (2003): School Chairs for Developing Countries: Designing for Strength and Durability, Simplicity and Ease of Construction. *Forest Products Journal* 53 (2): 1–8.
- Eckelman, C.A., Uysal, M. and Haviarova, E. (2016): Statistical Lower Tolerance Limits for Rectangular Mortise and Tenon Joints. *Bioresources*. 11 (3): 7162-7171
doi:10.15376/biores.11.3.7162-7171.
- Erdil, Y. Z., Kasal, A., and Eckelman, C.A. (2005): Bending moment capacity of rectangular mortise and tenon furniture joints. *Forest Products Journal* 55(12): 209- 213.
- Faulkenberry, G.D., and Daly, J.D. (1968): Sample Size Determination for Tolerance Limits. *Technometrics* 10 (2): 343–48.
- Fink, G., and Kohler, J. (2015): Probabilistic Modelling of the Tensile Related Material Properties of Timber Boards and Finger Joint Connections. *European Journal of Wood and Wood Products* 73 (3): 335–346. doi:10.1007/s00107-015-0895-z.
- Ireson, W.G., Smith, B.E. and Resnikoff, G.J. (1960): *Statistical Tolerance Limits*.
https://statistics.stanford.edu/sites/default/files/LIE_ONR2_1.pdf.
- Kasal, A., Eckelman, C. A., Haviarova, H., Erdil, Y. Z., and Yalcin, I. (2015): Bending moment capacities of L-shaped mortise and tenon joints under compression and tension loadings. *BioResources* 10(4): 7009-7020. DOI: 10.15376/biores.10.4.7009- 7020
- Likos, E., Haviarova, E., Eckelman, C.A., Erdil, Y.Z. and Ozcifci, A. (2012): Effect of Tenon Geometry, Grain Orientation, and Shoulder on Bending Moment Capacity and Moment Rotation Characteristics of Mortise and Tenon Joints. *Wood and Fiber Science* 44 (4): 462 -469.
- Little, R.E., and Ekvall J.C. (1981): Review of Statistical Analyses of Fatigue Life Data Using One-Sided Lower Statistical Tolerance Limits. *American Society for Testing and Materials*, 3–23.
- Pang, S., Oh, J., Park, J., Park, C., and Lee, J. (2011): Moment-carrying capacity of dovetailed mortise and tenon joints with or without beam shoulder. *Journal of Structural Engineering* 137(7): 785-789. DOI: 10.1061/(ASCE)ST.1943- 541X.0000323.
- Papadrakakis, M., Papadopoulos, V. and Lagaros, N.D. (1996): *Structural Reliability Analysis*

- of Elastic-Plastic Structures Using Neural Networks and Monte Carlo Simulation. *Computer Methods in Applied Mechanics and Engineering* 136 (1–2): 145–63. doi:10.1016/0045-7825(96)01011-0.
- Podlena, M. and Boruvka, V. (2016): Stiffness coefficients of mortise and tenon joints used on wood window profiles. *BioResources* 11(2): 4677-4687. DOI: 10.15376/biores311.2.4677-4687.
- Ratnasingam, J., Florin, I. and McNulty, T. (2010): Fatigue Strength of Mortise and Tenon Furniture Joints Made from Oil Plum Lumber and Some Malaysian Timbers. *Journal of Applied Sciences* 10 (22): 2869–74.
- Sediva, B., Vavra, F., Toupal, T. and Marek, P. (2010): Statistical Monitoring of Failures - Methods and Use. In *Proceedings of the 11th International Scientific Conference Electric Power Engineering 2010, EPE 2010*, 1–9.
- Smardzewski, J. (2009): The Reliability of Joints and Cabinet Furniture. *Wood Research* 54 (1): 1–10.
- Young, D.S. (2014): Normal Tolerance Interval Procedures in the Tolerance Package XX (1999): 1–12.
- Young, D.S., Gordon, M.C., Zhu, S. and Olin, B.D. (2016): Sample Size Determination Strategies for Normal Tolerance Intervals Using Historical Data. *Quality Engineering* 28 (3): 337–51. doi:10.1080/08982112.2015.1124279.
- URL – <https://stat.ethz.ch/R-manual/R-devel/library/stats/html/Binomial.html>: The R stat package, available on September 1st, 2017.

Corresponding author:

Eva Haviarova

Purdue University, College of Agriculture, Department of Forestry and Natural Resources,
West Lafayette, Indiana / USA

ehaviar@purdue.edu

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

FEATURES OF FURNITURE DESIGN AND MANUFACTURING THAT CONSTITUTE RISK FACTORS FOR CAUSING ACCIDENTS TO USERS

Vasiliki KAMPERIDOU¹, Ioannis BARBOUTIS²

^{1,2} Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment, Laboratory of Wood Products and Furniture Technology, Thessaloniki, Greece

Key words	Abstract
<i>Accidents, Design, Falls, Furniture, Injuries, Prevention</i>	A lot of accidents have been observed so far, referring to different age groups of people, during the use of furniture inside, as well as out of the house. Sharp edges and corners, improper choice of joints and fasteners, doors or drawers that change in a hazardous way the gravity center of the structure, wrong dimensions ratio of wooden elements or wrong arrangement of furniture in the interior, lack of additional support fittings or instructions to the consumer are only some of the most frequent causes of accidents. In the present study, a recording of the risks that may arise during the use of furniture is carried out, which may be attributed to mistakes or lack of attention during the design of the wooden structures and furniture, the construction or even to mistakes during the process of the final assembly and placement by the consumer.

Corresponding author: *vkamperi@for.auth.gr Kamperidou V., Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment, Laboratory of Wood Products and Furniture Technology, Thessaloniki, Greece*

1. INTRODUCTION

Although technology continues to evolve and the furniture industries provide nowadays a huge variety of products in the market, of different qualities, shapes, materials, textures, colors and prices, the use of furniture still continues to be associated with the cause of numerous accidents inside, as well as outside of the house, concerning different age groups of people.

Each age group of people tend to acquire different needs, expectations, behavior, different abilities or disabilities, tastes and habits and all these vary also from person to person. Adapting the living space to the needs, physical characteristics and habits of each furniture consumer or family could reduce the risk of injury by 30 % - 50 % (Hrovatin 2012), though it is difficult to provide personalized solutions of living conditions for each one of people or each family. Nevertheless, some basic safety rules can be followed in the design and construction of furniture so as to avoid part of the accidents in the future.

The objective of this study is to increase knowledge and awareness about the risks that may arise during the use of furniture. This record attempt focuses on various risk factors that may be attributed to mistakes or inattention during the design, the manufacture of the wooden structures and furniture or in some cases, even to mistakes during the process of the final assembly or arrangement by the consumer. Generally, the incentive of this study was to

contribute to the improvement of the conditions and processes of furniture design and the safety of housing environment conditions, anticipating to influence the world of designers and manufacturers, with the view to generate new construction practices, hopefully contributing in the development of appropriate furniture solutions that suit the various needs of the users, preventing accidents and injuries and making them feel more safe and satisfied using their furniture.

2. METHODS AND MATERIALS

The specific investigation is a record that was conducted on the basis of data and information resulted from personal visits and observations in various areas where furniture is being bought or furniture use takes place, and conversations with several cases of consumers, especially those who have encountered problems in the use of furniture, as well as taking into account the numerous press reports that referred to accidents emerged during the furniture use. An attempt was implemented to categorize the risk factors that tend to result in accidents, falls and injuries.

3. RESULTS AND DISCUSSION

Some of the most frequent causes of accidents using furniture, especially in interior environment, are summarized hereupon.

One of the most common cause that may pose great risks for injuries and wounding to furniture users is the sharp edges and corners, especially to age groups of children and elderly people (Figure 1). For example, necessary seem to be the rounding of the worktops in kitchen furniture, since round tables or tables with rounded edges tend to minimize the injuries. In recent years, wood based products such as fiberboard and particleboard are being used more widely in many applications, mainly because of the ease and convenience they provide in construction, but also for financial reasons, posing a great risk for accidents to users, compared to solid wood. This is due to the fact that these wood based panels is more difficult to be formed making them acquire round corners or round edges and in most of the cases they consist heavier materials compared to solid wood. Additionally, the melamine coating sheet that is often used to cover the edges of particleboards is proved to be very sharp, especially in old and worn structures where it has been slightly departed, and is responsible for many accidents (Figure 2).

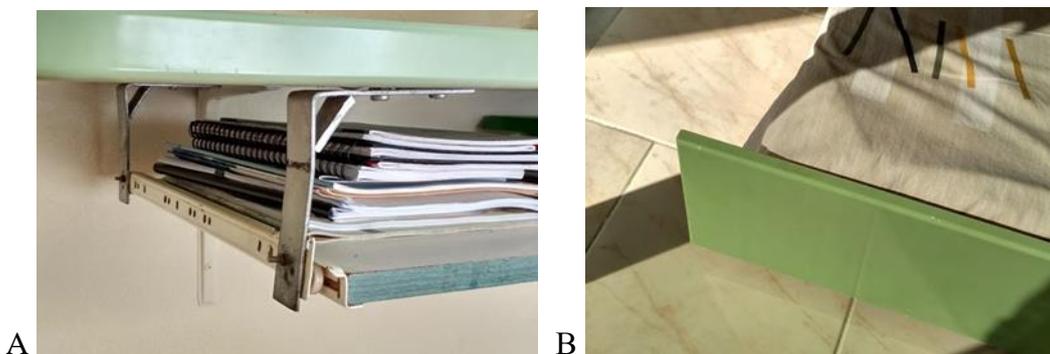


Figure 1. Defects in furniture manufacturing: A. Sharp edges of joints metal components in shelf supported under a desk, B. Protruding corner of furniture in expanding bed



Figure 2. Sharp protruding edges in hotel bed and the wound in leg caused by the accident

Dangerous for people could be also to use furniture doors with handles not easily enough identifiable, handles with sharp edges, unmarked or not appropriately incorporated glass (Figure 3). Furniture incorporating glass, should comply with BS7449:1991, which covers the use of glass in all furniture including cabinets, shelving systems and wall hangings, such as free standing mirrors or BS73 76: 1990, which refers to tables and trolleys. Also, furniture that are the same color as the wall or have jutting bases usually consist risk factors for users falls and injuries (Pinto et al., 1997). Referring to kitchen furniture, there should be provisions of continuous knee space beneath the countertop, the cooktop, and the sink, in order to prevent injuries (bruising, inflammation, swelling, lacerations, concussion and fractures) (Hrovatin 2012, Watson et al. 1997). Also, surface signage through the use of some clear icons seem to be crucial, since it helps people recognize the different surfaces, warns about edges, corners and potential dangers (Leung et al., 2012). The existence of sliding doors in cabinets or doors opening in the horizontal plane, opposed to the openable doors (with vertical axis of rotation) that have been commonly involved so far in accidents and the use of long horizontal handles, kitchen base cabinets on easy-to-roll castors and an appropriate way of placement of the furniture in house seem to be choices that contribute to home safety (Hrovatin 2012, Klos et al. 2014). Optimal, according to previous researches, is considered to be the cabinet width of 600 or 1000 mm, with sides at the angle of 85°. Also, the fronts of cabinets could be equipped with handle strips. Despite the fact that the use of push-opener mechanisms in cabinets is thought to provide easiness and convenience, its use is proved to be quite dangerous resulting in falling and injuries, since each user is not able to handle them properly.

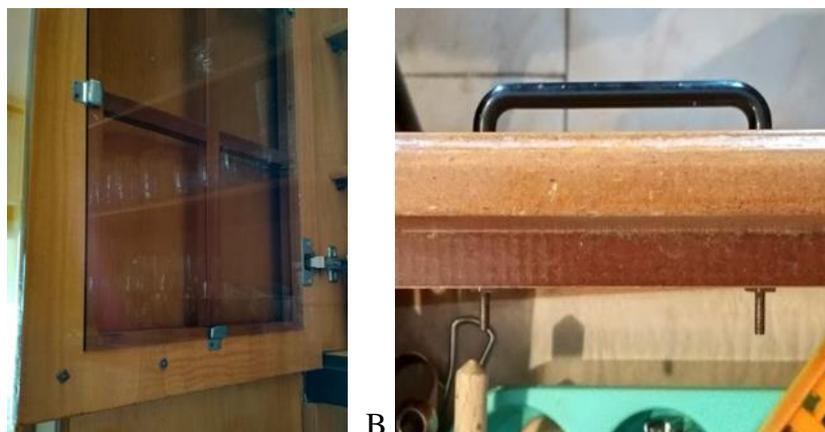


Figure 3. Defects in furniture construction: A. Glass not adequately supported, B. Sharp metallic edges of drawer handle

Another cause of accidents involving furniture use inside the house seem to be doors or drawers that change in a hazardous way the center of gravity of the structure. After the fatal accidents that emerged from the overturning of chest of drawers (Bucktin, 2016), the way of using this piece of furniture should be reconsidered. The consumers should place the heavier things contained in lower drawers and the lighter in higher levels, while television or other heavy objects should not be placed on drawers or other furniture not intended for this use. The researchers, at the Center for Injury Research and Policy at Nationwide Children’s Hospital in Columbus, Ohio, looked at injuries involving 12 types of furniture, including desks, dressers and cabinets and revealed that most of the injuries were found to children of 6 years and younger, and the most common involved televisions, placed on furniture not intended to hold them (Nagourney, 2009). Strapping TV to its stand, bracketing shelves and dressers to the wall and avoiding putting things that a child might want on top of furniture would contribute to the accident incidents decrease.

Chest of drawers of trapezoidal shape that has a larger base and a smaller top area seem to be more unlikely to be overturned and therefore, could be safer for the users, even though this would require more space. Of great significance is the drawers to have all an end-stopper and not to be easily detached from the main furniture and the chest of drawers to be quite low, much lower than the eye level and wide enough, in order to be difficult the center of gravity to be changed from the opening movement of a full drawer. Even if the above instructions are all followed, the chest of drawers also should be in any case sufficiently secured to the wall, using screws, screws with plugs etc., depending on the wall material. Generally, furniture should be totally stable, offer grip supports and be difficult to be turned over, in order to prevent falls and accidents during the use. Wheels could only be adapted to low furniture and in this case the furniture should not be overloaded, in order to prevent falls. Additionally, shelves, bookcases or other of bigger height pieces (>75 cm) of furniture should be always secured to the wall or fastened with safety straps to prevent tip over. Shelves should not be overburdened, for which is required to know the construction material used and the maximum load that each one is able to carry.



Figure 4. Chest of drawers that should be permanently secured to the wall (www.ikea.gr)

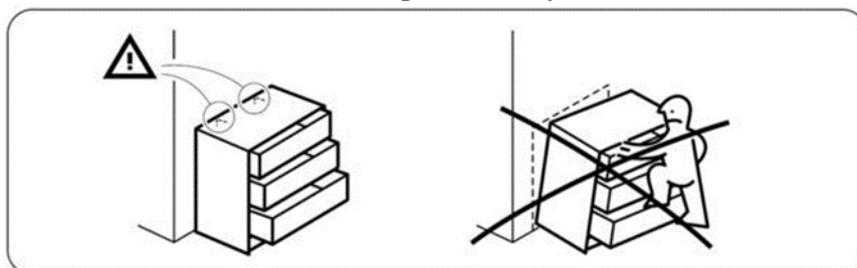


Figure 5. Drawing from the manual instructions concerning the necessity of security of the chest of drawers in the wall and the warning for accidents resulting from climbing on the drawers (www.ikea.gr)

Referring to children's furniture, the major items associated with injury, in the 0-4 year old kids are: prams, cots, high chairs, baby walkers, strollers, change tables and baby bouncers. Injury associated with nursery furniture is most likely to occur in the first year of life (Watson et al., 1997). Cots have the highest mortality with all identified deaths occurring as the result of asphyxia, while baby exercisers and bouncers are associated with the most severe non-fatal injuries with almost one-third resulting in hospital admission. This is due to the fact that falls from bouncers are usually from a height when care-givers place the bouncer on an elevated surface such as a bench-top. Falls are the most usual cause of non-fatal injury referring to children's furniture with injuries to the face and head being the most prevalent (Watson et al., 1997).

Information from the United States suggest that at least 38 children (mainly under 3 years) have died of asphyxia due to entrapment in the bunk bed structure, since 1990. The main cause of non-fatal injury is the falls from the top bunk while playing or sleeping, resulting in a fracture (33%), mainly to the upper extremity (75%) (Watson et al., 1997). Therefore, young children, under 3 or 4, perhaps should not be allowed to use bunk beds and structures of such raised level of surfaces. In one of the previous research works, Bunk bed falls accounted for only 10% of falls from beds (Kendrick et al., 2015). Furthermore, changing diapers of small children on high furniture and allow children seat and play on raised furniture surfaces lead to higher odds for falls and accidents (Kendrick et al., 2015).

Safety rails are undoubtedly necessary to prevent a part of the falls incidents. Additionally, use of baby walkers, playpens/travel cots and stationary activity centers should be strictly permitted only to children of ages 0-36 months. Children should not be allowed to play, jump, bump into or climb on furniture and teaching children safety rules about climbing on objects seem to be necessary (Nagourney, 2009).

For at least four of the children's furniture products (cots, prams, strollers and high chairs) about 6 percent of cases could be clearly identified as product failure (collapse, malfunction or entrapment hazard). High chairs had the greatest percentage of identified product failure (8%) due mainly to the tray falling off allowing the baby to fall out. 7% of cot injuries were attributed to failure on the part of the product, mainly entrapment hazards (Watson et al., 1997).

Generally, children's furniture safety standards should be reviewed and, if necessary, modified at least once every five years, to ensure that new requirements or revision of existing requirements occurs as new substantive information becomes available. While young children are most at risk for death due to tip-overs, over 43000 people sustain injuries every year due to falling furniture that is not manufactured to stability standards.

Additionally, it is very crucial for the furniture consumer to obtain from the time of purchase, all the necessary, as well as some additional support fittings of the structure, especially when the structure is assembled by the consumer, as well as the manual, extra instructions and support on the assembly procedure by experts. Thereby, numerous accidents could have been avoided. Although, wood is a preferred and widely used material in furniture, since it is a strong, durable material, associated with quality, good properties and high aesthetics, implementing an improper choice of connection types and fasteners, undoubtedly results in the creation of non-durable furniture that pose risks. Usually, these cases of furniture after a short period of use present malfunction and look like to be loose or disassembled or, even worse, sometimes without any warning, the structure can be led to total collapse or rupture. Therefore, the experience of the manufacturer of the furniture is necessary and the updated knowledge and results from several research works related to furniture connections strength and behavior should be taken into consideration.

Generally, furniture should be stable, durable, with high elasticity, having the proper type of strong and tight joints and in practice, be assembled using fittings, components or adhesives of high quality. As previous researchers mention, among others, the furniture users usually face

problems with disassembled joints in chairs and sofas and low quality of hinges in cabinets (Jonsson, 2013). Additionally, many accidents were recorded, especially in the age group of children, with cabinet doors, where no door breaks were adapted on them (hand entrapment hazard, hitting of the head etc.).

A frequent problem seem to be the non-appropriate dimensions of furniture, in other words the mismatch between the body dimensions and the furniture. Ergonomics optimizes performance and productivity, reducing the risks of injury, discomfort and disease (Pinto et al., 1997). When materials conform to specific anthropometrical and physiological-hygienic conditions, furniture can satisfy human needs in rest and sleep and help the body to recover. The chairs and beds are often too high or deep and tables are often high, presenting a negative effect on the sitting posture especially while reading or writing, having serious impact on the abilities of body in long term. Chairs and sofas should be chosen according to the size of the person. Specifically, taller people require deeper seats, while smaller persons need shallower seats.

The ease of ingress and egress of seating furniture depends on its dimensions, the position of the armrests, whether the user is able to put the feet in the space underneath the seat pan and the angle of the backrest. Head and neck rests promote the desirable experience of comfort. Soft seat pans should be thick enough for the user not to feel the hard surface underneath it and the compression of the material should be similar to that of human tissue, even make recommendations regarding optimal load distribution for different regions of the body. Sofas and other upholstered furniture should provide the user softer surfaces, contributing to a feel of relaxation and surrounding the body, while seats are required to be firm in order to help the person not to sink into the furniture. Chairs should generally allow changing sitting positions in an easy way, because constrained sitting is bad for health, contributes to chronic disorders, muscle pain, impaired circulation (Jonsson, 2013). The bottom of the legs of furniture should be non-slip, so that the furniture remain stable when people attempt to go off it. Seats should be in the range of 450mm to 475mm high and a recommended width of 500mm with firmly padded seats incorporating rounded front edges, in order to be considered safe to be used by several age profile groups. Inflexible sitting positions constitute risk factors causing neck, shoulder and back problems (Jonsson, 2013).

In sofas and seats it would be better to avoid the use of clothing with hard seams and sharp wrinkles and choose materials that feel pleasant. Upholstery should provide thermal comfort and transmission of moisture from the skin, also have good mechanical durability and should be no allergen material. Wool, raw silk, rubber and monomers containing polyamide should be avoided (Meinander and Varheenmaa, 2002). Generally, furniture should withstand wear and tear, cleaning and washing, demand a minimum of cleaning, such as surfaces that hide dust (Jonsson 2013). Waterproof seat cover materials could be used for the protection of the seat cushion from soiling and make the seat easily cleanable but these materials normally have poor breathability properties, which makes them uncomfortable to sit on and increases the risk of pressure sores (Meinander and Varheenmaa, 2002).

Additionally, the dining or coffee tables should be of appropriate height for the user, with rounded edges, in order to avoid injuries. Shelves, cabinets and appliances should be in appropriate height, taking into account the anthropometric characteristics, in order to avoid injuries, falls, brief or chronic pains in the body. Cabinets and wardrobes should be chosen after considering accurately the variable storage space needs and overloading should be avoided. Often, people store things in the space left over a wardrobe/closet, but this could be dangerous since the construction could be overloaded, fall easier or just collapse. Additionally, the space of storage should be easily accessible by the user. For instance, storage under the bed might not be a good idea because it involves bending, or manipulating the bed. Dressers with drawers that glide out easily could be a good choice.

Beds should correspond to dimensions of user, allow raising and lowering of each end separately, especially for elderly people, ensure proper alignment of the body during sleep (shape of the spine column and other body parts), ensure even load of the body upon the lying surface, ensure air-permeability, thermal conductivity, moisture permeability, correspond to different body weights and meet hygienic/health standards (Smardzewski et al., 2005). In beds, appropriate mattress could provide the needed support.

Possibly, less accidents would have taken place if attention was paid to the proper relation between the dimensions of the house and rooms, compared to furniture dimensions. This relation seem to be of such significance, since it affects the free space inside home, left to the user to move freely and maneuver the several pieces of furniture as well. The arrangement of the furniture pieces in the interior environment of home is a crucial factor for the safety of the user. Potential hazards often are generated also by the inadequate lighting of the place or room. In this case, a different arrangement of furniture is necessary. Cabinet lightning which could be fitted with a movement detector would be also very helpful. Furthermore, all furniture and furnishings included in accommodation, (beds, headboards of beds and mattresses, sofa-beds, futons and other convertibles, nursery furniture, garden furniture which is suitable for use in the dwelling, scatter cushions and seat pads, pillows and loose and stretch covers for furniture) whether new or second hand, must meet all the fire resistance requirements. All new furniture must carry a display label referring to that at the point of sale.

People usually prefers furniture easy to be cleaned, with flat surfaces, which will be easy to clean the floor beneath them and reach there with a vacuum cleaner easily. Furniture is required to be easy to move and not too big and bulky, since several accidents have been attributed to difficulties in access and transfer of furniture. They should be easy to get in and out of the room and probably the house. Also, they could be movable with the help of wheels, which is an easier way and do not damage the floors, taking into account the height and weight of the furniture (Jonsson, 2013). Lighter materials such as the honeycomb panels could be used to a greater extent in furniture construction, in order to ensure easy transfer and less risks.

Cleaning the surfaces of furniture, especially those that are inside the corners or shelves and under the cupboards is not easy, involves bending and stretching of the body and these poses a risk for accidents and back pains. Generally, a carefully planned arrangement of furniture as well as the elements inside furniture, such as kitchen furniture, ensures the safety of working with the minimum required motion (Hrovatin, 2012).

Additionally, attention should be paid during the use of flexible, technologically advanced, but at the same time complicated furniture. Especially older people seem to require a large range of adjustable tables, beds and chairs, because there are several body sizes and movements. Lift chairs are an option for anyone who has difficulty getting in and out of a seated position, but also require attention by the user. Products undoubtedly should be smart, easy to use, but not complicated, since users are not all so flexible and anxiety as well as accidents are frequently generated.

4. CONCLUSIONS

To sum up, this study, calls for the attention of furniture designers and manufacturers to examine the risks that arise during the use of the furniture structures. The sizes and dimensions of people bodies and their home interior environments should be taken into consideration. The final products should be comfortable, without sharp edges and corners, carefully and ergonomically designed and constructed without any manufacturing defect, should suit the individual and the way of the furniture usage, should also be practical, durable, constructed with the proper materials and types of joints, easy to be cleaned and transferred, providing

pleasant feelings, and all these would contribute furniture to be characterized also as safe to be used. Special attention should be paid to the users' informing and support about the proper securing, assembly and arrangement of the furniture to the final place/room, in order to avoid construction mistakes, insufficient binding, falls and accidents causing. Especially, referring to children's furniture, point of sale information about the correct use of products and the associated hazards should be provided for parents and care-givers.

Manufacturers and furniture industries would be essential to carry out frequent quality controls on the furniture they produce and be closely involved in the effort to eliminate accidents that take place during the use of furniture inside or outside of the house. Finally, research should be undertaken to investigate furniture second hand marketing, examining compliance with standards, modifications to design, maintenance, as well as general condition. The study on this topic is undoubtedly required to be continued, in order to assess associations between the use of furniture, and injuries/accidents.

References

- Bucktin C. (2016): IKEA UK sparks fury after refusing to withdraw drawers blamed for the deaths of three US toddlers. Daily Mirror News, 28 JUN 2016. (<http://www.mirror.co.uk/news/uk-news/ikea-uk-sparks-fury-after-8304485>).
- Hrovatin J, Širok K, Jevšnik S, Oblak L., Berginc J. (2012): Adaptability of Kitchen Furniture for Elderly People in Terms of Safety. *Drv. Indust.* 63(2), 113-120.
- Jonsson O. (2013): Furniture for later life-design based on older people's experiences of furniture in three housing forms. *Doct. Diss.*, Lund University, 2013.
- Kendrick D., Maula A., Reading R., Hindmarch P., Coupland C., Watson M., Hayes M., Deave T. (2015): Risk and Protective Factors for Falls From Furniture in Young Children. *JAMA Pediatr.* 169(2): 145-53. doi: 10.1001/jamapediatrics.2014.2374.
- Kłós R., Fabisiak B., Kaczmarek M. (2014): Analysis of Human Needs in Kitchen Design for People with Visual Impairment. *Drv Industrija* 65 (1) 43-50.
- Leung M., Yu S., Chong A., Jiao L. (2012): Facility management for the Elderly in Public and subsidized housing – A focus group investigation. Property and Facility Management Division, Hong Kong Institute of Surveyors. *Res. Proj.* 2009-10.
- Meinander H., Varheenmaa M. (2002): Clothing and textiles for disabled and elderly people. *Espoo 2002. VTT Tiedotteita – Research Notes* 2143. 57 p. + app. 4 p.
- Nagourney E. (2009): Hazards: Injuries From Falling Furniture Are Rising. *NY Times, Vital Signs*, May 4, (<http://www.nytimes.com/2009/05/05/health/05haza.html?mcubz=0>)
- Pinto MR, De Medici S, Zlotnicki A, Bianchi A, Van Sant C, Napou C (1997). Reduced visual acuity in elderly people: the role of ergonomics and gerontechnology. *Age and Ageing* 1997; 26: 339-344.
- Smardzewski J, Matwiej Ł, Grbac I (2005) Anthro-technical models in testing mattress, *EJPAU* 8(3), 38.
- Watson W., Ozanne-Smith J., Begg S., Imberger A., Ashby K., Stahakis V., 1997. Injuries Associated with Nursery Furniture and Bunk Beds. Monash University Accident Research Centre - Report #123.

Corresponding author:

V. Kamperidou

Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment, Laboratory of Wood Products and Furniture Technology, Thessaloniki, Greece

vkamperi@for.auth.gr

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.

DETERMINATION OF THE SUFFICIENCY OF WARDROBES IN PARENT BEDROOMS OF TODAY'S UPPER SOCIO ECONOMIC STATUS (SES) HOUSES

Kemal YILDIRIM¹, Mehmet Lütü HİDAYETOĞLU², Semih YILDIRIMTOP¹

¹ Gazi University, Department of Woodworking Industrial Engineering, Ankara / Turkey

² Selçuk University, Department of Industrial Design, Konya / Turkey

Key words

*House,
Parent bedroom,
Wardrobe,
Furniture,
SES*

Abstract

In this study, it was aimed to determine the sufficiency of wardrobes in parent's bedrooms of upper SES (Socio-Economic Status) houses. For this purpose; 92 upper SES houses from different areas of Izmir were included in the research and a detailed questionnaire was applied to the households about their wardrobes. Consequently; interior layout of the wardrobes, working systems of cover, materials and storage capabilities of the wardrobes were determined. As a result, it has been determined that users are satisfied with the room size and storage capacity in bedrooms with a clothing room. In addition, it was observed that the users rarely needed the wardrobe storage for out of seasonal usage, whereas they often required this storage for their daily usage. It is understood that the most of the users prefer independent clothing room with the sliding cover systems for storage requirement.

Corresponding author: kemaly@gazi.edu.tr Yıldırım K., Gazi University, Faculty of Technology, Department of Woodworking Industrial Engineering, Ankara / Turkey

1. INTRODUCTION

People's lifestyles, needs, expectations and habits constantly change in parallel with development and change in the world. The characteristics of the houses, the purpose of use of the spaces, the characteristics of the elements in the spaces, and the social class of the users can be different. It is beneficial to examine the differences in the needs of these social classes at periodic intervals. Nowadays, it is observed that the consumption of different classes and the tendency of consuming quickly have increased rapidly depending on the developing technology. Fashion is constantly changing, people want to have new clothes instead of wearing their clothes for a long time. In order to meet these needs, to ensure the continuity of sales, to be kept in the market, continuous production is being carried out; but this process, which sometimes goes from production to planning, is shortening due to rapid production and consumption, causing some disadvantages (Şahin, 2014). This may lead to an increase in the size of interior equipment elements such as a wardrobe in parent bedrooms, a change in materials, equipment and accessories used, and an increase in storage capacities.

The complaints about the inadequacy of the storage capacities of the equipment elements in the residences of the users are found in many researches on this area (Kansu, 1976, Bakır, 1987, Asatekin, 1995, Yıldırım, 1995, Sonmez and Yıldırım, 1996 and 1999). These complaints are mostly concentrated in the wardrobes of the parents' bedrooms. Previously, Grandjean (1978) reported that hanging and shelf ratios should be no more than 40% of the surface of the

wardrobe. In another study, Sönmez and Yıldırım (1999) reported that the ratio of wardrobes hangers should be 40%, shelf 41% and drawer 19%, respectively. Yıldırım et al. (2005), it has been reported that there are not enough studies in accordance with the claims and requirements of the users in the course of the design of the residential spaces and that the interior equipments made by the contractors are mostly changed during the usage phase. The replacement of these interior elements, which have been used in a small part of the product life cycle, harms both the country's economy and natural resources. From this point, it is useful to determine the complaints, if any, of the wishes and satisfaction of the existing storage capacities of the interior elements of the user's residences in the parent bedrooms.

PROBLEM DEFINITION

The first condition for the availability of residential spaces is that the space and interior elements are designed in accordance with the request and requirements of the users. When designing a bedroom space and interior elements of a house, it is necessary to calculate the optimum level of the clothes to be stored and the areas to be covered. All the clothes and equipments possessed in this vault will be easily stored in the interior elements and customized areas can be created in the internal arrangement of the wardrobe. Thus, designing the interior layout of the wardrobe (hangers, shelves, drawers, etc.) according to ergonomic principles such as importance, usage frequency and order, storage and sizing can affect the quality of life of the users positively.

RESEARCH HYPOTHESIS

Today, housing production is rapidly continuing in order to meet the housing needs that arise due to the growing population, especially in developing countries. According to the statistics of the Turkish Statistical Institute dated January 24, 2017, it is observed that 1.341.453 houses were sold in 2016 in Turkey. Depending on the reception power, the area of the parent bedrooms of the planned houses intended for the upper SES users grows, and the parent's bathroom and clothing room are included. The large parent bedroom can provide flexibility to the user when dimensioning and installing interior elements. According to the approaches discussed above, research hypotheses developed for the purpose of this research are given below.

H1: There is a difference between whether or not there is a clothing room in parent bedrooms and where users find room satisfaction levels and storage capacity adequate.

H2: There is a difference between the existing internal partitioning scheme of the wardrobe in the parent bedrooms and the desired internal partitioning scheme of the users.

2. RESEARCH METHOD

The scope of the research; it constitutes 92 residential bedrooms which are supposed to represent the upper SES families located in Karşıyaka, Bornova and Balçova in İzmir.

QUESTIONNAIRE DESIGN

In the design of the questionnaire; we have benefited from valid and reliable housing evaluation surveys in previous surveys conducted by Işık (1992), Yıldırım (1995, 1999) and Şahin (2014). The questionnaire consists of three parts. In the first part, general information (the gender of the user, age, ownership of the dwelling, residence time in the residence etc.), the second part of the question about the bedroom (the size of the bedroom, the size of the clothing room if it is, the satisfaction of the size of the bedroom and the dresser, etc.), and in the third section, there are questions about the wardrobe (the features of the clothing room that are desired, the interior layout, the sufficiency status of the storage capacity, etc.). Research data; it was obtained with

the help of a questionnaire from 92 users randomly selected by sampling method in 2014. The survey was conducted at different times of the day, including weekdays and weekends.

STATISTICAL EVALUATION

It was necessary to summarize and present the data obtained from the questionnaires for understanding and comparing them with other results. For this purpose, the percentage values, arithmetic mean and standard deviation values of the research data were calculated, and one-way analysis of variance (ANOVA) was performed to test whether the differences between dependent and independent variables were statistically significant at $P < 0.05$ level. In addition, the data are also graphically represented for comparison of the averages of the variables.

3. RESULTS AND DISCUSSION

Of the users participating in the survey, 54.3% were female, 45.7% were male, 13% were between the ages of 18-25, 32.6% were 26-35 years, 26.1% were between 36-45 years and 28.3% were over 46 years old and over; 21,7% of them are in secondary education, and 78,3% of them are high school graduates. There are 92 bedrooms of which 68 have a cupboard/wardrobe and 24 have independent clothing rooms. 18,4% of the bedrooms are 10-14 m², 33,7% is 15-19 m² and 47,8% is 20 and over m². The satisfaction levels of the users according to the sizes of the bedrooms studied are given in Table 1. According to the average values and ANOVA results in the table, the differences between bedroom size and room size satisfaction of users were statistically significant at $p < 0.10$ level. Accordingly, the users' satisfaction ratings are listed as negative 20 m² and over > 15-19 m² > 10-14 m². As a result, it seems that users are more satisfied with the large bedrooms.

Table 1. Satisfaction levels of users according to size of bedrooms

Parent Bedroom Space	10-14 m ²		15-19 m ²		20 m ² +		ANOVA		
	X	S	X	S	X	S	F-Value	df	Sig.
Room Size Satisfaction	2.94 ^a	1.08	2.80	1.19	2.31	1.11	2.622	2	0.078*
Number of Bedrooms	17		31		44				

Note: X: Mean, S: Std. Deviation, df: Degree of freedom, *: $P < 0.10$ level is significant.
a: Variables averaged from 1 to 5 (1: Very Satisfied, 5: Never Satisfied).

Table 2 shows the satisfaction levels of users and their storage capacities according to whether or not there is a clothing room in the research bedrooms. According to the mean values and ANOVA results in the table, the difference between the satisfaction rates of room size satisfaction and storage capacity of the users in the fact that there is a clothing room in the bedrooms was statistically significant at $p < 0.05$ level. As a result, it has been determined that users are satisfied with the room size and storage capacity in bedrooms with a clothing room.

Table 2. According to the fact that there is a clothing room in the bedrooms, the users are satisfied with the room size and the storage capacity is sufficient

Availability of Clothing Rooms	There is a Clothing Room		No Clothing Room		ANOVA		
	X	S	X	S	F-Value	df	Sig.
Room Size Satisfaction	1.63 ^a	1.01	2.94	1.00	30.263	1	0.000*
Storage Capacity Adequacy	2.63 ^b	1.09	3.19	1.04	5.111	1	0.026**
Number of Clothing Rooms	24		68				

Note: X: Mean, S: Std. Deviation, df: Degree of freedom, *: P <0.01 and **: P<0.05 levels are significant. a: Variables averaged from 1 to 5 (1: Very Satisfied, 5: Never Satisfied). b: Variables averaged from 1 to 5 (1: Very Sufficient, 5: Very Insufficient).

In order to be able to compare the mean values of the sources of variance found significant in the analysis of variance given in the table, the obtained data are given graphically in Fig. 1. According to this, it is seen that users have the lowest values (positive) of the bedrooms with the clothing room and the highest values (negative) with the bedrooms without the clothing room in evaluating the room size satisfaction and the storage capacity satisfactorily. This result supports the hypothesis proposed in H1.

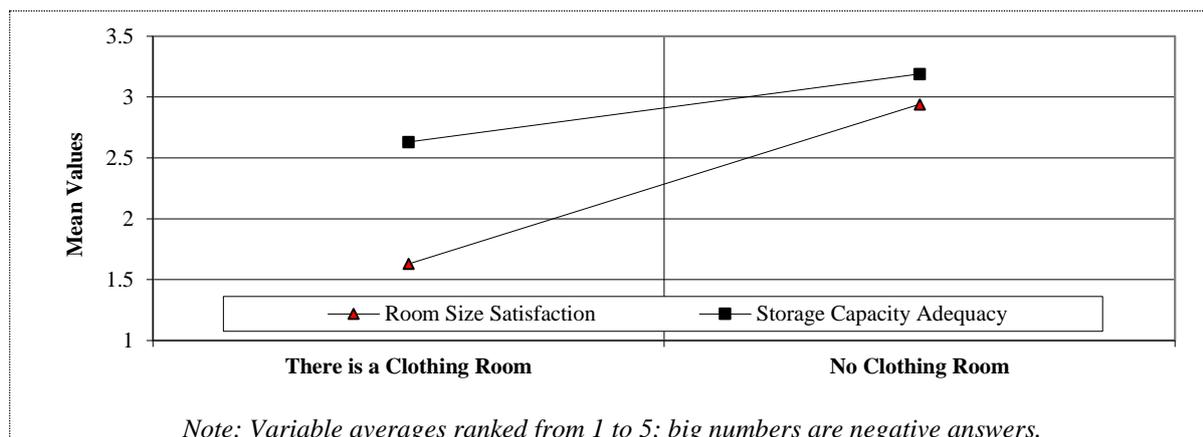


Figure 1. Users find room size satisfaction and storage capacity satisfactory depending on whether or not the user has a clothing room in the bedroom

Table 3 shows the usage patterns of the wardrobes according to whether or not there is a clothing room in the research bedrooms. According to the mean values and ANOVA results in the table, the difference between the presence of the clothing room in the bedrooms and the wardrobe usage patterns of the users was not statistically significant at p <0.05 level. As a result, it can be said that whether or not there is a clothing room connected to the bedroom does not have a significant effect on the usage patterns of the wardrobes. On the other hand, wardrobes are generally preferred by users for daily use, and less for seasonal use.

Table 3. The use of wardrobes according to the presence of a clothing room in the bedrooms

Wardrobe Usage Shape	There is a Clothing Room		No Clothing Room		ANOVA		
	X	S	X	S	F-Value	df	Sig.
Daily Storage	2.20 ^a	0.88	2.19	0.88	0.005	1	0.933*
Long Term Storage	2.66	1.01	2.67	0.90	0.002	1	0.965*
Storage by Seasonality	2.50	0.93	2.51	0.80	0.005	1	0.941*
Non-seasonal Storage	3.08	1.01	3.16	1.04	0.101	1	0.751*
Number of Clothing Rooms	24		68				

Note: X: Mean, S: Std. Deviation, df: Degree of freedom, *: P < .05 level is not significant. a: Variable averages ranked from 1 to 5 (1: preferred, 5: not preferred).

The interior layout of the wardrobes in the research bedrooms and the results of the interior layout requested by the users are given in Table 4. When we look at the mean values and ANOVA results given in Table 4, it is seen that there are statistically significant differences in the levels of p <0.001 and p <0.10 for both cases. Accordingly, in both cases, it seems that the

interior layout of the wardrobe is ordered as hanger > shelf > drawer. On the other hand, when looking at the percentage values of the averages, the ratio of the hanging area (58.8%) in the current situation seems to be considerably higher than the desired hanging area ratio (47.39%). It is also understood that the ratio of shelf and drawer is desired to be increased according to the current partitioning order. This result supports the hypothesis proposed in H2. The results of the present interior layout in Table 4 do not support the results previously proposed by Grandjean (1978) and Sönmez and Yıldırım (1999). On the other hand, it overlaps with the interior layout desired by users with the H2 hypothesis.

Table 4. Interior layout of wardrobes in bedrooms

Interior Layout of Wardrobes	Available Interior Layout		Desired Interior Layout		ANOVA		
	X	S	X	S	F-Value	df	Sig.
Shelf	28.54 ^a	10.98	37.23	11.84	26.934	1	0.000*
Hanger	58.80	11.63	47.39	13.79	36.789	1	0.000*
Drawer	12.66	7.42	15.38	9.84	3.457	1	0.065**
Total Ratio (%)	100		100				

Note: X: Mean, S: Std. Deviation, df: Degree of freedom, *: P < .001 and **: P < .10 levels are significant. a: The percentages of the surface measurement averages of the wardrobe examined.

It is also seen that 82.6% of the users want to have the wardrobes of sliding door, 16.3% of hinged door and 1.1% of folded door. It is also seen that 34,8% of the users are lacquered in the wardrobes, 43,5% are varnished on wood, 18,5% are MDFlam (melamine resin coated medium density fiberboard) and 4,3% are made of PBlam (melamine resin coated particleboard).

4. CONCLUSIONS

In this study, the interior layout and storage capacity of the wardrobe in the parent bedrooms of the upper SES residences are determined and the results are discussed below respectively.

In the comparison tests, the differences between bedroom size and users satisfaction were found statistically significant at p < 0.10 level. Accordingly, the users' satisfaction ratings are listed as negative 20 m² and over > 15-19 m² > 10-14 m². As a result, it seems that users are more satisfied with the large bedrooms. Moreover, the difference between finding of adequate storage capacity and satisfaction of users was found to be statistically significant at the level of p < 0.05, due to the absence of the clothing room in the parent bedrooms. As a result, it is observed that the storage capacity and room size satisfaction of the users are found to be sufficient in the rooms with the clothing room. From these results, it can be said that the differences between parent bedroom sizes and their storage capacities have a significant effect on the satisfaction levels of users.

As a further result, differences in the manner of use of wardrobes in the parent bedrooms were not statistically significant at p < 0.05 level. As a result, it can be said that whether or not there is a clothing room connected to the bedroom does not have a significant effect on the usage patterns of the wardrobe. On the other hand, wardrobes are generally preferred by users for daily use, and less for seasonal use. In addition, it was determined that there were statistically significant differences at the p < 0.001 and p < 0.10 levels between the current interior layout of the wardrobes in the bedrooms and the desired interior layout of the users.

According to this, in both cases, the interior layout order of the wardrobes is seen as "hanging > shelf > drawer". On the other hand, when the percentages of the averages are taken into consideration, it is seen that the ratio of hangers (58.8%) is much higher than the desired hangers (47.39%). It is also understood that the ratio of shelf and drawer is desired to be increased according to the current partitioning order.

References

- Asatekin, M. (1995). Düşük metrekaireli konutta mobilya tasarımına yaklaşım ve örnekleme çalışması. *Konut Araştırmaları Sempozyumu, T.C. Başbakanlık Toplu Konut İdaresi Başkanlığı, Konut Araştırmaları Dizisi:1*. Ankara: ODTÜ Basım İşliği, s. 385-402.
- Bakır, İ. (1987). Küçük alanlı konutlarda mekân kullanımı. *Toplu Konutlarda Mekân Standartları Paneli Bildirileri*, 104-110.
- Grandjean, E. (1978). *Ergonomics of the home* (Second edition). London: Taylor & Francis Ltd, 160.
- Işık, Z. (1992). Geleneksel ve Günümüz Konutlarının İç Mekan Analizi, G.Ü. Fen Bil. Enst. Doktora Tezi, Ankara, 1-10.
- Kansu, R. (1976). *Sosyal konut kullanıcılarının depo gereksinmelerini saptamak için gecekonduarda yapılan bir araştırma*, Yayınlanmamış Yüksek Lisans Tezi, İTÜ Mimarlık Fakültesi MMLS Mimari Tasarım Dalı Konut Tez Alanı, İstanbul.
- Sönmez, A., ve Yıldırım, K. (1996). Orta nitelikli konutlarda ebeveyn yatak odası planlaması için optimum çözümler. *Gazi Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 9(3), 439-446.
- Sönmez, A. ve Yıldırım, K. (1999). Orta nitelikli ebeveyn yatak odalarında bulunan elbise dolapları ve bunların modüler koordinasyonu. *Gazi Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 12(1), 35-44.
- Şahin, H.N. (2014). *Günümüz üst SED apartman konutlarının ebeveyn yatak odalarında depolama kapasiteleri üzerine bir araştırma*, Yüksek Lisans Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara.
- Türkiye İstatistik Kurumu (2017). *Konut İstatistikleri 2017*. Ankara: Türkiye İstatistik Kurumu Matbaası.
- Uzun, O. (2011). *Günümüz orta ve üst SED apartman konutlarının antre, mutfak ve banyolarında depolama kapasiteleri üzerine bir araştırma*, Yayınlanmamış Doktora Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara.
- Yıldırım, K., Başkaya, A., ve Hidayetoğlu, M. L. (2005). Farklı sosyo-ekonomik düzeye sahip blok-konut kullanıcılarının sabit iç donatım elemanlarından memnuniyeti. *Politeknik Dergisi*, 8(2), 189-197.
- Yıldırım, K. (1995). *Orta nitelikli konutlarda ebeveyn yatak odası planlaması için optimum çözümler, eylemlere yönelik kullanıcı gereksinimleri ve iç donatım elemanları*. Yayınlanmamış Yüksek Lisans Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara.
- Yıldırım, K. (1999). Konut Mutfaklarının Mekan ve Donatı Organizasyonunda Ergonomik Yaklaşım, G.Ü. Fen. Bil. Enst., Doktora Tezi, Ankara, 242-248.

Corresponding author:

Yıldırım K.,

Gazi University, Faculty of Technology, Department of Woodworking Industrial Engineering, Ankara / Turkey

kemaly@gazi.edu.tr

HEAT CONDUCTIVITY AND MOISTURE PERMEABILITY THROUGH THE POCKET SPRING MATTRESS

Zoran VLAOVIĆ¹, Ivica GRBAC¹, Kristina MARIĆ¹

¹ University of Zagreb, Faculty of Forestry, Department of Furniture and wood products, Zagreb/Croatia

Key words	Abstract
<i>Heat, Moisture, Mattress, Thermal comfort, Thermo-physiology</i>	A person with his thermo-physiological characteristics directly influence the mattress by changing his properties and a healthy bed climate. In this paper, the heat conductivity and moisture permeability through the mattress with the pocket spring core during the sleep were studied. Each of four subjects slept for seven nights on the same mattress in their own bedroom. Seven sensors measured the heat and moisture content released by the subject to the mattress and the environmental conditions. The results have shown that during first 180 minutes of lying, the temperature increases on all sensors and starts to decrease after that time. It has been observed that the moisture in most cases increases in the direction from the top layer of mattress towards the centre, and that the moisture above the coconut coir layer does not stay much longer than in the other mattress layers and can be relatively quick to dry out.

Corresponding author: ivica.grbac55@gmail.com, Grbac, I., University of Zagreb, Faculty of Forestry, Department of Furniture and wood products, Zagreb/Croatia

1. INTRODUCTION

In this paper, the heat conductivity and moisture permeability through the mattress with the pocket spring core during the sleep were studied. Each of four subjects slept for seven nights on the same mattress in their own bedroom. Heat and moisture that subjects were released in the mattress and surroundings were measured by seven probes placed between mattress layers and in the bedroom.

The aim of the paper was research on distribution of heat and moisture through the mattress in real conditions, and how long it takes to mattress release accumulated moisture.

Sleep can help people overcome tiredness and is very important to one's memory. It was commonly acknowledged that the quality of sleep was mainly affected by the mental-physical factors of a sleeping person and the environmental factors in a bedroom (Dongmei et al., 2013). It is well known that human body generates thermal energy all the time. The regulation of a normal physiological skin microclimate is necessary to maintain thermal equilibrium between the heat gained within the body from metabolic processes and heat losses from the skin to the environment (Nicholson *et al.*, 1999; Hänel *et al.*, 1997). In addition to the heat, the human body is constantly excreted moisture through the skin.

Sleep quality depends on materials touching the body, liquid absorption capacity and temperature (Grbac and Dalbelo Bašić, 1994; Grbac and Dalbelo Bašić, 1996). Difficulties in the test of comfort properties arise from the fact that comfort in a bed is a complex phenomenon, consisted of subjective feeling and physical properties of the interface between a mattress and the human body (Lee and Park, 2006).

The humidity at the skin/support interface should ideally be between 40 and 65% RH and the interface temperature should not change by more than a few degrees (Cochran and Palmieri,

1980), while e.g. [...] the temperature under the ischial tuberosity varies between 30 °C and body temperature, and [...] the heat flux away from the skin may vary during changes of (sitting) posture by anything from -9 to +106 W/m² (according to Nicholson *et al.*, 1999). Hänel *et al.* (1997) quoted that in a warm climate it is essential for the experience of good comfort that beds and car seats have sufficient capacity of transporting moisture away from the contact area. This capacity is closely connected to the air permeability properties of the upholstery. Their experiment has shown that thermal behaviour of [...] bed is mainly governed by the thermal properties of the upper layer, i.e. that which is in contact with the body. Varying the design of the supporting part has not shown any significant effect.

Bed climate plays a significant role in the thermal comfort during sleeping period. The temperature of mean bed climate is recommended as between 30.3 °C and 32.5 °C to satisfy the demand of human thermal comfort during sleep (Song *et al.*, 2015). The dream is greatly influenced by the quality and comfort of the mattress, which can negatively affect the rest, if the user is unwell and feels uncomfortable during lying down (Grbac, 2006).

Okamoto-Mizuno and Mizuno (2012) infers that the most frequent reason healthy people without insomnia woke up from sleep or felt uncomfortable during their usual sleep was that they felt excessively high or low ambient temperature. Sleep thermal comfort is one of the critical factors affecting sleep quality. A comfortable thermal environment is essential for shorter sleep latency and sound sleep duration (Liu, Y., *et al.*, 2014) (quoted in: Shen *et al.*, 2015). The main characteristics of a high-quality mattress are the conductivity of heat and moisture on the surface and through mattress layers, durability and mechanical properties (such as firmness and optimum hardness), and the fulfilment of anthropometric and hygienic requirements (Grbac, 1988; Grbac, 2006).

We become more sensitive to the influences of sleeping environment and bed quality. Diverse types of beds are manufactured today, using vertical or horizontal coil springs, or other materials. It was essential to obtain the most natural sleep environment and reduce external disturbing factors. Therefore, Bader and Engdal (2000) investigated the subjects in their own bedroom and instead of using electrodes fixed on the body they used sensor pads. Following a control of the methodology, they have studied the sleep quality of subjects sleeping in their own beds.

2. METHODS AND MATERIALS

SAMPLE

Sample of mattress (190 × 90 × 18) cm was standard model of one Croatian mattress producer, and for experimental purposes it was labelled with "M1", while surfaces (sides) were labelled with "A" and "B".

Sample "M1" was a mattress with a pocket spring core, layer of rubberised coconut coir (650 g/m², d = 5 mm), layer of polyurethane (PUR) foam (PT 2541, 25 kg/m³, d = 25 mm, 3.4 kPa) and upper fabric layer quilted with polyester (PES 60%) and lyocell (LYC 40%) fibres (250 g/m²), PES wool (300 g/m²) and flizeline (30 g/m²).



Figure 1. Cross-section of mattress-sample (www.bernarda.hr)

SUBJECTS

Four (two female and two male) healthy subjects were participated in experiment. The subjects' details are given in the following table:

Table 4. Anthropometric characteristics of subjects

Subjects' code	P1	P2	P3	P4	Average (SD)
Age (years)	26	24	26	19	23,8 (3,3)
Height (cm)	170	178	164	184	174,0 (8,8)
Mass (kg)	56	74	48	71	62,3 (12,3)
BMI (kg/m ²)	19,38	23,36	17,85	20,97	20,4 (2,4)

Female subjects were coded with P1 and P3, while male subjects with codes P2 and P4. Regarding to BMI it may be concluded that female subjects (P1, P3) were in groups of underweight and normal range, and male subjects (P2, P4) were in group of normal range (according to BMI classification, WHO).

METHODS

A study of heat conductivity and moisture permeability of the mattress with the pocket spring core was carried out for a total of 28 days, from May 23rd to June 22nd, 2016.

Subjects was sleeping on a mattress for seven consecutively nights, incorporating probes measuring temperature and relative humidity. Subjects P1 and P2 were slept on "side A" in first two weeks in the same bedroom/house, while subjects P3 and P4 were slept on "side B" in second two weeks in the same bedroom of another house.

Prior to the experiment it was determined that subjects should not drink alcohol at least six (6) hours before bedtime, should not rest or lie during the day on the mattress in which the experiment was being conducted, the duvet (or any kind of bedcover) should not be left on the mattress during the day for better ventilation. The subjects wore short-sleeved sleepwear (100% cotton) and slept on a bed covered with a bed sheet (100% cotton) and or without a duvet (cotton cover filled with silicon polyester fibres). The sleepwear covered the trunk, upper arms, and thighs.



a) measuring probe for temperature and RH



b) HOB0[®] Weather Station H21-001

Figure 2. Measuring equipment

Temperature and relative humidity measurements were carried out using seven measuring probes (*S-THB-M008*) with temperature and humidity sensors in the same housing, and data were collected using the *HOB0[®] Weather Station H21-001* electronic device (Onset Computer Corporation, USA) (Figure 2). Data processing was implemented with *MS Office Excel*.

Seven measuring probes were set up as follows, assuming that subject is lying on its back:

- Probe 3: on the mattress top layer, below the decorative fabric, approximately underneath the scapula of the subject,
- Probes 2 and 4: approximately 20-25 cm left and right of probe 3,

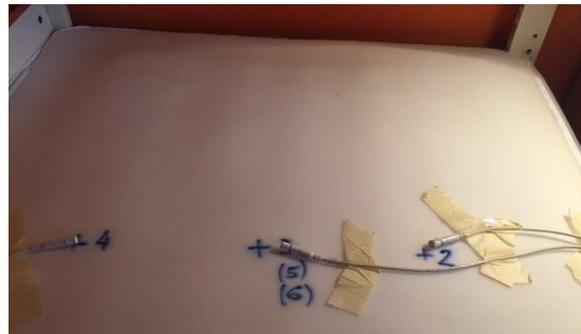


Figure 3. Location of probes 2, 3 i 4 setups on mattress top layer

- Probe 5: underneath probe 3, on a rubberised coconut coir layer, below the top mattress layer,
- Probe 6: underneath probe 5, at the centre of the height of the spring core,
- Probe 7: in the room (on a neutral wall or furniture without the influence of heat or direct sunlight) near the bed and at the level of probe 3. There was also a "Probe 1" located under the duvet but it was not considered in this paper.

STUDY LIMITATIONS

We acknowledge that this study has some limitations. First, the subjects slept in their own bedrooms and room conditions, at different temperature conditions, without heating or air conditioning. Outdoor air temperature and relative humidity had an impact on the bedroom climate. It should be taken into consideration that the weather conditions within a month during experiment were changed significantly and that there were colder and warmer days/nights with relatively great temperature differences. Second, some subjects were used duvet (previously defined) during the sleep, according to their needs or climatic conditions during night(s).

3. RESULTS AND DISCUSSION

Results are presented below, and due to limited space, only arithmetical means are shown. Complete data can be found in the original paper (Marić, 2016).

The following codes are used to represent data and results: T3/TH3 – temperature/moisture content between upper layer of mattress and decorative fabrics; T2/RH2 and T4/RH4 - temperature/moisture content left and right from T3/RH3; T5/RH5 – temperature/moisture content between rubberised coconut coir layer and upper layer; T6/RH6 – temperature/moisture content in the middle of pocket spring core; and T7/RH7 – temperature/relative humidity in the ambient.

Measuring took place in two bedrooms in two different buildings (houses), for two weeks in each. Mean values of ambient temperature (T7) and ambient relative humidity (RH7) during experiment are shown in Table 2.

Table 5. Mean values of ambient temperature and relative humidity during nights and days of experiment

	P1	P2	P3	P4
T7 at night (°C)	23,3	24,3	26,8	27,0
T7 at day (°C)	23,6	24,0	26,9	26,9
RH7 at night (%)	66,4	66,4	61,5	56,4
RH7 at day (%)	63,3	62,5	60,1	53,7

To simplify data obtained from probes 2, 3 and 4, their values were unified. Thus, in the following views, the temperature tags T2-3-4 and the moisture content tags RH2-3-4 refer to the average values of those measured at a given time on probe 2, probe 3 and probe 4. Since probe 3 was in the centre of the mattress width, it was expected to be most exposed to the temperature and moisture of the subjects' body. Probes 2 and 4 are partially affected if a person is sleeping supine, and when a person slept lateral, probes were completely exposed (but in this case, the middle and the probe on the edge were less affected).

One of the research aim was to explore distribution of temperature during first few hours in bed. Results have shown that the time in which temperature increase on all probes is around 3 hours from the moment of lying in bed, i.e. first notable temperature peak reach in that period. After approximately 180 minutes temperature start to behave unpredictably, but in most cases, decrease (Figure 4).

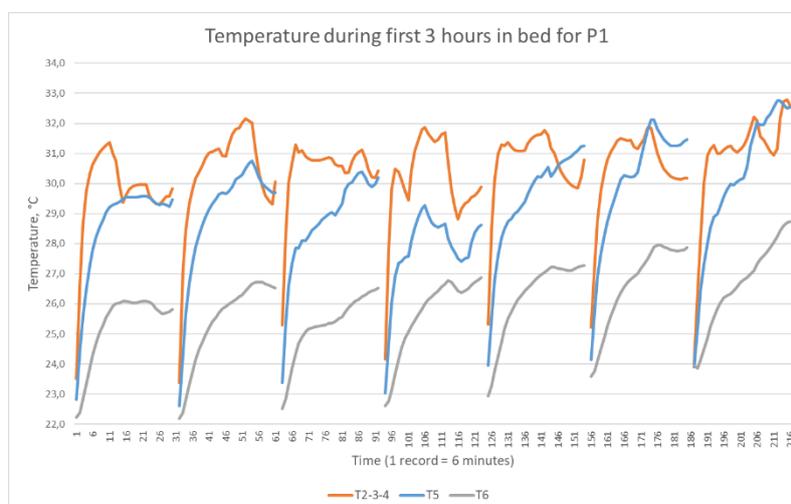


Figure 4. Example of temperature in mattress layers during first 3 hours, for seven nights

It was investigated how moisture in mattress behave during the usage of bed, and afterwards during the day.

In case of nights, moisture content increase from upper layer towards the middle of mattress (Figure 5), and it depends on relative humidity in bedroom as well.

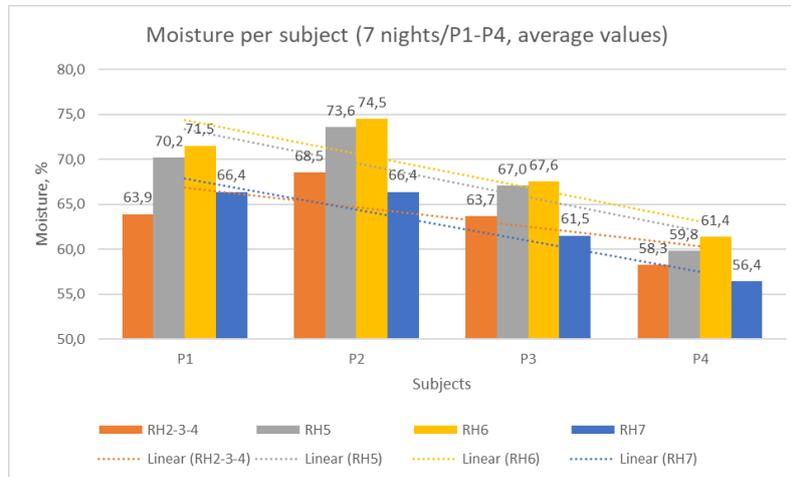


Figure 5. Average moisture content per subject during seven-night period

For seven days, relations between probes (RH2-3-4 vs. RH5 vs. RH6) remain the same in comparison with night ones, but the values are expectedly lower. Those differences were greater in inner layer of mattress than the one near the surface, and were in range 6-12 % RH. Differences on RH2-3-4 between night and day were from 2 % to 7 % RH, while in the bedroom was only around 1 % RH (Figure 6).

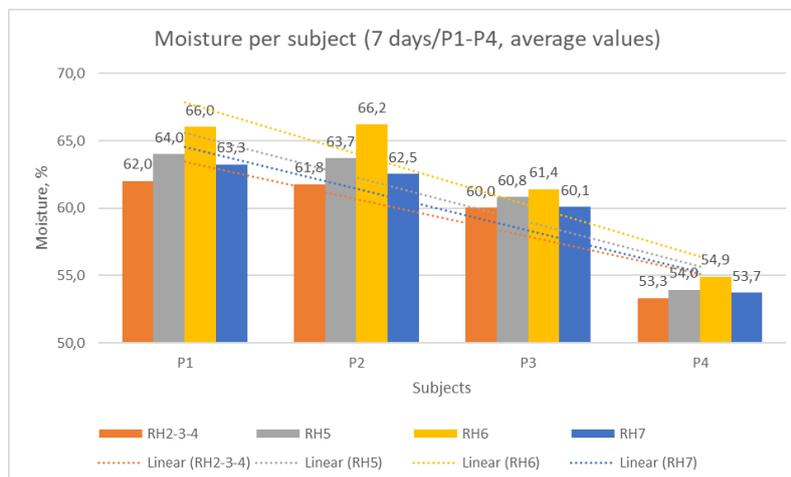


Figure 6. Average moisture content per subject during seven-day period

If we observe moisture content/relative humidity during weeks, we can see that in the first three weeks (what correspond with subjects P1, P2 and P3 on Figure 6) those values were higher up to 10 % RH than in the week four.

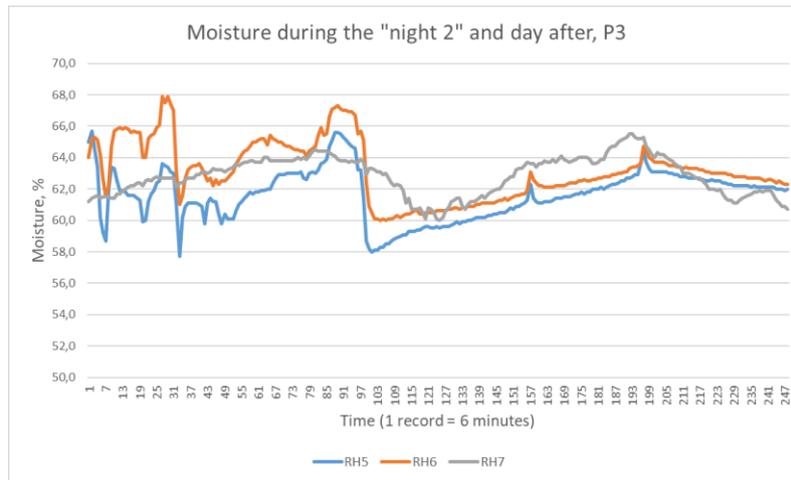


Figure 7. Example of moisture motion during the night, morning and day

After the subject got out of bed, the mattress begins to cool and dry. Figure 7 shows the motion of moisture on probes 5 and 6 in the mattress and in the room (probe 7). The sudden fall of the RH5 and RH6 curves (around 100th record) occurred after the person left the bed, and later there was a slight increase, which follow oscillations of relative humidity in the bedroom. It can be noticed that RH5 is always lower than RH6, and RH5 reach RH7 faster (more or less equals them). Moisture RH6 follows the movement of RH5 and from the moment of rising one from the bed begins to decline, but always keeps 1% to 2.5% higher than RH5.

The space between layer of rubberised coconut coir and PU foam (place where moisture sensor RH5 installed) was chosen because that layer is not in direct human body influence, it is deep inside mattress and relatively closed. On the other hand, sensor RH6 was place in the space between cotton pocket springs and showed trends in that structure of mattress.

4. CONCLUSIONS

The aims of the research were to explore distribution of heat and moisture through the mattress layers in real conditions, and how long it takes to mattress release accumulated moisture. Based on the results of research, can be concluded:

- During first 180 minutes of lying, the temperature increases on all sensors and after that usually decrease, even though temperature behaviour can be very unpredictable.
- Moisture always increases in the direction from the top layer of mattress towards the spring pockets, regardless of day or night.
- Moisture content in mattress layers depends on relative humidity in the air, and it is always lower during the day comparing with the night period.
- Moisture accumulated in the inner structures of mattress (between coconut coir and upper layers of foam) does not stay much longer than in the other mattress layers and can be relatively quick to dry out.

References

- Bader, G.G., Engdal, S. (2000): The influence of bed firmness on sleep quality. *Applied Ergonomics*, 31 (5): 487–497.
- Dongmei, P., Shiming, D., Zhongping, L., Ming-yin, C. (2013): Air-conditioning for sleeping environments in tropics and/or sub-tropics - A review. *Energy*, 51 18–26.

- Grbac, I. (1988): Mattress quality study and construction improvement – doctoral dissertation (in Croatian), University of Zagreb, Faculty of Forestry, Zagreb.
- Grbac, I., Dalbelo Bašić, B. (1994): Thermal conductivity and moisture permeability in mattress. *Drvna industrija* 45 (4): 130-134.
- Grbac, I., Dalbelo Bašić, B. (1996): Comparison of thermo-physiological properties of different mattress structures, *Proceedings of the 18th international conference on Information technology interfaces*. Pula June 18-21, University of Zagreb, University Computing Centre, Zagreb, Croatia, 113-118.
- Grbac, I. (2006): Bed and health (in Croatian), University of Zagreb, Faculty of Forestry, Zagreb.
- Hänel, S.-E., Dartman, T., Shishoo, R. (1997): Measuring methods for comfort rating of seats and beds. *International Journal of Industrial Ergonomics*, 20 (2): 163–172.
- Lee, H., Park, S. (2006): Quantitative effects of mattress types (comfortable vs. uncomfortable) on sleep quality through polysomnography and skin temperature. *International Journal of Industrial Ergonomics*, 36 (11): 943–949.
- Marić, K. (2016): Research of heat conductivity and moisture permeability through mattress with pocket spring core – graduate thesis (in Croatian), University of Zagreb, Faculty of Forestry, Zagreb.
- Nicholson, G.P., Scales, J.T., Clark, R.P., de Calcina-Goff, M.L. (1999): A method for determining the heat transfer and water vapour permeability of patient support systems. *Medical Engineering & Physics*, 21 (10): 701–712.
- Shen, T.-Y., Tan, S.-H., Wu, F.-G. (2015): Comparison of sleep quality and thermal comfort for innovative mattress design. *Procedia Manufacturing*, 3 (Ahfe): 5874–5880.
- Song, C., Liu, Y., Zhou, X., Liu, J. (2015): Investigation of human thermal comfort in sleeping environments based on the effects of bed climate. *Procedia Engineering*, 121 1126–1132.

Corresponding author:

I. Grbac

University of Zagreb, Faculty of Forestry, Department of Furniture and wood products, Zagreb/Croatia

ivica.grbac55@gmail.com

© Author(s) 2017. This article is published under Creative Commons Attribution (CC BY) license.