RESEARCH FOR FURNITURE INDUSTRY

The XXVIIIth International Conference
Poznań 21st-22nd of September 2017

POZNAŃ UNIVERSITY
of LIFE SCIENCES
DEPARTMENT
of FURNITURE DESIGN

GAZI UNIVERSITY
DEPARTMENT
of WOOD PRODUCTS
INDUSTRIAL ENGINEERING
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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 (Syrjanen, 2001; Viitaniemi, 2000).

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 (Dzincic and Skakic, 2012; Dzincic and Zivanic, 2014; Smardzewski, 2002).

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).

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 60 h because of a risk of cracks forming while drying but the time of exposure to the highest temperature was 3 h. The heat treatment was applied according to the method described in the 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 ±10 gr/m². 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 and 5 replicates for each configuration (Table 1).

The details of dowel joints are given in Fig. 2b. The test specimens for this connection prepared according to TS 4539.

Table 1. Experimental design of the study

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Heat treatment</th>
<th>Adhesive type</th>
<th>Joint type</th>
<th>Replication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siberian pine</td>
<td>heat treated</td>
<td>PVAc</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>PVAc</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PU</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
<tr>
<td>Iroko</td>
<td>heat treated</td>
<td>PVAc</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>PVAc</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PU</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
<tr>
<td>Common ash</td>
<td>heat treated</td>
<td>PVAc</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>PVAc</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PU</td>
<td>Dowel MT</td>
<td>5</td>
</tr>
</tbody>
</table>

Total: 120 specimens.
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 Fig. 3a and real specimens of density and MC is given at Fig. 3b.

SHEAR FORCE CAPACITY TESTS

The tests were carried out according to previous studies (Balıkçı, 2015; Dizel 2005; Örs and Efe, 1996). 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 Sitki 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 Fig. 4. The max force that produced on H-type joint elements were recorded as bending moment capacity and calculated by following equation:

\[ F = \frac{F_{\text{max}}}{m} \]

\( F \) – force,
\( F_{\text{max}} \) – maximum force in shear (N),
\( m \) – number of the joints.

**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.

**RESULTS AND DISCUSSION**

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

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

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.

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.

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.

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.

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 8.
Table 2. Result of density and MC

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Treatment process</th>
<th>Test moisture content (MC) (%)</th>
<th>Oven dry density (δₒ) (gr/cm³)</th>
<th>COV (%)</th>
<th>Density during the test (δ₁₂) (gr/cm³)</th>
<th>COV (%)</th>
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</thead>
<tbody>
<tr>
<td>Siberian pine</td>
<td>heat-treated</td>
<td>4,5</td>
<td>0,35</td>
<td>2</td>
<td>0,36</td>
<td>2</td>
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<tr>
<td></td>
<td>control</td>
<td>6,77</td>
<td>0,38</td>
<td>4</td>
<td>0,40</td>
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<td>0,57</td>
<td>3</td>
<td>0,61</td>
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<td>Common ash</td>
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<td>0,59</td>
<td>3</td>
<td>0,63</td>
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COV – Coefficient of variation.

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

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Heat treatment</th>
<th>Adhesive type</th>
<th>Joint type</th>
<th>Mean value (N)</th>
<th>Coefficient of variation (%)</th>
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<td>6838</td>
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Table 4. Results of multiple variation analysis (MONOVA)

<table>
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<tr>
<th>Variation sources</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F value</th>
<th>Probability (p &lt; 0.05)</th>
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<td>59,4184</td>
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<td>3</td>
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<td>3618731,191</td>
<td>19,7498</td>
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<td>6,4879</td>
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<td>1</td>
<td>4</td>
<td>4442058,017</td>
<td>4442058,017</td>
<td>24,2433</td>
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<td>2</td>
<td>3</td>
<td>695591,768</td>
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<td>1</td>
<td>4</td>
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<td>115,9729</td>
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<td>4273179,314</td>
<td>2136589,657</td>
<td>11,6608</td>
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Table 4. cont.

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<td>3836002,770</td>
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<td>639841,309</td>
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<td>–</td>
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<td>159187518,977</td>
<td></td>
<td>–</td>
<td>–</td>
<td></td>
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</tbody>
</table>

NS – insignificant; WS – wood species; HT – heat treatment; AT – adhesive type; JT – joint type

Table 5. LSD test results of WS factor

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Shear force capacity (N)</th>
<th>X (N)</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siberian pine</td>
<td>2653</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Iroko</td>
<td>4304</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Common ash</td>
<td>4067</td>
<td>B</td>
<td></td>
</tr>
</tbody>
</table>

LSD ±270,7; X – shear force capacity; HG – homogeneity group

Table 6. LSD test results of HT factor

<table>
<thead>
<tr>
<th>Specification</th>
<th>Shear force capacity (N)</th>
<th>X (N)</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat treatment</td>
<td>3374</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>3976</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

LSD ±155,1

Table 7. LSD test results of AT factor

<table>
<thead>
<tr>
<th>Adhesive type</th>
<th>Shear force capacity (N)</th>
<th>X (N)</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
<td>3575</td>
<td>B</td>
<td></td>
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<tr>
<td>PV Ac</td>
<td>3774</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

LSD ±155,1

Table 8. LSD test results of JT

<table>
<thead>
<tr>
<th>Joint type</th>
<th>Shear force capacity (N)</th>
<th>X (N)</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dowel</td>
<td>3254</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>MT</td>
<td>4096</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

LSD ±155,1

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

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Heat treatment</th>
<th>Adhesive type</th>
<th>Joint type</th>
<th>Bending moment capacity (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siberian pine</td>
<td>heat-treated</td>
<td>PU</td>
<td>Dowel</td>
<td>2826</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>PV Ac</td>
<td>MT</td>
<td>2446</td>
</tr>
<tr>
<td>Iroko</td>
<td>heat-treated</td>
<td>PU</td>
<td>Dowel</td>
<td>2051</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>PV Ac</td>
<td>MT</td>
<td>2510</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PV Ac</td>
<td>Dowel</td>
<td>2832</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PV Ac</td>
<td>MT</td>
<td>2880</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PV Ac</td>
<td>Dowel</td>
<td>2273</td>
</tr>
<tr>
<td>Common ash</td>
<td>heat-treated</td>
<td>PU</td>
<td>MT</td>
<td>3407</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>PV Ac</td>
<td>MT</td>
<td>5695</td>
</tr>
</tbody>
</table>

LSD ±537,4
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.

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.

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-HT-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.

References


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.


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., 1999a).

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 (Ustundağ, 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 PV Ac 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., 1999b).

In the study made in order to determine the impact of the dilution of PV Ac 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

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

Musa ATAR, Mehmet GUNES, Hakan KESKIN

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

**Abstract.** 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 (Fagus orientalis L.), European Oak (Quercus petreae Liebl.) and Scotch Pine (Pinus sylvestris 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.

**Keywords:** diagonal tensile strength, joint angle, dovetail, leg-to-rail joint, adhesives, woods

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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 et al., 2008).

As box furniture constructions are exposed to compression and tensile stress, it has been recommended to use the dowel joint type and the polymarine 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 trail joints techniques.

**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, knobs, color or density difference, and (annual rings are vertical to the surfaces) and prepared from sapwood according to TS 2470 standards (TS 2470, 1976). Lumbers 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 Trichetonol Acetate) adhesives which are proper for cold pressing operations were used.

**DOVETAIL TOOTH OPENING BLADE**

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

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

<table>
<thead>
<tr>
<th>Joint technique</th>
<th>Area (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75°</td>
<td>2916.13</td>
</tr>
<tr>
<td>78°</td>
<td>2820.21</td>
</tr>
<tr>
<td>81°</td>
<td>2725.15</td>
</tr>
<tr>
<td>84°</td>
<td>2631.66</td>
</tr>
<tr>
<td>Dowel</td>
<td>2858.64</td>
</tr>
<tr>
<td>End to side grain joint</td>
<td>3619.30</td>
</tr>
</tbody>
</table>

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 × 200 × 40 mm and recording element have been prepared as (B) 21 × 50 × 160 mm. Measurements of the test specimens are given in Fig. 2. Dovetail pined 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.

Fig. 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 Fig. 2. The mounted specimens were kept waiting at 20 ±2°C temperature and relative humidity of 65 ±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 g/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 Fig. 3. The mounted specimens were kept waiting at 20 ±2°C temperature and relative humidity of 65 ±3% until the test time.

Fig. 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 160–200 g/m², the
specimens were mounted. 2 N × mm⁻² force was applied in mounting processes and after 24 hours, the press was opened. The drawing of the test specimens is shown in Fig. 4. The mounted specimens were kept waiting at 20 ±2°C temperature and relative humidity of 65 ±3% until the test time.

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 Fig. 5.

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.

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.

The difference between diagonal tensile strengths of the wood type, adhesive type and joining techniques has been found statistically significant (a = 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 2. Diagonal tensile strength averages of wood type, adhesive type and joining techniques

<table>
<thead>
<tr>
<th>Wood type*</th>
<th>X</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oriental beech (B)</td>
<td>0.6644</td>
<td>B</td>
</tr>
<tr>
<td>European oak (O)</td>
<td>0.6951</td>
<td>A</td>
</tr>
<tr>
<td>Scotch pine (S)</td>
<td>0.5083</td>
<td>C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Joining technique**</th>
<th>X</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>75° (I)</td>
<td>0.6587</td>
<td>B</td>
</tr>
<tr>
<td>78° (II)</td>
<td>0.7465</td>
<td>A</td>
</tr>
<tr>
<td>81° (III)</td>
<td>0.6443</td>
<td>B</td>
</tr>
<tr>
<td>84° (IV)</td>
<td>0.6177</td>
<td>B</td>
</tr>
<tr>
<td>Dowel (V)</td>
<td>0.4349</td>
<td>C</td>
</tr>
<tr>
<td>Mortise and tenon (VI)</td>
<td>0.6335</td>
<td>B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Adhesive type***</th>
<th>X</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVAc (P)</td>
<td>0.8277</td>
<td>A</td>
</tr>
<tr>
<td>D-VTKA (D)</td>
<td>0.4176</td>
<td>B</td>
</tr>
</tbody>
</table>

*LSD: 0.02853, **LSD: 0.04035, ***LSD:0.02330
X – Arithmetic average, HG – Homogeneity Groups

Table 3. Multiple variance analysis results regarding the effect of the wood type, joining technique and adhesive type on diagonal tensile strength

<table>
<thead>
<tr>
<th>Variance source</th>
<th>Degree of freedom</th>
<th>Sum of squares</th>
<th>Average of squares</th>
<th>F value</th>
<th>p &lt; 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood type (A)</td>
<td>2</td>
<td>0.963</td>
<td>0.481</td>
<td>95.0677</td>
<td>0.0000</td>
</tr>
<tr>
<td>Adhesive type (B)</td>
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<td>6.054</td>
<td>6.054</td>
<td>1195.5063</td>
<td>0.0000</td>
</tr>
<tr>
<td>A × B</td>
<td>2</td>
<td>0.367</td>
<td>0.183</td>
<td>36.2288</td>
<td>0.0000</td>
</tr>
<tr>
<td>Joining technique (C)</td>
<td>5</td>
<td>1.260</td>
<td>0.252</td>
<td>49.7501</td>
<td>0.0000</td>
</tr>
<tr>
<td>A × C</td>
<td>10</td>
<td>0.297</td>
<td>0.030</td>
<td>5.8654</td>
<td>0.0000</td>
</tr>
<tr>
<td>B × C</td>
<td>5</td>
<td>1.043</td>
<td>0.209</td>
<td>41.1946</td>
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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)
Impacts of the dovetail tooth angle on diagonal tensile strength...

According to the wood type, the highest diagonal tensile strength has been found in the European oak (0.6951 N \times \text{mm}^{-2}), the lowest has been found in the Scotch Pine (0.5083 N \times \text{mm}^{-2}); according to the joining technique, the highest diagonal tensile strength has been found at 78° (0.7465 N \times \text{mm}^{-2}), the lowest has been found in the dowel joint (0.4349 N \times \text{mm}^{-2}); according to the adhesive type, the highest diagonal tensile strength has been found in PVAc (0.8277 N \times \text{mm}^{-2}), the lowest has been found in D-VTKA (0.4176 N \times \text{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.

In terms of wood type and joining technique, the highest diagonal tensile strength has been found in B+II (0.8080 N \times \text{mm}^{-2}), the lowest has been found in S+V

<table>
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<tr>
<th>Wood type + joining technique*</th>
<th>X</th>
<th>HG</th>
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<tbody>
<tr>
<td>B+I</td>
<td>0.7903</td>
<td>A</td>
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<tr>
<td>B+II</td>
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<tr>
<td>B+III</td>
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<td>B</td>
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<td>B+IV</td>
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<td>B+VI</td>
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<td>B</td>
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<td>O+II</td>
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<td>A</td>
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<tr>
<td>O+III</td>
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<td>O+D</td>
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<td>S+P</td>
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<td>S+D</td>
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*LSD: 0.06989, **LSD: 0.04035, ***LSD: 0.05706
See explanations for Table 3.

Table 5. Diagonal tensile strength Duncan test results

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<th>Process type</th>
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<th>HG*</th>
<th>process type</th>
<th>X</th>
<th>HG*</th>
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*LSD: 0.09883
(0.3747 N × mm⁻²); in terms of wood and adhesive type, the highest diagonal tensile strength has been found in O+P+II (1.184 N × mm⁻²), and the lowest has been found in S+D+V (0.2687 N × mm⁻²). With respect to type of wood, joining technique, and adhesive type, the highest diagonal tensile strength has been found in European oak + PVAc (0.9534 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° dovetail joint (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.

**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).

**References**


Impacts of the dovetail tooth angle on diagonal tensile strength...


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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-gain surface connection in furniture products, offering these products with greater resistance to bending forces and warping than mortise-tenon joints. For both the heartwood and sapwood of *E. cylindricum*, 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.

Keywords: adhesive, fibre diameter, furniture, joinery, joint strength, structural products

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

Kwadwo Boakye BOADU\(^1\), Charles ANTWI-BOASIAKO\(^1\)

\(^1\)Kwame Nkrumah University of Science and Technology, Faculty of Renewable Natural Resources, Department of Wood Science and Technology, Kumasi, Ghana

Abstract. 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 *Entandrophragma cylindricum* 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 *E. cylindricum*, 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.

Keywords: adhesive, fibre diameter, furniture, joinery, joint strength, structural products
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. (2013) 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.

**METHODS AND MATERIALS**

**SAMPLING OF *E. CYLINDRICUM***

*E. cylindricum* logs (30–40 years and 60–80 cm 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 10 mm 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 (IAWA, 1989) and protected with cover slips for viewing under the Micromaster Infinity Optics microscope (10× eye piece, objective lens and a measuring scale of 200 μm). Photomicrographs of straight and unbroken fibres (Fig. 1) were obtained under a set magnification (40×) and measuring scale (50 μm). Their lengths, diameters, lumen diameter and double wall thicknesses were measured from a total of 300 fibres.

**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 (497.2 × 51 × 30 mm) and rail (355 × 64 × 30 mm) of a standard working chair. The positions of mortise (44 × 10 × 31.8 mm) and tenon (31.8 × 44 × 10 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 (Fig. 2) at a rate of 3 mm/sec. The maximum load (F) that caused rupture at the...
The linear relationship between fibre morphological characteristics of *Entandrophragma cylindricum*...

The face of the joint was recorded and the ultimate strength of the joint \(f\)(Nm) calculated (Tankut, 2007):

\[ f = F \times L \]

where:

\[ L = \text{distance between the point of application of the load and the face of the joint.} \]

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.

RESULTS AND DISCUSSION

FIBRE MORPHOLOGICAL CHARACTERISTICS

Fibre dimensions for the heartwood of *E. cylindricum* [e.g. 20.3 μm (fibre diameter); 9.8 ±0.1 μm (double wall thickness)] were greater than those of the sapwood [e.g. 19.7 ±0.6 μm (fibre diameter); 8.9 ±0.9 μm (double wall thickness)], except for the lumen diameter. The differences were not significant \((p < 0.05)\) (Fig. 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) 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. 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 lumens 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.

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 and Antwi-Boasiako (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

![Fig. 3. Fibre morphological characteristics of the heartwood and sapwood of *E. cylindricum* (Bars = standard error)](image-url)
Fig. 4. Correlation between fibre diameter and strength of joint from *E. cylindricum* heartwood

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

Fig. 6. Correlation between fibre diameter and strength of joint from *E. cylindricum* sapwood
The linear relationship between fibre morphological characteristics of Entandrophragma cylindricum...

... 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 (Fig. 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 maprouneafolia* 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.

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

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<td>Strength of joints from the sapwood</td>
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</table>

### 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

Institute for Geo-information Science and Earth Observation (The Netherland) and Kwame Nkrumah University of Science and Technology (Ghana).


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INTRODUCTION

Furniture trade is directly related to the condition and stability of the countries. However, the last decade has shown uncertainties in international and domestic markets all over the world. As Turkey, the rapid changes and war situations around the country, and particularly, the attempted coup perpetrated by the proponents of the Gülenist Terror Group (FETÖ) exactly one year ago was no exception. In fact, the unorthodox coup attempt last July left even a heavier toll on the political, social, cultural and economic fabric of Turkey, as it was organized by a secretive, messianic order that had infiltrated state institutions, corporations, and civil society institutions at the same time. On the other side, the Middle East and North Africa (MENA), constitutes a critically important geographical entity that has been both the cradle of civilizations and Abrahamic religions as well as hegemonic conflicts throughout history. Especially over the course of the last two centuries, the region turned into a microcosm of all sorts of cultural, sectarian, ideological, geo-strategic, geo-economic and distributional conflicts. Today, as the major global powers continue to compete across the Atlantic, Eurasian and Pacific axes for unrivalled technological competitiveness and sustained supremacy in the knowledge economy, the Middle East continues to resist the flow of history amid existential conflicts, civil wars, terrorist attacks, human tragedies, forced migrations and a truly neo-medieval order (Gur et al., 2017). Furniture trade is directly related to the condition and stability of the countries. However, the last decade has shown uncertainties in international and domestic markets all over the world. The high furniture trade for Turkey is carried out to the Middle East, North Africa, which began to take a new shape with the Arab spring, near neighbors and Russia. The relationships and political situations seem to affect Turkey furniture industry.

The Turkish furniture industry has become a branch of information and capital weighted manufacture by the accession of medium and large scale enterprises. Being in a quick development and transition period, the sector presents a potential in domestic and foreign markets in the direction of the factors such as brands, quality, small – large scale enterprises in the sector, geographical position, general growth policy of the country, young population, improvement of national income per capita. Oriented to domestic and foreign markets, the Turkish furniture sector has a wide range of production for panel furniture, solid furniture, sofa, seating group, modular furniture (kitchen, bathroom, office, bedroom), garden furniture, furniture sections and parts, vehicle furniture, hospital furniture, hotel furniture, accessories, and the sector is located amongst the seldom sectors with limited import product/material use and high added value. Being one of the sectors in Turkey with the highest employment capacity, the sector is distributed Countrywide to any province and district. After the 1980’ies, economical and social development in Turkey has increased the quality, functional and modern furniture demand particularly in metropolises and accelerated to boost the sector and Country’s economy.

AN OVERVIEW OF GLOBAL FURNITURE COMPETITIVENESS IN FURNITURE INDUSTRIES WITH REFERENCE TO TURKEY

Hamza ÇINAR1, Nihat DONGEL1
1Gazi University, Technology Faculty, Wood Products Industrial Engineering Department, Ankara, Turkey

Abstract. Worldwide furniture production is approximately 463 billion dollar, 181 billion of its exports, while 170 billion dollar has been mentioned in trade in imports. Consumption is 457 billion dollar. A total of 4.0 trillion dollars for production and 3.6 trillion dollars for consumption in the last 10 years have created significant volumes in the world furniture. The last decade performance challenges the future likely to be 1 trillion dollar only for the production of 2050. This study gives a general outline of the furniture industry and discusses international trade of furniture in major markets in 2016 and 2017. All the leading markets have shown a greater degree of openness in the last decade and the furniture industry has become one of the major sectors that need to be analyzed on the basis of global considerations. As a result, naturally, there are important differences in the degree of openness of the various national markets, differences that depend on the history of the furniture industry, the structural conditions and the comparative advantage of the manufacturers in each country. In specific cases, the Turkish furniture industry shows a strong possibility for entering among the first 10 top furniture producers in the World furniture market.

Keywords: worldwide furniture trade, turkish furniture industry, competitiveness

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METHODS AND MATERIALS

The paper intends to examine the trend line of Turkish furniture in export-import; looks for the performance in the case of regional and political situations and gives its ranking position in the worldwide furniture markets. The data was obtained from ITC, Trade map, and Trade statistics for international business development and Turkish Statistics Institute.

RESULTS AND DISCUSSION

Number of enterprise and employment in the Turkish furniture industry

The number of enterprises and employment levels in the furniture industry by years follows a bumpy course. The number of enterprises and employment within the furniture sector are given in Table 1.

According to Table 1, it is possible to say that there is a sharp increase from 34.438 to 43.057 for enterprises, respectively 25% performances; from 115.898 to 177.944 for employees respectively 53% performances between 2009 and 2015. In other words, each year the increase is between 8.83% and 11.04% while 2010 and 2011 show a decline which seems to be noteworthy.

CAPACITY UTILIZATION

Evaluating the production capacity ratios, it is observed that the sector has difficulties to operate in full capacity in last year. Capacity rates for furniture production are given in Table 2.

The years of production capacity utilization ratios are parallel to each other except for 2009 and 2013. A decline is observed in 2015 when the capacity utilization has increased in overall manufacturing. According to the last eight years’ evaluation, 70% capacity utilization average was underestimated, but this value was below the general production capacity utilization rate of 75%. It can be argued that the current capacity utilization rates of the sector are below the rates of competitors. In TOBB Report (2016), the reasons for not working full capacity in the furniture sector were analyzed as follows; inadequate domestic demand, inadequate external demand, employee problems, raw material inadequacy, inadequate financing and other reasons. However, in recent years, growth in the construction sector in Turkey is thought to have increased domestic demand.

TURKEY EXPORT AND IMPORT

Turkey’s furniture export, performance and share to the 25 countries and its total volume is given in Table 3.

In 2016, Turkey’s furniture export is approximately 2.23 billion dollar to 225 countries. There is a notable increase of 8.3% to 17.2% between 2011 and 2014. However, following two years, the export trend line shows a decrease too. Country’s export is almost made to first 25% with 83.4% share. The export values to Arabic countries and near neighbours are given Table 4 and 5.

Table 1. Number of enterprise and employment

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Enterprises (general)</th>
<th>Rate to general production (%)</th>
<th>Employees (general)</th>
<th>Rate to general employees (%)</th>
<th>Annual trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>34.438</td>
<td>8,83</td>
<td>115.898</td>
<td>3.11</td>
<td>-0.03</td>
</tr>
<tr>
<td>2010</td>
<td>34.427</td>
<td>8.83</td>
<td>97.105</td>
<td>2.61</td>
<td>-16.2</td>
</tr>
<tr>
<td>2011</td>
<td>31.089</td>
<td>7.97</td>
<td>120.580</td>
<td>3.24</td>
<td>-16.2</td>
</tr>
<tr>
<td>2012</td>
<td>35.883</td>
<td>9.20</td>
<td>140.077</td>
<td>3.78</td>
<td>24.2</td>
</tr>
<tr>
<td>2013</td>
<td>39.036</td>
<td>10.01</td>
<td>159.246</td>
<td>4.27</td>
<td>16.7</td>
</tr>
<tr>
<td>2014</td>
<td>41.048</td>
<td>10.53</td>
<td>164.723</td>
<td>4.42</td>
<td>13.1</td>
</tr>
<tr>
<td>2015</td>
<td>43.057</td>
<td>11.04</td>
<td>177.944</td>
<td>4.78</td>
<td>3.4</td>
</tr>
</tbody>
</table>


Table 2. Capacity rates in furniture production

<table>
<thead>
<tr>
<th>Industry</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>Last 8 years average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furniture</td>
<td>66.9</td>
<td>70.4</td>
<td>72.6</td>
<td>69.8</td>
<td>71.4</td>
<td>71.7</td>
<td>70.0</td>
<td>71.4</td>
<td>70.65</td>
</tr>
<tr>
<td>Annual change</td>
<td>-2.39</td>
<td>4.93</td>
<td>3.03</td>
<td>-4.01</td>
<td>2.24</td>
<td>0.42</td>
<td>-1.65</td>
<td>2.0</td>
<td>-0.03</td>
</tr>
<tr>
<td>General production</td>
<td>65.2</td>
<td>72.7</td>
<td>75.4</td>
<td>74.2</td>
<td>74.6</td>
<td>74.3</td>
<td>77.0</td>
<td>77.4</td>
<td>75.16</td>
</tr>
<tr>
<td>Annual change</td>
<td>-17.6</td>
<td>10.31</td>
<td>3.58</td>
<td>-1.61</td>
<td>0.53</td>
<td>0.40</td>
<td>3.21</td>
<td>0</td>
<td>-0.99</td>
</tr>
</tbody>
</table>

In 2014, furniture exports in neighbouring countries showed an increase of 8.1%. However, there were decreases of 22% and 4.8% in 2015 and 2016, respectively. The most striking decline is Russia, which is continuing on a regular basis. With the export of 100 million dollars to Russia in 2013, the export value of each year has fallen and 2016 with an export volume of approximately 16 million dollars. Nearly one-third of the country’s exports are made to neighbouring countries. On the other hand, the last two years show a decrease with 22% nearby countries, 3.6% and 5.9% for Arabic countries. According to the data, the market size of the nearby countries and Arab countries is around 30 billion dollars. Although 70% of the country’s trade is done in these countries, only 1.7 billion dollars can be benefited from this market. It is recommended that the Turkish furniture industry, whose objectives are to be developed, should develop policies for the development of trade in neighbouring and Arab countries. It can be said that the development of relations with neighbouring and Arab countries will facilitate the goals of 2023. However, in recent years, the political situations and uncertainties in the region has pushed the sector to distant markets such as the USA, England, France. In these markets, the profitability of the enterprises decreased and the cost of sales increased. There is a downward trend ranging from 13.2%; 14.2% and 28.8% in 2012, 2015 and 2016. The furniture import for 2016 is worth about $ 605 million from 130 countries. Despite the fact that approximately 91% of the imports are made in the first 25 countries, the number of importing countries has increased in recent years. Principle five countries; China, Italy, Germany, Poland and France. It is significant that 35% of Turkey's imports are made from China. Countries in serious decline are China, Vietnam, Russia, Egypt, Japan, and Turkey.

### Table 3. Turkey furniture export for countries

<table>
<thead>
<tr>
<th>Countries</th>
<th>Years (1.000 ABD $)</th>
<th>2015–2016 performance</th>
<th>2011–2016 cumulative share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>2012</td>
<td>2013</td>
</tr>
<tr>
<td>Iraq</td>
<td>286,448</td>
<td>396,203</td>
<td>455,149</td>
</tr>
<tr>
<td>Germany</td>
<td>168,837</td>
<td>152,839</td>
<td>143,940</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>42,623</td>
<td>66,677</td>
<td>84,099</td>
</tr>
<tr>
<td>France</td>
<td>91,390</td>
<td>85,444</td>
<td>105,689</td>
</tr>
<tr>
<td>USA</td>
<td>26,823</td>
<td>30,335</td>
<td>38,946</td>
</tr>
<tr>
<td>Libya</td>
<td>17,494</td>
<td>167,211</td>
<td>237,097</td>
</tr>
<tr>
<td>England</td>
<td>40,777</td>
<td>49,672</td>
<td>57,597</td>
</tr>
<tr>
<td>BAE</td>
<td>18,267</td>
<td>20,865</td>
<td>41,028</td>
</tr>
<tr>
<td>Romania</td>
<td>19,490</td>
<td>18,536</td>
<td>27,977</td>
</tr>
<tr>
<td>Israel</td>
<td>23,300</td>
<td>23,419</td>
<td>30,506</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>108,470</td>
<td>131,495</td>
<td>166,777</td>
</tr>
<tr>
<td>Holland</td>
<td>56,552</td>
<td>53,156</td>
<td>46,351</td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>76,134</td>
<td>61,211</td>
<td>87,962</td>
</tr>
<tr>
<td>Algeria</td>
<td>13,828</td>
<td>14,272</td>
<td>18,827</td>
</tr>
<tr>
<td>Italy</td>
<td>34,100</td>
<td>30,345</td>
<td>33,895</td>
</tr>
<tr>
<td>Iran</td>
<td>110,754</td>
<td>71,527</td>
<td>31,354</td>
</tr>
<tr>
<td>Spain</td>
<td>15,264</td>
<td>11,946</td>
<td>22,353</td>
</tr>
<tr>
<td>Belgium</td>
<td>25,440</td>
<td>24,621</td>
<td>22,053</td>
</tr>
<tr>
<td>Georgia</td>
<td>28,540</td>
<td>32,126</td>
<td>30,891</td>
</tr>
<tr>
<td>Qatar</td>
<td>9,657</td>
<td>11,375</td>
<td>18,765</td>
</tr>
<tr>
<td>NCRT</td>
<td>22,526</td>
<td>21,512</td>
<td>24,036</td>
</tr>
<tr>
<td>Austria</td>
<td>25,475</td>
<td>22,634</td>
<td>25,392</td>
</tr>
<tr>
<td>Russia</td>
<td>49,111</td>
<td>59,347</td>
<td>100,774</td>
</tr>
<tr>
<td>Egypt</td>
<td>14,035</td>
<td>20,494</td>
<td>23,176</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>19,552</td>
<td>24,318</td>
<td>30,221</td>
</tr>
<tr>
<td>List total</td>
<td>1,344,887</td>
<td>1,601,580</td>
<td>1,904,855</td>
</tr>
<tr>
<td>225 countries</td>
<td>1,658,376</td>
<td>1,898,570</td>
<td>2,237,246</td>
</tr>
<tr>
<td>Annual change (%)</td>
<td>17.2</td>
<td>14.5</td>
<td>17.8</td>
</tr>
</tbody>
</table>

TÜİK, 2017b; Trademap, 2017a.
Table 4. Turkey furniture export for Arabic countries

<table>
<thead>
<tr>
<th>Countries</th>
<th>Years (1,000 ABD $)</th>
<th>2015</th>
<th>2016</th>
<th>S (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2014</td>
<td>2015</td>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>Iraq</td>
<td>481,160</td>
<td>428,651</td>
<td>420,228</td>
<td>–2.0</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>116,296</td>
<td>165,242</td>
<td>156,375</td>
<td>–5.4</td>
</tr>
<tr>
<td>Libya</td>
<td>197,656</td>
<td>137,565</td>
<td>80,368</td>
<td>–41.6</td>
</tr>
<tr>
<td>BAE</td>
<td>40,835</td>
<td>58,050</td>
<td>62,072</td>
<td>6.9</td>
</tr>
<tr>
<td>Algeria</td>
<td>37,372</td>
<td>39,189</td>
<td>45,293</td>
<td>15.6</td>
</tr>
<tr>
<td>Qatar</td>
<td>20,480</td>
<td>21,659</td>
<td>27,162</td>
<td>25.4</td>
</tr>
<tr>
<td>Morocco</td>
<td>16,548</td>
<td>18,679</td>
<td>23,348</td>
<td>25.0</td>
</tr>
<tr>
<td>Jordan</td>
<td>13,420</td>
<td>13,062</td>
<td>19,011</td>
<td>45.5</td>
</tr>
<tr>
<td>Lebanon</td>
<td>14,406</td>
<td>14,712</td>
<td>16,878</td>
<td>14.7</td>
</tr>
<tr>
<td>Kuwait</td>
<td>14,523</td>
<td>16,282</td>
<td>16,334</td>
<td>0.3</td>
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<tr>
<td>Oman</td>
<td>5,947</td>
<td>10,554</td>
<td>15,995</td>
<td>51.6</td>
</tr>
<tr>
<td>Egypt</td>
<td>27,820</td>
<td>28,870</td>
<td>14,204</td>
<td>–50.8</td>
</tr>
<tr>
<td>Bahrain</td>
<td>5,504</td>
<td>7,464</td>
<td>7,137</td>
<td>–4.4</td>
</tr>
<tr>
<td>Sudan</td>
<td>3,776</td>
<td>5,574</td>
<td>5,635</td>
<td>1.1</td>
</tr>
<tr>
<td>Tunisia</td>
<td>6,452</td>
<td>5,508</td>
<td>4,797</td>
<td>–12.9</td>
</tr>
<tr>
<td>Syria</td>
<td>8,496</td>
<td>6,090</td>
<td>3,051</td>
<td>–49.9</td>
</tr>
<tr>
<td>Somali</td>
<td>1,436</td>
<td>3,502</td>
<td>2,964</td>
<td>–15.4</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>1,712</td>
<td>1,694</td>
<td>2,177</td>
<td>28.5</td>
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<tr>
<td>Yemen</td>
<td>5,885</td>
<td>873</td>
<td>1,938</td>
<td>122.0</td>
</tr>
<tr>
<td>Oman</td>
<td>5,947</td>
<td>10,554</td>
<td>15,995</td>
<td>51.6</td>
</tr>
<tr>
<td>List total</td>
<td>1,021,243</td>
<td>984,377</td>
<td>926,597</td>
<td>–5.9</td>
</tr>
</tbody>
</table>

Annual (%) 7.8 –3.6 –5.9 –

P – Performance, S – Share

Table 5. Turkey furniture export for near neighbours

<table>
<thead>
<tr>
<th>Countries</th>
<th>Years (1,000 ABD $)</th>
<th>2015</th>
<th>2016</th>
<th>S (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2014</td>
<td>2015</td>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>Iraq</td>
<td>481,160</td>
<td>428,551</td>
<td>420,228</td>
<td>–2.0</td>
</tr>
<tr>
<td>Romania</td>
<td>47,995</td>
<td>44,693</td>
<td>56,678</td>
<td>26.8</td>
</tr>
<tr>
<td>Israel</td>
<td>33,077</td>
<td>36,962</td>
<td>54,837</td>
<td>48.4</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>178,007</td>
<td>102,189</td>
<td>51,379</td>
<td>–49.7</td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>99,871</td>
<td>83,444</td>
<td>45,466</td>
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</tr>
<tr>
<td>Iran</td>
<td>39,428</td>
<td>41,308</td>
<td>40,774</td>
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</tr>
<tr>
<td>Georgia</td>
<td>43,842</td>
<td>30,801</td>
<td>30,208</td>
<td>–1.9</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>15,775</td>
<td>16,116</td>
<td>25,959</td>
<td>61.1</td>
</tr>
<tr>
<td>Greece</td>
<td>22,158</td>
<td>19,724</td>
<td>25,147</td>
<td>27.5</td>
</tr>
<tr>
<td>NCRT</td>
<td>27,491</td>
<td>–</td>
<td>23,718</td>
<td>–</td>
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<tr>
<td>Austria</td>
<td>22,040</td>
<td>19,849</td>
<td>23,310</td>
<td>17.4</td>
</tr>
<tr>
<td>Russia</td>
<td>77,856</td>
<td>31,595</td>
<td>15,894</td>
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<tr>
<td>Uzbekistan</td>
<td>5,181</td>
<td>4,051</td>
<td>13,961</td>
<td>244.6</td>
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<tr>
<td>Macedonia</td>
<td>12,880</td>
<td>12,295</td>
<td>12,454</td>
<td>1.3</td>
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<tr>
<td>Kazakhstan</td>
<td>29,725</td>
<td>21,896</td>
<td>11,184</td>
<td>–48.9</td>
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<tr>
<td>Ukraine</td>
<td>14,801</td>
<td>6,145.00</td>
<td>8,159</td>
<td>32.8</td>
</tr>
<tr>
<td>List total</td>
<td>1,086,626</td>
<td>1,175,025</td>
<td>916,093</td>
<td>872,125</td>
</tr>
</tbody>
</table>

Annual % – 8.1 –22.0 –4.8 –

Explanations and source as for Table 4.
Table 6. Turkey furniture import for countries

<table>
<thead>
<tr>
<th>Countries</th>
<th>Years (1.000 ABD $)</th>
<th>2015–2016 performance share</th>
<th>2011–2016 cumulative share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>2012</td>
<td>2013</td>
</tr>
<tr>
<td>Chile</td>
<td>343.857</td>
<td>297.720</td>
<td>333.947</td>
</tr>
<tr>
<td>Italy</td>
<td>93.429</td>
<td>83.514</td>
<td>118.818</td>
</tr>
<tr>
<td>Germany</td>
<td>87.802</td>
<td>76.248</td>
<td>103.658</td>
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<tr>
<td>Poland</td>
<td>51.446</td>
<td>48.646</td>
<td>56.753</td>
</tr>
<tr>
<td>France</td>
<td>42.482</td>
<td>38.614</td>
<td>42.929</td>
</tr>
<tr>
<td>Spain</td>
<td>39.841</td>
<td>30.707</td>
<td>44.914</td>
</tr>
<tr>
<td>Romania</td>
<td>27.122</td>
<td>26.868</td>
<td>30.781</td>
</tr>
<tr>
<td>Indonesia</td>
<td>21.438</td>
<td>16.189</td>
<td>17.194</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>8.120</td>
<td>6.060</td>
<td>9.648</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>8.430</td>
<td>9.158</td>
<td>10.800</td>
</tr>
<tr>
<td>South Korea</td>
<td>8.127</td>
<td>5.236</td>
<td>5.288</td>
</tr>
<tr>
<td>Malaysia</td>
<td>8.422</td>
<td>6.983</td>
<td>8.232</td>
</tr>
<tr>
<td>Slovakia</td>
<td>10.386</td>
<td>7.199</td>
<td>6.443</td>
</tr>
<tr>
<td>Denmark</td>
<td>5579</td>
<td>4.073</td>
<td>5.733</td>
</tr>
<tr>
<td>Holland</td>
<td>4.712</td>
<td>4.730</td>
<td>4.698</td>
</tr>
<tr>
<td>Austria</td>
<td>7.773</td>
<td>6.195</td>
<td>5.869</td>
</tr>
<tr>
<td>Belgium</td>
<td>2.331</td>
<td>2.365</td>
<td>3.265</td>
</tr>
<tr>
<td>List total</td>
<td>881.815</td>
<td>763.927</td>
<td>906.428</td>
</tr>
<tr>
<td>130 countries</td>
<td>941.391</td>
<td>817.334</td>
<td>968.655</td>
</tr>
<tr>
<td>Annual change (%)</td>
<td>21.6</td>
<td>–13.2</td>
<td>18.5</td>
</tr>
</tbody>
</table>

Source: Trademap, 2017b; TÜİK, 2017c.

Fig. 1. Foreign trade balance

and Indonesia. The factor affecting the fall in imports from these countries is estimated to be the increase in taxes imposed on products imported from the Far East in 2015. However, the number of products imported from countries such as Romania, Sweden, Hungary, Britain is also seen to decrease. Increasingly remarkable countries are Malaysia, Bulgaria, Slovakia and Czech Rep. Fig. 1 shows the foreign Trade Balance for Turkey’s export and import since 1997.
WORLDWIDE PRODUCTION, CONSUMPTION, EXPORT, IMPORT AND POSITION OF TURKEY

World furniture production is about 473 billion US dollars in 2015, consumption is 466 billion dollars. While furniture production was approximately 463 billion dollars, 172 billion exports and 171 billion dollars were the subject of foreign trade in imports. The values for 2016 were 173 for exports and 174 billion for imports. In the last 12 years, production and consumption amounted to 4.5 trillion dollars. The performance of the last 12 years is likely to be 1 trillion dollars in the furniture market in the next 2030.

With 164 billion dollars in volume, China produces four quarters of the world furniture production alone and consumes 114 billion dollars in its domestic market. The second largest producer is the US with a volume of 50.75 billion dollars. However, production is not able to meet its consumption and it has given more than 27 billion dollars deficit in half of its production. Japan, France, Britain, India, Canada, Germany are the other countries that produce less than their consumption. The first 25 countries are predominantly in the world furniture trade. It can be said that 70 countries in this market are actively involved with about 200 companies. However, when evaluated as production and consumption, 17 countries are important producers and consumers of the market.

China is clearly the leading country in world furniture exports with its share of 35%. China is followed by Germany, Italy, Poland and USA respectively. While Turkey ranks 14th in the world market, it is the 6th most exporting country in Europe. Considering the decreasing and stagnating exports of European furniture producers and the increasing exports of far eastern countries, it can be said that the production center is moving towards the east. However, despite continuing determinations in recent years, the extreme increase in labor prices in China has influenced this country’s competitive pricing power. In particular, the increase in countries such as Vietnam, Taiwan (Taipei) gives the impression that Chinese furniture producers are leading these countries. Again, the increases in Sweden, Poland and Lithuania are noteworthy.

In 2016, the top 25 countries in the world furniture imports have realized 145 billion dollars of imports of about 174 billion dollars with an 84% share. The first five rank importers, according to the order of shares in the world; The United States (29.8%), Germany (9.2%), Britain (5.4%), France (4.5%) and Canada (4.0%). Turkey has experienced a decline of about 29% in volume by 605 million in 2016, the most serious decline in its history. Turkey’s import volume is low and there is a negative incompatibility with the export target, which is due to high labor costs.

### Table 7. Worldwide production and consumption

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Name</td>
<td>mln $</td>
<td>%</td>
<td>mln $</td>
</tr>
<tr>
<td>2004</td>
<td>284</td>
<td>China</td>
<td>164.781</td>
<td>34.8</td>
<td>114.256</td>
</tr>
<tr>
<td>2005</td>
<td>291</td>
<td>USA</td>
<td>50.705</td>
<td>10.7</td>
<td>77.715</td>
</tr>
<tr>
<td>2006</td>
<td>325</td>
<td>Germany</td>
<td>19.651</td>
<td>4.2</td>
<td>21.908</td>
</tr>
<tr>
<td>2007</td>
<td>340</td>
<td>Italy</td>
<td>17.131</td>
<td>3.6</td>
<td>9.154</td>
</tr>
<tr>
<td>2008</td>
<td>350</td>
<td>India</td>
<td>15.908</td>
<td>3.4</td>
<td>16.251</td>
</tr>
<tr>
<td>2009</td>
<td>352</td>
<td>Poland</td>
<td>10.966</td>
<td>2.3</td>
<td>3.683</td>
</tr>
<tr>
<td>2010</td>
<td>341</td>
<td>England</td>
<td>9.051</td>
<td>1.9</td>
<td>14.982</td>
</tr>
<tr>
<td>2011</td>
<td>376</td>
<td>Japan</td>
<td>8.945</td>
<td>1.9</td>
<td>13.416</td>
</tr>
<tr>
<td>2012</td>
<td>434</td>
<td>Canada</td>
<td>8.157</td>
<td>1.7</td>
<td>10.227</td>
</tr>
<tr>
<td>2013</td>
<td>446</td>
<td>France</td>
<td>7.634</td>
<td>1.6</td>
<td>12.000</td>
</tr>
<tr>
<td>2014</td>
<td>463</td>
<td>Vietnam</td>
<td>7.538</td>
<td>1.6</td>
<td>1.271</td>
</tr>
<tr>
<td>2015</td>
<td>473</td>
<td>Turkey</td>
<td>5.749</td>
<td>1.2</td>
<td>4.513</td>
</tr>
<tr>
<td>2016</td>
<td>–</td>
<td>Brasilia</td>
<td>5.423</td>
<td>1.1</td>
<td>5.397</td>
</tr>
<tr>
<td>2017</td>
<td>–</td>
<td>Malaysia</td>
<td>3.572</td>
<td>0.8</td>
<td>1.801</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>Russia</td>
<td>3.155</td>
<td>0.7</td>
<td>4.984</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>Mexico</td>
<td>2.860</td>
<td>0.6</td>
<td>1.736</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>South Africa</td>
<td>1.177</td>
<td>0.2</td>
<td>1.392</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>List total</td>
<td>342.403</td>
<td>72.3</td>
<td>314.686</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>70 countries</td>
<td>405.569</td>
<td>83.7</td>
<td>387.509</td>
</tr>
<tr>
<td>Total</td>
<td>4.475</td>
<td>General total</td>
<td>475.435</td>
<td>100.0</td>
<td>466.342</td>
</tr>
</tbody>
</table>

Source: CSIL, 2017
An overview of global furniture competitiveness in furniture industries...

increases and decreases in the period. It is thought that the tax rate brought to eastern products by 50% in 2015 will have a significant impact on Turkey's furniture imports.

**CONCLUSIONS**

In light of the data compiled in this study, Turkish furniture sector is considered as an effective industry in both local and global markets. The sector is the 12th biggest producers with the share of 1.2% world furniture production, the 14th in the world and 6th in European ranking with the export capacity of 2.4 billion dollar to 225 countries and the 27th in the world and 17th in Europe with import capacity of 605 million from 130 countries. Political situations and uncertainties in the region affect the export and import of furniture. Particularly, in the last years the industry seems to look for distant markets rather than nearby countries.

*Table 8. World furniture export, import and position of Turkey – product groups 9401–9404*

<table>
<thead>
<tr>
<th>No</th>
<th>Exporters</th>
<th>World export</th>
<th>World import</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Years (1.000 $)</td>
<td>Share in 2016 (%)</td>
<td>No</td>
</tr>
<tr>
<td>1</td>
<td>China</td>
<td>61,468,045</td>
<td>56,930,558</td>
</tr>
<tr>
<td>2</td>
<td>Germany</td>
<td>12,703,667</td>
<td>13,179,033</td>
</tr>
<tr>
<td>3</td>
<td>Italy</td>
<td>10,732,418</td>
<td>10,793,826</td>
</tr>
<tr>
<td>4</td>
<td>Poland</td>
<td>9,993,781</td>
<td>10,646,131</td>
</tr>
<tr>
<td>5</td>
<td>USA</td>
<td>8,648,504</td>
<td>8,477,672</td>
</tr>
<tr>
<td>6</td>
<td>Mexico</td>
<td>7,798,914</td>
<td>8,021,859</td>
</tr>
<tr>
<td>7</td>
<td>Vietnam</td>
<td>5,206,474</td>
<td>7,813,425</td>
</tr>
<tr>
<td>8</td>
<td>Canada</td>
<td>4,388,435</td>
<td>4,681,231</td>
</tr>
<tr>
<td>9</td>
<td>Czech Rep.</td>
<td>3,532,246</td>
<td>3,901,724</td>
</tr>
<tr>
<td>10</td>
<td>England</td>
<td>2,747,181</td>
<td>2,821,575</td>
</tr>
<tr>
<td>11</td>
<td>France</td>
<td>2,694,856</td>
<td>2,988,617</td>
</tr>
<tr>
<td>12</td>
<td>Malaysia</td>
<td>2,428,923</td>
<td>2,387,145</td>
</tr>
<tr>
<td>13</td>
<td>Romania</td>
<td>2,285,444</td>
<td>2,443,834</td>
</tr>
<tr>
<td>14</td>
<td>Turkey</td>
<td>2,256,793</td>
<td>2,234,221</td>
</tr>
<tr>
<td>15</td>
<td>Holland</td>
<td>2,233,933</td>
<td>3,032,631</td>
</tr>
<tr>
<td>16</td>
<td>Denmark</td>
<td>2,214,049</td>
<td>2,302,625</td>
</tr>
<tr>
<td>17</td>
<td>Spain</td>
<td>2,095,555</td>
<td>2,407,293</td>
</tr>
<tr>
<td>18</td>
<td>Sweden</td>
<td>2,005,824</td>
<td>2,077,820</td>
</tr>
<tr>
<td>19</td>
<td>Indonesia</td>
<td>1,752,209</td>
<td>1,652,357</td>
</tr>
<tr>
<td>20</td>
<td>Portugal</td>
<td>1,738,053</td>
<td>1,864,530</td>
</tr>
<tr>
<td>21</td>
<td>Taiwan</td>
<td>1,634,390</td>
<td>1,584,787</td>
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<tr>
<td>22</td>
<td>Belgium</td>
<td>1,585,436</td>
<td>1,650,754</td>
</tr>
<tr>
<td>23</td>
<td>Latvia</td>
<td>1,567,857</td>
<td>1,656,993</td>
</tr>
<tr>
<td>24</td>
<td>Austria</td>
<td>1,316,557</td>
<td>1,428,998</td>
</tr>
<tr>
<td>25</td>
<td>Hungary</td>
<td>1,313,468</td>
<td>1,363,534</td>
</tr>
<tr>
<td>27</td>
<td>Turkey</td>
<td>850,599</td>
<td>605,772</td>
</tr>
</tbody>
</table>

List total 160,514,121 162,647,440 93.4 List total 141,794,886 145,238,529 83.9

World total 172,687,376 173,061,382 100.0 World total 168,019,445 174,012,624 100.0

Source: Trademap, 2017b.

We should like to acknowledge our dept to the Turkish Furniture Products Assembly Sector, the Union Of Chambers And Commodity Exchanges Of Turkey.

**References**


TCMB (2017). Capacity Utilization Rate-Manufacturing Industry (Weighted-NACE REV.2) – Central Bank (Annual,%). In Turkish: Kapasite Kullanım Oram-
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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.

**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 polyvinylsilicate (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 Fig. 1.

![Chair Models](image_url)
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 struggles 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 (Fig. 2) (Eckelman ve Erdil, 2001b).

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 and 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 Fig. 3.

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 and Erdil, 2001b).

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.

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.

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

<table>
<thead>
<tr>
<th>Property</th>
<th>( X_{\text{min}} )</th>
<th>( X_{\text{max}} )</th>
<th>( X_{\text{ort}} )</th>
<th>( v ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (%)</td>
<td>7.59</td>
<td>9.32</td>
<td>8.45</td>
<td>6.99</td>
</tr>
<tr>
<td>Density ((r = 8%)) (g/cm(^3))</td>
<td>0.64</td>
<td>0.73</td>
<td>0.68</td>
<td>8.12</td>
</tr>
<tr>
<td>Tension strength parallel to grain ((N/mm^2))</td>
<td>98.32</td>
<td>121.84</td>
<td>110.08</td>
<td>6.24</td>
</tr>
<tr>
<td>Compression strength parallel to grain ((N/mm^2))</td>
<td>55.68</td>
<td>65.49</td>
<td>60.58</td>
<td>5.22</td>
</tr>
<tr>
<td>Shear strength ((N/mm^2))</td>
<td>15.12</td>
<td>17.65</td>
<td>16.38</td>
<td>3.26</td>
</tr>
<tr>
<td>Bending strength ((N/mm^2))</td>
<td>109.00</td>
<td>152.00</td>
<td>130.00</td>
<td>11.71</td>
</tr>
<tr>
<td>Modulus of Elasticity ((N/mm^2))</td>
<td>11063</td>
<td>15082</td>
<td>13072.5</td>
<td>12.23</td>
</tr>
</tbody>
</table>

\( X_{\text{min}} \): min. value, \( X_{\text{max}} \): max value, \( X_{\text{ort}} \): average value, \( v \): variation coefficient

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

<table>
<thead>
<tr>
<th>Average (N)</th>
<th>Standard deviation</th>
<th>Variation coefficient (%)</th>
<th>Average + standard deviation (N)</th>
<th>Average – standard deviation (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1449.8</td>
<td>517.7</td>
<td>35.7</td>
<td>1967.5</td>
<td>932.1</td>
</tr>
</tbody>
</table>

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.

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.

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

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

<table>
<thead>
<tr>
<th>Loading</th>
<th>Inadequate strength</th>
<th>Weak strength</th>
<th>Medium strength</th>
<th>High strength</th>
</tr>
</thead>
</table>

The chart showing the evaluation of chair models for the classification made is shown in Fig. 4.

Fig. 4. Front-to-back loading performances of chair types

CLASSIFICATION RESULTS OF BACK TO FRONT TESTS

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

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
Determination of allowable design loads for wood chairs

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.

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.

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 1221 N for lateral performance values were accepted as "medium-strength" groups and evaluated as suitable for inhouse use. The 649 N value which is below the mean value, was the lower limit for weak strength chair models. Accordingly, chair models between 649 and 934 N 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 4. Results of statistical data obtained from back to front loading

<table>
<thead>
<tr>
<th>Average (N)</th>
<th>Standard deviation</th>
<th>Variation coefficient (%)</th>
<th>Average + standard deviation (N)</th>
<th>Average – standard deviation (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>895.9</td>
<td>271.2</td>
<td>30.2</td>
<td>1167.1</td>
<td>624.7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Loading</th>
<th>Inadequate strength</th>
<th>Weak strength</th>
<th>Medium strength</th>
<th>High strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back-to-front</td>
<td>≤624 N</td>
<td>625–895 N</td>
<td>896–1167 N</td>
<td>≥1168 N</td>
</tr>
</tbody>
</table>

The chart showing the evaluation of the chair models for the classification made is shown in Fig. 5.

![Fig. 5. Back-to-front loading performance of chair models](image)

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.

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 1221 N for lateral performance values were accepted as "medium-strength" groups and evaluated as suitable for inhouse use. The 649 N value which is below the mean value, was the lower limit for weak strength chair models. Accordingly, chair models between 649 and 934 N 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 6. Statistical data obtained by lateral loading results

<table>
<thead>
<tr>
<th>Average (N)</th>
<th>Standard deviation</th>
<th>Variation coefficient (%)</th>
<th>Average + standard deviation (N)</th>
<th>Average – standard deviation (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>935.1</td>
<td>285.7</td>
<td>30.5</td>
<td>1220.8</td>
<td>649.4</td>
</tr>
</tbody>
</table>
Table 7. Classification results according to lateral loading test results

<table>
<thead>
<tr>
<th>Loading</th>
<th>Inadequate strength</th>
<th>Weak strength</th>
<th>Medium strength</th>
<th>High strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral loading</td>
<td>≤648 N</td>
<td>649–934 N</td>
<td>935–1221 N</td>
<td>≥1222 N</td>
</tr>
</tbody>
</table>

The chart showing the evaluation of the chair models for the classification according to the new approach is shown in Fig. 6.

Fig. 6. 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.

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 932–1449 N are in low strength, 1450–1968 N 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 932–1449 N are in low strength, 1450–1968 N 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


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INTRODUCTION

Wood is becoming a more widely used material in wood-en 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 (Aydin 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 ration-

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)
al 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 (1974a) 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:

\[ F = 3.204D (L - D) : 75 S_x \]  

(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:

\[ f = 39(\text{IB})^{0.85}D^{0.5}(L - D/3)^{1.25} \]  

(2)

where:
- \( f \) = holding performance,
- \( \text{IB} \) = 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):

\[ f = 18.4(\text{IB})^{0.85}D^{0.5}(L - D/3)^{1.25} \]  

(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 melamine-formaldehyde adhesive for 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.

### 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 screws 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.
Comparison of the screw holding capacity of solid wood and laminated Veneer Lumber (LVL)...

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.

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 × 75 mm × 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 Fig. 1.

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 Fig. 2.

### 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.

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>
<thead>
<tr>
<th>Glue type</th>
<th>Press pressure (N/mm²)</th>
<th>Press temperature (°C)</th>
<th>Press duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVAc</td>
<td>0.8</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td>UF</td>
<td>1.2</td>
<td>110</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 2. Moisture content and specific gravity values of the specimens.

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Material type</th>
<th>Test MC (%)</th>
<th>SG (test MC)</th>
<th>SG (over dry)</th>
<th>SG (air dry*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkish beech</td>
<td>solid</td>
<td>7.54</td>
<td>0.65</td>
<td>0.63</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>LVL – PVAc</td>
<td>7.05</td>
<td>0.66</td>
<td>0.65</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>LVL – UF</td>
<td>8.45</td>
<td>0.68</td>
<td>0.64</td>
<td>0.67</td>
</tr>
<tr>
<td>Scotch pine</td>
<td>solid</td>
<td>8.49</td>
<td>0.48</td>
<td>0.46</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>LVL – PVAc</td>
<td>8.09</td>
<td>0.56</td>
<td>0.54</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>LVL – UF</td>
<td>8.93</td>
<td>0.60</td>
<td>0.57</td>
<td>0.60</td>
</tr>
<tr>
<td>Poplar</td>
<td>solid</td>
<td>6.79</td>
<td>0.35</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>LVL – PVAc</td>
<td>6.77</td>
<td>0.45</td>
<td>0.43</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>LVL – UF</td>
<td>8.07</td>
<td>0.57</td>
<td>0.54</td>
<td>0.57</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Material type</th>
<th>Parallel to grain</th>
<th>Perpendicular to grain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X (N)</td>
<td>COV (%)</td>
</tr>
<tr>
<td>Turkish beech</td>
<td>solid</td>
<td>5184.59</td>
<td>11.58</td>
</tr>
<tr>
<td></td>
<td>LVL-PVAc</td>
<td>3741.53</td>
<td>16.32</td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>4070.17</td>
<td>11.03</td>
</tr>
<tr>
<td>Scotch pine</td>
<td>solid</td>
<td>2974.39</td>
<td>13.03</td>
</tr>
<tr>
<td></td>
<td>LVL-PVAc</td>
<td>2747.78</td>
<td>17.43</td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>2578.07</td>
<td>16.06</td>
</tr>
<tr>
<td>Poplar</td>
<td>solid</td>
<td>1538.21</td>
<td>13.81</td>
</tr>
<tr>
<td></td>
<td>LVL-PVAc</td>
<td>2580.03</td>
<td>9.627</td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>2168.01</td>
<td>28.79</td>
</tr>
</tbody>
</table>

*COV – coefficients of variation.

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

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>F value</th>
<th>Prob. (sig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA for parallel to grain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood species (A)</td>
<td>2</td>
<td>78740641.489</td>
<td>39370320.744</td>
<td>158.3847</td>
<td>0.0000</td>
</tr>
<tr>
<td>Material type (B)</td>
<td>2</td>
<td>1659921.489</td>
<td>829960.744</td>
<td>3.3389</td>
<td>0.0404</td>
</tr>
<tr>
<td>A × B</td>
<td>4</td>
<td>16766070.844</td>
<td>4191517.711</td>
<td>16.8623</td>
<td>0.0000</td>
</tr>
<tr>
<td>Error</td>
<td>81</td>
<td>20134493.300</td>
<td>248573.991</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>89</td>
<td>117301127.122</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

ANOVA for perpendicular to grain

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>F value</th>
<th>Prob. (sig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood species (A)</td>
<td>2</td>
<td>55698617.867</td>
<td>27849308.933</td>
<td>182.4069</td>
<td>0.0000</td>
</tr>
<tr>
<td>Material type (B)</td>
<td>2</td>
<td>613332.867</td>
<td>306666.433</td>
<td>2.0086</td>
<td>NS</td>
</tr>
<tr>
<td>A × B</td>
<td>4</td>
<td>4616723.667</td>
<td>1154180.917</td>
<td>7.5596</td>
<td>0.0000</td>
</tr>
<tr>
<td>Error</td>
<td>81</td>
<td>12366825.200</td>
<td>152676.854</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>89</td>
<td>73295499.600</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

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 × B) were also statistically significant (p ≤ 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

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Screw holding capacity (N)</th>
<th>X</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkish beech</td>
<td>4315</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Scotch pine</td>
<td>2790</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Poplar</td>
<td>2072</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

LSD value: 256.1 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 traheids are great in number in Poplar and they have wide diameter. Beech wood has higher specific gravity (0.63 g/cm³) when compared with poplar wood (0.33 g/cm³) 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 7. Results of mean comparisons of screw holding capacity parallel to grain for each level of wood species

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Material type</th>
<th>Screw holding capacity (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>HG</td>
</tr>
<tr>
<td>Turkish beech</td>
<td>LVL-PVAc</td>
<td>3692</td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>4070</td>
</tr>
<tr>
<td>Scotch pine</td>
<td>LVL-PVAc</td>
<td>2748</td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>2578</td>
</tr>
<tr>
<td>Poplar</td>
<td>LVL-PVAc</td>
<td>2531</td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>2168</td>
</tr>
</tbody>
</table>

LSD value: 256.1 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 of screw holding capacity parallel to grain for material type

<table>
<thead>
<tr>
<th>Material type</th>
<th>Screw holding capacity (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVL-PVAc</td>
<td>2931</td>
</tr>
<tr>
<td>LVL-UF</td>
<td>2531</td>
</tr>
<tr>
<td>Poplar</td>
<td>1148</td>
</tr>
</tbody>
</table>

LSD value: 200.7 N.

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

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Screw holding capacity (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>HG</td>
</tr>
<tr>
<td>Turkish beech</td>
<td>2931</td>
</tr>
<tr>
<td>Scotch pine</td>
<td>1407</td>
</tr>
<tr>
<td>Poplar</td>
<td>1148</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Material type</th>
<th>Screw holding capacity (N)</th>
<th>X</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>1909</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>LVL-PVAc</td>
<td>1861</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>LVL-UF</td>
<td>1715</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

LSD value: 200.7 N.

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

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Material type</th>
<th>Screw holding capacity (N)</th>
<th>X</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkish beech</td>
<td>solid</td>
<td>3464</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LVL-PVAc</td>
<td>2764</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>2565</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Scotch pine</td>
<td>solid</td>
<td>1267</td>
<td>CDE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LVL-PVAc</td>
<td>1538</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>1415</td>
<td>CD</td>
<td></td>
</tr>
<tr>
<td>Poplar</td>
<td>solid</td>
<td>997.8</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LVL-PVAc</td>
<td>1280</td>
<td>CDE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LVL-UF</td>
<td>1166</td>
<td>DE</td>
<td></td>
</tr>
</tbody>
</table>

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 Fig. 3–5 for each wood species, material type and wood species-material type on the parallel to grain and perpendicular to grain.

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.

CONCLUSION

Strength properties of LVL constructed of three wood species, Beech, Pine, and Poplar with two different adhe-
Comparison of the screw holding capacity of solid wood and laminated Veneer Lumber (LVL)...

sives, 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-PV Ac 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


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

Iancho GENCHEV¹, Nelly STANEVA¹, Desislava HRISTODOROVA¹
¹University of Forestry, Forest Industry Faculty, Furniture Production Department, Sofia/Bulgaria

Abstract. 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 (Pinus sylvestris L.) for the rails and Particle Board (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.

Keywords: upholstered furniture, skeleton, staple joints, stresses, deformation, FEM

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.

Lateley 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 etc. (Jivkov et al., 2010) and joints (Norvydas et al., 2012) for its made of PB is available.

Marinova and Kyuchukov (1997) and Kjutschukov and Marinova (1998) 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 exceed the material strength by even 10% and it is possible to achieve maximal load bearing capacity of construction.

Archonowicz (2012) has investigated semi-rigid furniture joints with two beech dowels made of one- 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 profile.

Imirzi and Efe (2001) 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).

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 25 × 50 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, \( G_{LT} = 800.10^6 \) N/m², \( G_{RT} = 500.10^6 \) N/m², \( v_{LR} = 0.030, \) \( v_{LT} = 0.38, \) \( v_{RT} = 0.040 \) according to Pencik (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 \( E_R = 2700.10^6 \) N/m²; bending strength 11.10^6 N/m²; resistance to perpendicular tensile stress (internal bond) 0,3510^6 N/m²; Poisson ratios \( v_{12} = 0,18 \) and \( v_{21} = 0,30 \), according to Bodig and Jayne (1982):

\[
\frac{v_{12}}{E_L} = \frac{v_{21}}{E_R}
\]  

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:

- \( L_1 \): load \( F_{rail} = 800 \) N on the upper front rail of the seat,
- \( L_2 \): load \( F_{rail} = 800 \) N on the upper rear rail of the seat,
- \( L_3 \): load \( F_{rail} = 800 \) N in the middle of the upper rails,
- \( L_4 \): load \( F_{rail} = 800 \) N on 100 mm in front of rear rail.

Both loads \( L_1 \) and \( L_4 \) are distributed only between upper rails of the seat, simulating upholstery base made of zig-zag springs.

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

METHODS AND MATERIALS

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\[
\frac{v_{12}}{E_L} = \frac{v_{21}}{E_R}
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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.

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- \( L_3 \): load \( F_{rail} = 800 \) N in the middle of the upper rails,
- \( L_4 \): load \( F_{rail} = 800 \) N on 100 mm in front of rear rail.

Both loads \( L_1 \) and \( L_4 \) are distributed only between upper rails of the seat, simulating upholstery base made of zig-zag springs.

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

RESULTS AND DISCUSSION

The results of static analysis for linear displacements \( u \), nodal rotations \( \Theta \), von Mises stress \( \sigma_{von Mises} \), maximum principal stresses \( \sigma_1 \), minimum principal stresses \( \sigma_3 \) and equivalent strains \( \varepsilon_{von Mises} \) as well as the changed angle \( \gamma \)
between the joint shoulers 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 – Table 3. 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.

---

**Fig. 1.** FEM skeleton model and loading \( L_1, L_2, L_3 \) and \( L_4 \)

**Fig. 2.** Distribution of linear resultant displacements for \( L_1, L_2, L_3 \) and \( L_4 \)

**Fig. 3.** Distribution of resultant displacements in the side plates for \( L_1, L_2, L_3 \) and \( L_4 \)
The maximal values of the rotation displacements $\theta$ 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.

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.

The change of angle $\gamma$ between the joint shouders at upper rail for front rail is bigger for load $L_1$. For rear rail the change of the angle $\gamma$ 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 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 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

---

**Fig. 4.** Distribution of von Mises stresses for $L_1$, $L_2$, $L_3$ and $L_4$

**Fig. 5.** Distribution of minimum principal stresses for $L_1$, $L_2$, $L_3$ and $L_4$

**Fig. 6.** Distribution of maximum principal stresses for $L_1$, $L_2$, $L_3$ and $L_4
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.

Table 1. Maximal displacements and stresses for the model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u_{x_{1}}$ [mm] front rail</td>
<td>4.11</td>
<td>4.04</td>
<td>2.32</td>
<td>0.86</td>
</tr>
<tr>
<td>$u_{x_{2}}$ [mm] rear rail</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$u_{y}$ [mm] front rail</td>
<td>0.06</td>
<td>0.21</td>
<td>–0.22</td>
<td>0.25</td>
</tr>
<tr>
<td>$u_{z}$ [mm] rear rail</td>
<td>–</td>
<td>–</td>
<td>–4.04</td>
<td>–2.31</td>
</tr>
<tr>
<td>$u_{r}$ [mm]</td>
<td>2.41</td>
<td>0.34</td>
<td>–0.17</td>
<td>0.24</td>
</tr>
<tr>
<td>$\theta_{rel}$ [$^\circ$]</td>
<td>1.13</td>
<td>1.09</td>
<td>2.08</td>
<td>1.65</td>
</tr>
<tr>
<td>$\theta_{x}$ [$^\circ$]</td>
<td>1.12</td>
<td>1.09</td>
<td>0.65</td>
<td>0.87</td>
</tr>
<tr>
<td>$\theta_{y}$ [$^\circ$]</td>
<td>0.32</td>
<td>0.46</td>
<td>0.22</td>
<td>0.28</td>
</tr>
<tr>
<td>$\theta_{z}$ [$^\circ$]</td>
<td>–0.07</td>
<td>0.04</td>
<td>2.08</td>
<td>0.38</td>
</tr>
<tr>
<td>$\varepsilon_{von\ Mises}$ [m/m]</td>
<td>0.012</td>
<td>0.009</td>
<td>0.033</td>
<td>0.0245</td>
</tr>
<tr>
<td>$\gamma$ [$^\circ$] front rail</td>
<td>89.49</td>
<td>–</td>
<td>89.65</td>
<td>89.88</td>
</tr>
<tr>
<td>$\gamma$ [$^\circ$] rear rail</td>
<td>–</td>
<td>89.53</td>
<td>89.68</td>
<td>89.58</td>
</tr>
</tbody>
</table>

Table 2. Maximal displacements and stresses for the side plates

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u_{x_{1}}$ [mm]</td>
<td>0.266</td>
<td>0.357</td>
<td>0.499</td>
<td>0.309</td>
</tr>
<tr>
<td>$u_{x_{2}}$ [mm]</td>
<td>0.059</td>
<td>0.214</td>
<td>–0.280</td>
<td>0.219</td>
</tr>
<tr>
<td>$u_{y}$ [mm]</td>
<td>–0.145</td>
<td>–0.156</td>
<td>0.436</td>
<td>0.384</td>
</tr>
<tr>
<td>$u_{z}$ [mm]</td>
<td>0.238</td>
<td>0.335</td>
<td>0.165</td>
<td>0.241</td>
</tr>
<tr>
<td>$\theta_{rel}$ [$^\circ$]</td>
<td>0.994</td>
<td>0.932</td>
<td>1.108</td>
<td>0.940</td>
</tr>
<tr>
<td>$\theta_{x}$ [$^\circ$]</td>
<td>0.993</td>
<td>–0.932</td>
<td>–0.597</td>
<td>–0.763</td>
</tr>
<tr>
<td>$\theta_{y}$ [$^\circ$]</td>
<td>0.323</td>
<td>0.425</td>
<td>0.221</td>
<td>–0.275</td>
</tr>
<tr>
<td>$\theta_{z}$ [$^\circ$]</td>
<td>–0.074</td>
<td>–0.042</td>
<td>1.072</td>
<td>–0.598</td>
</tr>
<tr>
<td>$\varepsilon_{von\ Mises}$ [m/m]</td>
<td>0.013</td>
<td>0.009</td>
<td>0.032</td>
<td>0.0242</td>
</tr>
<tr>
<td>Stress von mises, [N/mm²]</td>
<td>2.27</td>
<td>2.48</td>
<td>4.809</td>
<td>3.645</td>
</tr>
<tr>
<td>Max principal stress, [N/mm²]</td>
<td>1.09</td>
<td>1.94</td>
<td>5.195</td>
<td>3.079</td>
</tr>
<tr>
<td>Min principal stress, [N/mm²]</td>
<td>–2.052</td>
<td>–1.88</td>
<td>–4.569</td>
<td>–4.070</td>
</tr>
</tbody>
</table>

Table 3. Comparison of the linear vertical displacements

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u_{y}$ [mm] front rail</td>
<td>4.11</td>
<td>4.93</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$u_{y}$ [mm] rear rail</td>
<td>–</td>
<td>–</td>
<td>4.04</td>
<td>4.42</td>
</tr>
</tbody>
</table>

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.

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


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

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1University of Forestry, Faculty of Forest Industry, Department of Interior and Furniture Design, Sofia, Bulgaria
2University of Forestry, Faculty of Forest Industry, Department of Furniture Manufacturing, Sofia, Bulgaria

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 (18 mm), plywood made from beech, birch and poplar veneer (18 mm), non-laminated MDF (18 mm), cherry veneered MDF (18 mm) and OSB (18 mm). Three different sandwich panels have been produced additionally with combination of particleboards (12 mm) and LHDF (3 mm) and MDF (4 and 6 mm). 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.

Keywords: withdrawal capacity of screw, wood-based panels, screw for wood, Confirmat

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 dismountable 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 Y osifov, 1968; Kyuchukov and Y osifov, 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 Celebi, G., Kilic, M. (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 Confiramet 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 compared 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 Ozcitici (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 (Bal et al., 2016; Bal, 2017; Erdil et al., 2002; Simeonova, 2015). 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 Φ 5 × 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 compared 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 Wolpiuk (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. Çolakoğlu (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 Joščák 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 Confiramet (Jivkov, 2002a; Jivkov, 2002b; Jivkov and Grbac, 2011; Jivkov and Marinova, 2003; Jivkov and Marinova, 2005; Jivkov and Marinova, 2009; Marinova, 2010; Kasal et al., 2011; Simeonova, 2015; Yüksel et al., 2015; Zhang et al., 2005). Main conclusion of these studies is that Confiramet is giving higher strength and stiffness of the joints compare to the universal screw.
In most of the studies for evaluation of the withdrawal resistance of the screws have been used universal screws with diameter of Φ 4 mm but with different length – 12 mm (Joščák et al., 2014), 25 mm (Taj et al., 2009), 35 mm (Joščák et al., 2014; Sydor and Wolpiuk, 2016), 40 mm (Kjučukov and Enčev, 1977a; Kjučukov and Enčev, 1977b; Kyuchukov and Yosić, 1968; Kyuchukov and Yosić, 1979; Kyuchukov et al., 2011; Özçiçi, 2009), 45 mm (Bal, 2016), 50 mm (Bal et al., 2016a; Bal et al., 2016b; Özçiçi, 2009; Sydor and Wolpiuk, 2016). Some researchers have been using screws with diameter of Φ 3,5 mm with length of 16, 18, 25, 40 mm (Chen et al., 2016; Özçiçi, 2009), diameter of Φ 5 mm with length of 40 or 50 mm (Celebi and Kilic, 2006; Chen et al., 2016; Simeonova, 2015) and diameter of Φ 6 mm with length of 12 or 40 mm (Chen et al., 2016; Joscak et al., 2014).

Very few studies have been conducted for evaluation of the withdrawal resistance of Confirmat 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 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 (Bal et al., 2016; Bal, 2017; Joscak et al., 2014; Sempe and Smith, 2006; Taj et al., 2009) 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 (Chen et al., 2016; Hafikhani et al., 2011; Kyuchukov et al., 2011; Sydor et al., 2015; Sydor and Wolpiuk, 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 (Chen et al., 2016; Çolakoglu, 2009; Simeonova, 2015). Same calculation method is used in EN 320 „Fibreboards – Determination of resistance to axial withdrawal of screws”. Only Çolakoglu (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, 2007; Özçiçi, 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 Confirmat 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 “Confirmat” into different commercial and self-produced wood-based materials were evaluated.

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 (PoPIL), birch-faced lightweight plywood – 18 mm (BiPIL), beech plywood – 20 mm (BePIL) and OSB – 18 mm. Additionally, three types of 3-ply wood-based panels were produced (Fig. 1). The first one (3Pl-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 (3Pl-MDF-20) is from particleboard (12 mm) and 2 layers of MDF (4 mm) with thickness of 20 mm and the third one (3Pl-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 (ℓυ, mm), measured thickness (ℓm, mm) and density (ρ, mm) followed by descriptive statistic included values of standard deviation (SD, kg/mm³) and coefficient of variation (CoV, %) of all tested materials are given in Table 1.

![Fig. 1. Type and structure of 3-ply wood-based panels: a – 3-ply panel with PB and 2 layers laminated HDF (3Pl-LHDF); b – 3-ply panel with PB and 2 layers MDF (3Pl-MDF-20); c – 3-ply panel with PB and 2 layers of MDF (3Pl-MDF-24); 1 – laminate over layer; 2 – HDF-3 mm; 3 – PB-12 mm; 4 – MDF-4 mm; 5 – MDF-6 mm](image-url)
Two types of screws were used. The first one was universal, galvanized, rolled cut, metal, fully threatened screw for wood and particleboards, with nominal size of $\Phi 4 \times 40 \text{ mm}$ and the second was one-piece connector Confi rmat with nominal size of $\Phi 7 \times 50 \text{ mm}$ for drill hole of $\Phi 5 \text{ mm}$. Both screws were with countersunk head and PZ cross slot. The shape and the parameters of the screw and Confi rmat are shown on Figure 2 and the dimensions are given in Table 2.

<table>
<thead>
<tr>
<th>Type of panel</th>
<th>Nominal thickness $t_n$ (mm)</th>
<th>Measured thickness $t_m$ (mm)</th>
<th>Mean $\rho$ (kg/m$^3$)</th>
<th>SD (kg/m$^3$)</th>
<th>CoV, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminated particleboard (LPB)</td>
<td>18</td>
<td>18.10</td>
<td>697.93</td>
<td>3.33</td>
<td>0.48</td>
</tr>
<tr>
<td>Poplar plywood (PoPlW)</td>
<td>18</td>
<td>18.22</td>
<td>408.15</td>
<td>7.21</td>
<td>1.77</td>
</tr>
<tr>
<td>Birch-faced lightweight plywood (BiPlW)</td>
<td>18</td>
<td>17.59</td>
<td>478.37</td>
<td>16.76</td>
<td>3.50</td>
</tr>
<tr>
<td>Medium density fiberboard (MDF)</td>
<td>18</td>
<td>18.03</td>
<td>681.10</td>
<td>4.40</td>
<td>0.65</td>
</tr>
<tr>
<td>Cherry veneered-faced MDF (ChrVMDF)</td>
<td>19</td>
<td>18.80</td>
<td>750.59</td>
<td>3.99</td>
<td>0.53</td>
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<tr>
<td>3-ply panel with laminated HDF (3Pl-PB-LHDF)</td>
<td>18</td>
<td>17.34</td>
<td>668.54</td>
<td>9.32</td>
<td>1.39</td>
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<tr>
<td>Poplar plywood (PoPlW)</td>
<td>18</td>
<td>18.22</td>
<td>408.15</td>
<td>7.21</td>
<td>1.77</td>
</tr>
<tr>
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<td>18.03</td>
<td>681.10</td>
<td>4.40</td>
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<tr>
<td>Cherry veneered-faced MDF (ChrVMDF)</td>
<td>19</td>
<td>18.80</td>
<td>750.59</td>
<td>3.99</td>
<td>0.53</td>
</tr>
<tr>
<td>3-ply panel with MDF 4 mm (3Pl-PB-MDF-20)</td>
<td>20</td>
<td>20.72</td>
<td>692.33</td>
<td>8.37</td>
<td>1.21</td>
</tr>
<tr>
<td>3-ply panel with MDF 6 mm (3Pl-PB-MDF-24)</td>
<td>24</td>
<td>23.29</td>
<td>736.80</td>
<td>5.84</td>
<td>0.79</td>
</tr>
<tr>
<td>Oriented strand board (OSB)</td>
<td>18</td>
<td>17.55</td>
<td>654.88</td>
<td>14.59</td>
<td>2.23</td>
</tr>
<tr>
<td>Beech plywood (BePW)</td>
<td>20</td>
<td>19.32</td>
<td>755.08</td>
<td>13.36</td>
<td>1.75</td>
</tr>
</tbody>
</table>

**Table 2.** Dimensions of the screw and Confi rmat (mm)

<table>
<thead>
<tr>
<th>Type of screw</th>
<th>Nominal size</th>
<th>$d$</th>
<th>$D$</th>
<th>$L$</th>
<th>$B$</th>
<th>$p$</th>
<th>$d_1$</th>
<th>$d_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal screw</td>
<td>$\Phi 4 \times 40$</td>
<td>3.79</td>
<td>7.71</td>
<td>39.57</td>
<td>34.51</td>
<td>2.33</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Confi rmat</td>
<td>$\Phi 7 \times 50$</td>
<td>6.81</td>
<td>9.99</td>
<td>49.53</td>
<td>37.19</td>
<td>3.69</td>
<td>6.85</td>
<td>4.05</td>
</tr>
</tbody>
</table>

**SCREWS**

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

**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 $\Phi 2.8 \text{ mm}$ for the screw and $\Phi 5 \text{ mm}$ for Confi rmat were drilled through the panel in each specimen perpendicular to the plain of the board (Kyuchukov and Kyuchukov, 2016). One screw or one Confi rmat 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 $20 \pm 2°C$ 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

$$f = \frac{F_{\text{max}}}{d \cdot l_p}$$

where:

- $f$ – is specific withdrawal capacity of screw, N/mm$^2$
- $F_{\text{max}}$ – ultimate load, required to withdraw the screw from the specimen, N
Withdrawal capacity of screws and confirmat into different wood-based panels

\[ d \] – diameter of the screw, mm
\[ t_p \] – depth of penetration of the screw (thickness of the board), mm

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%.

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 \( \Phi \ 4 \times 40 \) mm into different wood-based material. Statistical data for the mean values of ultimate load \( (F_{\text{max}}) \) in Newtons, calculated specific withdrawal capacity \( (f) \) followed by descriptive statistic included minimal \( (f_{\text{min}}, \text{N/mm}^2) \) and maximal \( (f_{\text{max}}, \text{N/mm}^2) \) values, standard deviation \( (SD, \text{N/mm}^2) \) and coefficient of variation \( (CoV, \%) \) are shown in the Table 3. In Fig. 4 the results are displayed graphically.

According to the results the lowest SWC was shown from laminated particleboard (12.78 N/mm²) following with 15.34 N/mm² by 3-ply panel with particleboard and laminated with 3mm HDF (3Pl-PB-LHDF) and MDF with 15.52 N/mm². Similar ultimate load from laminated particleboard were obtained by Joščák 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 \( \Phi \ 5 \times 50 \) mm in beech plywood (45.10 N/mm²) is slightly different from this study but in calculation method according BDS EN 13466:2003 the screw diameter is in-

![Fig. 3. Loading scheme and test jigs](image)

<table>
<thead>
<tr>
<th>Name of series</th>
<th>Type of the board</th>
<th>( t ) (mm)</th>
<th># of samples</th>
<th>Mean ( F_{\text{max}} ) (N)</th>
<th>Mean ( f ) (N/mm²)</th>
<th>( f_{\text{min}} ) (N/mm²)</th>
<th>( f_{\text{max}} ) (N/mm²)</th>
<th>SD (N/mm²)</th>
<th>CoV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-S</td>
<td>Laminated PB (LPB)</td>
<td>18</td>
<td>20</td>
<td>920.32</td>
<td>12.78</td>
<td>11.35</td>
<td>14.26</td>
<td>1.05</td>
<td>8.22</td>
</tr>
<tr>
<td>2-S</td>
<td>Poplar Plywood (PoPlW)</td>
<td>18</td>
<td>22</td>
<td>1336.86</td>
<td>18.56</td>
<td>13.78</td>
<td>27.40</td>
<td>3.69</td>
<td>20.03</td>
</tr>
<tr>
<td>3-S</td>
<td>Birch-faced Plywood (BiPlW)</td>
<td>18</td>
<td>20</td>
<td>1709.71</td>
<td>23.75</td>
<td>20.96</td>
<td>26.97</td>
<td>1.85</td>
<td>7.79</td>
</tr>
<tr>
<td>4-S</td>
<td>Medium Density Fiberboard (MDF)</td>
<td>18</td>
<td>20</td>
<td>1117.80</td>
<td>15.52</td>
<td>10.62</td>
<td>19.76</td>
<td>2.08</td>
<td>13.38</td>
</tr>
<tr>
<td>5-S</td>
<td>MDF, Cherry Veneered (ChrVMDF)</td>
<td>19</td>
<td>21</td>
<td>1690.52</td>
<td>22.24</td>
<td>17.55</td>
<td>25.43</td>
<td>2.15</td>
<td>9.67</td>
</tr>
<tr>
<td>6-S</td>
<td>3-ply board with lam. HDF (3Pl-PB-LHDF)</td>
<td>18</td>
<td>24</td>
<td>1104.25</td>
<td>15.34</td>
<td>12.19</td>
<td>17.56</td>
<td>1.68</td>
<td>10.92</td>
</tr>
<tr>
<td>7-S</td>
<td>3-ply board with MDF 4 mm (3Pl-PB-MDF-20)</td>
<td>20</td>
<td>21</td>
<td>1578.49</td>
<td>19.73</td>
<td>16.78</td>
<td>23.22</td>
<td>1.48</td>
<td>7.48</td>
</tr>
<tr>
<td>8-S</td>
<td>3-ply board with MDF 6 mm (3Pl-PB-MDF-24)</td>
<td>24</td>
<td>22</td>
<td>1845.08</td>
<td>19.22</td>
<td>16.42</td>
<td>23.15</td>
<td>1.58</td>
<td>8.23</td>
</tr>
<tr>
<td>9-S</td>
<td>Oriented strand board (OSB)</td>
<td>12</td>
<td>20</td>
<td>1376.76</td>
<td>28.68</td>
<td>14.01</td>
<td>44.63</td>
<td>10.85</td>
<td>37.83</td>
</tr>
<tr>
<td>10-S</td>
<td>Beech Plywood (BePW)</td>
<td>19</td>
<td>21</td>
<td>4066.29</td>
<td>53.50</td>
<td>43.55</td>
<td>59.55</td>
<td>4.54</td>
<td>8.48</td>
</tr>
</tbody>
</table>

Table 3. Ultimate load and specific withdrawal capacity of screw \( \Phi \ 4 \times 40 \) mm
fluenced 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 α = 0.05 and level of confidence of 95% was found between the obtained withdrawal capacity of universal screw Φ 4 × 40 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) they 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.

**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 Φ 7 × 50 mm into different wood-based material.

![Fig. 4. Specific withdrawal capacity of universal screw Φ 4 × 40 mm into wood-based materials](image)

### Table 4. Tukey HSD analysis of the differences between the group of panels with a confidence interval of 95% of withdrawal capacity of screw Φ 4 × 40 mm of all pairwise comparisons

<table>
<thead>
<tr>
<th>Name of series</th>
<th>Type of panel</th>
<th>Groups of homogeneities (α = 0.05)</th>
<th>Mean of specific withdrawal capacity of universal screw (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>10-S</td>
<td>BePlW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-S</td>
<td>OSB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-S</td>
<td>BiPlW</td>
<td>53.50</td>
<td></td>
</tr>
<tr>
<td>5-S</td>
<td>ChrVMDF</td>
<td>32.64</td>
<td>23.75</td>
</tr>
<tr>
<td>7-S</td>
<td>3Pl-MDF-20</td>
<td>22.24</td>
<td></td>
</tr>
<tr>
<td>8-S</td>
<td>3Pl-MDF-24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-S</td>
<td>PoPlW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-S</td>
<td>MDF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-S</td>
<td>3Pl-LHDF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-S</td>
<td>LPB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Withdrawal capacity of screws and Confirmat into different wood-based panels

Statistical data for the mean values of ultimate load ($F_{\text{max}}$) 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 (3Pl-PB-LHDF) with capacity of 13.92 N/mm² and 3-ply panel with particleboard and MDF 4 mm (3Pl-PB-MDF-20) with capacity of 14.34 N/mm². Similar ultimate load from laminated particleboard were obtained by Joščák 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 Confirmat screw is 3.75 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 Confirmat screw $\Phi 7 \times 50$ 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)

### Table 5. Ultimate force and specific withdrawal capacity of Confirmat screw $\Phi 7 \times 50$ mm

<table>
<thead>
<tr>
<th>Name of series</th>
<th>Type of the panel</th>
<th>$t$ (mm)</th>
<th>$#$ of samples</th>
<th>Mean $F_{\text{max}}$ (N)</th>
<th>Mean $f$ (N/mm²)</th>
<th>$f_{\text{min}}$ (N/mm²)</th>
<th>$f_{\text{max}}$ (N/mm²)</th>
<th>SD (N/mm²)</th>
<th>CoV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-C</td>
<td>Laminated PB (LPB)</td>
<td>18</td>
<td>21</td>
<td>1523.38</td>
<td>12.09</td>
<td>10.89</td>
<td>13.49</td>
<td>0.70</td>
<td>5.78</td>
</tr>
<tr>
<td>2-C</td>
<td>Poplar plywood (PoPlW)</td>
<td>18</td>
<td>21</td>
<td>2169.65</td>
<td>17.20</td>
<td>13.86</td>
<td>23.47</td>
<td>2.26</td>
<td>13.12</td>
</tr>
<tr>
<td>3-C</td>
<td>Birch plywood (BiPlW)</td>
<td>18</td>
<td>21</td>
<td>2382.21</td>
<td>18.89</td>
<td>15.79</td>
<td>22.10</td>
<td>1.74</td>
<td>8.96</td>
</tr>
<tr>
<td>4-C</td>
<td>MDF (MDF)</td>
<td>18</td>
<td>21</td>
<td>2036.34</td>
<td>16.16</td>
<td>13.58</td>
<td>18.37</td>
<td>1.21</td>
<td>7.46</td>
</tr>
<tr>
<td>5-C</td>
<td>MDF, Cherry Veneered, (ChrVMDF)</td>
<td>19</td>
<td>21</td>
<td>2715.95</td>
<td>20.42</td>
<td>17.81</td>
<td>22.64</td>
<td>1.33</td>
<td>6.50</td>
</tr>
<tr>
<td>6-C</td>
<td>3-ply panel with lam. HDF (3Pl-PB-LHDF)</td>
<td>18</td>
<td>24</td>
<td>1689.50</td>
<td>13.92</td>
<td>19.36</td>
<td>27.89</td>
<td>2.66</td>
<td>10.92</td>
</tr>
<tr>
<td>7-C</td>
<td>3-ply panel with MDF 4 mm (3Pl-PB-MDF-20)</td>
<td>20</td>
<td>27</td>
<td>2091.32</td>
<td>14.94</td>
<td>12.96</td>
<td>17.34</td>
<td>1.33</td>
<td>8.91</td>
</tr>
<tr>
<td>8-C</td>
<td>3-ply panel with MDF 6 mm (3Pl-PB-MDF-24)</td>
<td>24</td>
<td>26</td>
<td>2807.43</td>
<td>16.71</td>
<td>15.30</td>
<td>17.79</td>
<td>0.70</td>
<td>4.22</td>
</tr>
<tr>
<td>9-C</td>
<td>Oriented strand board (OSB)</td>
<td>12</td>
<td>19</td>
<td>2118.41</td>
<td>33.45</td>
<td>31.08</td>
<td>35.57</td>
<td>1.33</td>
<td>27.82</td>
</tr>
<tr>
<td>10-C</td>
<td>Beech plywood (BePW)</td>
<td>19</td>
<td>18</td>
<td>6032.70</td>
<td>45.36</td>
<td>35.67</td>
<td>49.51</td>
<td>3.96</td>
<td>8.72</td>
</tr>
</tbody>
</table>

![Fig. 5. Specific withdrawal capacity of Confirmat screw $\Phi 7 \times 50$ mm into wood-based materials](image.png)
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.

It is obvious from the results given in this study that the type of material is a main factor affecting withdrawal capacity of universal screw and Confrmat 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 Confrmat ($r = 0.22$) which is opposite to the results obtained by some other authors (Joščák et al., 2014; Vassiliou and Barboutis, 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 Confrmat screw has is a little difference which is statistically significant. Higher SWC is shown by universal screw (23.30 N/mm$^2$) compare to Confrmat (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 ($F_{\text{max}}$) under withdrawal force in

![Image](image-url)

*Fig. 6. Ultimate loading capacity ($F_{\text{max}}$) of universal screw and Confirmat screw into different wood-based materials*

---

**Table 6.** Tukey HSD analysis of the differences between the group with a confidence interval of 95% of withdrawal capacity of Confrmat screw Φ 7 × 50 mm of all pairwise comparisons

<table>
<thead>
<tr>
<th>Name of series</th>
<th>Type of panel</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
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<tbody>
<tr>
<td>10-C</td>
<td>BePlW</td>
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<td>45.36</td>
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<td>9-C</td>
<td>OSB</td>
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<td></td>
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<td></td>
<td>33.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-C</td>
<td>ChrVMDF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20.31</td>
<td>18.91</td>
<td>18.91</td>
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</tr>
<tr>
<td>3-C</td>
<td>BiPlW</td>
<td></td>
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<td></td>
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<td>17.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-C</td>
<td>PoPlW</td>
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<td></td>
<td>17.22</td>
<td>16.71</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>16.16</td>
<td></td>
<td>14.94</td>
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<td>4-C</td>
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<td>16.16</td>
<td>14.94</td>
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<td>12.09</td>
</tr>
<tr>
<td>6-C</td>
<td>3Pl-LHDF</td>
<td></td>
<td></td>
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</tr>
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<td>1-C</td>
<td>LPB</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12.09</td>
</tr>
</tbody>
</table>
Newton is presented in Fig. 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 (3Pl-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.

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

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SPLITTING RESISTANCE OF PLYWOOD IN THE AREA OF COUNTERSUNK HOLES

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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 Φ 4, Φ 5 and Φ 6 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.

Keywords: plywood, split resistance, countersunk holes, split resistance test method

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 Confirmat 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 (Darwish et al., 2013; Park and Grandt, 2007; Shivakumar and Newman, 1992; 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 faster 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).

Smardzewski and Ożarska (2005) were developed mathematical model of a semi-rigid angle joint of the Confirmat type screw loaded in bending and they came 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.

**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/m² 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/mm².

The physical and mechanical characteristics of the plywood are as follows (Jivkov et al., 2013):
- Density – 760,1 kg/m³;
- Bending strength under loading perpendicular to panel layers – 55,58 N/mm²;
- Bending strength under loading parallel to panel layers – 63,16 N/mm²;
- Modulus of elasticity in bending under loading perpendicular to the veneer layers – 5286 N/mm²;
- Modulus of elasticity in bending under loading parallel to the veneer layers – 6650 N/mm².

**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 Fig. 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 ($\delta$) 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 ($l_y$).
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 – \(\Phi 4\) mm with the countersunk dimension of \(\Phi 8\) \((d_2)\) \(\times 2.4\) mm \((h)\); \(\Phi 5\) mm with countersunk dimension of \(\Phi 10\) \((d_2)\) \(\times 2.9\) mm \((h)\) and \(\Phi 6\) mm with countersunk dimension of \(\Phi 12\) \((d_2)\) \(\times 3.4\) 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 \(20 \pm 2^\circ\text{C}\) and at \(65 \pm 3\%\) humidity for 1 week.

**Fig. 2.** Type and parameters of test specimen made of plywood

**Table 1.** Dimensions of the countersunk hole

<table>
<thead>
<tr>
<th>№</th>
<th>(d_1), mm</th>
<th>(d_2), mm</th>
<th>(h), mm</th>
<th>(\alpha)°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(\Phi 4)</td>
<td>(\Phi 8)</td>
<td>2.4</td>
<td>39.8</td>
</tr>
<tr>
<td>2</td>
<td>(\Phi 5)</td>
<td>(\Phi 10)</td>
<td>2.9</td>
<td>40.8</td>
</tr>
<tr>
<td>3</td>
<td>(\Phi 6)</td>
<td>(\Phi 12)</td>
<td>3.4</td>
<td>41.4</td>
</tr>
</tbody>
</table>

**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 Fig. 3. The material is stainless steel class EN 1.4301.

**TEST METHOD**

Tests were done according to the test method principle describe above. The loading scheme is shown in Fig. 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.

**Fig. 3.** Type and dimensions of loading devices for splitting test in the area of countersunk holes

\(a – \Phi 4\) mm; \(b – \Phi 5\) mm; \(c – \Phi 6\) mm

**Fig. 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%.

**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\(_1\)), width of the test specimen (b) and distance from the end edge (l\(_1\)). Additionally, are given the group of homogeneity (HG) according to Duncan test at significant difference of α = 0.05 and level of confidence of 95%.

Among the factors it was found that the diameter of the countersunk hole (d\(_1\)) is most important. The highest ultimate splitting load was shown by the group of samples with diameter (d\(_1\)) Φ 6 mm and lowest by the group with diameter (d\(_1\)) Φ 4 mm. The force increased in average with 23% between the groups of Φ 4 to Φ 5 and 27% between Φ 5 and Φ 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 Φ 4 mm the conical area is 58.4 mm\(^2\), for Φ 5 mm – 89.5 mm\(^2\) and Φ 6 mm – 127.2 mm\(^2\). No data were obtained for diameter of Φ 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\(_1\),b\(_6\)-b\(_5\)-l\(_1\),60 and lowest of 5876 N obtained by d\(_1\),4-b\(_4\)-l\(_1\),30 is 36%.

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 Φ 6 mm (8414 N) and for Φ 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 α = 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 Fig. 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.

**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 Φ 6 mm and lowest by diameter of Φ 4 mm. The most dangerous
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
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EFFECT OF CUTTER TYPES, SPINDLE SPEED AND FEED RATE ON THE SURFACE QUALITY IN CNC MILLING

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Abstract. The aim is to test the influence of bit type, spindle speed, and feed rate on wood surface roughness in CNC milling. For this purpose, MDF samples processed with spindle speed of 18 000 and 24 000 rpm, feed rate of 8000 mm/min and 10 000 mm/min using three different types of bits. The surface roughness values of specimens were determined using a stylus-type profilometer Mitutoyo-SJ 301 according to the ISO 4287 standards. Then, an analysis of variance of the data from all the samples with the three factors in the experimental design were performed using MSTAT-C software package. Results showed that bit type, spindle speed, and feed rate are the factors that significantly affect surface roughness. The highest surface roughness value was found for the cutter type in the solid carbide spiral cutter while the insert straight cutter the lowest value. For the spindle speed, 18 000 rpm gave higher surface roughness than 24 000 rpm. With regards to the feed rate, the highest surface roughness was obtained in the 10 000 mm/min, whereas, the lowest surface roughness was obtained in the 8000 mm/min.

Keywords: CNC milling, surface roughness, spindle speed, feed rate, MDF

INTRODUCTION

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 (Gu et al., 2017; Porankiewicz, 1985; Stefaniak, 1970; Szymanski and Gorski, 2011). Many researchers have tested the influence of cutting parameters on surface roughness in MDF milling (Davim et al., 2009; Sutcu and Karagöz, 2012; Aguilera et al., 2000).

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; Soğutlu et al., 2016). 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 (Soğutlu, 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 (Gurau and Irle, 2017; Gurau et al., 2017; Hiziroglu, 1996).

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.

METHODS AND MATERIALS

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 (Fig. 1) located in the panel processing center at the application laboratories of the Gazi University under the conditions of a 24 000-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. 2a). Two each razor blade cutters (turnable knife) with a diameter of 16 mm from the NETMAK Company were used (Fig. 2b).

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 determin-
ing the roughness values, were drawn with the CAD-CAM program as shown in Fig. 2a in a square geometry in the measurements of 30 cm × 30 cm was processed by determining the codes at the CNC processing center.

Fig. 1. Automatic CNC controlled panel processing center (SCM Group, 2015)

![Fig. 1. Automatic CNC controlled panel processing center (SCM Group, 2015)](image)

**a) Tool path  b) Cutters**

Fig. 2. Tool path and cutters used in the experiments

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.

Type of cutter, spindle speed, feed rate 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.

### RESULTS AND DISCUSSION

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

The analysis of variance result was to determine whether the effect on surface roughness (Ra) in terms of cutter type, spindle speed, and feed rate are given in Table 2.

The cutter type (A), spindle speed (B), feed rate (C), interaction B*C for surface roughness (Ra) were found to be statistically significant, whereas, interaction A*C and interaction A*B*C were found to be statistically insignificant.

The Duncan test comparison results at the level of cutter type, spindle speed and feed rate have been given in Table 3 and Fig. 3.

According to the effect of type of tool on the average surface roughness (Ra) in Table 3, the effect of each three

<table>
<thead>
<tr>
<th>Cutter types</th>
<th>Spindle speed (rpm)</th>
<th>Feed rate (mm/min)</th>
<th>Surface roughness (Ra) – (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Straight cutter (A)</td>
<td>18 000</td>
<td>8 000</td>
<td>14.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 000</td>
<td>15.20</td>
</tr>
<tr>
<td></td>
<td>24 000</td>
<td>8 000</td>
<td>14.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 000</td>
<td>16.93</td>
</tr>
<tr>
<td>Turnblade cutter (B)</td>
<td>18 000</td>
<td>8 000</td>
<td>15.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 000</td>
<td>15.08</td>
</tr>
<tr>
<td></td>
<td>24 000</td>
<td>8 000</td>
<td>12.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 000</td>
<td>14.02</td>
</tr>
<tr>
<td>Helical cutter (C)</td>
<td>18 000</td>
<td>8 000</td>
<td>14.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 000</td>
<td>14.90</td>
</tr>
<tr>
<td></td>
<td>24 000</td>
<td>8 000</td>
<td>13.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 000</td>
<td>14.58</td>
</tr>
</tbody>
</table>

X̄ – mean.
The effects of cutter types, spindle speed, and feed rate were also at values close to each other. Especially, this ratio was higher in the value of the end mill type of tool. When the effects of the number of revolutions on average surface roughness (Ra) were considered, then it was observed that as the number of revolutions increased, the surface roughness decreased.

It can be stated that the reason for this was that the roughness value decreased connected to cutting speed. On the other hand, according to the effect of feed rate on average surface roughness (Ra), it was observed that as the feed rate decreased, the surface roughness also decreased.

The Duncan test comparison results of the cutter type-spindle speed interaction have been given in Table 4 and Fig. 4.

When the dual interactions of the factors of tool type and number of revolutions was considered according to Table 4 for the average surface roughness (Ra), then the lowest Ra value appeared in the razor cutter tool type and at 24 000 rpm.

The Duncan test comparison results of the spindle speed-feed rate interaction have been given in Table 5 and Fig. 5.

When the dual interactions of the factors of number of revolutions and feed rate were considered according to Table 8 for the average surface roughness (Ra), then the lowest Ra value appeared at 24 000 rpm and 8000 mm/min feed rate. This result affected to a great extent the unit time cost and provided benefits.

### Table 2. Analysis of variance

<table>
<thead>
<tr>
<th>Cutter types (A)</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle speed (B)</td>
<td>2</td>
<td>27.678</td>
<td>13.839</td>
<td>5.2548</td>
<td>0.0066</td>
</tr>
<tr>
<td>Interaction (A*B)</td>
<td>1</td>
<td>11.066</td>
<td>11.066</td>
<td>4.2017</td>
<td>0.0428</td>
</tr>
<tr>
<td>Feed rate (C)</td>
<td>2</td>
<td>48.771</td>
<td>24.386</td>
<td>9.2595</td>
<td>0.0002</td>
</tr>
<tr>
<td>Interaction (A*C)</td>
<td>1</td>
<td>17.282</td>
<td>17.282</td>
<td>6.5623</td>
<td>0.0118</td>
</tr>
<tr>
<td>Interaction (B*C)</td>
<td>2</td>
<td>4.604</td>
<td>2.302</td>
<td>0.8742</td>
<td>NS</td>
</tr>
<tr>
<td>Interaction (A<em>B</em>C)</td>
<td>1</td>
<td>15.624</td>
<td>15.624</td>
<td>5.9327</td>
<td>0.0165</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
<td>1.243</td>
<td>0.622</td>
<td>0.2361</td>
<td>NS</td>
</tr>
<tr>
<td>Total</td>
<td>108</td>
<td>284.426</td>
<td>2.634</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Cutter Types (A)</td>
<td>119</td>
<td>410.695</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

*Significant at 95% confidence level. NS – no significance.

### Table 3. Duncan tests for cutter type, spindle speed and feed rate

<table>
<thead>
<tr>
<th>Cutter types (LSD ± 0.7186)</th>
<th>Spindle speed (LSD ± 0.5867)</th>
<th>Feed rate (LSD ± 0.5867)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight cutter</td>
<td>turnblade cutter</td>
<td>helical cutter</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>HG</td>
<td>HG</td>
<td>HG</td>
</tr>
<tr>
<td>15.41 A</td>
<td>14.30 B</td>
<td>15.04 A</td>
</tr>
<tr>
<td>X— HG</td>
<td>X— HG</td>
<td>X— HG</td>
</tr>
</tbody>
</table>

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).
Musa KAYA, Hasan Ozgur IMIRZI, Cevdet SOGUTLU

Furthermore, as the feed speed increased in the group of all the processing parameters, then an increase occurred in the surface roughness (Ra) value. This has that meaning that the roughness also increased. Low levels of surface roughness in the literature have been reported to play an important role in the success of subsequent surface treatments and product quality (Gurau and Irlé, 2017; Gurau et al., 2017; Hiziroglu, 1996; Soğutlu, 2010).

The operation parameters were designed differently in the study process, that is, the effect of the average surface roughness was examined experimentally, and the results of the effects were set forth. Each of the three cutting tool varieties used in this study were manufactured from carbide steel material. The reason for this was because the cutters manufactured from this material in the furniture manufacturing sector have a greater area of use due to their being economical and durable. However, higher quality cutters (DIA – Diamond Cutters) are also used as materials in the furniture manufacturing industry. Since these new types of cutters have higher cost values, they are not used in a widespread manner. Many different materials have been developed in parallel with the technological advancements in the present-day industrial field. In this context, it has become inevitable to research different tool materials and other operation parameters for use in these types of experimental operations aimed at research of the cutting tools manufactured from different materials, both from the aspect of the furniture manufacturing sector and for reducing the costs to low levels and from the aspect of providing for the expected quality and esthetic appearance from the furniture surfaces. It is proposed that these types of multifaceted research studies be made with this objective for being able to engage

### Table 4. Comparison results of the Duncan tests for cutter type-spindle speed

<table>
<thead>
<tr>
<th>Cutter types</th>
<th>Surface roughness (Ra) – (μm)</th>
<th>18 000 rpm</th>
<th>24 000 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight cutter (A)</td>
<td>$\bar{X}$ - BC</td>
<td>14.88</td>
<td>15.93</td>
</tr>
<tr>
<td>Turnblade cutter (B)</td>
<td>$\bar{X}$ - AB</td>
<td>15.33</td>
<td>13.27</td>
</tr>
<tr>
<td>Helical cutter (C)</td>
<td>$\bar{X}$ - ABC</td>
<td>14.92</td>
<td>14.10</td>
</tr>
</tbody>
</table>

LSD $\pm$1.016, $\bar{X}$ – mean, HG – homogeneity groups.

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

### Table 5. Comparison results of the Duncan tests for spindle speed-feed rate

<table>
<thead>
<tr>
<th>Spindle Speed</th>
<th>Surface roughness (Ra) – (μm)</th>
<th>8 000 mm/min</th>
<th>10 000 mm/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 000 rpm</td>
<td>$\bar{X}$ - A</td>
<td>15.02</td>
<td>15.06</td>
</tr>
<tr>
<td>24 000 rpm</td>
<td>$\bar{X}$ - B</td>
<td>13.70</td>
<td>15.18</td>
</tr>
</tbody>
</table>

LSD $\pm$0.8298, $\bar{X}$ – mean, HG – homogeneity groups.

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

### CONCLUSIONS

It was observed at the conclusion of the analyses made that the number of revolutions and feed speed have an important effect on surface roughness (Ra). In the literature, as the feed rate decreased, the surface roughness also decreased. Furthermore, it was also stated that as the feed rate decreased and the number of revolutions increased, then the surface roughness also decreased (Sönmez and Soğutlu, 2005).

In a study made, it was also observed that as the number of revolutions increased and the feed rate decreased, then the average surface roughness (Ra) value decreased even more. Furthermore, as the feed speed increased in the group of all the processing parameters, then an increase occurred in the surface roughness (Ra) value. This has that meaning that the roughness also increased. Low levels of surface roughness in the literature have been reported to play an important role in the success of subsequent surface treatments and product quality (Gurau and Irlé, 2017; Gurau et al., 2017; Hiziroglu, 1996; Soğutlu, 2010).

The $Ra$ of the operation parameters were designed differently in the study process, that is, the effect of the average surface roughness was examined experimentally, and the results of the effects were set forth. Each of the three cutting tool varieties used in this study were manufactured from carbide steel material. The reason for this was because the cutters manufactured from this material in the furniture manufacturing sector have a greater area of use due to their being economical and durable. However, higher quality cutters (DIA – Diamond Cutters) are also used as materials in the furniture manufacturing industry. Since these new types of cutters have higher cost values, they are not used in a widespread manner. Many different materials have been developed in parallel with the technological advancements in the present-day industrial field. In this context, it has become inevitable to research different tool materials and other operation parameters for use in these types of experimental operations aimed at research of the cutting tools manufactured from different materials, both from the aspect of the furniture manufacturing sector and for reducing the costs to low levels and from the aspect of providing for the expected quality and esthetic appearance from the furniture surfaces. It is proposed that these types of multifaceted research studies be made with this objective for being able to engage...
in manufacturing in the desired quality and in a shorter period.

References


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

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

Abstract. 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 × 300 × 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 (Ra). 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.

Keywords: MDF, pocket milling, tool path, step over, depth of cut, CNC

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 (Aydin and Colakoglu, 2005; Kopac and Sali, 2003). 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; Söğütlü, 2010; Söğütlü 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 1985; Stefaniak, 1970; Szymanowski and Górski, 2011). Many researchers have tested the influence of cutting parameters on surface roughness in MDF milling (Aguilera et al., 2000; Davim et al., 2009; Sütçü and Karagöz, 2012).

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 (Peters and Cumming, 1970; Stumbo, 1963).

The surface roughness is an important factor that influences the upper surface finishing and bonding strength of adhesives (Söğütlü, 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.

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 24,000-rpm rotation speed, 8,000 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. 1). Two each razor blade cutters (turnblade knife) with a diameter of 16 mm from the NETMAK Company were used (Fig. 1b).

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 × 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 Surf test 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.

![Fig. 1. Tool paths and cutter used in the experiments](image)

**RESULTS AND DISCUSSION**

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

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.

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.

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.

When the average surface roughness (Ra) dual interaction of the factors of tool path and depth of wood shavings were considered according to Table 4, then the highest Ra 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 1. Surface roughness values (Ra)

<table>
<thead>
<tr>
<th>Tool path geometry</th>
<th>Step over</th>
<th>Depth of cut (mm)</th>
<th>Surface roughness (Ra) – (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Outside lines tool path (A)</td>
<td>50% (8 mm)</td>
<td>4</td>
<td>15.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>12.17</td>
</tr>
<tr>
<td></td>
<td>70% (11.2 mm)</td>
<td>4</td>
<td>14.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>12.53</td>
</tr>
<tr>
<td>Linear tool path (B)</td>
<td>50% (8 mm)</td>
<td>4</td>
<td>16.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>14.97</td>
</tr>
<tr>
<td></td>
<td>70% (11.2 mm)</td>
<td>4</td>
<td>13.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>15.36</td>
</tr>
<tr>
<td>Spiral tool path (C)</td>
<td>50% (8 mm)</td>
<td>4</td>
<td>16.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>13.32</td>
</tr>
<tr>
<td></td>
<td>70% (11.2 mm)</td>
<td>4</td>
<td>14.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>13.87</td>
</tr>
</tbody>
</table>

Table 2. Analysis of variance

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool path geometry (A)</td>
<td>2</td>
<td>38.130</td>
<td>19.065</td>
<td>4.2168</td>
<td>0.0172</td>
</tr>
<tr>
<td>Step over (B)</td>
<td>1</td>
<td>12.708</td>
<td>12.708</td>
<td>2.8106</td>
<td>0.0965*</td>
</tr>
<tr>
<td>Interaction (A*B)</td>
<td>2</td>
<td>5.170</td>
<td>2.585</td>
<td>0.5717</td>
<td>NS</td>
</tr>
<tr>
<td>Depth of cut (C)</td>
<td>1</td>
<td>55.665</td>
<td>55.665</td>
<td>12.3120</td>
<td>0.0007</td>
</tr>
<tr>
<td>Interaction (A*C)</td>
<td>2</td>
<td>46.098</td>
<td>23.049</td>
<td>5.0979</td>
<td>0.0077</td>
</tr>
<tr>
<td>Interaction (B*C)</td>
<td>1</td>
<td>35.154</td>
<td>35.154</td>
<td>7.7754</td>
<td>0.0063</td>
</tr>
<tr>
<td>Interaction (A<em>B</em>C)</td>
<td>2</td>
<td>6.355</td>
<td>3.177</td>
<td>0.7028</td>
<td>NS</td>
</tr>
<tr>
<td>Error</td>
<td>108</td>
<td>488.291</td>
<td>4.521</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>119</td>
<td>687.570</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 95% confidence level, NS – no significance.

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

<table>
<thead>
<tr>
<th>Surface roughness (Ra) – (μm)</th>
<th>tool path geometry (LSD ±0.9414)</th>
<th>depth of cut (LSD ±0.7687)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>X</td>
<td>HG</td>
<td>HG</td>
</tr>
<tr>
<td>13.63</td>
<td>B</td>
<td>14.99</td>
</tr>
</tbody>
</table>

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).

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

<table>
<thead>
<tr>
<th>Surface roughness (Ra) – (μm)</th>
<th>Tool path geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>depth of cut – 4 mm</td>
</tr>
<tr>
<td>X</td>
<td>HG</td>
</tr>
<tr>
<td>14.91</td>
<td>AB</td>
</tr>
<tr>
<td>Outside lines tool path (A)</td>
<td>14.82</td>
</tr>
<tr>
<td>Linear tool path (B)</td>
<td>15.46</td>
</tr>
</tbody>
</table>

LSD ±1.331, 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 (Ra) dual interactions of the factors of step over and depth of wood shavings were considered according to Table 5, then the lowest Ra value appeared at an 8-mm depth of wood shavings for the 50% step over.

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 (Ra) 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 (Ra), on the contrary, it decreased. A similar situation, by also determining the step over, it was produced at a lower level of surface roughness (Ra) 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 (Gurau and Irle, 2017; Gurau et al., 2017; Hiziroglu, 1996; Söğütülu, 2010).

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


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COMPUTER AIDED ERGONOMICS IN FURNITURE DESIGN: BABY CRIB CASE STUDY

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2Akro Mühendislik, GOSB Teknopark – Kemal Nehraçoğlu Cad. High Tech Building, Kocaeli, Turkey
3Gazi University, Faculty of Technology, Department of Woodworking and Industrial Engineering, Ankara, Turkey

Abstract. 66% percent of the care giving parents experience musculoskeletal pain during the first 4 years of their children (Sanders and 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). 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 lumber 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).

Keywords: baby crib, ergonomics, furniture ergonomics, computer aided ergonomics, AnyBody Modelling System

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 and 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 defects) and neck disorders (24.6%) (neck pain, neck hernia, other neck defects) (TUIK, n.d.).

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.
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 scalable, 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

<table>
<thead>
<tr>
<th>Age group</th>
<th>Total (cm)</th>
<th>Male (cm)</th>
<th>Female (cm)</th>
<th>Total (kg)</th>
<th>Male (kg)</th>
<th>Female (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>167.2</td>
<td>173.2</td>
<td>161.4</td>
<td>72.8</td>
<td>77.4</td>
<td>68.4</td>
</tr>
<tr>
<td>15–24</td>
<td>168.4</td>
<td>173.9</td>
<td>162.7</td>
<td>63.6</td>
<td>68.9</td>
<td>58.2</td>
</tr>
<tr>
<td>25–34</td>
<td>169.1</td>
<td>175.5</td>
<td>162.8</td>
<td>71.1</td>
<td>77.7</td>
<td>64.5</td>
</tr>
<tr>
<td>35–44</td>
<td>168.1</td>
<td>173.9</td>
<td>162.2</td>
<td>76.2</td>
<td>81.4</td>
<td>71.0</td>
</tr>
<tr>
<td>45–54</td>
<td>166.5</td>
<td>172.2</td>
<td>160.7</td>
<td>78.2</td>
<td>81.3</td>
<td>74.9</td>
</tr>
<tr>
<td>55–64</td>
<td>165.5</td>
<td>171.2</td>
<td>160.0</td>
<td>78.4</td>
<td>80.6</td>
<td>76.2</td>
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<tr>
<td>65–74</td>
<td>164.1</td>
<td>170.1</td>
<td>158.9</td>
<td>75.3</td>
<td>77.2</td>
<td>73.7</td>
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<tr>
<td>75+</td>
<td>161.3</td>
<td>168.3</td>
<td>156.7</td>
<td>69.6</td>
<td>72.8</td>
<td>67.5</td>
</tr>
</tbody>
</table>

Source: TUIK, n.d.

This age group was evaluated because of births statistics by age group of mother (TUIK, n.d.). Mothers 25–34 years old are 55.33% of total births by age group of mother in 2015 (Table 2).

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).

Table 2. Births by age group of mother, 2015

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>18–19</th>
<th>20–24</th>
<th>25–29</th>
<th>30–34</th>
<th>35–39</th>
<th>40–44</th>
<th>45–49</th>
<th>50+</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>1325783</td>
<td>60893</td>
<td>313345</td>
<td>412331</td>
<td>321302</td>
<td>151591</td>
<td>34954</td>
<td>2465</td>
<td>431</td>
<td>10438</td>
</tr>
</tbody>
</table>

Source: TUIK, n.d.

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

<table>
<thead>
<tr>
<th>Percentile</th>
<th>3</th>
<th>10</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>90</th>
<th>97</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth</td>
<td>2.58</td>
<td>2.85</td>
<td>3.13</td>
<td>3.43</td>
<td>3.73</td>
<td>4.0</td>
<td>4.27</td>
</tr>
<tr>
<td>3rd month</td>
<td>4.75</td>
<td>5.26</td>
<td>5.79</td>
<td>6.38</td>
<td>6.99</td>
<td>7.54</td>
<td>8.1</td>
</tr>
<tr>
<td>6th month</td>
<td>6.21</td>
<td>6.79</td>
<td>7.41</td>
<td>8.12</td>
<td>8.85</td>
<td>9.54</td>
<td>10.25</td>
</tr>
<tr>
<td>9th month</td>
<td>7.27</td>
<td>7.87</td>
<td>8.51</td>
<td>9.26</td>
<td>10.06</td>
<td>10.81</td>
<td>11.58</td>
</tr>
<tr>
<td>12th month</td>
<td>7.96</td>
<td>8.61</td>
<td>9.32</td>
<td>10.16</td>
<td>11.05</td>
<td>11.92</td>
<td>12.82</td>
</tr>
<tr>
<td>15th month</td>
<td>8.61</td>
<td>9.28</td>
<td>10.01</td>
<td>10.89</td>
<td>11.83</td>
<td>12.75</td>
<td>13.72</td>
</tr>
</tbody>
</table>

Source: Neyzi et al., 2015.
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.

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 95 cm). 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 (Fig. 1).

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

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 height and results was shown in the Fig. 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 Fig. 2.

Lifting the baby from 55 cm 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 Fig. 3.

Fig. 2. Joint reaction force in lumbar region while lifting the baby from 55 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 Fig. 4.

_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 Fig. 5.

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

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

Fig. 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 (Fig. 5a).

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

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


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INTRODUCTION

After industry and transportation, housing, where we continue our life activities, are the areas in which the largest ratio of energy consumption is realized. The energy consumed in housing changes according to climatic conditions. The greatest energy consumption in cold regions is made with the objective of heating. The fuels used for heating, while they increase global warming with the toxic smoke gases they produce as the result of burning, at the same time, also produce environmental pollution. Together with the installment of heat insulations in housing, there would be improvements in housing for energy conservation, for being economical, for being secure and for health and there would also be a decrease in environmental problems. The performances of heat insulation systems implemented in housing are directly related to the selection of materials used in insulation and the system of implementation (Bayer, 2006).

Floors are covered with various materials, besides heat and sound insulation, with the objective making suitable the space that is hygienic and easily cleaned, that appears beautiful and for use (home, business, sports hall, etc.) (Döngel, 2005).

Many varieties of materials are used today with the purpose of covering floors. Solid wooden materials and wood-based materials, polyvinyl chloride (PVC), textile products, stones and ceramics are among the products used with this objective. Solid wood and wood-based floor covering materials constitute the main reasons for preference due to the harmony that they provide with other fitting elements and the feeling of warmth in the space organizations, that they are hygienic and have a long lifespan (As, 1998).

Many studies have been made for the determination of the heat conductivity attributes of wood and wood-based composite materials. It has been reported that the change in heat occurring on the surface with the contact of material things having different temperatures is less in solid and wood-based floor covering materials compared to inorganic materials (Song Yung and Powen, 1995).

It has been reported that the average coefficient value of heat conductivity in a direction perpendicular to the fibers is 0.1548 W/m.K in solid oak materials, 0.1032 W/m.K in solid Scots pine materials, whereas, in High Density Fiberboard (HDF) materials, which have a density of 0.800 g/cm³, it is 0.1978 W/m.K (Örs and Keskin, 2001).

As the result of a study that examined the coefficients of heat conductivity of the air-dried laminated wood materials impregnated with different impregnation materials, it was reported that the heat conductivity attributes

DETERMINATION OF THERMAL CONDUCTIVITY PROPERTIES OF WOOD AND WOOD-BASED FLOORING MATERIALS

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²Mersin University, Vocational School of Technical Sciences, Materials and Material Processing Technologies Department, Mersin, Turkey

Abstract. In this study, thermal conductivity properties of solid wood and wood-based flooring materials were investigated. For this purpose, total nine kinds of sample consisting of three kinds of solid parquet prepared from wood of yellow pine (Pinus silvestris L.), oriental beech (Fagus orientalis L.), and oak (Quercus petreae L.); three kinds of laminated parquet of which top layer is oak, mahogany and Iroko; three kinds of laminate parquet of which middle layer is HDF and having thickness of 10 mm, 8 mm and 6 mm have been prepared. Moreover, three kinds of materials which are mattresses in thickness of 1 mm and 3 mm and styrofoam in thickness of 4.5 mm were used as sub-parquet insulation material. Samples were tested by the standard test methods such as; moisture content in accordance with TS 2471 and TS EN 322, density with TS 2470 and TS EN 323/1, thermal conductivity and thermal transmittance coefficients according to TS EN 12667. As a result of the study, regarding thermal conductivity coefficient; value of beech solid wood parquet was the highest; while the value of Iroko laminated parquet was the lowest. Regarding thermal transmittance coefficient; value of 6 mm laminate parquet was the highest; while the value of pine solid wood parquet was the lowest. Insulation materials of laminate parquet with the thickness of 8 mm reduced the thermal conductivity and thermal transmittance coefficient values.

Keywords: floor coverings, solid wood parquet, laminated wood parquet, laminated parquet, thermal conductivity, thermal transmittance

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of wooden composite materials were different from solid wooden materials and that the attributes of composite wooden materials also showed a difference according to the type of adhesive used (Şahin Kol and Altun, 2009).

As the result of a study that researched the thermal characteristics of wood-based boards in different densities (chipboard, fiberboard, oriented strand board – OSB), it was reported that they showed a variability according to the board type for the effect on heat and heat conductivity and that low-density fiberboards also increased the heat conductivity (Czajkowski et al., 2016).

The objective of this study was to determine the heat conductivity attributes of wood and wood-based floor covering materials, which showed a difference from the aspect of the materials used and the production technique and accordingly, to present parameters from the aspect of selection of materials and quality evaluation criteria to the producers, designers and users.

METHODS AND MATERIALS

MATERIALS

In this study, a total of 9 types of parquet test materials were used with 3 types of solid parquet, which were prepared from Scots pine (Pinus silvestris L.), Oriental beech (Fagus orientalis L.) and oak (Quercus petreae L.) woods, which are produced and used extensively in the covering of floors in Turkey, with 3 types of laminated parquet, which has an upper layer of oak, mahogany and iroko, and 3 types of laminate parquet in thicknesses of 10 mm, 8 mm and 6 mm, which has HDF in the center layer.

SOLID PARQUETS

The solid parquets used within the scope of the study were obtained by selecting randomly from among the first-class products of the enterprises. Scots pine parquets in the measurements of 400 × 65 × 19 mm, Oriental beech parquets in the measurements of 400 × 85 × 16 mm and oak parquets in the measurements of 400 × 95 × 21 mm, were obtained in a sufficient number. The parquet specimens have been shown in Fig. 1.

LAMINATED PARQUETS

The specimens were obtained by selecting randomly from among the first-class products of the enterprises. Oak, mahogany and iroko with a thickness of 3 mm were used as the laminated parquet surfaces. The upper layer was covered with polyurethane varnish that was dried with ultraviolet (UV) light, the center layer of fir and the lower layer from Gaboon mahogany materials in a thickness of 1 mm were prepared and parquets with an average thickness of 14 mm were used in the experiments. A sufficient number of parquets in the measurements of 400 × 200 mm were obtained. The parquet specimens have been shown in Fig. 2.

LAMINATE PARQUETS

The specimens were obtained by selecting randomly from among the first-class products of the enterprises. HDF, which is the center layer (carrier layer), was used in
thicknesses of 10 mm, 8 mm and 6 mm in the specimens as a laminate parquet. A sufficient number of parquets in the measurements of 400 × 200 mm were obtained. The parquet specimens have been shown in Fig. 3.

The specimens kept in a climatization chamber until they reached an unchanging weight under conditions at a temperature of 23 ±2°C and at a relative humidity of 50 ±5%. It was determined that the average humidity of the 10 specimens selected randomly was 8–9 ±0.5%.

INSULATION MATERIALS UNDERNEATH THE PARQUET

The specimens were obtained by selecting randomly from among the first-class products of the enterprises. As a material underneath the parquet, 3 types of specimens were used with a mattress type insulation in a thickness of 1 mm, and styrofoam material used for insulation in thicknesses of 3 mm and 4.5 mm. A sufficient number of specimens were obtained and kept in a climatization chamber under conditions at a temperature of 23 ±2°C and at a relative humidity of 50 ±5% and after they reached an unchanging weight, their density values were determined (Table 1).

Table 1. Density values of insulation materials

<table>
<thead>
<tr>
<th>Materials type</th>
<th>Density (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm mattress</td>
<td>7.63</td>
</tr>
<tr>
<td>3 mm styrofoam</td>
<td>24.26</td>
</tr>
<tr>
<td>4.5 mm styrofoam</td>
<td>30.43</td>
</tr>
</tbody>
</table>

The insulation material specimens have been shown in Fig. 4.

METHODS

MOISTURE CONTENT

The TS 2471 standards were complied with in the solid specimens and the TS EN 322 standards were complied with in the laminated and laminate specimens for the determination of moisture content. With this objective, a total of 90 (9 × 10) each specimens were prepared with 10 each specimens from the solid materials with 20 mm in the direction of the fibers and with 20 × 15 mm in cross-section to the width and 10 each for each group from the laminated and laminate materials in the measurements of 50 × 50 mm.

DENSITY

The TS 2472 standards were complied with for solid specimens and the TS EN 323/1 standards were complied with for laminated and laminate specimens for the determination of density. With this objective, a total of 90 (9 × 10) specimens were prepared with 10 each from the solid materials in measurements of 30 mm in the direction to the fibers and 15 × 15 mm in cross-section to the width and 10 each for each group in the measurements of 50 × 50 mm from the laminated and laminate materials.
THERMAL CONDUCTIVITY

The TS EN 12667 standards were complied with for the determination of thermal conductivity. With this objective, a total of 27 (9 × 3) each specimens were prepared for 3 each in the measurements of 300 × 300 mm for each type by adding the parquet panels side-by-side. The test specimens prepared were kept in a climatization chamber under conditions at a temperature of 23 ±2°C and at a relative humidity of 50 ±5% until they reached an unchanging weight. The Linseis Heat Flow Meter Model HFM 300 test mechanism located in the test laboratory of the Gazi University, Faculty of Technology, Department of Wood Products Industrial Engineering was used for the determination of thermal conductivity (Fig. 5).

Before starting the tests, the cooling unit was adjusted to a temperature of 20°C, the upper plate to 25°C and the lower plate to a temperature of 15°C and the equipment was operated until these values were provided through the computer-controlled software. Subsequently, calibration was made for 20°C by placing the Institute for Reference Materials and Measurements (IRMM) 440 coded rockwool inside the equipment for the calibration of the equipment and by entering the U value stated in the catalog.

The test specimen was placed between the plates of the equipment and the test was started through the computer software. At the end of the test, the thermal conductivity coefficient values were recorded through the software.

The thermal conductivity coefficient with the computer-controlled software (Lambda) (λ) was calculated with the following equation:

\[
\lambda = \frac{q \cdot d}{A \cdot \Delta T} \text{ (W/m.K)}
\]  

where:
- \(\lambda\) – thermal conductivity coefficient (W/m.K)
- \(q\) – power provided to the measuring part of the heating unit
- \(d\) – thickness of the test specimen
- \(A\) – measurement area of the test piece
- \(\Delta T\) – difference in temperature among the plates.

RESULTS AND DISCUSSION

DENSITY

The density values of the test specimens have been given in Table 2.

<table>
<thead>
<tr>
<th>Material type</th>
<th>Density (g/cm³) x</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid wood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>scots pine</td>
<td>0.524</td>
<td>0.002</td>
</tr>
<tr>
<td>oriental beech</td>
<td>0.777</td>
<td>0.006</td>
</tr>
<tr>
<td>oak</td>
<td>0.735</td>
<td>0.001</td>
</tr>
<tr>
<td>Laminated oak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mahogany</td>
<td>0.502</td>
<td>0.003</td>
</tr>
<tr>
<td>iroko</td>
<td>0.474</td>
<td>0.019</td>
</tr>
<tr>
<td>Laminate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 mm</td>
<td>0.910</td>
<td>0.007</td>
</tr>
<tr>
<td>8 mm</td>
<td>0.894</td>
<td>0.005</td>
</tr>
<tr>
<td>6 mm</td>
<td>0.889</td>
<td>0.016</td>
</tr>
</tbody>
</table>

The highest density was obtained in the 10 mm laminate parquet, whereas, the lowest density was obtained in the iroko laminated parquet. The results were found to be close to the values given in the literature.

THERMAL CONDUCTIVITY COEFFICIENT (λ)

The effect of the type of materials on the thermal conductivity coefficient were found to be statistically significant (α = 0.05). The comparative results of the LSD test made at the level of type of materials have been given in Table 3.
Table 3. Thermal conductivity values of test specimens

<table>
<thead>
<tr>
<th>Material type</th>
<th>Thermal conductivity (W/m.K)</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid wood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>scots pine</td>
<td>0.1077</td>
<td>BC</td>
</tr>
<tr>
<td>oriental beech</td>
<td>0.1272</td>
<td>A*</td>
</tr>
<tr>
<td>oak</td>
<td>0.1215</td>
<td>AB</td>
</tr>
<tr>
<td>Laminated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>oak</td>
<td>0.1189</td>
<td>AB</td>
</tr>
<tr>
<td>mahogany</td>
<td>0.0929</td>
<td>CD</td>
</tr>
<tr>
<td>iroko</td>
<td>0.0893</td>
<td>D**</td>
</tr>
<tr>
<td>Laminate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 mm</td>
<td>0.1209</td>
<td>AB</td>
</tr>
<tr>
<td>8 mm</td>
<td>0.1104</td>
<td>B</td>
</tr>
<tr>
<td>6 mm</td>
<td>0.1062</td>
<td>BC</td>
</tr>
</tbody>
</table>

HG – homogeneity group.

The highest thermal conductivity coefficient was obtained in the Oriental beech solid parquets, whereas, the lowest heat conductivity coefficient was obtained in the iroko laminated parquets. The differences between the solid oak and laminated oak with the 10 mm laminate and the Scots pine solid with the 6 mm laminate specimens were insignificant. The graph for these has been given in Fig. 6.

It was reported in the literature that the average heat conductivity coefficient value in a direction perpendicular to the fibers was 0.1548 W/m.K in the solid oak materials, was 0.1032 W/m.K in the solid Scots pine materials and the density was 0.800 g/cm³, whereas, it was 0.1978 W/m.K in the HDF materials (Song Yung and Powen, 1995). Whereas, in this study, it was found to be 0.1215 W/m.K in the solid oak parquets, 0.1077 W/m.K in the solid Scots pine parquets and was 0.1209 W/m.K in the 10 mm HDF-based laminate parquets. The value of the Scots pine materials was close to the literature value, but the solid oak and HDF laminate parquets were obtained at lower values in this study. It can be stated that the difference could stem from density and production conditions.

In another study, the thermal conductivity coefficient of Scots pine in a tangential direction was obtained at 0.1015 W/m.K, in a radial direction at 0.1040 W/m.K and the heat conductivity coefficient of Oriental beech in a tangential direction was obtained at 0.1203 W/m.K and in a radial direction at 0.1281 W/m.K (Arslan, 2015).

The results for the effect on the thermal conductivity coefficient of the under-parquet insulation materials in the 8 mm laminate parquets have been given in Table 4.

Table 4. Effect on the thermal conductivity of the under-parquet insulation materials

<table>
<thead>
<tr>
<th>Factor</th>
<th>Material type</th>
<th>8 mm laminate</th>
<th>+ 1 mm mattress</th>
<th>+ 3 mm styrofoam</th>
<th>+ 4.5 mm styrofoam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity</td>
<td>0.1104</td>
<td>0.0851</td>
<td>0.0607</td>
<td>0.0560</td>
<td></td>
</tr>
<tr>
<td>Change (%)</td>
<td>-</td>
<td>-23%</td>
<td>-45%</td>
<td>-49%</td>
<td></td>
</tr>
</tbody>
</table>

The entire under parquet insulation materials for the 8 mm laminate parquet specimens decreased the thermal conductivity coefficient value. The largest decrease was
obtained with the 4.5 mm styrofoam insulation material (49%), whereas, the lowest decrease was obtained with the 1 mm mattress type insulation material (23%).

CONCLUSIONS

In conclusion, by considering the test results, the proposals stated below can be given:

1. It was observed that there was a reverse relationship between the density in the solid materials with the heat conductivity coefficient. In this situation, in spaces where the heat conductivity is more important, then materials with lower density could be preferred and from this aspect, Scots pine, oak and Oriental beech can be preferred.

2. It was determined that the heat conductivity values of laminated parquets were lower compared to solid parquets. In this situation, laminated parquets can be preferred compared to solid parquets from the aspect of the heat conductivity advantage.

3. It was observed that there was also a reverse relationship between the density with the thermal conductivity coefficient in the laminate parquets. Laminate parquets with lower densities can be proposed from this aspect.

4. In the under the parquet insulation materials, the thermal conductivity values of the 3-mm styrofoam material insulations and the 4.5 mm styrofoam material insulations were found to be close. It can be proposed that the 3-mm styrofoam material insulations be preferred from the aspect of cost.

5. It can be proposed to researchers that similar studies be made for parquets produced from different wood species and with different insulation materials.

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

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Abstract. 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.

Keywords: ageing, design, furniture, human-product interaction, usability, user experience

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 et al., 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 (De Looze et al., 2003; Engdahl, 1968; Farage et al., 2012; Franz et al., 2012; Holden et al., 1988; Mills, 2007; Moes, 2005; Pirkl, 1994; Vink, 2008; Vink and Brauer, 2011; William-Olsson and Svanborg, 1984; 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 (2008), 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?

**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.

Fig. 1. 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.

Fig. 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.
Fig. 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.

Fig. 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.

Fig. 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.

Fig. 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.

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

Fig. 8. Armchair (no. 8, group C) Sandö designed by Marit Stigsdotter for Stolab. The test chair was upholstered in a green patterned fabric.
**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 1. Participants (N = 30)**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>18</td>
</tr>
<tr>
<td>Males</td>
<td>12</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
</tr>
<tr>
<td>56–67</td>
<td>13</td>
</tr>
<tr>
<td>68–77</td>
<td>11</td>
</tr>
<tr>
<td>78–87</td>
<td>6</td>
</tr>
<tr>
<td>Self-reported inconvenience with ingress</td>
<td></td>
</tr>
<tr>
<td>Females ($n = 18$)</td>
<td>2</td>
</tr>
<tr>
<td>Males ($n = 12$)</td>
<td>2</td>
</tr>
<tr>
<td>All</td>
<td>4</td>
</tr>
<tr>
<td>Self-reported inconvenience with egress</td>
<td></td>
</tr>
<tr>
<td>Females ($n = 18$)</td>
<td>3</td>
</tr>
<tr>
<td>Males ($n = 12$)</td>
<td>5</td>
</tr>
<tr>
<td>All</td>
<td>8</td>
</tr>
</tbody>
</table>

**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**

<table>
<thead>
<tr>
<th>Satisfaction level</th>
<th>Number of points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very satisfied</td>
<td>10, 9</td>
</tr>
<tr>
<td>Rather satisfied</td>
<td>8, 7</td>
</tr>
<tr>
<td>Neither nor</td>
<td>6, 5</td>
</tr>
<tr>
<td>Rather dissatisfied</td>
<td>4, 3</td>
</tr>
<tr>
<td>Very dissatisfied</td>
<td>2, 1</td>
</tr>
</tbody>
</table>
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 (Fig. 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.

Fig. 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/dis-satisfaction 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

<table>
<thead>
<tr>
<th></th>
<th>1 Visual appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Ingress (after two ingresses)</td>
</tr>
<tr>
<td>3</td>
<td>Adjustments (if applicable)</td>
</tr>
<tr>
<td>4</td>
<td>Appearances and usability of adjustments levers (if applicable)</td>
</tr>
<tr>
<td>5</td>
<td>Seat comfort (after properly seated)</td>
</tr>
<tr>
<td>6</td>
<td>Seat comfort while reading (after browsing in a book)</td>
</tr>
<tr>
<td>7</td>
<td>Egress (after two egresses)</td>
</tr>
<tr>
<td>8</td>
<td>Movable</td>
</tr>
</tbody>
</table>

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 numeri-
cal 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.

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 = x) 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/Fig. 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 ingressing 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 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 \((n = 3)\).

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.

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

**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 \((n=\text{Fig.9 and 10})\) or chair \(n=\text{Fig.3}\) 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 an 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 \(n=\text{Fig.6}\) 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 \(n=\text{Fig.9}\) 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. Simularly, 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).

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 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 acknowledged. Many thanks to the persons participating in the study.

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LATVIAN FURNITURE INDUSTRY’S COMPETITIVENESS POTENTIAL IN THE BALTIC STATES

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Abstract. 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.

Keywords: furniture industry, competitiveness, Baltic States, Latvia

INTRODUCTION

Competitiveness is crucial to the success of a highly competitive market (Fedotovs and 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. 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 (Eiropas..., 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).

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.

**Fig. 1.** Number of enterprises in the Baltic States  
Source: own elaboration.

**Fig. 2.** Number of persons employed in the Baltic States  
Source: own elaboration.

**Fig. 3.** Production in the Baltic States  
Source: own elaboration.

**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.

**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.
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).

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 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

Table 1. Determining the strengths of the furniture industry in the context of the Baltic States

<table>
<thead>
<tr>
<th>Strengths (internal environment)</th>
<th>Estonia</th>
<th>Latvia</th>
<th>Lithuania</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profitable geographical location, facilitating short distances to major outlet markets and shorter delivery times</td>
<td>Available local wood resources and cheaper available wood raw materials (indirectly cheap timber resources)</td>
<td>Lower available labor costs compared to EU countries in its western and northern regions</td>
<td></td>
</tr>
<tr>
<td>State support for increasing the production capacity of local producers in export markets</td>
<td>The ability of individual companies or their groups to improve their performance effectively in both domestic and external product exports markets</td>
<td>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</td>
<td></td>
</tr>
<tr>
<td>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</td>
<td>Strategic approach at the level of sectoral management to implement cooperation principles in increasing the turnover of the sector and improving efficiency</td>
<td>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</td>
<td></td>
</tr>
<tr>
<td>Strategic competence of high-level leaders in improving the overall competitiveness of the industry</td>
<td>A liberal economic environment for attracting foreign investors, as well as the openness and ability of state institutions to cooperate</td>
<td>Stable international company IKEAs orders and investment flows in the industry, also promoting mass production of furniture products</td>
<td></td>
</tr>
<tr>
<td>A liberal economic environment for attracting foreign investors, as well as the openness and ability of state institutions to cooperate</td>
<td>Increasing industry productivity indicators, using functionally oriented marketing opportunities and experience in export markets</td>
<td>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</td>
<td></td>
</tr>
</tbody>
</table>

Source: own elaboration.
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, 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

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

<table>
<thead>
<tr>
<th>Weaknesses (internal environment)</th>
<th>Estonia</th>
<th>Latvia</th>
<th>Lithuania</th>
</tr>
</thead>
<tbody>
<tr>
<td>When introducing new outlets, Estonian furniture manufacturers are small, unable to execute / sell</td>
<td>When introducing new outlets, furniture manufacturers in Latvia are small, unable to execute / sell</td>
<td>High dependence on the business decisions of large furniture manufacturing companies and even on one of the main furniture manufacturers, i.e. IKEA</td>
<td></td>
</tr>
<tr>
<td>The poorly developed products of local enterprises and their brands influenced by the dependence on products produced by large foreign furniture companies</td>
<td>The growth of furniture production in the domestic market is influenced by Lithuanian and Polish companies operating in Latvia</td>
<td>The poorly developed products of local enterprises and their brands influenced by the strong dependence on products produced by large foreign furniture companies</td>
<td></td>
</tr>
<tr>
<td>The creation of local brand names does not involve enough professional professionals</td>
<td>There is no involvement of professional specialists in the creation of local brand products</td>
<td>Transferring of limited intermediate competencies (knowledge and skills) on the process and trends of modern furniture production</td>
<td></td>
</tr>
<tr>
<td>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</td>
<td>Transferring of limited intermediate competencies (knowledge and skills) on the process and trends of modern furniture production</td>
<td>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</td>
<td></td>
</tr>
<tr>
<td>Transferring of limited intermediate competencies (knowledge and skills) on the process and trends of modern furniture production</td>
<td>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</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: own elaboration.
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 im-

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

<table>
<thead>
<tr>
<th>Opportunities (external environment)</th>
<th>Estonia</th>
<th>Latvia</th>
<th>Lithuania</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to offer lower shipping costs and faster delivery times</td>
<td>- Ability to offer lower shipping costs and faster delivery times</td>
<td>- Ability to offer lower shipping costs and faster delivery times</td>
<td>- Ability to offer lower shipping costs and faster delivery times</td>
</tr>
<tr>
<td>Enhanced cooperation between enterprises and public administration in strengthening competitiveness by exchanging good practice approaches through projects of common interest</td>
<td>- Collaboration between enterprises and research institutions, creating a strong cluster of the furniture industry, boosting the export market</td>
<td>- Strategic support at national level for attracting foreign capital, also by promoting good practice and transfer of relevant competences</td>
<td>- Create strong product lines and brands (national design schools), gradually reducing the dependence on the impact of products from foreign companies</td>
</tr>
<tr>
<td>Enhanced cooperation between enterprises in the field of high technology integration, education and innovation, developing their own furniture products</td>
<td>- To promote the transfer of professional competences by developing their products and their brands</td>
<td>- 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</td>
<td>- Make effective use of IKEA’s business and business experience</td>
</tr>
<tr>
<td>Raising enterprise productivity and business specialization</td>
<td>- Consumer orientation towards the use of environmentally friendly materials and energy saving creates a prerequisite for wider use of wood</td>
<td>- Consumer orientation towards the use of environmentally friendly materials and energy saving creates favorable preconditions for wider use of wood</td>
<td>- Consumer orientation towards the use of environmentally friendly materials and energy saving creates favorable preconditions for wider use of wood</td>
</tr>
<tr>
<td>Financial support for entry into new markets as well as long-term investment in raising productivity</td>
<td>- Increasing competition from producers in Poland, Lithuania and Russia, i.e. the pressure of “cheap” furniture supply from the East</td>
<td>- Rising raw material prices and labor cost increases, resulting in shortages</td>
<td>- Rising raw material prices and labor cost increases, resulting in shortages</td>
</tr>
<tr>
<td>Consumer orientation towards the use of environmentally friendly materials and energy saving creates a prerequisite for wider use of wood</td>
<td>- Rising raw material prices and labor cost increases, resulting in shortages</td>
<td>- Low productivity of production and a small proportion of innovative technologies and new products in industry, attracting EU co-financing</td>
<td>- Rising raw material prices and labor cost increases, resulting in shortages</td>
</tr>
<tr>
<td>Threats (external environment)</td>
<td>- Stagnation in the banking and financial sector, increasing tax burden, facilitating a slow recovery of the market</td>
<td>- Weak and inadequately coordinated forest sector development cooperation with related sectors in the context of the overall national sustainable development</td>
<td>- Stagnation in the banking and financial sector, increasing tax burden, facilitating a slow recovery of the market</td>
</tr>
<tr>
<td></td>
<td>- The deterioration of business conditions in the country may reduce the interest of foreign investors, as well as IKEA to stop its activities</td>
<td>- Stagnation in the banking and financial sector, increasing tax burden, facilitating a slow recovery of the market</td>
<td>- The deterioration of business conditions in the country may reduce the interest of foreign investors, as well as IKEA to stop its activities</td>
</tr>
<tr>
<td></td>
<td>- The shortage of skilled labor in the long-term emigration of skilled labor, especially in engineering and technology</td>
<td></td>
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</tbody>
</table>

Source: own elaboration.
formulated the following options: the furniture sector in the Baltic States, the author has opportunities and threats of furniture production 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.

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, i.e., 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 cooperation, 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 as 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.

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.

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

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Abstract. The Approach towards product design and furniture for people 65+ has changed lately. 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.

Keywords: research, design process, user experience, ergonomics, communication, 65+ users

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, which, 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 AND 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 wither 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.

"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 theirs life’s passions and dreams (Dąbrowska and Rey, 2008, s. 20–23). 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.

“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.

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.

As Opaschowski said ‘human being doesn't have to spend Money to feel happiness’ (Opaschowski, 1992).

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 (Schneider, 2000).

METHODS AND MATERIALS
USER ROLE IN DESIGN PROCESS: PERSONA BUILDING, RESEARCH, MOODBOARDS, PROBLEM SOLVING

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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 (Fig. 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.

**Fig. 8.** Photos of real surrounding of persona

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

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

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

**Fig. 12.** Basin UNO (Catalog 10 PE-P), 10PE-P, design Anna Dull, manufacturer: Marmorin

Unia 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 used 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.

**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.

**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.

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INFORMATION SYSTEM FOR FURNITURE INDUSTRY KNOWLEDGE BASE TRANSFER

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Abstract. 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.

Keywords: furniture, industry support, information system, quality, database

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.

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 – ACN) 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

GOALS AND CRITERIA

The goal of our project was the development of an 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:

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.
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.

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.

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 (Fig. 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, understand-able 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 custom 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.

**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.

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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.

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MODELING OF DENISTY OF PERIODIC STRUCTURES
CORES OF HONEYCOMB PANELS

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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.

Keywords: honeycomb, auxetic, density

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 (Alqassim, 2011; Balawi and Abot, 2008; Chang and Ebcioğlu, 1961; Chen and Pugno, 2012; Chi et al., 2010; He and Hu, 2008; Hu et al., 2013; Jeyakrishnan et al., 2013; Schultz et al., 2012; Smardzewski, 2013; Yin et al., 2012). 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.

METHODS AND MATERIALS

HEXAGONAL CELL

Fig. 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 rib- (common cell wall), \( t \) wall thickness, \( L_c \) cell length, \( S_y \) width of the cell, \( \varphi \) angle of inclination of the wall.

Fig. 1. Elementary unit of a cellular cell core with a hexagonal shape

The relative density \( \rho \) of the analyzed structure can be written as the quotient of the core density \( \rho^* \) and the density of the substance forming the framework of the structure \( \rho_s \):

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The relative density $\rho_A$ of the analyzed structure can be written as the quotient of the core density $\rho_A^*$ and the density of the substance forming the framework of the structure $\rho_sA$:

$$\rho_A = \frac{\rho_A^*}{\rho_sA}$$  \(8\)

Assuming the same assumptions as above (for hexagonal cells) the relative density should be written as:

$$\rho_A = \frac{F_sA}{F_A^*}$$  \(9\)

According to Fig. 2, the surface of the elementary section of the core is expressed by equation:

$$F_A^* = 4(l_A + l_A\cos(\varphi_A))(h_A - t_A\text{ctg}(\varepsilon_A) - l_A\sin(\varphi_A))$$  \(10\)

while the surface of the substance forming the skeleton of the structure:

$$F_sA = 4(l_A + l_A\cos(\varphi_A))(h_A - t_A\text{ctg}(\varepsilon_A) - l_A\sin(\varphi_A)) - 4l_A\cos(\varphi_A)(h_A - 2t_A\text{ctg}(\varepsilon_A) - l_A\sin(\varphi_A))$$  \(11\)

hence:

$$\rho_A = 1 - \frac{l_A\cos(\varphi_A)(h_A - 2t_A\text{ctg}(\varepsilon_A) - l_A\sin(\varphi_A))}{(t_A + l_A\cos(\varphi_A))(h_A - t_A\text{ctg}(\varepsilon_A) - l_A\sin(\varphi_A))}$$  \(12\)

where:

$$\varepsilon_A = \frac{90^\circ - \varphi_A}{2}$$

Critical condition of the existence of an auxetic cell with the presented geometry is:

$$l_0 > 0.$$  \(13\)

where:

$$l_0 = 2\left(h_A - l_A\sin(\varphi_A) - tA\text{ctg}(\varepsilon_A)\right)$$

AUXETIC CYLINDRICAL CELL

Analysis of the geometry of the section of the auxetic cellular core structure (Fig. 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:

$$L_x = 2(2R_1 + t - m)$$  \(14\)

height $S_y$ is equal to:

$$S_y = 2(R_1 + n)$$  \(15\)
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).

Following succeeding equations:

\[
\begin{align*}
\mathbf{f} &= \frac{1}{2}( (2R_1 + t - m)^2 + (R_1 + n)^2 - (2R_1 + t)^2)^{0.5} \\
\mathbf{z} &= \frac{(m + t)(2R_1 + t)}{4f}
\end{align*}
\]

and

\[
\begin{align*}
\sin(\varphi) &= \frac{2x}{2R_1 + t} \\
\mathbf{z} &= \frac{(m + t)(2R_1 + t)}{4f}
\end{align*}
\]

result:

\[
\mathbf{z} = \frac{(m + t)(2R_1 + t)}{2((2R_1 + t - m)^2 + (R_1 + n)^2 - (2R_1 + t)^2)^{0.5}}
\]

\[
\sin(\varphi) = \frac{m + t}{((2R_1 + t - m)^2 + (R_1 + n)^2 - (2R_1 + t)^2)^{0.5}}
\]

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 (Fig. 4). In this case for \( n = 0 \) and \( \varphi = 30^\circ \)

\[
\sin(30^\circ) = \frac{m + t}{((2R_1 + t - m)^2 + (R_1)^2 - (2R_1 + t)^2)^{0.5}} = \frac{1}{2}
\]

In addition, Fig. 3b shows another regularity:

\[
\begin{align*}
\left\{ \begin{array}{l}
\mathbf{e}^2 = \left( \frac{1}{2}( \frac{L}{2} ) \right)^2 + \left( \frac{1}{2}( \frac{S}{2} ) \right)^2 \\
\mathbf{f}^2 = \mathbf{e}^2 - \left( \frac{R_1}{2} \right)^2
\end{array} \right.
\end{align*}
\]

hence:

\[
\mathbf{f} = \frac{1}{2}( (2R_1 + t - m)^2 + (R_1 + n)^2 - (2R_1 + t)^2)^{0.5}
\]
\[ 3m^2 + (4R_1 + 10t)m - ((R_1 + n)^2/2 - 4t^2) = 0 \] (26)

hence:
\[ \Delta = (4R_1 + 10t)^2 + 12((R_1 + n)^2 - 4t^2) \] (27)
\[ m_{1,2} = \frac{1}{6} \left( -4R_1 + 10t \pm \sqrt{\Delta} \right) \] (28)

The value of one of the roots of the equation is the maximum horizontal module \( m_1 \) for the core structure, where:
\[ L_x = 2(2R_1t - m) \]
\[ S_y = 2R_1 \]
\[ \varphi = 30^\circ \] (29)

For \( n = 0 \) and \((-t) \leq m \leq m_1\):
\[ L_x = 2(2R_1t - m) \]
\[ S_y = 2R_1 \]
\[ \varphi = \arcsin \left( \frac{m + t}{((2R_1 + t - m)^2 + (R_1)^2 - (2R_1 + t)^2)^{\frac{1}{2}}} \right) \] (30)

For \( 0 < n \) and \((-t) \leq m \leq R_1\):
\[ L_x = 2(2R_1 + t - m) \]
\[ S_y = 2(R_1 + n) \]
\[ \varphi = \arcsin \left( \frac{m + t}{((2R_1 + t - m)^2 + (R_1 + n)^2 - (2R_1 + t)^2)^{\frac{1}{2}}} \right) \] (31)

The relative density \( \rho \) of the analyzed structure can be written as the quotient of the core density \( \rho^* \) and the density of the substance forming the skeleton of the structure \( \rho_s \):
\[ \rho = \frac{\rho^*}{\rho_s} \] (32)

therefore:
\[ \rho^* = \frac{w}{V^*} = \frac{W}{HF^*} \] (33)
\[ \rho = \frac{w}{V_S} = \frac{W}{HF_S} \] (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:
\[ \rho = \frac{F_S}{F^*} \] (35)

According to Fig. 5 surface of the elementary core section follows the equation:
\[ F^* = 4(2R_1 + t - m) (R_1 + n) \] (36)

Surface of the substance forming the skeleton of the structure follows the equation:
\[ F_S = 4 \left( \frac{1}{2} \pi (R_2^2 - R_1^2) + \frac{\varphi \pi}{180} ((R_1 + t)^2 - R_1^2) + 2tf \right) \] (37)
\[ \rho^* = \frac{1}{2} \pi (R_2^2 - R_1^2) + \frac{\varphi \pi}{180} ((R_1 + t)^2 - R_1^2) + 2tf } \] (38)

**RIB SHAPE CELL**

Geometry of the elementary section of the rib shape core structure of the cellular panel (Fig. 6), it worth noticing that it is composed of two orthogonal arms of the dimensions as shown in Fig. 7. Where: the height of the core \( h \), the angle of inclination of the ribs in the plane ZX and ZY respectively \( \varphi_x, \varphi_y \), the width of the rib base \( a \), rib width \( s \), rib thickness \( t \).
Fig. 6. Elementary unit of the structure of the rib shape core of the cellular panel

Because:

\[ \varepsilon_x = \varphi_x \text{ and } \varepsilon_y = \varphi_y \]

lengths \( L_x \), \( L_y \) of elementary section are equal to:

\[ L_x = 2(2a + t \cdot \tan \left( \frac{\varphi_x}{2} \right) + (h - t) \cot \varphi_x) \quad (39) \]

\[ L_y = 2(2a + t \cdot \tan \left( \frac{\varphi_y}{2} \right) + (h - t) \cot \varphi_y) \quad (40) \]

where:

\[ \tan \left( \frac{\varphi_y}{2} \right) = \tan \left( \frac{\varepsilon_y}{2} \right) = \frac{a_y}{t} \quad (41) \]

\[ \tan \left( \frac{\varphi_y}{2} \right) = \tan \left( \frac{\varepsilon_y}{2} \right) = \frac{a_y}{t} \quad (42) \]

\[ l_x = \frac{h - t}{\sin \varphi_x} \quad , \quad l_y = \frac{h - t}{\sin \varphi_y} \quad (43) \]

\[ l_x' = (h - t) \cot \varphi_x \quad (44) \]

\[ l_y' = (h - t) \cot \varphi_y \quad (45) \]

The relative density \( \rho \) of the analyzed structure can be written as the quotient of the core density \( \rho^* \) and the density of the substance forming the skeleton of the structure \( \rho_S \):

\[ \rho = \frac{\rho^*}{\rho_S} \quad (46) \]

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, \( V_t \) – 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 Fig. 7, volume of the arms of the elementary core section follows the equations:

\[ V_{s(ZX)} = \delta \left( hl_x - 4(h - t)(a + \frac{1}{2}l_x') \right) \quad (50) \]

\[ V_{s(ZY)} = \delta \left( hl_y - 4(h - t)(a + \frac{1}{2}l_y') \right) \quad (51) \]

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:

\[ F_S = 4 \left( \frac{1}{2} \pi (R_1^2 - R_2^2) + \frac{q \pi}{180} ((R_1 + t)^2 - R_1^2) + 2t_f \right) \quad (53) \]
hence:
\[ \rho = \frac{V_{h(ZX)} + V_{h(ZY)}}{L_x l_y h}. \] 

(AUXETIC RIB SHAPE CELL)

To maintain symmetrical structure, auxetic cell with the spatial structure (Fig. 8) 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 (Fig. 9).

Spatial geometry of the spatial structure of the rib shape core of the cellular plate (Fig. 8, 9), 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 \( \phi \) 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 \( \phi \) should be between \( 0^\circ < \phi < 40^\circ \).

Lengths of single cell arms are equal \( L_x = L_y = L_z \), therefore:

Fig. 8. Auxetic cell with the spatial structure

Fig. 9. Compilation of cells to panel core: a) 12 mm, b) 14 mm

Fig. 10. Elementary unit of the rib shape cor structure of cell panel
Modeling of density of periodic structures cores of honeycomb panels

\[ l = \frac{L_x - 3t}{2} \]  \hspace{1cm} (55)

\[ h' = \frac{t}{2tg(\phi)} \]  \hspace{1cm} (56)

For equal masses of cells substance, the relative density \( \rho \) 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:

\[ \rho = \frac{V_s}{V^*} \]  \hspace{1cm} (57)

According to Fig. 10 volume of arms of elementary section of the core follows the equation:

\[ V_s = 6t\left(t(L_x - 3t)tg(\phi) + \left(\frac{1}{2}t + x\right) + t^2\right) \]  \hspace{1cm} (58)

where:

for \( h' \leq l' \ x = 0 \),
for \( h' > l' \ x = (Lx - 3t) tg(\phi) \),
while, volume of the elementary core follows the equation:

\[ V^* = (L_x - t)^3 \]  \hspace{1cm} (59)

RESULTS AND DISCUSSION

EFFECT OF RIBBON SHAPE CELL PARAMETERS ON ITS RELATIVE DENSITY

Fig. 11 shows the results of an analytical calculations for an auxetic ribbon shape cell, showing the effect the angular deviation of the arms \( \phi \), 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.

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 (Fig. 12). The reference cell is a cell with isotropic properties. Fig. 12 shows the effect of the cell type on its linear dimensions.

Cell E exhibits most orthotrophic 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.

Fig. 11. Relative density \( \rho \) as function of: a) cell wall angle \( \phi \); b) cell wall thickness \( t \); c) length of common side of cell \( h \); d) length of free side of cell \( l \)
EFFECT OF CYLINDRICAL CELL PARAMETERS ON ITS RELATIVE DENSITY

Fig. 14 shows the effect of variable parameters on cylindrical cell properties.

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 \( \varphi \) 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 (Fig. 15). Fig. 16 shows the effect of cell type on its linear dimensions.

**Fig. 14.** Relative density \( \rho \) as function of:
- a) horizontal module \( m \)
- b) vertical module \( n \)
- c) tape thickness \( t \)
- d) outer radius \( R_1 \)
- e) cell wall angle

**Fig. 12.** Geometry of selected core cells

**Fig. 13.** 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 PARAMETERS ON ITS RELATIVE DENSITY**

Fig. 17 shows the effect of variable parameters on rib shape cell properties.

Increase of rib inclination angle, both the $\phi_x = \phi_y$ and the $\phi_x \neq \phi_y$ 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 (Fig. 18).

Fig. 19 shows the 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 isotrophic character. It’s possible to achieve smaller cells with iso- or ortotrophic 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

Fig. 20 shows the effect of variable parameters on rib shape auxetic cell properties.

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 (Fig. 21).

Fig. 22 shows the 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 it’s overall dimensions but exhibits in geometrical shape of obtained cell.

CONCLUSIONS

The obtained results on novel cell constructions made it possible to draw the following conclusions:
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.

There is a close correlation between the variable cell dimensions and its relative density.

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 ortotrophic character.

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WITHDRAWAL CAPACITY OF GLUED-IN RODS IN BIRCH PLYWOOD

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Abstract. 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.

The aim of this study was to determine the effect of plywood panel thickness and rod embedment length to the withdrawal force. 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.

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.

Keywords: glued-in rods, plywood, pull-out, threaded bar, joints

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.

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.

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, 2015). 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, ad – 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 et al., 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 Fig. 2.

**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 Fig. 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 Fig. 4, the complete summary of withdrawal capacity is given.

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 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


SFS 2413 Quality requirements for appearance of plywood with outer plies of birch


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CURRENT CONCEPTS FOR TECHNOLOGY ALLOWING INDEPENDENT AND ACTIVE LIVING FOR ELDERLY PEOPLE

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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.

Keywords: ambient assisted living, modularization, personalization, smart home, seamless integration

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.

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 Aldige") and LISA HABITEC ("Habitat, Bits and Technology in an Ageing Society"), which have been recently conclu-
ed 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 Fig. 1.

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 Fig. 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, Fig. 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 Fig. 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 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

**Fig. 1.** First generation of the terminal for the wardrobe with integrated functions.
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 Fig. 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.

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 and 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 and 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 Fig. 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.

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 Fig. 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), 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 Fig. 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.

BEDROOM

In the bedroom, elderly often do not face the challenge of getting in but rather getting up from the bed. To fa-
cilitate these everyday activities, handles have been de-
cent 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 Fig. 6. If required, both handles
can be pulled out and thereby brought into the approp-
riate position and the elderly can easily and safety 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 read-
ing position of a book or a tablet, see Fig. 6.

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 individ-
ual 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
Fig. 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 cam-
era or a laser scanner, (3) telepresence for online par-
ticipation at meetings (through a correspondingly large
screen, an almost life size transmission is possible), (4)
3D printer for competitive production of the custom-
ized 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 Fig. 7.

RESULTS AND DISCUSSION

The terminals for old people with their various function-
alities 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 func-
tions of the terminals (Anne and Eva, 2016, 2017). Only
elderly with dementia or heavy gait disorder (e.g. wheel-
chair driver) were excluded from the tests. Among the
test persons, mainly female subjects above 65 years eval-
uated 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 sub-
ject invitation (Zirk and 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.

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.

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THE ELDERLY AND DISABLED IN NURSING HOMES: COMPLIANCE WITH HARDWARE FURNITURE IN MERSIN

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²Necmettin Erbakan University, Faculty of Fine Arts Department of Interior Architecture and Environmental Design, Turkey
³Gazi University, Faculty of Technology Department of Woodworking Industrial Engineering, Turkey

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.

Keywords: aging, safety in space, ergonomic furniture

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.

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

Table 1. Turkey population distribution by age groups in 2016

<table>
<thead>
<tr>
<th>Specification</th>
<th>Age</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>65–69</td>
<td>70–74</td>
</tr>
<tr>
<td>Percentages</td>
<td>3,02</td>
<td>2,11</td>
</tr>
</tbody>
</table>

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is defined as "Old", and the age group 85+ is defined as “the Oldest old”. In 2016 Türkiye nüfusunun yaş gruplarına göre nüfus dağılımı ve nüfus yüzdesi (http://transgenerational.org/aging/demographics.htm).

The Nursing homes are institutions 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).

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. Number of nursing homes in Turkey

<table>
<thead>
<tr>
<th>Specification</th>
<th>Number of NH</th>
<th>Capacity</th>
<th>Number of elderly</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH attached to the Ministry</td>
<td>107</td>
<td>11,717</td>
<td>10,692</td>
</tr>
<tr>
<td>NH attached to other Ministries</td>
<td>2</td>
<td>566</td>
<td>566</td>
</tr>
<tr>
<td>NH for the municipalities</td>
<td>20</td>
<td>2,013</td>
<td>1,409</td>
</tr>
<tr>
<td>NH belonging to Association and foundations</td>
<td>31</td>
<td>2,556</td>
<td>1,789</td>
</tr>
<tr>
<td>NH belonging to minorities</td>
<td>7</td>
<td>920</td>
<td>644</td>
</tr>
<tr>
<td>NH Private</td>
<td>130</td>
<td>6,422</td>
<td>4,495</td>
</tr>
<tr>
<td>Total</td>
<td>297</td>
<td>24,194</td>
<td>19,596</td>
</tr>
</tbody>
</table>

*NH – Nursing Homes.

Table 3. Reasons for the elderly to consider the nursing home as a life choice in the future, 2016

<table>
<thead>
<tr>
<th>Reason</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inability to burden their children</td>
<td>48,9</td>
</tr>
<tr>
<td>The possibilities of nursing homes are more comfortable</td>
<td>20,2</td>
</tr>
<tr>
<td>Children do not want to live with themselves</td>
<td>11,2</td>
</tr>
<tr>
<td>Thinking about who will not be interested</td>
<td>9,5</td>
</tr>
<tr>
<td>Living alone, living with their own peers</td>
<td>6,4</td>
</tr>
<tr>
<td>Their bride/groom wants to live with them</td>
<td>3,8</td>
</tr>
</tbody>
</table>

Source: Anonim (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).
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>
<thead>
<tr>
<th>Table 4.</th>
<th>Demographic characteristics of survey participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>County f</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Tarsus</td>
<td>8 12,3</td>
</tr>
<tr>
<td>Erdemli</td>
<td>43 66,2</td>
</tr>
<tr>
<td>Silifke</td>
<td>14 21,5</td>
</tr>
<tr>
<td>Total</td>
<td>65 100,0</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>43 66,2</td>
</tr>
<tr>
<td>Female</td>
<td>22 33,8</td>
</tr>
<tr>
<td>Total</td>
<td>65 100,0</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>&lt;60</td>
<td>1 1,5</td>
</tr>
<tr>
<td>60–64</td>
<td>1 1,5</td>
</tr>
<tr>
<td>65–69</td>
<td>14 21,5</td>
</tr>
<tr>
<td>70–74</td>
<td>13 20,0</td>
</tr>
<tr>
<td>75–79</td>
<td>15 23,1</td>
</tr>
<tr>
<td>80+</td>
<td>21 32,3</td>
</tr>
<tr>
<td>Total</td>
<td>65 100,0</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>9 13,8</td>
</tr>
<tr>
<td>Single</td>
<td>10 15,4</td>
</tr>
<tr>
<td>Widow</td>
<td>46 70,8</td>
</tr>
<tr>
<td>Total</td>
<td>65 100,0</td>
</tr>
<tr>
<td>Number of child</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>17 26,2</td>
</tr>
<tr>
<td>1</td>
<td>7 10,8</td>
</tr>
<tr>
<td>2</td>
<td>14 21,5</td>
</tr>
<tr>
<td>3</td>
<td>11 16,9</td>
</tr>
<tr>
<td>4</td>
<td>4 6,2</td>
</tr>
<tr>
<td>5+</td>
<td>12 18,5</td>
</tr>
<tr>
<td>Total</td>
<td>65 100,0</td>
</tr>
</tbody>
</table>

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 di-
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.

**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

**Table 5. Ease of Use of Furniture**

<table>
<thead>
<tr>
<th></th>
<th>Very Difficult</th>
<th>Difficult</th>
<th>Middle</th>
<th>Easy</th>
<th>Very Easy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>Bed</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Wardrobe</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Armchair</td>
<td>1</td>
<td>1.5</td>
<td>1</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Commodore</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>Dinning table and chairs</td>
<td>1</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Kitchen cupboard</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>29</td>
</tr>
</tbody>
</table>

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**References**

Towards a Generic Design Frame for Ageing-Friendly Development for Seniors

Andrew Sirkka¹, Sari Merilampi¹, Sirpa Sandelin¹
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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.

Keywords: ageing-friendly design, changes in ageing, welfare technology, service design, productisation

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 (Crundall-Goode et al., 2017; Ibrahima and 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 and 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 and 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 and 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 specifi c 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 specifi c 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 modifi able modules that make the product or service usable 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 and 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.

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 quantifi cation, such as publication time, research methodology, and research outcomes), 3) Vote counting (used to draw inferences about focal relationships by combining individual research fi ndings by a tally of the frequency with which existing research fi ndings 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 specifi cally examining the relationships between certain Independent Variables (IVs) and Dependent Variables (DVs) derived from existing research fi ndings) or 5) Integrated Literature Review (Whittemore and KnafI, 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 (Whittemore and KnafI, 2005).

The key problem identifi ed 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 age- ing”, 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 fi nally passed the relevance test, and were analysed by a qualitative contents analysis method.

RESULTS AND DISCUSSION

Based on the conducted literature search, main categories regarding changes in/of ageing were identifi ed: 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 diffi culties, disabilities, or accidents. In most cases, the enablement of optimal functioning could be done by redesign and modifi cation 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 defi nes 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 modifi cation 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
Towards a generic design frame for ageing-friendly development for seniors

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 this 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 (Bhardwaj et al., 2011; National Instruments, 2017).

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 pos-
tures, 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 au-

Fig. 1. Proposal for a generic frame in age-friendly design
tonomy 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).

The goal in ageing/aged-friendly concept and environment design is to support maintenance and 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 (ADA, 2010; ARA, 2015; Sievänen et al., 2007; 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 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, 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; Kwalu, 2017; Lumon 2017; Sievänen et al., 2007).

References


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DETERMINING REASONABLE DESIGN VALUES OF RECTANGULAR MORTISE AND TENON JOINTS BY USING PROBABILISTIC APPROACHES

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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.

Keywords: statistical lower tolerance limits, rectangular mortise and tenon joints, static loading test of joint

INTRODUCTION

Engineering design practices of furniture include: 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 (Kasal et al., 2015; Likos et al., 2012; Pang et al., 2011; 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 exists, 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 does not satisfied 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 developed 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.

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.

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 (Fig. 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 (Fig. 2) (Erdil et al., 2005).

Ultimate bending moment capacities for each specimen were calculated by using following expression;

\[ M = F_{\text{max}} \times l \]  

where, \( M \) is the bending moment capacities (N.m), \( F_{\text{max}} \) 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);

```r
> norm.ss(x = data, alpha = 1-g, P = b, side = 1, spec = μ-3σ, + method = “YGZO”, hyper.par = list(mu.0 = X̄, sig2.0 = s))
```

**LOWER TOLERANCE LIMITS**

Since population parameters, population mean (\( \mu \)) and population standard deviation (\( \sigma \)), 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).
\[ LTL = \bar{X} - (k_{n,C,P} \times s) \]  \hspace{1cm} (2)

where: \( \bar{X} \) is the sample mean, \( k_{n,C,P} \) 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 (Ayyub and McCuen, 1997; Cai and Wang, 2009);

\[ P(X_i < \xi) = \binom{n}{X} \times p^X \times q^{n-X} \]  \hspace{1cm} (3)

where, \( X_i \) represents the values below LTL, \( \xi \) 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);

```r
> 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 \((\alpha)\) 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.

**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 Fig. 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, 90/95, 95/95, 95/95, 99/99, 99/99 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.

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.

![Fig. 3. Minimum sample size requirements corresponding C/P levels](image)

**BENDING MOMENT CAPACITIES OF THE JOINTS**

Results of 220 specimens constructed of red oak are given Fig. 4. 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.

Results of 220 specimens constructed of white oak are given Fig. 5. Average bending moment capacity 341.17

![Fig. 4. Ultimate bending moment capacities of T-shaped RMT joints constructed of red oak](image)
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.

NORMALITY TEST

Results of Shapiro-Wilk normality test show that data T-shaped RMT joint specimens constructed of red oak ($p$-value = $3.016 \times 10^{-6} < 0.05$) is not normally distributed, whereas those joints constructed of white oak ($p$-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

<table>
<thead>
<tr>
<th>Joint</th>
<th>$W$</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMT – Red Oak</td>
<td>0.95632</td>
<td>$3.016 \times 10^{-6}$ &lt; 0.05</td>
</tr>
<tr>
<td>RMT – White Oak</td>
<td>0.99395</td>
<td>0.5172 &gt; 0.05</td>
</tr>
</tbody>
</table>

LOWER TOLERANCE LIMITS

Results of LTLs are given in Table 2.

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-b)% 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<sub>75/75</sub>. 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 (Fig. 3). 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.

**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.

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FEATURES OF FURNITURE DESIGN AND MANUFACTURING THAT CONSTITUTE RISK FACTORS FOR CAUSING ACCIDENTS TO USERS

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Abstract. 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.

Keywords: accidents, design, falls, furniture, injuries, prevention

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 et al., 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.

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.

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 (Fig. 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 (Fig. 2).

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 (Fig. 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 et al., 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 et al., 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.

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.

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 43 000 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 com-
pression 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 450 mm to 475 mm high and a recommended width of 500 mm 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 lounge 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 et al., 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.

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


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DETERMINATION OF THE SUFFICIENCY OF WARDROBES IN PARENT BEDROOMS OF TODAY’S UPPER SOCIO ECONOMIC STATUS (SES) HOUSES

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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.

Keywords: house, parent bedroom, wardrobe, furniture, SES

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 (Asatekin, 1995; Bakır, 1987; Kansu, 1976; Sönmez and Yıldırım, 1996 and 1999; Yıldırım, 1995). These complaints are mostly concentrated in the wardrobes of the parent’s 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 users’ 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.

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 Baçova 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.

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 m² and over. 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 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

<table>
<thead>
<tr>
<th>Parent Bedroom Space</th>
<th>10–14 m²</th>
<th>15–19 m²</th>
<th>20 m² +</th>
<th>ANOVA</th>
<th>$F$-Value</th>
<th>$df$</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room size satisfaction</td>
<td>X</td>
<td>S</td>
<td>X</td>
<td>S</td>
<td>X</td>
<td>S</td>
<td>2.622</td>
</tr>
<tr>
<td>Number of bedrooms</td>
<td>17</td>
<td>31</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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).
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.

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.

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.

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.

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...

---

**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

<table>
<thead>
<tr>
<th>Availability of Clothing Rooms</th>
<th>There is a clothing room</th>
<th>No clothing room</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>S</td>
<td>X</td>
</tr>
<tr>
<td>Room size satisfaction</td>
<td>1.63$^a$</td>
<td>1.01</td>
<td>2.94</td>
</tr>
<tr>
<td>Storage capacity adequacy</td>
<td>2.63$^b$</td>
<td>1.09</td>
<td>3.19</td>
</tr>
</tbody>
</table>

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).

---

**Fig. 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.** The use of wardrobes according to the presence of a clothing room in the bedrooms

<table>
<thead>
<tr>
<th>Wardrobe usage shape</th>
<th>There is a clothing room</th>
<th>No clothing room</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>S</td>
<td>X</td>
</tr>
<tr>
<td>Daily storage</td>
<td>2.20a</td>
<td>0.88</td>
<td>2.19</td>
</tr>
<tr>
<td>Long term storage</td>
<td>2.66</td>
<td>1.01</td>
<td>2.67</td>
</tr>
<tr>
<td>Storage by seasonality</td>
<td>2.50</td>
<td>0.93</td>
<td>2.51</td>
</tr>
<tr>
<td>Non-seasonal storage</td>
<td>3.08</td>
<td>1.01</td>
<td>3.16</td>
</tr>
</tbody>
</table>

Number of clothing rooms: 24, 68

Note: X – Mean, S – Std. deviation, df – degree of freedom, *p < 0.05 level is not significant.
a – Variable averages ranked from 1 to 5 (1 – preferred, 5 – not preferred).

**Table 4.** Interior layout of wardrobes in bedrooms

<table>
<thead>
<tr>
<th>Interior layout of wardrobes</th>
<th>Available interior layout</th>
<th>Desired interior layout</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>S</td>
<td>X</td>
</tr>
<tr>
<td>Shelf</td>
<td>28.54a</td>
<td>10.98</td>
<td>37.23</td>
</tr>
<tr>
<td>Hanger</td>
<td>58.80</td>
<td>11.63</td>
<td>47.39</td>
</tr>
<tr>
<td>Drawer</td>
<td>12.66</td>
<td>7.42</td>
<td>15.38</td>
</tr>
</tbody>
</table>

Total ratio (%): 100, 100

Note: X – Mean, S – Std. deviation, df – degree of freedom, *p < 0.001 and **p < 0.10 levels are significant.
a The percentages of the surface measurement averages of the wardrobe examined.

are lacquered in the wardrobes, 43.5% are varnished on wood, 18.5% are MDF lam (melamine resin coated medium density fiberboard) and 4.3% are made of PB lam (melamine resin coated particleboard).

**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 in the storage capacity and room size satisfaction of the users is 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**


Determination of the sufficiency of wardrobes in parent bedrooms...


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HEAT CONDUCTIVITY AND MOISTURE PERMEABILITY THROUGH THE POCKET SPRING MATTRESS

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Abstract. 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.

Keywords: heat, moisture, mattress, thermal comfort, thermo-physiology

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) and is very important to one’s memory. With the gradual understanding of the influence of thermal parameters in a sleeping environment on the quality of sleep, different thermal environmental control approaches, such as electric blankets, space heating for cold sleep environments and circulation fans and air-conditioning for hot sleep environments, have been used to maintain a suitable thermal environment for sleep, so that sleep quality could not be adversely affected. In this review paper, firstly, the concept of thermal comfort applicable to sleeping environments is introduced and the relevant studies reviewed. Secondly, the review of the two important issues related to air-conditioning for sleeping environments in tropics and sub-tropics, i.e., night-time space cooling load characteristics, and ventilation requirement for a sleeping person, is presented. Thirdly, different air-conditioning systems used in sleeping environments and these related energy consumptions are reviewed, with an emphasis on bed-based (task/ambient) conditioning.

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 (Hänel et al., 1997; Nicholson et al., 1999) mattresses, chairs, cushions and pads. 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; 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 (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; 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.

**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/m², 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).

**SUBJECTS**

Four (two female and two male) healthy subjects were participated in experiment. The subjects’ details are given in the following table:

<table>
<thead>
<tr>
<th>Subjects’ code</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>Average (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>26</td>
<td>24</td>
<td>26</td>
<td>19</td>
<td>23,8 (3,3)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170</td>
<td>178</td>
<td>164</td>
<td>184</td>
<td>174,0 (8,8)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>56</td>
<td>74</td>
<td>48</td>
<td>71</td>
<td>62,3 (12,3)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>19,38</td>
<td>23,36</td>
<td>17,85</td>
<td>20,97</td>
<td>20,4 (2,4)</td>
</tr>
</tbody>
</table>

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.
Heat conductivity and moisture permeability…

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.

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 HOBO® Weather Station H21-001 electronic device (Onset Computer Corporation, USA) (Fig. 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,
- 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/night 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).

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 2. Mean values of ambient temperature and relative humidity during nights and days of experiment

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7 at night (°C)</td>
<td>23.3</td>
<td>24.3</td>
<td>26.8</td>
<td>27.0</td>
</tr>
<tr>
<td>T7 at day (°C)</td>
<td>23.6</td>
<td>24.0</td>
<td>26.9</td>
<td>26.9</td>
</tr>
<tr>
<td>RH7 at night (%)</td>
<td>66.4</td>
<td>66.4</td>
<td>61.5</td>
<td>56.4</td>
</tr>
<tr>
<td>RH7 at day (%)</td>
<td>63.3</td>
<td>62.5</td>
<td>60.1</td>
<td>53.7</td>
</tr>
</tbody>
</table>

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 aims 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 (Fig. 4).

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 (Fig. 5), and it depends on relative humidity in bedroom as well.

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

![Fig. 4](image1.png)

**Fig. 4.** Example of temperature in mattress layers during first 3 hours, for seven nights

![Fig. 5](image2.png)

**Fig. 5.** Average moisture content per subject during seven-night period
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 (Fig. 6).

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 Fig. 6) those values were higher up to 10% RH than in the week four.

After the subject got out of bed, the mattress begins to cool and dry. Fig. 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.

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.

![Fig. 6. Average moisture content per subject during seven-day period](image)

![Fig. 7. Example of moisture motion during the night, morning and day](image)
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

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.

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