Edited by
Petr Čech et al.

TRENDS IN FURNITURE AND LIVING 2024

Proceedings of the 4th International Scientific Conference

24th October 2024
Chateau Křtiny, Křtiny, Czech Republic

MENDELU
Faculty of Forestry
and Wood
Technology

2025

ISBN 978-80-7701-044-3 (online ; pdf)
https://doi.org/10.11118/978-80-7701-044-3

CONTENTS

PREFACE

We are pleased to present the proceedings of the International Conference of Trends in Furniture and Living 2024, held on 24 October at Chateau Křtiny in the Czech Republic. The conference was organised under the auspices of Department of Furniture and Design, Faculty of Forestry and Wood Technology, Mendel University in Brno.

Set in the heart of the Moravian Karst, the event offered not only a platform for academic exchange but also a unique setting—surrounded by history, nature, and architecture. Near to the conference venue stands the Church of the Name of the Virgin Mary, a baroque masterpiece by Jan Santini Aichel, whose work is also recognized by UNESCO. The nearby arboretum offered a serene backdrop for informal discussions and reflection.

The focus of the conference included topics such as Material in Furniture Production, Furniture Manufacturing Technology, and Furniture Design. Through expert seminars, research presentations, and open discussion, the conference aimed to highlight current challenges and innovations in the design and manufacture of furniture. In doing so, it sought to strengthen connections within the professional community, accelerate knowledge exchange, and support the implementation of research results into practice.

This year's conference further underlined the importance of interdisciplinary and international collaboration in addressing the evolving needs of the furniture and living sectors. As consumer preferences, technologies, and sustainability requirements shift rapidly, dialogue between researchers, designers, manufacturers, and institutions is more crucial than ever. Events like this provide the space where such cooperation can take root, bringing innovation closer to everyday life.

These proceedings serve as a lasting record of the ideas, results, and discussions shared at the event. We hope they will inspire further cooperation, innovation, and research across the furniture and related industries.

We extend our sincere gratitude to all authors, presenters, and participants for their valuable contributions. Your expertise and engagement were essential to the success of this conference.

OVERVIEW OF HANGING FURNITURE AND ITS CONSTRUCTION

Horák Dominik[1], Maňák Hynek[1]

[1] Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech republic

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0005

Abstract

The topic of this paper is hanging furniture. Nowadays, the principle of hanging furniture is applied in many furniture groups: these are mainly kitchens, bathrooms but also living and office spaces. In general, hanging furniture can be found in almost all definable furniture groups that interact with the building structure. Furniture is suspended from vertical walls or structures but also from ceilings or other auxiliary horizontal structures. The article defines the basic subdivision of suspended furniture into shelving systems, upper cabinets, lower cabinets and ceiling cabinets. In addition to basic aspects such as functionality of the furniture, principles of assembly and disassembly, manufacturability and transportability, safety is an important aspect of hanging furniture. A comprehensive assessment of the overall safety of the application of hanging furniture is required, which does not focus rigidly on the furniture part of the issue, but also perceives the interaction with the building or structure on which the furniture is hung. The paper describes the research started in this area, which is divided into sub-areas: the construction material of the hanging furniture, the connecting fittings of the hanging furniture structure, special connecting fittings, hanging fittings including anchoring technology, and finally the material design of the supporting structure (wall, ceiling).

Keywords: hanging furniture, dowels, construction material, connecting fittings, construction material, hanging fittings

INTRODUCTION

Nowadays, when we have the possibilities to furnish our homes with various furniture items according to our liking and at the same time we try to make the most of our small spaces for storing furniture items [1]. One of the options is hanging furniture, whose history is linked to the invention and patenting of the dowel in 1911 in England by John Joseph Rawlings, when it was an impregnated hemp cord, with bovine blood [2]. Until then, dowels were made using wooden blocks placed in drilled holes with a hand drill. The invention of the plastic dowel in 1957, made of nylon by Fischer S. It allowed us to hang even heavier objects, as the function of plastic dowels was higher than that of wooden dowels, including the development of screw and bolt fasteners from the original conventional nails [2]. Thanks to these advances, we can now hang various objects on walls without much difficulty. Another pioneer is chemical anchors. It is a chemical reaction between two components that starts its reaction after mixing the two components [2]. Thanks to this technology, we can hang much heavier objects than was previously possible.

The History of Hanging Furniture

Hanging furniture is an integral part of our private and public interiors. One important pioneer of hanging furniture is the required String Wall Storage System, when in 1949 its authors, Nisse and Karin Strinning, won first place in a competition for simple interior library furnishings [3]. It is a modular wall storage system that allows its owner to configure it according to his requirements by purchasing individual modules, which he uses to build the wall storage system in his home (Fig. 1). An undeniable advantage is their further possible variation in the sense of browsing the storage of individual modules. The basic load-bearing element is the metal „grid“ with which the individual modules are fixed. This construction solution is fixed to the wall using classic dowels and screws. This modular system is manufactured today under the brand name String.

Another important designer of hanging furniture was Dieter Rams, who in 1960 designed the Vitsoe wall system, which is to some extent directly based on the String hanging system of 1949 [3]. Rams

1: *Example of the String 1949 wall storage systém [3]*

simplified his design to aluminium profiles, on which the individual bodies are placed according to the height and proportion requirements of their owner, made of bent metal flat profiles (Fig. 2). The undeniable advantage of this furniture object is its variability and the possibility of replacing the individual bodies with others. This system is also produced to this day.

2: *Example of the Vitsoe wall system 1960 - Dieter Rams and its design [3]*

A later important hanging furniture element is the Bookworm variable „bookshelf" designed by Ron Arad in 1993 [4]. It is a system of dividing partitions that are also the supporting element of the whole structure and are connected by a common moulded element. The original design was in metal, but in agreement with Kartell, this design was adapted to be manufactured in extruded PVC and then subsequently in ABS [4]. This adaptation

3: *Example of the 1993 Bookworm by Ron Arad and its design [4]*

subsequently allowed for greater bends in the connecting element and therefore the subsequent final shape. This system is still in production to this day (Fig. 3).

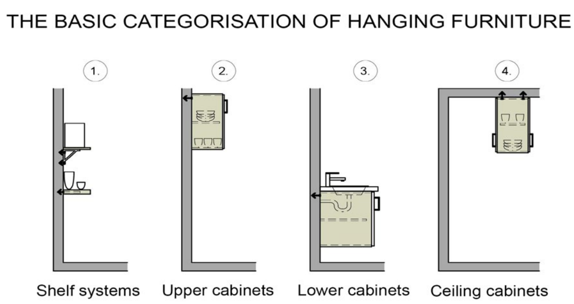
An important suspension system of the first decade of the 21st century is the ceiling suspension system. This system had been used before, but in 2004 Jean Nouvel came up with an innovative solution for a suspension system from the ceiling. His creation is the Graduate ceiling hanging shelving system from Molteni [5]. It is a shelving system whose supporting structural element is metal rods suspended from the ceiling, on which shelves made of overhanging material are arranged using adjustable stops. This system allows the bookcase to be placed in a space without being tied to the floor (Fig. 4).

4: *Example of Graduate 2004 - Jean Nouvel and its structural design [4]*

Basic Classification of Hanging Furniture

Hanging furniture can be classified according to several criteria: where it will be placed; what function it will have in the interior; the size of the hanging furniture; how it will be hung on the wall (hanging hardware and dowels); what material the construction will be made of; etc.

The most important factor is the location of the hanging furniture in the interior. Hanging furniture can be divided into four categories according to the technical difficulty of hanging: shelves including shelving systems, upper cabinets, lower cabinets and ceiling cabinets (Fig. 5).



5: *Example of the basic categorisation of hanging furniture*

Shelving Systems

Shelving systems, or individual shelves, are the most basic hanging furniture. This category has been in use since ancient times, when massive wooden planks were inserted into the resulting holes in the walls (a niche, or also called a niche, is usually a decorative depression in the thickness of the masonry of a building.), which were stuck and then walled both ends into the wall [6]. This solution gave us a storage system for putting small items on the walls, in this case just into the walls. The development of separate shelves without the need to be stuck into the wall, came with the development of anchoring technology (dowels themselves). This technical solution made it easier to create storage or storage spaces on the walls. Today, shelves and shelving systems are primarily used to store small furniture items such as books, crockery, jewellery, plants etc. We must not forget the decorative items that are an integral part of our interiors, e.g. various souvenirs from our travels, statuettes, art objects, framed photographs, etc.

The methods of hanging shelves and shelving systems can be divided into three different ways of attaching them to the wall. The first way is that the shelf itself has a hole drilled in it, using which and a screw to attach the shelf to the wall. The second way is that the shelf itself contains a hanging fitting which allows it to be fixed to the wall. The third and final way is by means of auxiliary support elements which transfer the load-bearing capacity of the shelves to themselves. These can be divided into hanging spikes on which the shelf or shelving system slides, and metal angles. The use of these methods of attachment to the wall allows me to make greater use of shelves and shelving systems in our interiors (Fig. 6).

Upper Cabinets

Upper hanging cabinets are the category of hanging cabinets that are most visible in kitchens, especially for storing kitchen equipment (plates, bowls, glasses, mugs, etc.) The depth of these cabinets is generally half that of the lower hanging cabinet category and therefore they are also subject to fewer requirements, including variability in terms of furniture hanging hardware, where they can be divided into three groups according to their location: in the cabinet, in the back of the cabinet and, last but not least, part of the cabinet. When the furniture hanging hardware in question is applied to the construction material. In short, it becomes part of the construction material, usually DTD and MDF. The category of hanging upper cabinets is already a standard part of every kitchen cabinet, especially in terms of the need to store kitchen items, and mainly thanks to this category we use the maximum space under storage.

Top cabinets are not only found in kitchen cabinets, in some cases they are also used in other rooms of a given interior. The main function is still to store items. A possible typical example, specifically in my home. When we were limited by the size of the bathroom space including other spaces to find a solution to store towels and hygiene products without having to place them in another room. The resulting solution was hanging overhead cabinets that were placed over the entry door to the room and positioned above the built-in toilet bowl. Where hygiene products and towels were stored separately, of course. Another use is living room walls, which are not as massive as in the last century. In some cases these living walls took up one entire wall in a room [6]. Nowadays these living walls have been replaced by smaller storage units either placed on the floor or, for maximum use, hung on the wall of the room. A separate group is specifically the hanging overhead cabinets in office spaces, which mainly store massive binders of important documents. This group should be particularly taken into account when selecting the hanging hardware and its connection (Fig. 7).

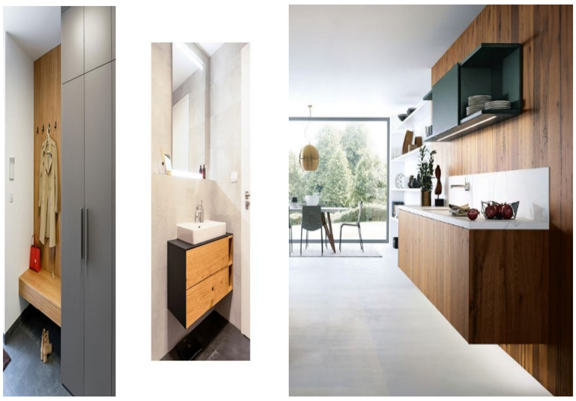
6: *Example of shelving systems and shelves including design solutions in interiors [4]*

7: *Example of another use of upper hanging cabinets in interiors [4]*

Lower Cabinets

Bottom hanging cabinets are the category of hanging furniture that shows up most in bathroom design from a practical standpoint, as previous locations of bathroom cabinets reached the floor. But the effect of moisture and water in the bathroom resulted in surface degradation in the lower part of the cabinetry that was in direct contact with the floor. One way to prevent the degradation of the cabinet is to hang it on the wall. This solution prevents unwanted degradation of the enclosure and allows cleaning underneath the enclosure, as environmental hygiene is an integral part of any sanitary facility. This category and its hanging is solved by means of special hanging fittings for lower hanging bodies from Haffele [7]. Another possible solution is the classic hanging fitting for hanging upper cabinets. Alternatively, a solution by inserting a profile between the sides of the cabinet, in which holes are drilled and fixed to the wall using anchors.

Lower hanging cabinets are also appearing more in interiors instead of bathrooms. Their variety and design solutions allow for application in kitchens, living rooms, bedrooms and other interior rooms. The reason for this use is primarily due to environmental hygiene. Built-in kitchen units are a typical example. Who among us has ever cleaned up the accumulated dust underneath the base units of a kitchen cabinet? Perhaps someone who has never cleaned it has come to the conclusion that they cannot clean the area so thoroughly. The frequent removal of the skirting board results in fatigue of the plastic grip material of the rectifier leg with the skirting board. An innovative solution to limiting the access of dirt under the kitchen base units is the isolation strips, which prevent dirt and liquids from entering under the kitchen unit. The use of hanging the lower cabinets on the walls achieves the result of easy access to a more hygienic environment. This solution can be more visible in other rooms of our interiors (Fig. 8). The disadvantage of this category of hanging furniture is their depth for hanging and the load of these furniture items. The solution to this problem is the new design solutions for the hanging itself, which the manufacturers are guarding and patenting.



8: *Example of the use of hanging lower cabinets in interiors*

Ceiling Cabinets

A special separate category is the hanging of ceiling cabinets, the method of hanging which, for some of us, may seem an unconventional solution, but in some cases there is no other option than just anchoring them to the ceiling, since the partition in question does not have the appropriate parameters for the classic hanging of upper cabinets. An example of this solution was implemented in the last half of the 20th century in the Brno-Lesná district, where the parameters of the partition were not suitable enough for classic anchoring of upper cabinets. The subsequent solution was to suspend the upper cabinets from the ceiling. This solution solved the problem of the unsuitable partition parameters without the kitchen being without upper storage spaces.

Currently, hanging cabinets from the ceiling is a very unusual solution for kitchen units. This category is mostly used just above the kitchen islands that are placed into the kitchen cabinet space, these islands are incorporated into the kitchen cabinet space (Fig. 9). The important parameter for hanging these cabinets is just the ceiling structure and its composition.

9: *Example of the current use of ceiling cabinet suspension in interiors*

A separate category of overhead suspension of furniture items in interiors and exteriors from the ceiling structure are various chairs or „sofas“. An important parameter is their anchoring to the ceiling structure. Thus, we must not overlook the fact that this type of furniture item will be subjected to a lot of load, as its users can weigh up to around 120 kg. For these purposes, we must choose a suitable anchoring system with a combination of suspension elements that will support the structure.

Special Suspension Furniture

A separate category is special hanging furniture, which is in the development stages of the various manufacturers and developers of furniture items.

10: *Example of specialty hanging furniture*

Typical indicators are unusual dimensions and special technical and structural solutions for hanging on the wall (Fig. 10). This category can be found at furniture fairs and in private interiors or public spaces. This type of hanging furniture is still very expensive to produce, including the technology and design solutions used. For these purposes, specialised suspension fittings are designed and guarded by the manufacturers. With the development of technology and design solutions this category will reach all interior spaces in the future.

Materials and Methods

Hanging furniture is an integral part of our homes, public interiors and exteriors. In earlier times, hanging furniture was not very common with the development of furniture fittings and anchoring fixtures (dowels), hanging furniture has become a common part of our homes. Nowadays we have many ways of attaching hanging furniture to building materials (concrete, brick, aerated concrete, board materials, plasterboard, etc.) using various furniture fittings, systems, and most importantly, wall anchors.

Construction Material for Hanging Furniture

Today we have many board materials with different finishes for the production of hanging furniture. The most widely used board materials are particleboard (DTD) and medium-density fibreboard (MDF). Solid wood boards are another widely used material [8].

Classification of Construction Materials by Manufacture

Agglomerated materials can be divided according to production into solid wood boards (spars, biodesks), plywood boards (PD, slats), particleboard (DTD), fibreboard (MDF, HDF), flat chipboard (OSB) and lightweight board materials (honeycomb board) [8].

Fasteners for Hanging Furniture Construction

Each piece of furniture includes connecting hardware that allows us to join the individual furniture pieces into a body. The most important connecting hardware for hanging furniture is the corner connection between the top piece (the floor) and the side pieces (the sides). It also depends on the position of the top piece, whether it is loaded or inserted these parameters can affect the strength and rigidity of the cabinet [9].

Basic Categorization of Fasteners

The most common fasteners for corner joints are wooden pins, screws, industrial fasteners, confirmers, fastener slats, eccentric fasteners, trapezoidal fasteners, spherical eccentric fasteners, and other specific fasteners from various manufacturers [10].

Special Fasteners

Each fastener manufacturer have their special fasteners which they have patented for their own purposes. The undeniable advantage of these special fasteners is their variability and their special solutions for placement in the parts themselves. The disadvantage of these connecting fittings is their financial aspect and also their more complicated installation in the parts and subsequent connection to the bodies.

Hinged Fittings

Hanging hardware is an integral part of hanging furniture. They can be classified according to their load-bearing capacity and their design in the furniture body [11]. There are three major manufacturers of furniture fittings in the furniture industry: Hafele, Hettich, Blum and other smaller manufacturers of furniture fittings.

Dowels

A dowel is an insert for fastening screws, bolts, threaded rods in rigid, inflexible materials, most commonly masonry buildings or building board materials. Dowels are usually made of plastic, the better quality dowels of nylon and there are also metal variants (steel, stainless steel, brass) for which the term anchor is used [11]. There are many types of construction materials and mounting options, and many types of special dowels are produced.

Types of Dowels

Dowels can be classified according to the material produced, as well as their use in different building materials. For different types of building materials we select dowels designed for them. For example, we have: steel, frame, universal, expansion, special dowels for the building material [2]. Next, we should focus on which dowel will carry what. After selecting the dowel, drill a hole in the wall where the dowel will be placed. The hole for the dowel should be deep enough, and wide enough for easy placement of the dowel. Before placing the dowel, the drilled hole must be cleaned of any remaining drilling material. Then we can install the dowel, and the remaining parts that the dowel will carry.

The Building Material Used

Nowadays, we have many options for building masonry materials to build walls, from load-bearing walls to partition walls in interiors. Walls can be made of the following materials: stone, burnt brick, concrete, plasterboard, aerated concrete, hollow bricks (blocks), polystyrene and wood panelling [2].

Concrete

Concrete is a mixture of cement, aggregate, water and additives with reinforcing bars. The main properties of concrete include: High compressive strength but low tensile strength (about 10% of the compressive strength). An important component of concrete is the reinforcing bars or rebar, which compensates for the low tensile strength (steel + concrete = reinforced concrete) [2].

Masonry

Compared to concrete, masonry is a considerably more diverse anchorage substrate with varying texture and strength. The main components include burnt clay or concrete or other material. Masonry can be classified according to: The type of lump masonry (e.g., burnt brick, natural stone, or aerated concrete). Further, by type of wall (e.g., single-layer, double-layer). And according to the strength and density of the piece masonry [2].

Slab material

Slab building materials are thin-walled and generally have low strength e.g. gypsum plasterboard, gypsum fibreboard or particleboard, fibreboard, plywood etc. They are used to construct non-load bearing walls or partitions, and are also used as cladding material [12].

Mechanical and Physical Properties of Hanging Furniture

For hanging furniture and its interrelationship with the supporting element (wall). They are an integral part of the physical and mechanical properties that will determine the final values of this study and subsequent experimental measurements. Of the mechanical properties of the materials, the values of Strength = failure and Stiffness = deformation, or Toughness are particularly important, but these are not indicative for this work [9]. Furthermore, from the physical properties, the values of the densities of the materials will be particularly important for this work. To obtain these physical and mechanical properties, at least the basic dimensions and data will be necessary, which will influence the results of the actual experimental measurements. An integral mechanical part in testing, and especially in normal use in our homes, will be the application of forces or also the application of loads to the hanging furniture (body). Where the load will not only be applied to the body, but will mainly be transferred to the hanging hardware and from it to the supporting anchor (hook, screw, etc.) and then to the anchor (dowel) itself placed in the drilled hole of the wall (supporting material). In particular, pressure will be applied to the anchor and also to the anchoring element, and bending will be applied to the anchor itself. These main mechanical properties will influence the resulting measurement values and, more importantly, the hanging furniture itself [13]. Part of this work is just the appropriate selection of both the structural material (the body) and the supporting material (the wall) to obtain the best experimental testing results. When maximum loads are applied to hanging furniture, three types of failure and deformation of the integrity of the body and its connection to the wall can generally occur.

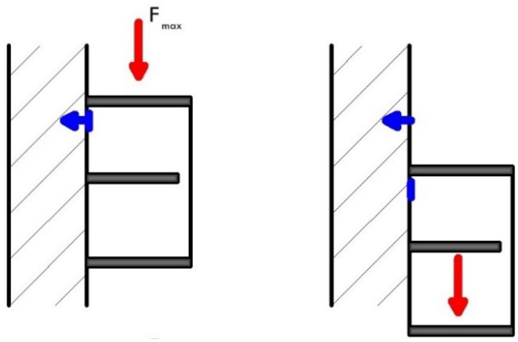
1. The failure can be caused by overloading the load capacity of the hanging body and the so-called shearing of the anchoring technique or the hanging material occurs, or the material fatigues under a greater load than planned (Fig. 11).
2. The breach may be caused by improper use of the anchor or anchors, or by the type of masonry of the wall on which the body has just been hung (Fig. 12).
3. Breach may be caused to some extent by the incorrect use of the connecting fittings, where the subsequent use or load.
4. Has not been taken into account. Or it may be caused by the improper use of the construction material of the body, where again the load applied in normal use may not have been taken into account (Fig. 13).

RESULTS

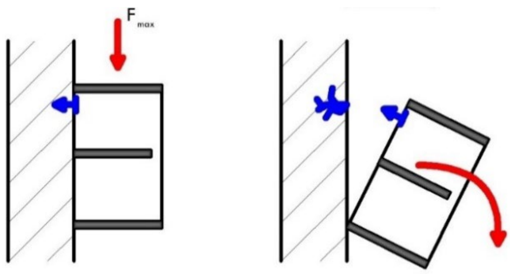
Suspension furniture is still an unexplored and untested scientific discipline worthy of investigation.

Hanging furniture and its issues are divided into four research sections: When the first research section has already been completed. And its results will soon be published. The section itself dealt with research on the connecting hardware used in hanging furniture. The fasteners were divided into 2 categories of three types of fasteners each. The first category is called glued = fixed connection, which includes wooden pins, connecting slats, and embedded pens. The second category is called mechanical = disassembled connection, which includes screws, fasteners and eccentrics. It has been tested using two methods in compression and tension. The disassembled connections using confirmatives were the best. Of the bonded joints, fastener slats performed best. However, connections using eccentrics performed the worst.

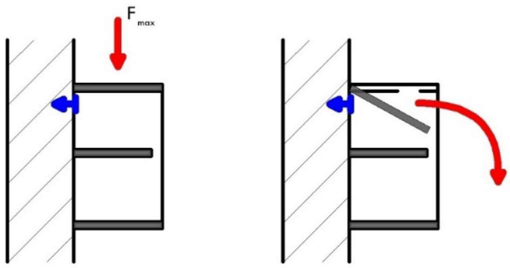
The next research section will test the hinge fittings used in hanging furniture. The attachment of the back to the hanging body will need to be considered in this research section. Since according to the fit of the back, a certain type of hanging hardware is used. The hanging hardware can be



11: *Graphical treatment of the problem 1. failure of hanging furniture*



12: *Graphical treatment of the problem 2. breach of hanging furniture*



13: *Graphical treatment of the problem 3. failure of hanging furniture*

divided into embedded in the body, loaded on the back of the body and laterally attached to the body and the category itself is the hanging hardware that is part of the body. In this research section, it will be necessary to predefine the most used hinge fittings for a given categorization. Subsequently, the manufacturers of the fittings themselves will have to be taken into account. Furthermore, the dimensions of the test bodies and the number of test bodies will have to be defined in order to obtain objective results.

Another subsequent research section will be research into the construction materials used in hanging furniture. It will be necessary to analyse the overall physical-mechanical properties of the structural materials in question, followed by their statistical evaluation. The course will be similar to the previous research sections.

The last research section will be the use of anchoring material in the walls on which we hang the hanging furniture. This section is not yet predefined it will have to be defined.

DISCUSSION

Overall, hanging furniture is still a potential hazardous furniture item in the home. In terms of its hanging. Inappropriate way of hanging corpora on walls and ceilings can cause unwanted events e.g. personal injury at worst, at best it can damage other things underneath. The hanging of furniture cabinets is not so much a matter of getting it right, it always depends on the installation and who is doing the installation. The assembler chooses the right anchor according to their discretion and experience. Others have the hanging furniture mounted by a shared service called *an hourly man* or by a company whose hanging furniture users buy and then have anchored to the wall or ceiling. Part of this research on hanging furniture will take into account the selection and definition, based on scientific knowledge, of the correct use of anchoring techniques for hanging corpuses. A separate category is the occasional painting of walls and ceilings in the home. In this case, we can take the hanging furniture down from its placement on the wall or ceiling. After the painting activity is completed, we put the hanging furniture back in its proper place. Frequent handling of the hanging furniture in terms of taking it down and putting it back can cause wear and tear on the anchoring technology. Possibly to the hanging hardware and the corner ties of the cabinetry itself. At the same time, the correct recommended loads set by the manufacturer of the hanging furniture should be observed. If we choose the wrong anchoring technique and its suspension, we may unintentionally reduce the maximum and recommended load without meaning to. When hanging furniture, we have to take into account more factors that affect it than we might expect.

CONCLUSION

Hanging furniture is a hot topic in modern interior design. In addition to aspects such as the functionality of the furniture, the principles of assembly and disassembly, manufacturability and transportability, safety aspects are essential. A comprehensive assessment of the topic of suspended furniture, including the interaction with the building or structure on which it is suspended, is necessary for an overall safety assessment of the application of suspended furniture. Such research has not yet been carried out. The article describes the division of the research in this area into individual sub-areas: the construction material of hanging furniture, the connecting fittings of the hanging furniture structure, special connecting fittings, suspension fittings and, of course, anchoring technology, as well as the material design of the supporting structure (wall, ceiling). The text presents the results of the first part of this research, concentrating on the mechanical and physical properties of hanging furniture. The principles of the physical interaction between the suspended furniture and the supporting material are described. The basic types of failure are defined: overloading of the load capacity of the hanging body causing so-called shear of the anchoring technique, inappropriate use of an anchoring element with insufficient load capacity, improper use of the connecting hardware of the hanging element. Research will continue in other formulated areas. The section developed so far holds promise for a comprehensive picture of the topic with the aim of defining critical moments and recommendations for the safe use of suspended furniture in interiors.

REFERENCES

[1] HALABALA, Jindřich. 1982. *Furniture design and construction* [in Czech: *Výroba nábytku*]. Third Edition. Prague: SNTL – publishing house of technical literature.

[2] HORSKÝ, Antonín; PETRÁŠEK, Ivo. 2020. *Design basis* [in Czech: *Podklad pro navrhování*]. 16th Edition. Wienerberger s.r.o.

[3] KARASOVÁ, Daniela. 2001. *History of Furniture Art in 19. and 20. century (Volume 4)* [in Czech: *Dějiny nábytkového umění 19. a 20. století (4. díl)*]. Prague: Argo. ISBN 80-7203-339-5

[4] FIELL, Charlotte; FIELL, Peter. 2022. *Design of the 20th Century*. Cologne: Taschen. ISBN 978-3-8365-4106-0

[5] SVOJTKA & CO. 2008. *An encyclopedia of furniture* [in Czech: *Encyklopedie Nábytek*]. Translated from english original by Veronika Matysová. Praha: Svojtka & Co. ISBN 978-80-256-0104-4

[6] DLABAL, Stanislav. 2000. *Furniture art: selected chapters from history* [in Czech: *Nábytkové umění vybrané kapitoly z historie*]. Brno: Grada Publishing, spol. ISBN 80-7169-655-2

[7] HAFELE. 2024. *Hafele*. [Accessed: 2024-11-18] https://www.hafele.cz/cs/

[8] HRÁZSKÝ, Jaroslav; KRÁL, Pavel. 2007. *Wood-based composite materials – Part I* [in Czech: *Kniha Kompozitní materiály na bázi dřeva. - Část I.*]. Brno: Mendel University of Agriculture and Forestry in Brno. ISBN 978-80-7375-034-3

[9] JOŠČÁK, Pavol; LANGOVÁ, Naděžda. 2018. *Strength design of furniture* [in Slovak: *Pevnostné navrhovanie nábytku*]. Zvolen: Technical University of Zvolen. ISBN 978-80-228-3146-8

[10] JOŠČÁK, Pavol; GAFF, Milan; LANGOVÁ, Naděžda. 2011. *Furniture structural joints* [in Slovak: *Nábytové konštrukčné spoje*]. Zvolen: Technical University of Zvolen. ISBN 978-80-228-2255-8

[11] JOŠČÁK, Pavol, LANGOVÁ, Naděžda. 2019. *Technical equipment of furniture* [in Slovak: *Technické vybavenie nábytku*]. Zvolen: Technical University of Zvolen. ISBN 978-80-228-3215-1

[12] BOHM, Martin; REISNER, Jan; BOMBA, Jan. 2012. *Wood-based materials* [in Czech: *Materiály na bázi dřeva*]. Praha: Czech University of Agriculture in Prague. ISBN 978-80-213-2251-6

[13] JOŠČÁK, Pavol; LANGOVÁ, Naděžda; KRASULA, Patrik. 2014. *Mechanical tests of furniture* [in Slovak: *Mechanické skúšky nábytku*]. Zvolen: Technical University of Zvolen. ISBN 978-80-228-2788-1

[14] ASHBY, Michael; SHERCLIFF, Hugh; CEBON, David. 2007. *Materials: engineering processing and design*. Oxford: Elsevier. ISBN 978-0-7506-8391-3

[15] ASHBY, Michael, F. 2005. *Materials Selection in Mechanical Design*. Third Edition. Oxford: Elsevier. ISBN 0-7506-6168-2

[16] ASHBY, Mike; JOHNSON, Kara. 2002. *Materials and design: the art and science of materials, Selection in product design*. Oxford: Elsevier. ISBN 0-7506-5554-2
[17] ASHBY, Michael, F. 2009. *Materials and the Environment: Eco-Informed Material Choice.* Burlington: Elsevier. ISBN 978-1-85617-608-8
[18] ASHBY, Michael, F.; JONES, David, R. H. 2006. *Engineering Materials 2: An Introduction ti Microstructures, Processing and Design.* Third Edition. Oxford: Elsevier. ISBN 978-0-7506-6381-6
[19] DRÁPELA, Jindřich ***et al.*** 1980. *Furniture manufacturing technology* [in Czech: *Výroba nábytku: technologie*]. Prague: SNTL - publishing house of technical literature.
[20] DRÁPELA, Karel. 2000. *Statistical methods II* [in Czech: *Statistické metody*]. Brno: Mendel University of Agriculture and Forestry in Brno. ISBN 80-7157-474-0
[21] GANDELOVÁ, Libuše; ŠLEZINGEROVÁ, Jarmila. 2014. *Wood construction* [in Czech: *Stavba dřeva*]. Second Edition. Brno: Mendel University in Brno. ISBN 978-80-7375-966
[22] GAFF, Milan; GÁBORÍK, Jozef. 2009. *Surface properties of wood modified by embossing* [in Slovak: *Vlastnosti povrchu dreva modifikovaného reliéfovaním*]. Zvolen: Technical University of Zvolen. ISBN 978-80-228-2035-6
[23] HOLOUŠ, Zdeněk; MÁCHOVÁ, Eliška. 2013. *Furniture construction I.: Processes, instructions, examples* [in Czech: *Konstrukce nábytku I.: procesy, návody, příklady*]. Brno: Mendel University in Brno. ISBN 978-80-7375-844-8
[24] HOLOUŠ, Zdeněk; MÁCHOVÁ, Eliška. 2014. *Furniture construction II.: Construction, construction of supporting frames of upholstered furniture and furniture tests* [in Czech: *Konstrukce nábytku II.: konstrukce nosných koster čalouněného nábytku a zkoušky nábytku*]. Brno: Mendel University in Brno. ISBN 978-80-7509-010-2
[25] HOLOUŠ, Zdeněk; MÁCHOVÁ, Eliška. 2015. *Furniture construction* [in Czech: *Konstrukce nábytku*]. Modification 2016. Brno: Mendel University in Brno. http://user.mendelu.cz/holous/konstrukce_nabytku.pdf
[26] HORÁČEK, Petr. 2008. *Physical and mechanical properties of wood I* [in Czech: *Fyzikální a mechanické vlastnosti dřeva I*]. Brno: Mendel University of Agriculture and Forestry in Brno. ISBN 978-80-7375-169-2
[27] KASAL, Ali; SMADRZEWSKI, Jerzy; KUSKUN, Tolga; GURAY, Ersan. 2011. Analyses of L-type Corner Joints Connected with Auxetic Dowels for Case Furniture. *Materials*. 16(13), 4547.
[28] KRÁL, Pavel. *Veneers, plywood and glued materials* [in Czech: *Dýhy, překližky a lepené materiály*]. Brno: Mendel University in Brno. ISBN 978-80-7375-552-2
[29] KŘUPALOVÁ, Zdeňka. 2000. *Technology for the first year of SOU in wood processing* [in Czech: *Technologie pro 1. ročník SOU oborů zpracování dřeva*]. Prague: Sobotáles. ISBN 80-85920-74-3
[30] KŘUPALOVÁ, Zdeňka. 2023. *Science of materials for the 1st and 2nd year of the SOU carpenter's apprenticeship.* Fourth, revised. Prague: Sobotáles. ISBN 978-80-86817-52-1
[31] LANGOVÁ, Naděžda; JOŠČÁK, Pavol. 2018. *Mechanical properties of bolted joints of furniture structures* [in Slovak: *Mechanické vlastnosti skrutkových spojov nábytkových konštrukcií*]. Zvolen: Technical University of Zvolen. ISBN 978-80-228-3153-6
[32] MÁCHOVÁ, Eliška. 2017. *Structural furniture joints of wood-plastic composite materials applied for furniture production*. Dissertation. Brno: Mendel University in Brno.
[33] MUZIKÁŘ, Zdeněk; TESAŘOVÁ, Daniela; HOLOUŠ, Zdeněk; JERGL, Zdeněk; MELOUN, Milan. 2008. *Materials II. for the carpenter's apprenticeship* [in Czech: *Materiály II – Pro učební obor Truhlář*]. Prague: Informatorium, spol. ISBN 978-80-7333-061-3
[34] ŠLEZINGEROVÁ, Jarmila; GANDELOVÁ, Libuše. 2019. *Wood construction – exercises* [in Czech: *Stavba dřeva*]. Second Edition. Brno: Mendel University in Brno. ISBN 978-80-7375-168-5
[35] WOHRLING, Traugott. 2008. *Furniture styles from antiquity to the present* [in Czech: *Nábytkové slohy: Od antiky po současnost*]. Brno: Grada Publishing, spol. ISBN 978-80-247-2034-0
[36] ZEMIAR, Jan; GÁBORÍK, Jozef; MUZIKÁŘ, Zdeněk; NAVRÁTIL, Vojtěch; RUŽINSKÁ, Eva; ŠEBO, Norbert. 2016. *Technology of furniture production* [in Slovak: *Technológia výroby nábytku*]. Zvolen: Technical University of Zvolen. ISBN 978-80-228-2064-6
[37] BLUM. 2024. *Blum*. https://www.blum.com/cz/cs/
[38] HETTICH. 2024. *Hettich*. [Accessed: 2024-11-18] https://web.hettich.com/cs-cz/domu

Reviewer
prof. Dr. Jerzy Smardzewski – Poznań University of Live Sciences (Poland)

Contact information
Dominik Horák: dominik.horak@mendelu.cz

OPTIMAL METHOD FOR MEASURING THE INTERIOR

Hruška Michal[1], Kořený Adam[1]

[1] Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0014

Abstract

The purpose of the work was to determine the optimal method for interior measuring. The study gives an overview of measuring instruments, then discusses metrology, tolerances in furniture manufacturing, multi-criteria analysis and software support related to Industry 4.0. For each type of measuring device, their properties were analyzed by using multicriteria analysis. In order to compare the time consumption of each method, results from a separate research study were used in the analysis. A methodology for the analysis is also included to allow modification to meet the specific requirements for particular users.

The result is a comparison of the different facilities and associated procedures, taking into account technical, time and economic influences.

Keywords: measuring, furniture, gauges, room, interior, software

INTRODUCTION

It can be said that every time a furniture manufacturer, whether a small joiner or a medium-sized furniture company, wants to make customized furniture, they need to measure the interior where the furniture is to be placed. To do this, they usually use either classic tape measures, which can be bought for a few crowns, or laser measure, which are a bit more expensive, but again much more accurate. These measurements produce data that must be processed. Once this data has been processed, a 3D model of interior should be created that is ready to design bespoke furniture. The advantage of such 3D software is that the furniture can be placed in precisely oriented interiors, and therefore at least partially eliminate any imperfections during the actual installation in the space.

MATERIALS AND METHODS

Tolerances in Furniture Production

Due to the nature of the product, it is necessary to determine what tolerances are permissible or necessary for proper operation or installation prior to manufacture. These may be tolerances in the opening of furniture doors, tolerances between drawer fronts or tolerances for convenient installation or tolerances permitted in terms of safety and design.

„A standard describes a rule or set of rules setting out requirements for human characteristics, things or behaviour that can be described as ‚normal', ‚usual' or ‚acceptable' [1]. On the basis of an analysis of the standards, it can be noted that, for example, the external dimensions of table, reclining or cabinet furniture can vary by up to ± 2 mm.

At the same time, the permitted deviations must not reduce the aesthetic standard of the product. At the same time, it is not permissible for non-conforming dimensions to cause poor product function, for example in doors, sliding glass or other movable or removable parts.

„Accuracy is particularly important when designing embedded parts to be manufactured off-site. Small discrepancies can lead to big problems on site. Drawings of the original building may exist, but their accuracy should always be questioned. Buildings are never built exactly as their original designer drew them" [2].

Tolerances that are not allowed for any piece of furniture are those that reduce its aesthetic level or even prevent the proper functionality of the product itself. Such furniture is not suitable for delivery to the customer, as it may cause injury during use or will not be accepted by the customer.

Tolerances in furniture assembly are a significant area of concern for designers, as well as tolerances in manufacturing. Any errors and flaws in the product can have a negative effect on marketing, reputation and brand in the long term. Hence, the risks in assembling products, both standardised and custom, should be identified before the product is launched. This can be achieved, especially for custom products, by proper measuring of the interior for which the products are designed. Here, the person carrying out the measurement has to verify what construction work has or has not been completed. This fact has animportant role when designing custom-made furniture. The dimensions of the interior without plaster/with plaster, the presence of the final floor covering, the presence of window sills are key. Therefore, the design and measurement of interior furniture should be done at the latest stage of renovation or construction.

For correct and high-quality interior measuring, it is advisable to use a suitable gauge and a suitable measuring procedure. Obviously, an inappropriate methodology using a 3D scanner will lead to lower quality results than using a suitable methodology with a tape measure. Thus, it is not only the gauges and its principle which is used that matter. Also the professional experience is crucial.

To avoid unsightly gaps that are associated with tolerance, there are several methods of masking. Some customers or manufacturers will not accept agap next to a wall, which may be caused by the finishing skirting board. For example, this problem can be solved with a false part, or a concealing trim. Small unsightly gaps are also solved for sloping upper cabinets. This can be solved by gluing and shaping a covering edge that is tightly bound into the joint between the furniture and the wall.

Analysis of Gauges Market

Tape Measure

When choosing a tape measure, the length and width of the tape measure play a major role. These are the basic key features that should be considered when buying a tape measure. Their price depends not only on their length or width, but also on the brand of the manufacturer (Prices are as of 25 February 2024 in CZK.) (Tab. I).

Laser Rangefinder

Three completely different types of laser rangefinders were found here. Their price here is mainly based on the features they can help with measuring. This could be the maximum distance that can be measured, the ability to target angles, or the ability to write data to a mobile app. These are all factors that should be considered when buying a given type of laser distance measuring tool (Prices are as of 25 February 2024 in CZK.) (Tab. II).

3D Scanners

When researching the market for 3D scanners, it is essential to allocate an appropriate category of products suitable for interior measuring. Exclude scanners used for mapping small objects for example for subsequent 3D printing. 3D scanners for surveying and mapping buildings are offered in a limited range and prices are usually not publicly available. An exception where pricing is publicly available is the Leica brand, which deals with 3D scanners on a professional level. For this reason, only scanners from this company are listed in the price overview table.

These scanners differ from each other not only in size but also in the possible scanning distance. While the Leica 3D DISTO deals with scanning rooms, the Leica ScanStation is for scanning outdoor objects such as buildings, dams or traffic junctions (Prices are as of 25 February 2024 in CZK.) (Tab. III).

I: *Analysis of the market for Tape Measure [3, 4]*

Name of product	Price (from-to) (CZK)	Seller
Tape Measure 2 m × 13 mm	28	www.briol.cz
Tape Measure Stanley 8 m × 25 mm	547	www.mall.cz

II: *Analysis of the market Laser Rangefinder [5, 6, 7]*

Name of product	Price (from-to) (CZK)	Seller
Asist LM030	499	www.asist.cz
Bosch GLM 120 C	6,719	www.dek.cz
Leica DISTO S910	38,398	www.shop.leica-geosystems.com

III: *Analysis of the market for 3D scanners [8, 9]*

Name of product	Price (from-to) (CZK)	Seller
Leica 3D DISTO	192,390	www.geoserver.cz
Leica ScanStation P50 3D Laser scanner	2,109,149	www.secure.fitgeosystems.com

Mobile Phones

For example, the technology company Apple has been implementing LIDAR technology in its PRO series mobile phones for several years. Each year, it improves these technologies to create a comprehensive device that is not just for making phone calls. To determine whether this technology can be fully exploited in a commercial setting, specifically for measuring spaces, it would be necessary to test the accuracy and speed of measuring. In any case, this possibility can be included in the market analysis research.

METHODOLOGY

Methods of Operation of Measuring Devices

Tape Measure

The first method that was investigated in this study was the method of measuring with a classical tape measure. The measure tape is produced in various lengths from one metre upwards.

The tape meter works on the principle of a coiled metal plate on which a measuring scale is printed. The measuring scale is indicated by commas, which are always separated by longer commas after five and ten millimetres for better orientation. Each line indicating ten millimetres is then given a number indicating the length in centimetres.

In this study, a conventional tape measure was used, which can be purchased at any home improvement store. In order to determine whether the tape measure was indeed measuring correctly it was subjected to a calibration check at M & B Calibr, spol. s. r. o., from which a record was made in the form of a calibration report.

Laser Measure Bosch Zamo

The laser measure used in this work was a Bosch rangefinder. Specifically, the Bosch Zamo was used here.

„Laser measure work by emitting an electromagnetic pulse in the form of a laser beam through an opto-electronic circuit. The beam of laser light is reflected from the area to be measured and returned to the measuring instrument. The rangefinder circuitry then processes the beam and determines the measured distance. The device circuitry performs the distance measurement by detecting the time of traversal of a section in two planes based on the phase shift of the transmitted and returning EM wave“ [10].

Again to verify the accuracy of the measurements, a calibration measurement was carried out at M & B Calibr, spol. s. r. o.

Technical data:

- measuring range: 0.15–20.00 m,
- measuring accuracy: ± 3 mm,
- smallest display unit: 1 mm,
- measuring time: 0.50–4.13 s,
- weight: 0.08 kg,
- dimensions: 101.4 × 38.0 × 22.3 mm.

The manufacturer lists two specifications that affect the quality of the measurement.

1. Caution on the measuring range:

The range increases the better the laser light reflects off the target surface (good scattering, no glare) and the brighter the laser spot is compared to the ambient brightness (indoors, dusk). Under adverse conditions, such as very intense indoor lighting or a surface with poor reflectivity, the measuring range may be limited.

2. Note on measurement accuracy:

Under adverse conditions, such as very intense indoor lighting, surfaces with poor reflectivity, or room temperature significantly deviating from 25 °C, the maximum deviation may be ± 5.00 mm at 20.00 m. Under favourable conditions, you must allow for an influence ± of 0.05 mm/m“ [11].

3D scanner

Another method that was used in this study was the 3D scanner measurement method. Here a 3D scanner from Leica was used - specifically the Leica RTC 360. This high speed scanner is used to collect accurate and clean data. Due to the advanced technology that can collect the data, high quality output data can be obtained.

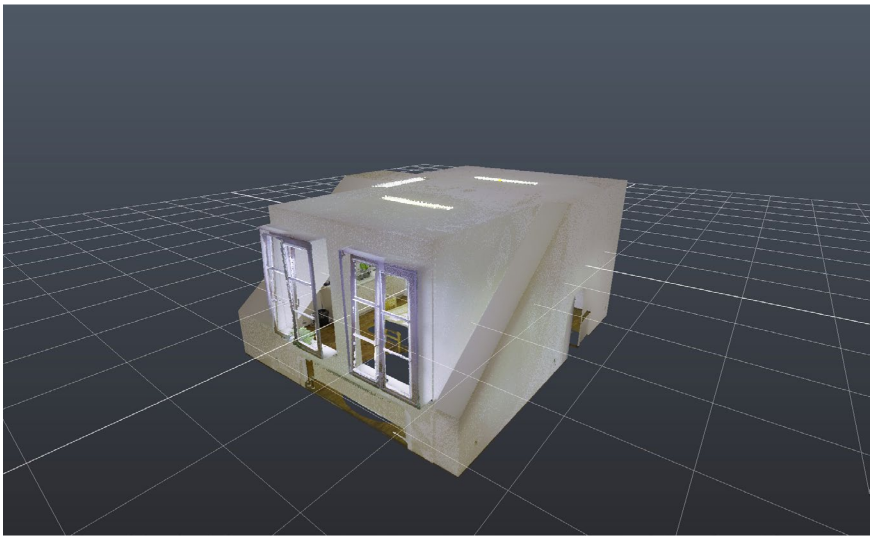
The scanner uses scanning up to 2,000,000 points per second to capture 3D reality (Fig. 1). Furthermore, thanks to its integrated cameras that allow HDR quality and panoramic photographs in 360°, a complete textured overview of the measurement can be obtained. The output of the whole measurement is a point cloud file, which is then ready for further use.

To get the best scan without further adjustments, e.g. removing moving people, it is best to leave the room and let the scanner work independently. Of course, in this case, the scanner can be controlled remotely using a tablet. If there is a need to be present at the scanner, a double measurement function can be used, where the scanner can remove moving persons.

„Virtual Inertial System - Automatic Scan Linking in the Field

The Leica RTC 360 scanner comes with the novelty of an integrated VIS system that works on the basis of five cameras and one integrated IMU unit. This robust system allows the positioning between two consecutive scans to be determined in real time and automatically links the two scans together without the need for user interaction.

Technical specifications:
Scanner dimensions: 120 × 240 × 230 mm
Weight: 5.35 kg



1: *Sample data from 3D scanner*

2: *Sample data from Leica BLK3D*

Scanning speed:
- Up to 2,000,000 points per second.

Resolution and scanning speed:
- 3 mm @ 10 m = 1:51 minutes,
- 6 mm @ 10 m = 51 seconds,
- 12 mm @ 10 m = 26 seconds,
- Panoramic 360° calibrated image in RAW quality - 432 MPx,
- 3 camera system 36 MPx.

Scan accuracy settings:
- Angular Accuracy 18°,
- length accuracy 1.0 mm.

3D point accuracy:
- 1.9 mm @ 10 m,
- 2.9 mm @ 20 m,
- 5.3 mm @ 40 m.

Operating temperature:
- 5° to + 40°.

Sensors:
- Altimeter,
- compass,
- GNSS“ [12].

Leica BLK3D

The last method used in this study is the measurement of 2D/3D dimensions using stereo photographs. The Leica BLK 3D was used for this purpose. This instrument allows the measurement of lengths in 3D space directly from a captured photograph (Fig. 2). To be able to make this measurement, the instrument combines the functions of a laser rangefinder and photogrammetry.

The instrument is small, compact allows the data to be manipulated directly after it has been acquired. Thanks to the touchscreen display, the edges to be measured and can be marked and the instrument calculates them immediately. The data can also be transferred to a computer, where it is much easier to work with the larger display and the computer mouse.

RESULTS

Sample of Data from 3D Scanner and Photogrammetric Instrument

Multicriteria Analysis

The multi-criteria analysis involves scoring on six different parameters relevant for evaluating. (Tab. IV) In this case, the multicriteria analysis will evaluate the time that was obtained using the Kruskal-Wallis test. We take this time into account because the occurrence of outliers during the corridor measuring, in the subjective opinion of the author, is not so frequent and therefore we can just use the results from the statistical evaluation. If the occurrence of these values were important for furniture manufacturers, the average values of the measuring times from the different methods have to be taken.

The second main factor that is an important part of multicriteria analysis is the data transfer time. If the measuring method saves enough time, but then we will lose it when when transferring data from the instrument to the computer, the instrument is unsuitable for further use.

Another evaluation criteria is the weight of the device itself. After all, lifting loads of, for example, five kilograms is very uncomfortable, so the lower the weight of the sight, the better.

The fourth evaluation criterion in this analysis is size. For a one-person carry, the size of the instrument is very important in terms of convenience during operation.

The fifth factor to consider is the number of people needed for measuring. After all, a 3D scanner can be assembled by one person, but with a tape measure, for example, a second person is sometimes desirable for convenience and accuracy.

Another factor that will be taken into account in this multicriteria analysis is the precision of the measurement. With the data obtained from the calibration measurements and the manufacturer's data, it is very easy to determine which device is the most accurate.

The last evaluation criterion in the multi-criteria analysis will be price. Price is a very important aspect that must be taken into account. Not every small enterprise has several hundred thousand, if not millions of crowns to spare to buy an expensive measuring instrument, because they would not be able to pay for such an instrument at all and would not pay it back.

DISCUSSION

First, it was necessary to find out whether there was interest in this issue among furniture manufacturers. The main objective of the study was to find out whether new measuring methods can save measuring time and thus money.

Other data were also taken from the surveying of the premises in the form of rough sketches of the premises on paper, scans and photogrammetric photographs. This data had to be transferred to AutoCAD 2023 software where it would be used for subsequent production preparation.

The work with individual data was different. While data from the laser rangefinder and the tape measure were manually entered directly into the software. The 3D scanner data were converted almost instantaneously. All that was needed was to select the correct file format type.

The data from the Leica BLK3D had to be first „extracted“ from the photogrammetric images taken. Here the limit of the instrument itself was found, which in low light and low colour contrast (e.g. white rooms) is not able to accurately determine the boundary anchor point. Due to this limitation, the oriented dimensions were very different from the dimensions oriented using the other three methods investigated. However, the data acquisition from the BLK3D software is not the final data processing. This data then had to be transferred to AutoCAD software, thus increasing the data conversion values considerably.

In order to compare not only the times, but also the compactness and cost of the individual devices, a multicriteria analysis was chosen. The factors of measuring time, data transfer time, weight, size, number of persons, labour cost, accuracy and price were compared.

The highest weighting was given to the accuracy of the individual gauges. The second highest weighting was given to measuring and data transfer times. The factors of cost, number of people and labour costs were ranked next. Price is important to most manufacturing companies - they want to know if the instrument will be worthwhile and if the payback on the cost will be within a reasonable timeframe. The number of people and labour costs are closely related to the financial costs of the company. It is very important for a company whether it sends two people to do the measuring or whether an individual can do the measuring. The last factors were weight and size. Both of these factors are important because of carryover.

According to the results found, which are presented in Tab. IV. Multicriteria Analysis, it was found that the best instrument for aiming is the classic tape measure. Although the roll meter came out higher in terms of sighting time and number of persons for sighting, yet the data transfer time, size, weight, cost and accuracy of the meter came out best. The second best measuring device was

IV: *Multicriteria Analysis*

	Measuring Time (s)	Data Transfer Time (s)	Weight (kg)	Size (mm)	Workers	Total Wages (CZK)	Device Presicions (mm)	Price (CZK)	
Tape Measure	594.5	574	0.2	70.0 × 70.0 × 25.0	2	102	± 0.7	128	
Laser Rangefinder	380.0	574	0.08	101.4 × 38.0 × 22.3	2	77	± 4.0	1,269	
3D scanner	722.0	85	5.35	120.0 × 240.0 × 230.0	1	47	± 1.9	1,499,900	
Leica BLK3D	133.5	1,251	0.48	180.6 × 77.6 × 27.1	1	80	± 3.0	120,000	**Total:**
Weight	8	8	6	5	7	7	10	7	
Tape Measure	15	10	10	5	10	20	5	5	580
Laser Rangefinder	10	10	5	10	10	10	20	10	650
3D scanner	20	5	20	20	5	5	10	20	730
Leica BLK3D	5	15	15	15	5	15	15	15	720

the photogrammetric device Leica BLK3D and laser rangefinder, and the least effective was the 3D scanner. The similar result for the laser rangefinder and Leica is surprising. Although the Leica is significantly better than the laser rangefinder in the factors of measuring time, number of people needed and labour costs, it is worse than the laser rangefinder in the factors of data transfer time, weight and price. The weight to be given to these factors according to the preferences of the manufacturing company must therefore be considered here. Changing the weights of the individual factors could change the overall ranking of the measuring instruments.

CONCLUSION

Conclusion of this study is assignment the optimal gauge for measuring interior. Four targeting instruments were selected and compared with each other. The first one is a classical tape measure, a laser rangefinder, a LEICA BLK3D and a 3D scanner.

From the evaluated data, the classical tape measure came out as the most effective targeting method. The second most effective device was the laser rangefinder, followed by the Leica BLK3D photogrammetric device and the 3D scanner.

The implication of these results is that modern measuring methods are only suitable under pre-specified conditions. However, they are neither the fastest nor the most inaccurate. Therefore, for any complicated targeting caused by large interior subdivisions, it is advisable to use classical targeting methods.

Every gauges have some benefits and downsides. For example, tape measure benefits are device presicions, size and weight, but downsides are total wages and workers.

The weight for only criterion is individual and everyone can change it along their preferences.

REFERENCES

[1] KANICKÁ, Ludvika. 2011. *Nábytek*. Grada Publishing, p. 16–17. ISBN 978-80-247-7406-0

[2] BOOTH, S.; PLUNKETT, D. 2014. *Furniture for Interior Design*. London: Laurence King Publishing. ISBN 9781780673226.

[3] BRIOL s. r. o. 2024. *Tape measure 2 m × 13 mm* [in Czech: *Metr svinovací 2 m × 13 mm*]. [Accessed: 20 January 2024] https://www.briol.cz/cs/p-1210-metr-svinovaci-2-m-x-12-5-mm?srsltid=AfmBOopAP4vt4AAYGJD7F2YtBgg-E3f9jURS6ZxyjKh1IuPETZY4uLj7

[4] ALLEGRO RETAIL a. s. 2024. *Stanley Tylon 8 M × 25 Mm Tape measure*. [Accessed: 22 January 2024] https://www.mall.cz/ampermetry/stanley-tylon-8m-x-25mm-svinovaci-metr-100096810935

[5] WETRA ČR a. s. 2024. *Laserový měřič 30m ASIST LM030*. [Accessed: 9 March 2024] https://www.asist.cz/p/laserovy-meric-30m-asist-lm030

[6] DEK a. s. 2024. *Laser measure Bosch GLM 120 C.* [Accessed: 14 March 2024] https://www.dek.cz/produkty/detail/3260001902-laserovy-dalkomer-glm-120-c?srsltid=AfmBOoor-HSt6SIlOl93f7Rg65FlDTCNeMsNm20fO4kbBEdAbuXrUO37Jyk

[7] LEICA GEOSYSTEMS AG, SWITZERLAND. 2024. *Leica DISTO S910*. [Accessed: 22 March 2024] https://shop.leica-geosystems.com/global/measurement-tools/disto/leica-disto-s910/buy
[8] LEICA GEOSYSTEMS AG, SWITZERLAND. 2024. *Leica 3D Disto.* [Accessed: 26 March 2024] https://shop.leica-geosystems.com/measurement-tools/3d-disto/leica-3d-disto/buy.
[9] FLT GEOSYSTEMS. 2024. *Leica ScanStation P50 3D Laser Scanner (ea)*. [Accessed: 26 March 2024] https://secure.fltgeosystems.com/laser-scanners-3d/leica-scanstation-p50-3d-laser-scanner-lca6012700/
[10] TME CZECH REPUBLIC, s. r. o. 2024. *Laser measure – how it works and which one choose?* [in Czech: *Laserový dálkoměr – jak funguje a jaký vybrat?*]. [Accessed: 13 April 2024]. https://www.tme.eu/cz/news/library-articles/page/21956/laserovy-dalkomer-jak-funguje-a-jaky-vybrat/
[11] BOSCH. 2018. *User Manual Bosch Zamo*. p. 25. [Accessed: 13 April 2024] https://www.manualypdf.cz/bosch/zamo/manuál
[12] GEFOS a. s. 2024. *Leica RTC360*. [Accessed: 13 May 2024] https://www.gefos-leica.cz/o-produktech/3d-laserove-skenovani/3d-laserove-skenery/rtc360

Reviewer
Dr. Manja Kitek Kuzman, PhD – University of Ljubljana (Slovenia)

Contact information
Michal Hruška: michal.hruska.udn@mendelu.cz

DESIGNING A SEATING ELEMENT FOR A SACRED SPACE

Krupičková Petra[1], Svoboda Jaroslav[1]

[1] Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0021

Abstract

The issue of sacred space falls into the category of the use of furniture in the public interior. In contemporary religious buildings, due to wear and tear or pest infestation, both individual parts of the interior and entire church interiors are being restored. It is desirable that new furniture already meets the criteria of modern church pews with regard to typology and ergonomics, safety requirements, construction and material design. However, these criteria must be closely related to the overall existing and planned space, aesthetics and liturgy of worship and ceremonies. The design and construction of the church pew was done through sketching, 3D modelling and also by creating several cardboard models. Subsequently, the production of a 1 : 1 model in the chosen materials was proceeded. The design of the church pew is situated in the so-called winter chapel, which is part of the Church of the Virgin Mary in Křtiny. This chapel is used mainly in the winter months or during services for smaller numbers of people. The chapel is currently undergoing renovation and therefore completely new furniture is planned.

Keywords: design, church pews, wooden furniture, sacral interior, public interior

INTRODUCTION

The furniture, created for public spaces, was constructed in accordance with modern design methods [1]. The sustainability aspect of the product is important due to the quality of workmanship. Thus, in conjunction with meeting the requirements for furniture in public spaces [2]. The current social climate in the church [3] and the condition of historic interiors are leading to the restoration and repair of sacred interiors [4] that are more in line with current church rules and needs. A significant part of the historic sacral buildings dates back to the Baroque period [5]. During this style, ergonomic principles were not yet known [6] the use of furniture, nor the principles of the use of public spaces [7]. Much of the current historic furnishings in churches are now often infested with pests or in a poor state of repair that does not lend itself to safe use.

Ergonomic dimensions, the right material and construction determine the overall impact on the use of the church pew. This is also linked to the social climate of the users in the place where the furniture is located and the interaction with other furniture and other people [8]. Thus, the composition of the church pew design was done with all historical, ecclesiastical, [9] ergonomic and structural and material contexts. Furthermore, the research and creation of cardboard models, see Fig. 1.

MATERIALS AND METHODS

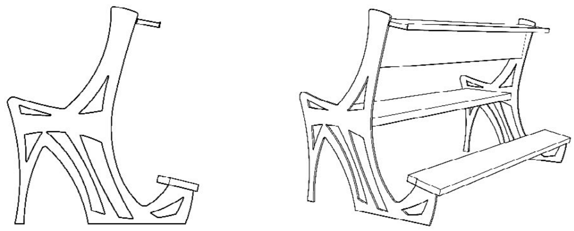
Materials

Research into the historical sources of church pews and research into modern church pews was the initial design phase. The design part included.

It is important to determine the parameters of the planned design of the entire product, including a survey of the ergonomics of seating and resting furniture. As this is not some furniture for long-term sitting, it was possible to choose parameters that were closer to resting furniture [10]. It was also necessary to consider the length of time the bench is used. An unusual and special part of the furniture - the kneeler - was subjected to research on its function and the dimensions usual for this part of this atypical furniture. In sacred settings, the kneeler is used not only for kneeling purposes, but also as a footrest.

1: *Cardboard models*

2: *Model of a church pew, front view*



3: *Sketch of concept No. 3*

Standards to be considered when designing furniture for non-residential premises:

- CSN 91 0100 (910100) Furniture - Safety requirements,
- EN 12775 (490004) Planks made of growing wood - Classification and terminology,
- EN 16139 (910650) Furniture - Strength, durability and safety - Requirements for non-domestic seating furniture,
- EN 204 (668503) Classification of thermoplastic wood adhesives for non-structural applications,
- EN 13353 (492810) Solid wood panels (SWP) - Requirements,
- EN 16139 (910650) Furniture - Strength, durability and safety - Requirements for non-domestic seating furniture,
- EN 1728 (910235) Furniture - Seating furniture - Test methods for determining strength and durability.

Methodology

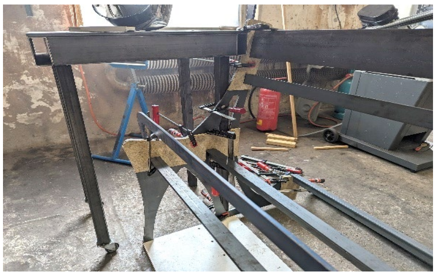
The design process was implemented in several steps:

1. survey of historical benches;
2. researching the current market for similar products and measuring the average values of other church pews against subjective feelings;
3. analysis of the obtained data and application to new design and material solutions;
4. analysis of the current layout of sacred space in selected churches and furniture in them, analysis of the behaviour of church pew users;
5. layout of the structural design using basic sketches with subsequent elaboration into variant solutions of the church pew - possibilities in relation to functionality and strength properties, the emergence of 3 variants - A. variant of the all-wooden pew, B. variant with a hinged kneeler, C. variant with a fixed kneeler - the resulting variant, see Fig. 3;

4: *Samples of surface treatment of solder and steel*

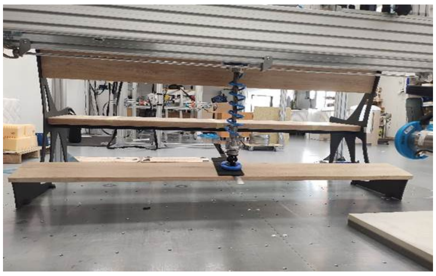
5: *All parts machined by milling*

6. 3D software modelling and visualisation in the planned space, see Fig. 2;
7. creation of models of sidewall shaping using cardboard and laser - scale 1 : 1 - see Fig. 1;
8. creation of samples of materials and their surface treatments - see Fig. 4;
9. creation of a 1:1 functional model from real materials - see Fig. 9, 10 and 11;
10. physical stress test using 3 persons - see Fig. 7;
11. testing of the 1:1 functional model in a certified furniture testing room for static loads - see Fig. 8.



6: *Creation of the structure before removing the templates*

7: *Assembly test and ergonomic seating test*



8: *Rear view of bench testing*

9: *Detail of the church pew-view from above*
Source: photo Pavel Jelínek

10: *General view of the church pew from the front*
Source: photo Pavel Jelínek

11: *Photo of the sidewall of the church pew*
Source: photo Pavel Jelínek

RESULTS

Production

The bench model consists of several parts. The basis of the whole construction is a metal frame, which is formed by two 8 mm thick steel side walls. These sidewalls are laser cut and connected by welding with 5 mm thick steel profiles. To this structure are attached the individual parts made of oak sprue, see Fig. 5. In total there are three parts: the seat, the backrest with book holder (consisting of two parts) and the kneeler. The pieces are attached to the metal frame with two types of screws. The backrest is made up of two parts and is attached on both sides by gluing so that the joints are not visible. All the wooden parts are milled on the inside of the non-visible side according to the shape of the steel ribs so that they fit together exactly, and the metal ribs are as little visible as possible.

The visible edges of the metal parts are milled to 2.5 mm, the wooden parts are milled with R10, R5 and R3. The metal sides of the bench are fitted with six 8 mm thick plates on the inside near the ground to accommodate the 3D printed rubber glides [11].

Samples of both materials and a sample of the edge of the seat were made before the surface treatment. This was to verify the correctness of the considerations for the new product, so that the final design would match the ideas of the overall product design.

The surface treatment of the metal parts is made by blasting and then powder coating in anthracite shade. The surface of the wooden parts is scratched, stained and treated with waterborne paints. Before the surface treatment, samples of both materials and a sample of the edge of the seat were made to verify the correctness of the product considerations and to ensure that the final design corresponds to the proposed idea of the overall design of the product.

Steel Construction

The steel structure consists of several parts - laser cut side surfaces (sidewalls) and steel T and L profiles that connect, strengthen and ventilate the entire structure.

A template had to be created for the exact welding of the connecting profiles. This was made using a CNC machine from MDF according to the data from the 3D model of the bench and glued to the laser cut sidewalls see Fig. 6. After welding all the parts together, the wooden templates were removed. Next, the platforms for the placement of the rubber gliders were welded to the fabricated structure.

Production of Wooden Parts

Oak wood was chosen for the production of the jointing board because of the attractive wood grain and the properties of this wood species. Oak planks, beech slats and PVAC glue were used. The selected parts for the production of the joints were glued together using D3 glue - a high strength waterproof PVAC glue, according to ČSN EN 204, designed for stressed interiors. Cut-outs were made using a milling head for fitting the wooden parts to the steel structure. In the next step, the edge of the seat was bevelled using a formatting saw, and all other edges were also modified to ensure safe use of the product.

Product Assembly

After the production and surface treatment of all the components of the product, i.e. the steel structure and the wooden parts, it was possible to proceed with the assembly.

A metal bar was glued into the milled hole in the bookshelf as a stop for the books to keep them from sliding down. After drying, this part was screwed to the underside of the L profile of the steel structure. It was also coated with PVAC adhesive and attached to both upper metal profiles. The back of the backrest was knocked down with the other part and also glued with PVAC glue. The seat and kneeler were then bolted to the steel structure.

Since it was not possible to find adequate gliders on the market that would meet the parameters for the bench, the possibility of 3D printing using rubber TPU filament was used.

12: *Probable form of „bradellas" according to the work of K. Boromejský, 3D modelling of perspective*

DISCUSSION

The aim of the work was to design and realise a church pew for the sacred space, which would be designed for three adults and fit into the planned interior of the "winter chapel" in Křtiny. This chapel is used by the parish of Krtina for various meetings. It is a public space where people with limited mobility can move around. Therefore, the whole interior should be adapted to this. The design of the bench should also meet the requirements for stability and safety, so that it changes its position as little as possible, which affects the ergonomics of use throughout the chapel. The bench is therefore also characterised by a higher weight than, for example, furniture for private spaces.

The research focused first on a literature search regarding the historical development of church pews. Due to the less available historical sources of this specific furniture, a more detailed analysis was carried out. While researching the history, an accurate description was found in the writings of Boromejsky [12] similar to the Renaissance church benches called "bradelas", see Fig. 12, which had not been depicted anywhere before. In the historical part of the research obtained by mapping the typology of pews from the period, it is evident that the church pews of the Baroque period experienced the greatest boom in ornamentation and elaboration. However, the ergonomic requirements for this type of furniture did not begin to be applied until the modern history of the twentieth century.

The options and characteristics of the intended materials for the bench were set to steel and oak continuous joint. An important part was also the determination of the technological processes that were planned to be used in the production. This was followed by an analysis of the typology of church pews which was an important starting point in considering the design and dimensions that the future pew would have. In connection with the considerations of dimensions, measurements of several modern pews were taken. The average values from the measurements taken were considered in the design. In addition to the average, the subjective feelings of the user when trying to use the measured benches were also decisive. It turned out that average values are not always related to the feeling of comfort, and it is necessary to work with the fact that there are more factors for pleasant use. Here one can also include the layout of the space itself, both in terms of ergonomic or standard parameters for public spaces and in terms of the artistic value of the space and the atmosphere of the sacred space. The furnishings designed for the sacred space must then be in harmony with the overall concept of the church or chapel. This knowledge was then used in the design itself. They are interrelated and one cannot be separated from the other.

It is evident that the above-mentioned surveys of all possible influencing factors were part of the design process. This was followed by first sketches, creation of paper models (5 variants in total) and 3D visualizations, up to the realization of the 1 : 1 model.

The main inspiration was the interior of the chapel itself and the unique architect Jan Blažej Santini-Aichel, the creator of the Church of the Virgin Mary in Křtiny. When dealing with the issue of ergonomics, extensive research into the dimensions and shapes of modern church pews and their fitting into the interiors was important.

By creating samples of both the shaping of the furniture parts and the samples for the surface treatment, it was possible to eliminate errors in the final model. The side metal parts were laser cut and the steel sections were welded together to form the base of the structure. This was followed by the surface treatment of the metal and wooden parts.

An important part of the successful creation of the model was the participation of the designers in the production process. Thanks to the immediate feedback, it was possible to change some details directly in production and react faster to the situation. In fact, some product parameters and their consequences may only become apparent during production. This was confirmed in the production of the kneeler, where the inclination was slightly reduced as the kneeling proved too steep in the physical test. The kneeler was therefore adjusted to a more moderate inclination, since steepness and slipperiness could be dangerous for use.

The functionality and basic stability of the physical model was first verified by a test with three volunteers directly on the workshop. The results of the testing were then confirmed with a small deviation by a physical test of the model at a certified furniture testing facility.

Testing of the real model showed that the kneeling part shows slightly more flexibility in the middle at higher loads. Also, the seating section showed a small amount of flexibility in the load area. This therefore means that if the bench were to be made longer than the current model, the design should be modified and stiffened at the stressed areas to eliminate this phenomenon.

CONCLUSION

The work describes the development of the church pew from extensive research to its production. The church pew is designed for a specific sacred space. Ideally, it should become part of the interior of the “winter chapel” in Křtiny, for which it was designed.

Initially, the work was concerned with analysing seating furniture in sacred space, with a focus on the church pew for the faithful people.

By visiting many sacred interiors and measuring ergonomics in several modern church interiors and extensive literature research, a better orientation in the design of furniture for these spaces was possible. The creation of cardboard models based on sketches and 3D models helped in the creation of the final shape of the side metal parts of the pew. The production of the 1 : 1 model confirmed the correctness of all ergonomic assumptions with a minor modification in the kneeling part. Subsequently, the surface treatment was carried out by scratching, pickling and painting.

The bench makes an interesting impression, its elegant, subtle appearance connects with the interior of the chapel. The seating is comfortable and pleasant, the seat does not slip, and the sides do not press in any way. The stiffness and stability of the structure stood up to the load of the seat and backrest by three adults, as well as to the static load test in the furniture testing room.

REFERENCES

[1] SVS FEM. 2023. *Finite Element Method neboli FEM: Jak funguje a proč je tak důležitá v technických aplikacích?* [Accessed: 2024-04-07] https://www.svsfem.cz/finite-element-method-neboli-fem-jak-funguje-proc-je-tak-dulezita-v-technickych-aplikacich

[2] ČSN EN 1728 (910235). 2020. *Furniture - Seating furniture - Test methods for determining strength and durability* [in Czech: *Nábytek bytový - Sedací nábytek - Zkušební metody pro stanovení pevnosti a trvanlivosti*]. Česká Agentura pro Standardizac.

[3] DĚDIČ, Ondřej. 2017. *Sacred space after the Second Vatican Council and its liturgical functionality* [in Czech: *Sakrální prostor po II. vatikánském koncilu a jeho liturgická funkčnost*]. Master thesis,

supervisor S.L.D., Ing. Pavel K. Olomouc: Palacký University in Olomouc, Cyril and Methodius Faculty of Theology, Department of Liturgical Theology.

[4] DRÁPAL, Jaroslav. 2022. *Architectural structures* [in Czech: *Architektonické struktury*]. Brno University of Technology, VUTIUM Publishing House. ISBN 978-80-214-5858-1

[5] BOHR, Michael. 2021. *Sakralmöbel aus Österreich: Von Tischlern und ihren Arbeiten im Zeitalter des Absolutismus. Ii: Kunstlandschaften im Norden, Süden und Westen.* Wien, Köln, Weimar: Böhlau Verlag. ISBN 9783-205-21246-1

[6] HOLOUŠ, Zdeněk; MÁCHOVÁ, Eliška. 2013. *Furniture construction I.: instructions and examples* [in Czech: *Konstukce nábytku I.: Konstrukce nábytku, procesy, návody, příklady*]. Brno: Mendel University in Brno. ISBN 978-80-7375-844-8

[7] EN 16139 (910650). 2013. *Furniture - Strength, durability and safety - Requirements for non-domestic seating furniture*. European Committee for Standardization.

[8] KOTRADYOVÁ, Veronika. 2009. *Furniture design: development, designing,terminologia, typologia, ergonimia, materialy, konstrukcie, technilogia* [in Slovak: *Dizajn nábytku: vývoj, navrhovanie, terminológia, typológia, ergonómia, materiály, konštrukcie, technológia*]. Bratislava: Slovak Technical University. University textbook edition. ISBN 978-80-227-3006-8

[9] KOPEČEK, Pavel. 2022. *Mysterium Christi in the rites of the Church: history, theology and pastoral care* [in Czech: *Speciální liturgika: Mysterium Christi v obřadech církve: historie, teologie a pastorace*]. Olomouc: Palacký University in Olomouc. ISBN 978-80-244-6252-3

[10] POTŮČKOVÁ, Iva. 2022. *Housing: interior design* [in Czech: *Bydlení: Navrhování bytového interiéru*]. Prague: UMPRUM. ISBN 978-80-88308-62-1

[11] 3D MANUFAKTRUA. 2024. *TreeD Flexmark 8 flexible TPU filament 80A white 1,75 mm 500 g* [in Czech: *TreeD Flexmark 8 flexibilní TPU filament 80A bílá 1,75 mm 500 g*]. [cited 2024-03-30] https://eshop.3dmanufaktura.cz/treed-flexmark-8-flexibilni-tpu-filament-80a--bila-1-75mm-500g/

[12] BOROMEO, Karel. 1577. *Instructiones Fabricae et Superllectilis ecclesiasticae.*

Reviewer
doc. Ing. Milan Gaff, Ph.D. – Mendel University in Brno, Czech Republic

Contact information
Petra Krupičková: petra.krupickova@mendelu.cz

WOMAN AND DESIGN

Hynek Maňák[1], Ludvika Kanická[1], Dominik Horák[1]

[1] Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech republic

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0027

Abstract

The generally assumed lower proportion of women in technical fields is due to a historical development full of gender stereotypes and persistent anxieties. The proportion of women studying design at LDF Mendel has long been around 80%. At the Department of Design and Furniture, the technical difficulty of the content of the study programme has been discussed with regard to this high proportion of women, and the subjects of mathematics, physics and geometry have been reintroduced into the study programme. At the same time, higher requirements were set for knowledge in the areas of mechanical and physical properties of materials, furniture design and dimensioning and production technology. The defended final theses of the students prove that women are able to process these works with the high technical complexity required by this level of education. The study thus creates a high prerequisite for women's further career development.

Keywords: study of furniture design, woman, gender stereotypes, female role models, technical fields, professional career of women

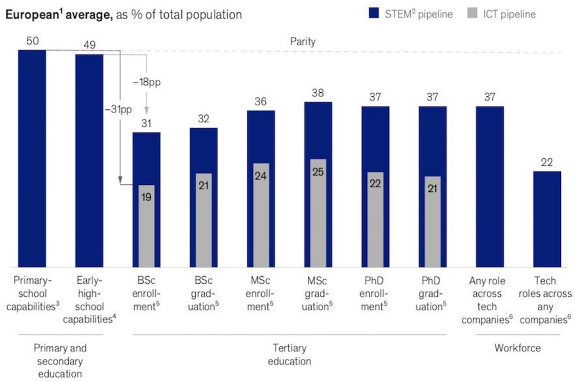
Introduction

Some fields are perceived as specifically male or female. Yet research on brain function is busting myths such as that men have better spatial perception and women have better communication skills. The predisposition to different types of jobs illustrated by the myth: „Girls don't have the cells for maths“ is not true. The problem lies only in the stereotypical settings of society [1].

Women in technical fields

In addition to compensating for the general labour shortage, the main reason for including more women in corporate management processes is to make companies more efficient. Gender intelligence expert Barbara Annis says that when you include women leaders in your organizations, you not only save money and reduce employee turnover, but also improve brand reputation. Research shows that women bring valuable insights and approaches to the idea generation process, leading to simpler solutions to complex problems [2].

The labour market in Western Europe and the US addresses the under-representation of women in technology professions in senior positions. The decline of women in the European labour market during the development process from primary school to the workplace occurs at two points in time when there is a significant percentage of women in STEM fields (science, technology, engineering and mathematics (Fig. 1), [3].



1: *Graph of female attrition on entry to university and employment*

The first moment is in the transition from primary and secondary education to university (with a decrease of 18%). The second moment is in the transition from university to the workplace (a decrease of 15%).

Even after women enter the technical workforce, another key issue is keeping women in positions of influence without interrupting their professional growth. The interruption in women's professional growth is caused by several factors:

- interruption of work due to maternity leave,
- lack of management support,
- persistent masculine preferences.

To retain women in technical occupations, employers offer job benefits (in order of popularity) [4]:

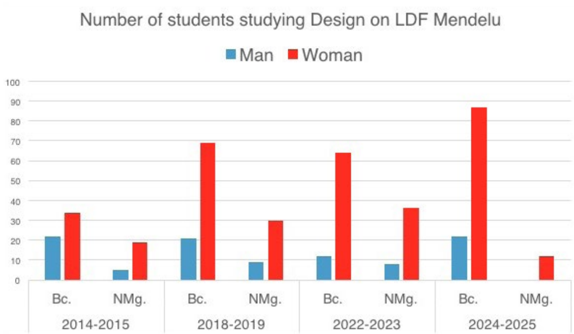
- Hybrid telework (Home Office);
- Paid time off;
- Medical benefits;
- Professional development / training opportunities;
- Family holidays;
- Coaching / Mentoring / Career counselling;
- Childcare.

Lack of Female Role Models

An important factor influencing the lower proportion of women in technical fields is related to the lack of female role models to look up to for career advancement and growth. Research has shown that women in technology lack mentors, face challenges in a male-dominated environment and have more family responsibilities than their male counterparts. Female role models and mentors were difficult to find in the technology field because it is mostly male dominated. Yet women have made a major contribution to the development of technical fields in the past. In fact, in the past, the role of women in science has been overshadowed by their male colleagues. Achievements and prizes were attributed only to men. This phenomenon is known as the „Matilda effect“ [1].

Women Studying Design at LDF Mendel University

In recent years, the proportion of women studying design at the Institute of Design and Furniture at LDF Mendel Brno has stabilised at around 80% (Fig. 2). At the same time, there have been discussions on whether the field of Furniture Design is an artistic or technical direction and what the content structure of teaching should be. In the previous period, subjects such as mathematics, physics and geometry were removed from the curriculum. The return of the technical field of study, in view of the high proportion of women, was hindered by stereotypes and the view that women do not have the aptitude for technical fields.



2: *Representation of women studying Design at LDF Mendel University in Brno*

According to the accreditation [5] of the study programme Furniture Design, the main emphasis is on balancing artistic skills and technical and technological knowledge in the field of furniture production. The current study programmes already include these subjects again, and the demands on technical knowledge in the field of furniture construction, furniture dimensioning and verification of mechanical and physical properties of materials have also increased. This knowledge is especially necessary with the advent and solutions of new eco-friendly materials such as hemp structural boards, seaweed and other materials newly being considered for furniture production.

Inspirational / Female Professional Role Models

An important part of the study of design at the Institute of Design and Furniture at LDF Mendel Brno is knowledge of the history of furniture design. Here it is possible to look for patterns and find sources of inspiration. Although in the overcrowded male world, for the reasons mentioned above, „brave female designers“ are almost disappearing, there are a few personalities who have literally wiped the male world's eyes clean.

The imaginary bar for design as a result of the combination of science and the design process was set at the beginning of the 20th century by Margarete Schutze Lihotsky, who proposed the division of kitchen operations into working, cooking and washing zones based on the measurement of kitchen tasks. She was then able to test her theory in several thousand kitchens, which formed the basis for the furnishings of the post-war housing developments in Frankfurt am Main. The principle of the Frankfurt Kitchen is still in use almost 100 years later, but has been supplemented by new appliances and the application of new technologies.

Other successful women include Ray Eames. Today we do not know to what extent her husband Charles had her back, but both are shining examples of the fructification of the results of war research in the peace process. The knowledge of plywood bending required to make wounded men's splints resulted after the war in the design of an elegant chair which, nearly 100 years on, is still the ornament of every headmaster's office. Their almost endless list of technological innovations is unrivalled on a planetary scale.

Another example of the feminine approach is the work of „lone wolf“ Eileen Gray. Her work oscillated between functionalism and art deco. She was one of the first to deal comprehensively with interiors, looking for new functions for storage systems, which she tested on herself, as did her later Scandinavian colleague Nana Ditzel.

3: *Photograph of Mrs. Zdena Maňáková at work, sucesful and popular kitchen AROMA*

4: *Bedroom ADAM and DIES, by Eva Bubláková*

We should not forget Charlotte Perriand, Le Corbusier's right-hand woman. Her unquestionable contribution to the design of furniture for the highly acclaimed „god“ of architecture somewhat disappears with the designation of the team's products as LC. In the case of this woman, her managerial and popularising activities must also be added to the scales. She managed to bring Japanese culture to France, which was also a source of inspiration for her.

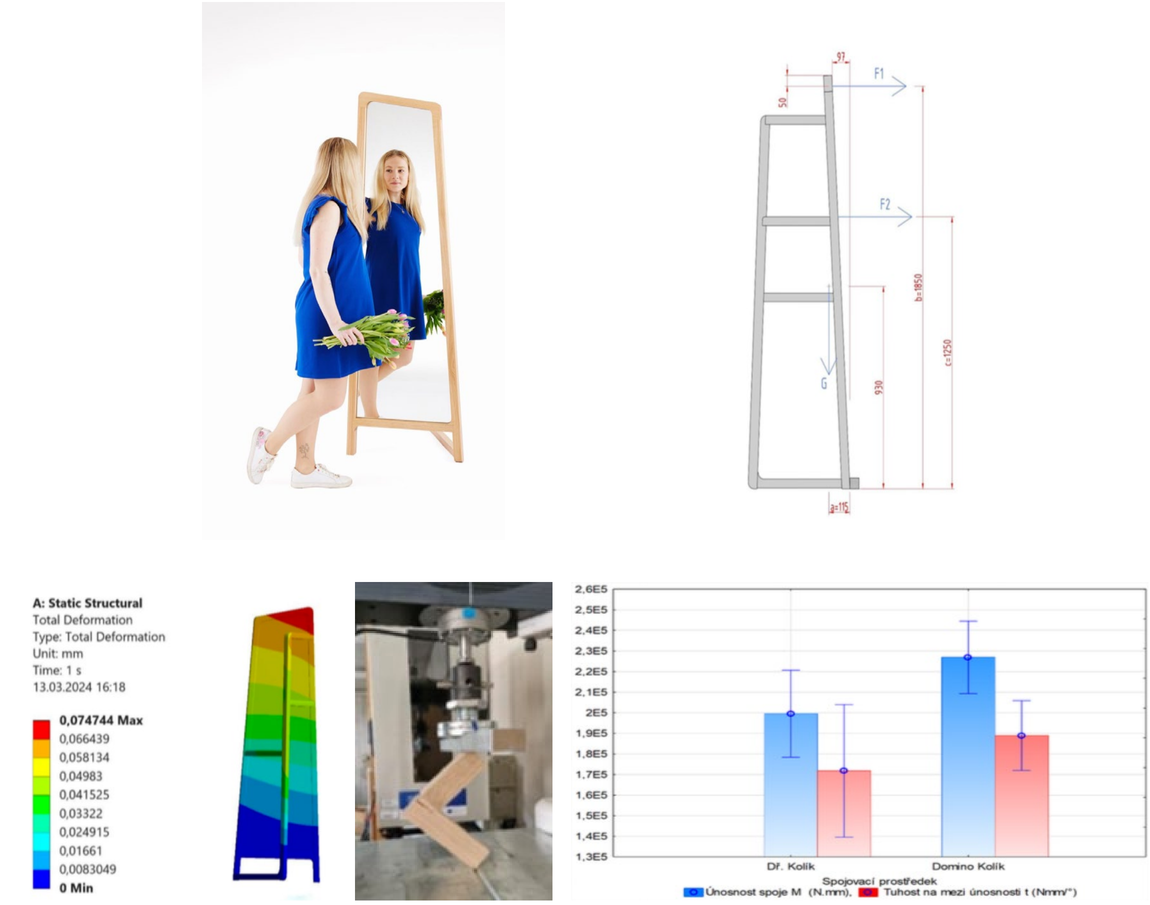
Finally, it should also be mentioned that prominent women designers were able to excel in managerial positions, such as Florence KNOLL, who, after her husband's death, headed the highly successful American company KNOLL, which she brought to the position of a competitor of Hermann Miller, not only thanks to a precisely chosen production programme, but also thanks to the licensed production of European furniture icons (e.g. the Barcelona chair).

There are more similar examples from around the world, the situation in socialist Czechoslovakia is admirable. Here, women interior architects (the word designer was almost taboo) had to face the unqualified opinions of the then management of furniture colossuses. At this stage, one cannot fail to mention the stubbornness of Zdena Maňáková (Fig. 3), [6], or Eva Bubláková (Fig. 4), [7], whose designs combined elegance with function. Perhaps that is why they were put into practice despite enormous problems. These ladies of Czech design can in no way be accused of plagiarism, because their designs were placed behind an impenetrable wall, which was imaginatively reinforced by the information barrier imposed by the then absence of literature and the Internet.

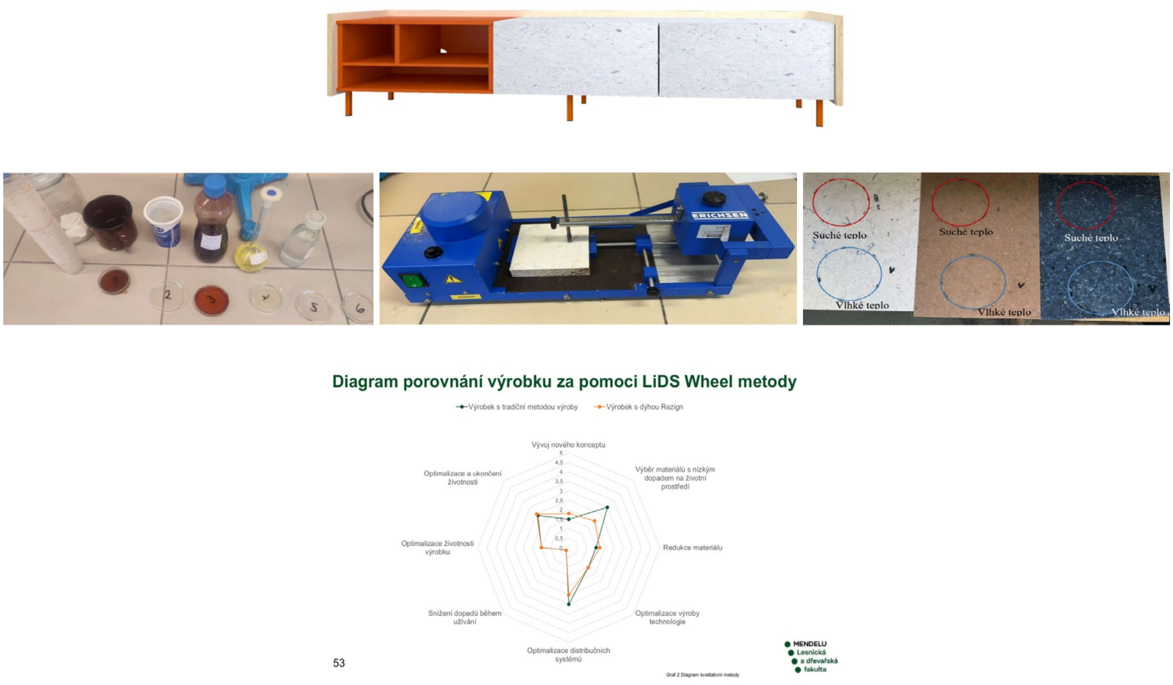
METHODOLOGY

The article uses a quantitative approach for evaluation based on primary and secondary sources, professional literature in the field of labor resources. Four bachelor's theses defended by women at the Institute of Furniture Design in 2023 and 2024 were selected for analysis. The selection criterion was the complexity of the work, including, in addition to studies, design and production documentation, product stability calculations, FEM analyses, practical testing of material properties, as well as the students' participation in development of new ecological materials for sustainable management.

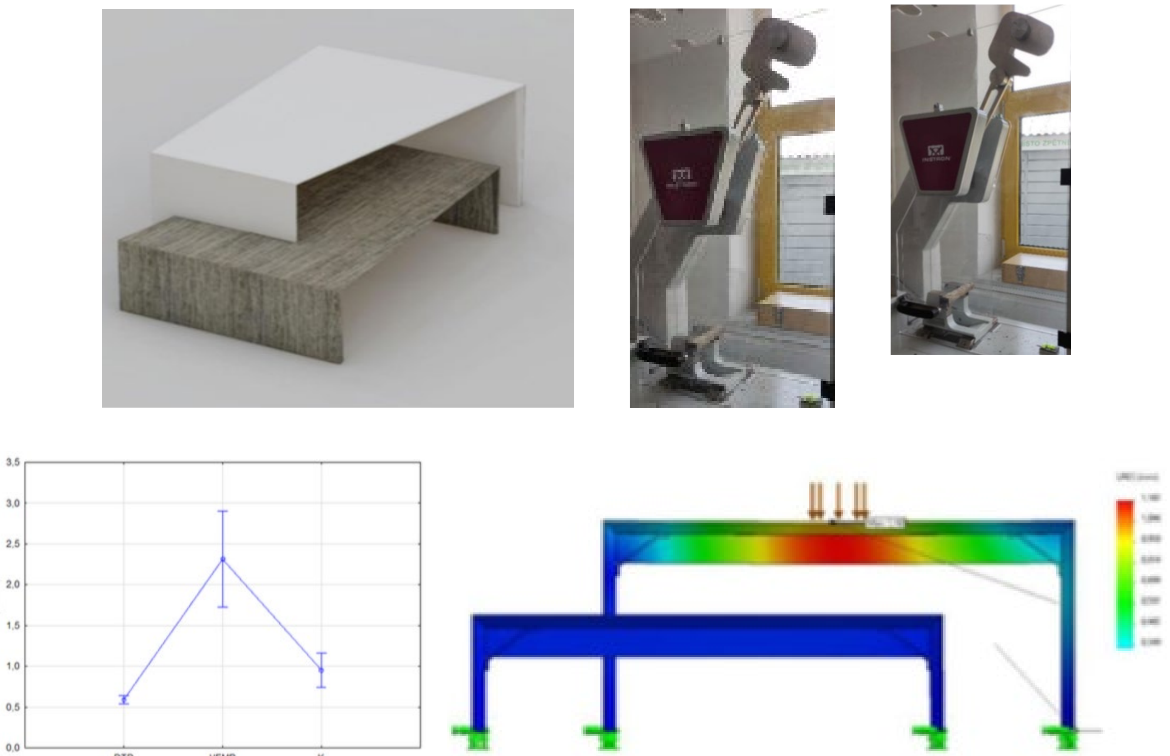
- In order to clarify the current state of the argumentation on the issue of the employment of women in technical fields, a question on ChatGTP was used in the form of four questions, two formulated positively and two formulated negatively:
- 1A Why can women be successful in designing furniture?
- 1B Why can't woman be successful in designing furniture?
- 2A Why can women be successful in technical fields?
- 2B Why can't woman be successful in technical fields?



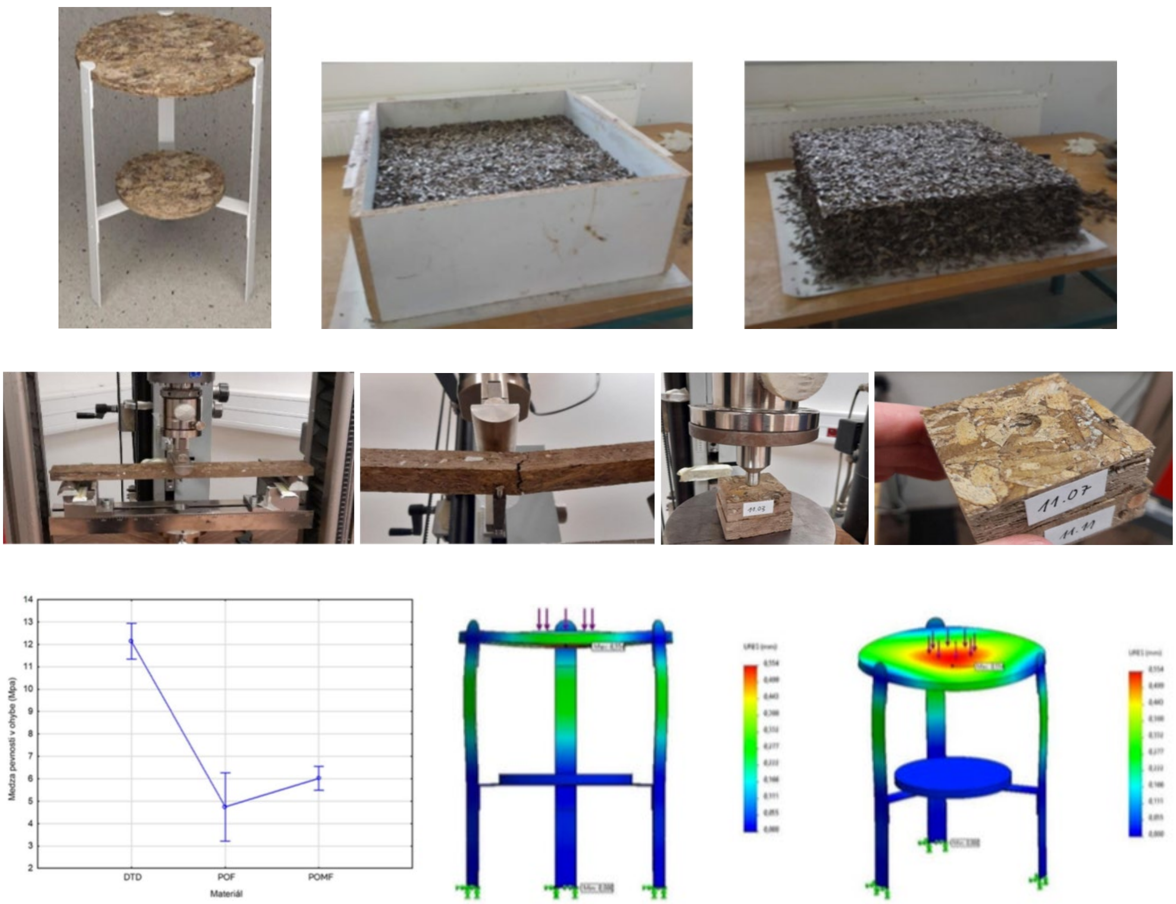
5: *Samples from the final thesis Mirrof as furniture solitare by Gabriela Vaculíková [8]*



6: *Examples from the final work Furniture from recycled material Reigin by student Anežka Petrušková [9]*



7: *Examples from the final thesis Conference table made of Cannabis Sativa L material by student Jana Michlová* [10]



8: *Samples from the final thesis Furniture element made of seagrass material by student Veronika Bellayová [11]*

9: *Student participation in the development of new materials from hemp and seagrass*

RESULTS

Thesis topics

Currently, the thesis topics of students of the Furniture Design study programme are assigned with the requirement of interaction of product design with testing and evaluation of physical and mechanical properties of materials and design principles. The theses of female authors defended in 2023 and 2024 demonstrated their ability to produce work with a high proportion of technical parameters (Fig. 5, 6, 7, 8). As part of final theses students also participated in the development of new ecological materials for sustainable management (Fig. 9).

What about ChatGTP?

To test the validity of the arguments, the following questions were posed to AI [12]:

1A Why can women be successful in furniture design?

Women can be successful in furniture design for several reasons based on their specific approaches, skills and perspectives. Women often demonstrate a high level of empathy and ability to understand the needs of users. This enables them to design furniture that is not only aesthetically appealing but also functional and comfortable for everyday use. They are sensitive to details that can improve the user experience, such as ergonomics, safety and comfort.

1B Why can’t women be successful in furniture design?

There is no objective reason why women cannot be successful in furniture design. If one tried to argue against it, it would be more about prejudices or stereotypes that have influenced various professional fields, including design, in the past. Here is one of the fallacious arguments that may have been put forward by so-called „historical stereotypes“: in the past, some professions were seen as male domains and furniture design, like other technical or craft fields, may have been happy to be less accessible to women. However, this prejudice does not hold true in modern times, as women have the same educational and professional opportunities as men.

2A Why can women be successful in technical fields?

The longer answer is systematically broken down into the following points, which contain brief positive arguments:

1. Equal access to education;
2. Logical and analytical thinking;
3. Ability to work in a team and communicate;
4. Different perspective and innovative thinking;
5. Resilience and ability to overcome obstacles;
6. Growing support and mentoring;
7. Adaptability and ability to learn with new technologies;
8. The contribution of diversity in the fields;
9. Improving working environment.

2B Why can’t women be successful in technical fields?

The answer is again structured into multiple points which, in turn, refute the reasons:

1. Stereotypes about “male” and “female” roles;
2. Underestimating the technical abilities of women;
3. Lack of female role models;
4. Preconceptions about the emotional nature of women;
5. Male-dominated culture of technical disciplines;
6. Unequal opportunities and lack of support;
7. Social expectations;
8. Lower self-esteem and imposter syndrome;
9. Biological differences.

What is interesting about ChatGTP's responses, then, is that it brings specific point-by-point reasoning to the positively phrased question on the successful application of women in AI technical fields. To the negatively worded question, the AI answers: „There is no objective reason why women cannot be successful in furniture design“ and presents various societal reasons and biases for women's employment in technical fields. AI refutes the biological differences between men and women.

DISCUSSION

Gender stereotypes and prejudices that women are not suited for technical fields have now been overcome in Western economies and do not prevent women from entering technical fields. Studies in various fields have refuted these stereotypes. On the contrary, positive role models of women's success in technical fields confirm and inspire female applicants choosing to study technical fields. In addition to the presentation of female role models, the creation of suitable working conditions once women have entered the workforce also helps to increase the proportion of women in technical fields. For the future career growth of women in the technical profession, it will be necessary for employers to offer women valuable bonuses and remove the persistent masculine atmosphere from the workplace.

The proportion of female students studying Design at LDF Mendel has stabilised at 80% in recent years. This paper describes the emphasis on the technical demands of studying at the Department of Design and Furniture at LDF Mendel University Brno, regardless of the gender composition of the students. The presented final theses prove that if the demands on students are set by the professional management without any gender stereotypes and prejudices, women are able to produce final theses with high technical difficulty, just like men. Technical studies free from gender prejudices can prepare a new generation of educated professionals capable of tackling current issues in furniture production and design with a high proportion of women in practice.

CONCLUSION

The final theses of women defended in 2024 in the framework of design studies at the Institute of Design and Furniture at LDF Mendel Brno prove that if the demands on students are set by the professional management without any gender stereotypes and prejudices, women are able to produce final theses with high technical complexity, just like men. This way, the study prepares a new generation of educated professionals capable of tackling current topics in furniture production and design with a high proportion of women in practice.

REFERENCES

[1] MENDELU. 2024. *Mendelova univerzita výstavou vyvrací genderové stereotypy*. Published 13. 2. 2024. https://mendelu.cz/mendelova-univerzita-vystavou-vyvraci-genderove-stereotypy/

[2] SHITANSHU, Srivastava. 2019. *Women in Technology-Reasons for Underrepresentation and What Can Corporates Do to Improve the Gender Diversity*. https://www.researchgate.net/publication/330621152_Women_in_Technology-Reasons_for_Underrepresentation_and_What_Can_Corporates_Do_to_Improve_the_Gender_Diversity

[3] BLUMBERG, Sven; KRAWINA Melanie; MÄKELÄ Elina; SOLLER Henning. 2023. *Women in tech: The best bet to solve Europe's talent shortage*. McKinsey & Company. https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/women-in-tech-the-best-bet-to-solve-europes-talent-shortage#/

[4] SKILLSOFT. 2024. Women in Tech Report 2024. 3rd Edition. https://s3.us-east-1.amazonaws.com/skillsoft.com/prod/documents/Skillsoft-Women-In-Tech-Report-24.pdf

[5] VYSOKESKOLY:COM. 2025. *Furniture Design (B0212A16001)* [in Czech: *Design nábytku (B0212A160001)*]. https://www.vysokeskoly.com/obor/96489

[6] NÁRODNÍ GALERIE V PRAZE, VYSOKÁ ŠKOLA UMĚLECKOPRŮMYSLOVÁ V PRAZE. 2022. *Woman in architecture: Zdenka Maňáková (Pekárková)* [in Czech: *Ženy v architektuře: Zdenka Maňáková (Pekárková)*]. https://zenyvarchitekture.cz/architektka/biografie/?arch=104

[7] NÁRODNÍ GALERIE V PRAZE, VYSOKÁ ŠKOLA UMĚLECKOPRŮMYSLOVÁ V PRAZE. 2022. *Woman in architecture: Eva Bubláková* [in Czech: *Ženy v architektuře: Eva Bubláková*]. https://zenyvarchitekture.cz/architektka/biografie/?arch=100

[8] VACULÍKOVÁ, Gabriela. 2024. *Mirror as a furniture solitaire* [in Czech: *Zrcadlo jako nábytkový solitér*]. Bachelor thesis. Ústav designu a nábytku, Mendelova univerzita v Brně. https://is.mendelu.cz/zp/index.pl?podrobnosti=114999

[9] PETRUŠKOVÁ, Anežka. 2024. *Ecodesign in furniture design*. [in Czech: *Ecodesign v návrhu nábytku*]. Bachelor thesis. Ústav designu a nábytku, Mendelova univerzita v Brně. https://is.mendelu.cz/zp/index.pl?podrobnosti=114996

[10] MICHLOVÁ, Jana. 2023. *Ecodesign Design of a coffee table made of Cannabis sativa L*. [in Czech: *Návrh konferenčního stolku z materiálu na bázi Cannabis sativa L.*]. Bachelor thesis. Ústav designu a nábytku, Mendelova univerzita v Brně. https://is.mendelu.cz/zp/index.pl?podrobnosti=109003

[11] BELLAYOVÁ, Veronika. 2023. *Design of a furniture element using material made of seagrass*. [in Czech: *Návrh nábytkového prvku s využitím materiálu vyrobeného z morskej trávy*]. Bachelor thesis. Ústav designu a nábytku, Mendelova univerzita v Brně. https://is.mendelu.cz/zp/index.pl?podrobnosti=108994

[12] OPEN AI. 2024. *ChatGPT*. San Francisco: OpenAI. [cit. 2024-23-10]. https://chatgpt.com

Reviewer
Dr. Manja Kitek Kuzman, PhD – University of Ljubljana (Slovenia)

Contact information
Hynek Manak: hynek.manak@mendelu.cz

POTENTIAL NEW WOOD SPECIES FOR THE FURNITURE INDUSTRY

Németh Róbert[1], Fehér Sándor[1], Ábrahám József[1], Komán Szabolcs[1], Csordós Diána[1], Szeles Péter[1], Báder Mátyás[1]

[1] Faculty of Wood Engineering and Creative Industries, University of Sopron, Bajcsy-Zs. 4, 9400 Sopron, Hungary

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0035

Abstract

The effects of climate change, which are becoming more pronounced today, mean that unconventional wood species must be used in the wood industry, of which the furniture industry is an important integral part. Less used wood species for furniture are poplar and robinia. Poplar is unsuitable as a surface component because of its low density, hardness, etc. This can be improved by compression, which would significantly increase the usability of this species, which is found in large quantities worldwide. The Brinell-Mörath surface hardness can be improved up to 22 MPa. Robinia already has interior, furniture and outdoor furniture applications, but its difficult machinability and variable colouration, especially in the case of so-called „black stripe“ discolouration, are major limiting factors. The latter can be improved by various thermal treatments. For this purpose, dry thermal-treatment was considered to be a better solution than steaming in water vapour.

Keywords: black stripe, colour, cielab, hardness, thermal treatment, steaming

INTRODUCTION

Uncountable wood species may be available for further uses, for example as furniture or at least as furniture parts. The woodworking industry is slow to accept new wood species and raw materials, so good preparation is needed before a new material is introduced. At the same time, there is time and opportunity to think through and study the possibilities in depth. There are many species of wood found in large quantities throughout Europe, including Hungary, which have limited use. In addition to rethinking the methods of use, this can be helped by the improvement (modification) of wood, for which there are a number of methods already in operation or under development. In this study, two such options are discussed.

Poplar Top Layer for Furnitures

The aim of our research is to use poplar as a raw material to make more valuable furniture and interior design products. To achieve this, the possibilities of modifying the physical and mechanical properties and the aesthetic appearance of the wood have been explored. The aim of this research is to establish the scientific basis for a thermo-mechanical refinement method that will allow the combined improvement of the hardness, strength and aesthetic appearance of the thin cell-walled, low-density poplars.

Colour Variations in Robinia

We obtain a large part of our information by sight, so visual perception and its effects on us are of paramount importance. Nowadays, in addition to the technical properties and durability of wood, aesthetics and appearance are of very important, too. In many cases, the colour of the material is the determining factor for the use. The already rich variety in colour of black locust wood or robinia wood (*Robinia pseudoacacia* L.) is even more true for fast-growing hybrids (e.g. Shipmast locust, „Obelisk“, „Turbo“). These newer cultivars have different anatomical structure (growth ring width, earlywood to latewood ratio) due to their rapid growth. Previous mechanical and physical studies suggest that the cultivars could become important industrial raw materials, but the colour variation thus raises important additional issues (e.g. computer optimisation, surface treatment) that require instrumental, objective colour determination and solutions.

Homogenisation of the Abnormal Discolouration of Robinia

One of the characteristic wood defects of black locust (*Robinia pseudoacacia* L.) is „black stripe" discolouration, which is increasingly occurring according to feedbacks from the wood industry. This is the dark discolouration of some growth rings, which significantly affects the market value of the robinia wood. Our research team has carried out preliminary research to explain this phenomenon to find out what causes this wood defect and how it modifies wood properties. Using a stereo microscope, we found vessels with red-coloured tyloses and high levels of yellow deposits (robinetin), as well as vessels with no visible tylose and red-coloured wall. The tylose has probably collapsed and deposited on the vessel wall. Liquid chromatography measurements were used to determine the extract material content and an increase of about 15% was observed compared to the control sample without black stripes. In all cases, the amount of robinetin increased significantly (by 23–70%). It is likely that the wood is protecting itself against biological degradations.

The colour of the wood is a very important characteristic for users, so in this part of the study we tried to remove or decrease the existing discolouration caused by black stripes by water vapour steam and dry thermal treatments. Steaming is not only justified by its beneficial colour-changing effect, but also by its influence on the mechanical properties of the hard robinia wood (e.g. machinability) in a way that is favourable to the user.

The two most important factors affecting colour change during treatments are the temperature applied and the treatment time. The role of temperature is the greater, but above 220 °C does not happen further colour change [1]. The medium used also affects the extent of colour change, with greater change (darker wood) in the presence of air than in inert atmospheres (e.g. water vapour steam, nitrogen) [2]. Steaming between 80–130 °C can reduce large colour differences of turkey oak, robinia or beech with falseheart, as examples [3].

It is clearly visible to the naked eye that thermal treatment significantly reduces the clarity of the wood. Its colour shifts towards red and loses its yellow content. In the case of dry thermal treatment at higher temperatures, the thermal treatment resulted in a more uniform colour (with a significant loss of brightness), but here the pattern formed by the different sheaths is already blurred, which is not advantageous, as the pattern of the wood is an important aesthetic factor.

MATERIALS AND METHODS

Poplar Top Layer for Furnitures

For the tests, we used Pannonia poplar timber (*Populus × euramericana* cv. Pannónia), which after drying was sawn into lamellae. The lamellae were compressed at temperatures of 160, 180 and 200 °C with compressed ratios of 15, 30 and 45%. During compression, the materials were kept in the press for 10, 20 and 30 minutes, taking care to maintain constant temperature and pressure. After compression, the thickness of the lamellae was 20 mm, so the initial lamellae thicknesses were 25.0, 28.5, 33.3 mm. After the treatment, the changes in colour, density, shrinkage properties, surface hardness (Brinell-Mörath), bending strength, bending modulus of elasticity and compression ratio of the lamellae as a function of initial thickness were investigated.

Colour Variations in Robinia

30 logs from different trees, coming from six different growing areas in Eastern Hungary were analysed for colour. In addition to the black locust (*Robinia pseudoacacia* L.) used as a control, several cultivated varieties were included in the samples. A disc was taken from each log at a height of one meter. One specimen was prepared from each disc passing through the pith. Colour measurements were taken on specimens with air-dry moisture content using a Konica-Minolta CM - 2600d spectrophotometer at centimetre intervals from the pith to the sapwood.

Homogenisation of the Abnormal Discolouration of Robinia

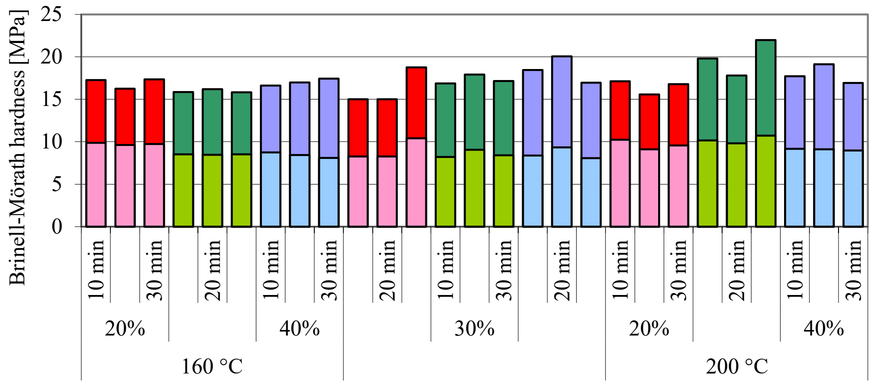
Selected black locust (*Robinia pseudoacacia* L.) wood specimens were used containing black stripes. Colour measurements were performed as described previously on samples conditioned in normal climate. Thermal treatments were carried out at 160 °C for 1 hour and 180 °C for 3 hours in air atmosphere, as well as in water vapour at 110 °C for 20 hours and 120 °C for 120 hours.

RESULTS

Poplar Top Layer for Furnitures

Looking at the overall colour difference, the change is noticeable to the naked eye, as $\Delta E^* > 3$ [4]. The extent of the differences is highly dependent on the treatment parameters. Since the change was similar for all three colour coordinates (a^*, b^*, L^*), the overall colour difference is also most affected by the temperature applied (the highest values are obtained with the parameters 200 °C, 30%, 30 min). The pressing time has a smaller effect, with no difference visible to the naked eye for elements pressed at 160 and 180 °C for 10, 20 and 30 min at the same density. No correlation between the total colour difference and the compression ratio can be detected.

One of the main aims of the experiment was to increase the surface hardness. The initial average Brinell-Mörath hardness of the lamellae ranged from 8 to 11 MPa, while after compression these values were between 15 and 22 MPa. These



1: *Changes in surface hardness as a function of treatments*

values clearly show that in all cases the surface hardness increased significantly as a result of the treatment. Looking at Fig. 1 (the lighter part is the value before compression, the darker is the value after compression), it can be seen that varying the compression parameters results in different degrees of hardness. The change in hardness is most strongly determined by the ratio of compression, the more the material was compressed, the higher the surface hardness became. There is no clear correlation with the change in hardness for compression temperature and time.

The average bending strength (*MoR*) of the control sample was 79.85 MPa, while after compression these values were between 87 and 116 MPa. The average bending modulus of elasticity (*MoE*) of the control sample was 8.2 GPa, while after compression these values were between 9.3 and 13.3 GPa. In all cases, the *MOR* and *MOE* increased as a result of the treatment. However, no clear correlation between the treatment parameters and the increase in *MOR* and *MOE* was observed. One reason for this may be that many specimens were sheared during bending test, resulting in a high variance (sometimes 20–25%).

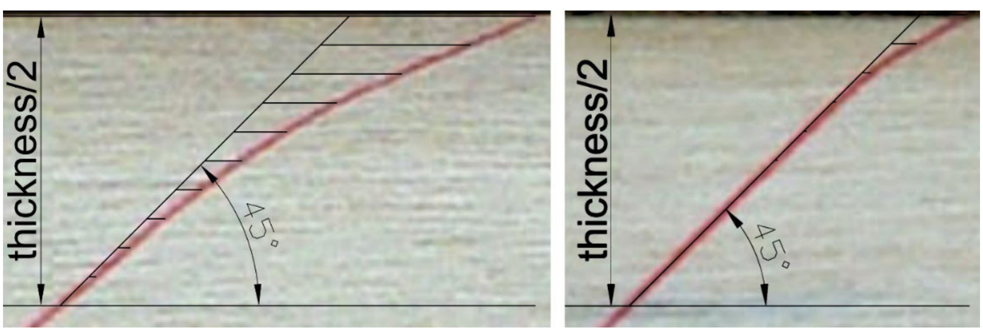
During the shrinkage test, three linear shrinkage values were measured, in the direction of fibre, in the direction of compression and perpendicular to the compression. No change in shrinkage properties was observed in the fiber direction or perpendicular to the compression direction. In the direction of compression, the shrinkage values increased and the increase was closely related to the ratio of compression, which indicates the presence of the memory-effect.

Looking at the absolute dry density, the increase in density increased with the degree of compression, so the extent of this was determined only by the initial density of the lamellae. However, compression is not uniform as a function of thickness.

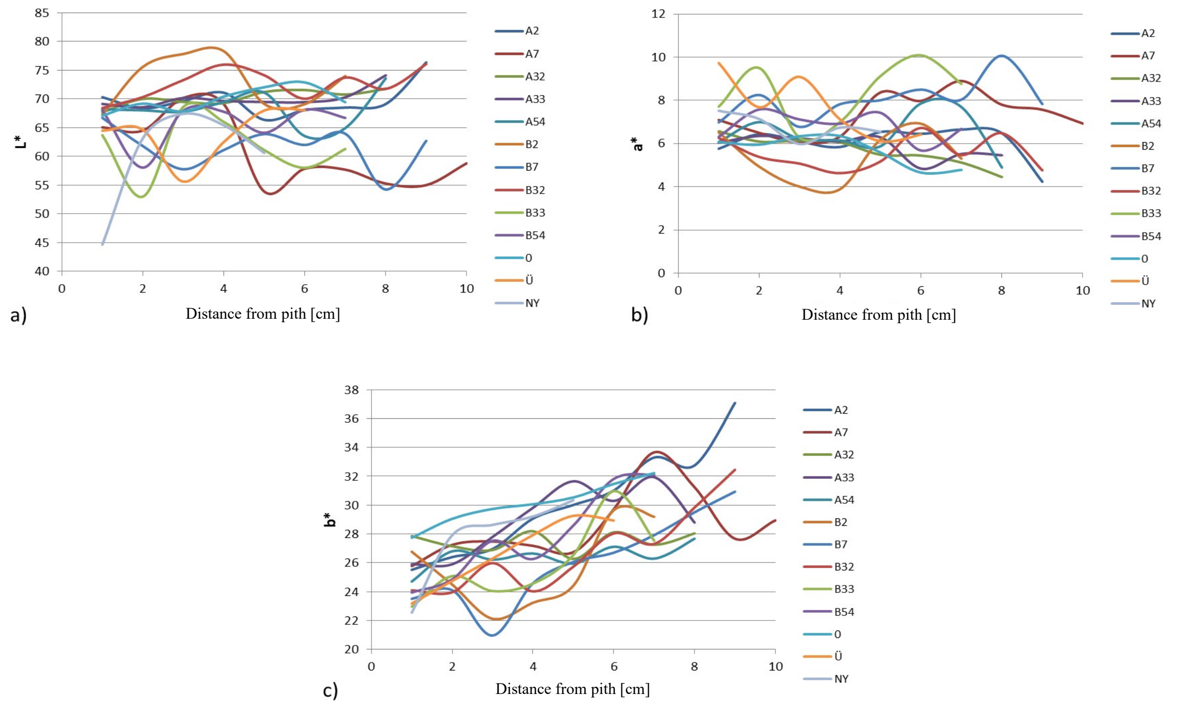
When examining the degree of compression, it was found that materials with different compression levels compressed differently (Fig. 2). At 20% compression, the top 1/3 layer compressed at around 40%, while the inner parts compressed at a low rate of around 0-10%. At 30% compression, the top 1/3 layer compresses around 45–50%, the middle 1/3 layer around 30%, and the inner 1/3 layer around 10–15%. At 40% compression, the top 1/3 layer compresses around 50–55%, the middle 1/3 layer around 30–40% and the inner 1/3 layer around 20–25%.

Colour Variations in Robinia

Looking at the average values of L* and a* colour components along the radius from the pith to the sapwood, no clear trend can be observed for either the fast-growing varieties or the control. In contrast, when looking at the variation of the colour coordinate b*, there is a clear increasing trend from the pith to the sapwood. Relatively high variability appears in case of all colour components (Fig. 3).



2: *Measuring the degree of compression for 40% (left) and 20% (right) specimens*



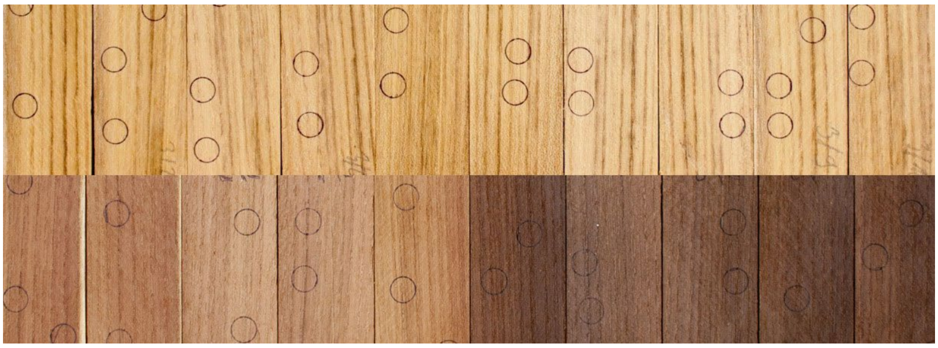
3: *Results of the measurements of colour coordinate L* (lightness of the colour; a), a* (colour position between green and red; b), b* (colour position between blue and yellow; c)*

4: *Typical appearance of a control (O), a fast-growing variety with low colour variation (A32), and two fast-growing varieties with high colour variation (B7 and B2)*

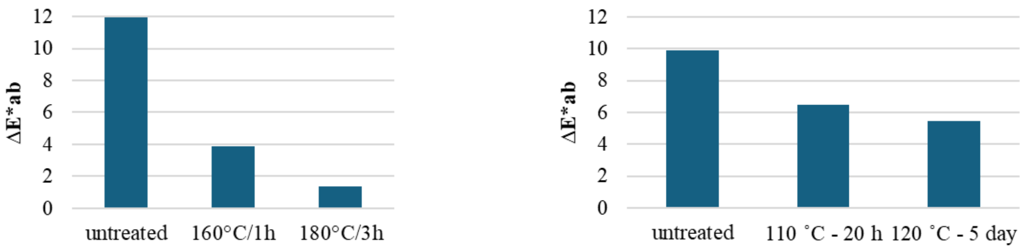
The darker, brownish staining visible to the naked eye on the wood (Fig. 4) is not reflected in the results of the colour measurement. No significant differences between the species were found when the mean values of the colour characteristics of heartwood and sapwood were examined. Accordingly, the average colour properties do not allow to determine the aesthetic usability of robinia wood, and it is necessary to investigate the variance of the colour componenets to reveal the colour variability.

Homogenisation of the Abnormal Discolouration of Robinia

Colour homogenisation was observed in the experiments at all temperatures and treatments tested (Fig. 5, 6). It is also observed that the homogenizing effect of steaming is smaller. The decrease in differences between colour components was mainly due to an overall decrease in lightness (L*), with a slower darkening of the originally dark parts. The colour differences of the thermal-treated specimens remained below that of the steamed



5: *Comparison of untreated (top) and thermal-treated (160˚C - 1h bottom left, 180˚C - 3h bottom right) specimens*



6: *Colour homogenisation by dry thermal treatment (left) and by water vapour steaming (right)*

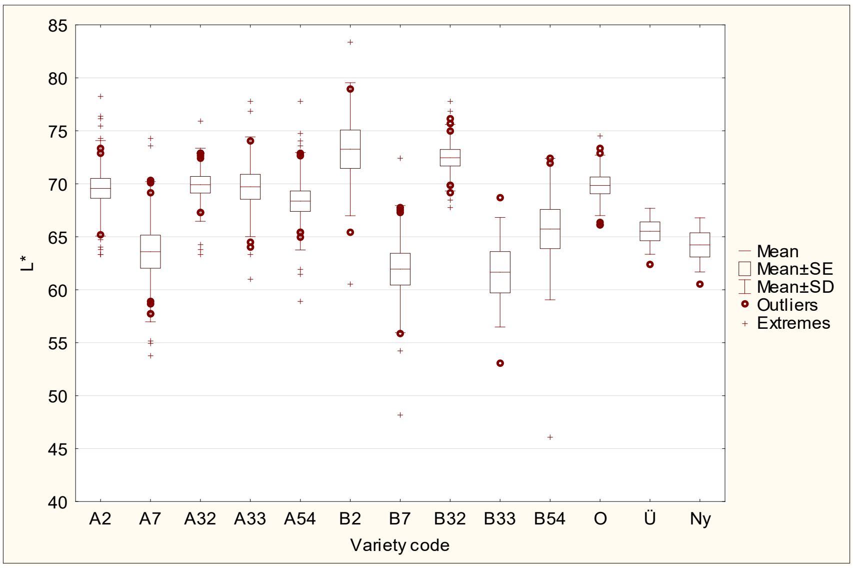


Fig. 7 Basic statistics for the colour coordinate L (lightness factor)*

specimens even when the steamed specimens were finally darker. This phenomenon may be related to the increased extractive content of the black stripe, that is important for darkening, and reacts differently in dry and vapour atmospheres.

DISCUSSION

Colour Variations in Robinia

The standard deviations of the colour components are generally higher for the tested fast-growing robinia cultivars, and there is a high proportion of outliers and extremes compared to the controls (Fig. 7). The exception was one fast-growing cultivar (A32), for which the standard deviation of no colour components exceeds that of the control. However, there is no correlation between the average annual ring width and the standard deviation of the colour components. Thus, the increase in colour variation is not primarily due to an increase in the growth rate. Compared with the colour data of varieties from the same growing area, it can be stated that the degree of colour variation, i.e. the variance of colour components, can be considered a genetic trait of the cultivars.

CONCLUSION

This paper explores the potential of less used wood species in the furniture industry today. The low hardness of poplar (*Populus* spp.) is the most significant limiting factor, while the highly variable colour of robinia wood (*Robinia* spp.) also causes problems.

Pannonia poplar (Populus × euramericana cv. Pannónia) specimens were compressed perpendicular to the grain using different compression ratios, temperatures and times. The initial average Brinell-Mörath hardness of the lamellae ranged from 8 to 11 MPa, while after compression these values were between 15 and 22 MPa. The change in hardness is most strongly determined by the ratio of compression. There is no clear correlation with the change in hardness for compression temperature and time. In the direction of compression, the shrinkage values increased and the increase was closely related to the ratio of compression. Shrinkage remained the same in the other directions. Bending modulus of rupture increased between 9 and 45%, while modulus of elasticity increased by 13–62%.

The rich variety in colour of *Robinia pseudoacacia* L. is even more pronounced for fast-growing cultivars. Using CIELAB colour measurement, L* and a* colour components between the pith and the sapwood, do not show clear trend for either the fast-growing varieties or the control robinia. In contrast, when looking at the colour coordinate b*, there is a clear increasing trend from the pith to the sapwood. The variability of the colour components is always high.

Colour homogenisation of *Robinia pseudoacacia* L. was observed in the experiments at all temperatures and treatments tested (thermal treatment at atmospheric pressure and steaming in water vapour). This may be necessary due to the increasing appearance of so-called ‚black stripes‘. The homogenising effect of steam tratment is weaker. The reduction in the differences between colour components was mainly due to an overall decrease in lightness (L*), with a slower darkening of the originally dark parts.

Acknowledgements

This article was made in frame of the project TKP2021-NKTA-43 which has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

REFERENCES

[1] MILITZ, H. 2002. *Thermal treatment of wood: European processes and their background*. IRG/WP 02-40241. International Research Group on Wood Preservation. https://www.irg-wp.com/irgdocs/details.php?f6f6ffad-b3c3-433d-aaaa-647a154fd4c7

[2] ESTEVES, B.; VELEZ MARQUES, A.; DOMINGOS, I.; PEREIRA, H. 2008. Heat-induced colour changes of pine (Pinus pinaster) and eucalypt (Eucalyptus globulus) wood. *Wood Science and Technology.* 42(5), 369–384. https://doi.org/10.1007/s00226-007-0157-2

[3] NÉMETH, R.; MOLNÁR, S.; TOLVAJ, L.; ÁBRAHÁM, J. 2004. Physical and mechanical properties of steamed beech wood (with and without red heart). In: *COST E44 „Wood Processing Strategy“ Training course „Beech wood: From forestry to end products“.* Göttingen, Németország.

[4] MOKRZYCKI, W. S.; TATOL, M. 2011. Color difference ΔE: A survey. *Machine Graphics and Vision.* 20(4), 383–411.

Reviewer
prof. Dr. Rado Gažo – Purdue university Indiana (U.S.A.)

Contact information
Báder Mátyás: bader.matyas@uni-sopron.hu

ANALYSIS OF THE DEVELOPMENT OF MATERIALS AND TECHNOLOGIES USED IN THE PRODUCTION OF ICONIC SINGLE-SEATING INTERIOR PIECES FROM THE EARLY 20TH CENTURY TO THE PRESENT

Ošťádalová Michaela[1], Sovják Richard[1]

[1] Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0041

Abstract

This article examines the role of materials and technologies in product design, focusing on iconic chairs from the early 20th century to the present. It explores the impact of ground-breaking materials, such as bent steel and plastics, on aesthetics, ergonomics, and industrial production transformations. The analysis extends beyond the design, highlighting the application of traditional and modern materials. The article traces historical milestones where design responded to emerging technological possibilities. Additionally, it investigates current challenges designers face in addressing sustainability and resource efficiency. The concluding section emphasizes how these factors increasingly shape not only the aesthetic but also the functional and ethical dimensions of contemporary design, with potential implications for its future evolution.

Keywords: interior, design, chair, armchair, materials, plastic, steel, leather, plywood, aluminium

INTRODUCTION

The turn of the 19th and 20th centuries in product and interior design was characterized more by nostalgia than by embracing the new opportunities brought by the Industrial Revolution. Although the Art Nouveau (Belle Époque) style was historically inspired, it began incorporating machinery and modern materials, such as iron and steel in architecture and new chemical compounds in glass and ceramics production [1].

The early 20th century brought revolutionary changes in furniture design, enabled by new materials and production technologies. Chairs and armchairs played a pivotal role in shaping the modern interior design aesthetic. The introduction of tubular steel, molded plywood, and plastics profoundly influenced seating furniture design, particularly the shift from craft-based to mass production [1].

Today, over a century of intense development in these products has been shaped by innovations in materials and technologies. These changes have reflected the spirit of their respective eras and addressed their challenges and priorities, such as creating the Navy Chair during World War II for the US Navy [2].

This article focuses on how new materials and technologies have influenced the design of iconic single-seating pieces and their societal and aesthetic impacts across different periods. Often, the most ground-breaking transformations occur during crises. For example, chromium, initially used in projectile heads during World War I, was later employed in Functionalist furniture for finishing bent tubular steel. Similarly, polyethylene, developed as insulation for electrical cables, found applications in furniture design among traditional materials like metal and rubber, which were in short supply [1].

The present era represents another turning point. On one hand, traditional materials are well understood but often environmentally unsustainable. On the other hand, emerging materials and technologies offer novel ways to adapt or improve existing resources. Based on the analysis of a selected group of iconic seating pieces, this article maps the current state and future possibilities.

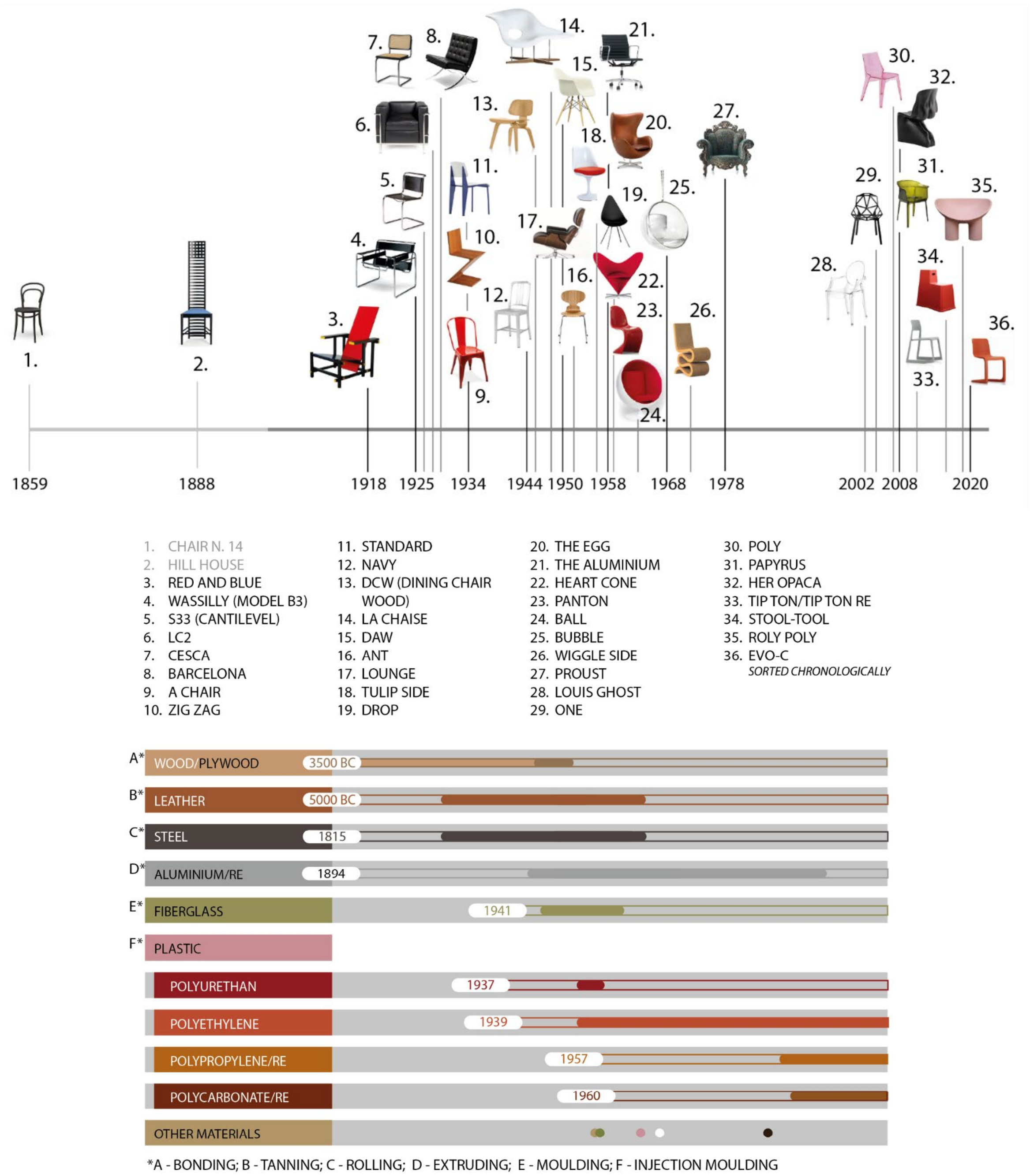
Research Questions:

1. How has the development of materials and manufacturing technologies influenced the design of iconic single-seating furniture in the 20th century?
2. What key material and technological innovations have shaped contemporary furniture design?
3. How has the focus on sustainability and environmental responsibility impacted the evolution of modern seating furniture?

METHODOLOGY

This study employs a qualitative research methodology based on primary and secondary sources, including historical records and specialized design and materials engineering literature.

Iconic single-seating pieces, such as the *Barcelona Chair* by Ludwig Mies van der Rohe, the *Eames Lounge Chair* by Ray and Charles Eames, the *Panton Chair* by Verner Panton, and the *Louis Ghost Chair* by Philippe Starck, were selected for analysis [11][20][26][31]. A historical timeline was compiled for these iconic products (Fig. 1). The timeline highlights



1: *Timeline of iconic seating elements and materials used for them [4–39][40, 41, 45, 50, 52, 58–62, 66–68]* the primary materials used, which are subsequently examined in terms of their material composition, manufacturing techniques, and design aesthetics. The analysis also incorporates the approach of contemporary designers and reviews literature focusing on sustainable design practices.

Five representative material groups (plus related materials) for seating furniture were selected (for their historical significance and innovations in materials and manufacturing technologies. The selection criteria included design iconicity, material innovation, technological advancements, influence on design history, and application in modern interiors.

These groups were analyzed regarding the materials used, production processes, and design philosophy. The analytical parameters included material composition, manufacturing technology, aesthetics and design philosophy, sustainability, historical impact, and relevance.

RESULTS

Wood, a foundational material, was succeeded by molded plywood in the mid-20th century.

The Finnish architect and designer Alvar Aalto pioneered using bent plywood, creating iconic furniture pieces in the 1930s. Following the war, Charles and Ray Eames designed a collection of plywood furniture—the *Plywood Group*—which achieved mass production. (In contrast to these simple forms, the upholstered *Lounge Chair*, which design theorist Zdeno Kolesár likened to a sculptural work, was later introduced.) These designers experimented with the spatial shaping of plywood through pressing techniques to create comfortable, ergonomic, lightweight, and durable forms [1][40].

Plywood became a favored material due to its strength, flexibility, and ease of processing. An additional advantage is its relatively low manufacturing cost, facilitating broader industrial furniture production [40].

Plywood chairs have a relatively low carbon footprint compared to materials such as metal or plastic, mainly when made from certified wood (eliminating risks associated with unsustainable resource extraction) and eco-friendly adhesives (as conventional adhesives often contain harmful substances) [40].

Early 20th Century: Steel Tubes and Modernism

The introduction of tubular steel in furniture design at the beginning of the 20th century revolutionized seating furniture. Dutch architect Mart Stam created the concept of the metal two-legged chair (*S33*) [8][1]. Alongside Stam, Ludwig Mies van der Rohe *(Barcelona Chair)* and Marcel Breuer (*Cesca*) explored tubular steel construction. Their designs represented a modernist ideal of “form follows function” [9][11].

In 1925, Marcel Breuer created the iconic Wassily Chair (*B3*), one of the first chairs to feature chrome-plated tubular steel [7]. Inspired by bicycle frames, Breuer experimented with bending steel tubing to produce lightweight, structurally strong, and industrially manufacturable furniture pieces [1][49]. Tubular steel utilization introduced elegance and lightness, contrasting the heavy, traditional wooden furniture of the time [1].

While steel is a non-renewable material, it is the most recycled industrial material globally. Annually, up to 630 million tonnes of steel re-enter the supply chain, with typical recycling rates ranging from 70% to over 90% [46][47]. Recycling chrome-plated materials, however, is more challenging due to removing the chemical coating, which requires additional energy-intensive processes. To enhance sustainability, emphasis should be placed on green energy sources, recycled materials, surface treatment innovations, and efficient recycling at the end of the product lifecycle [48].

Elegance and Quality of Leather

Leather is one of the oldest materials processed by mankind, together with stone and wood. People have extensive historical experience with leather and excellent knowledge of its material characteristics [41]. It remains unrivaled as an upholstery material, offering exceptional durability, adaptability to body temperature, and resistance to staining. Over time, leather develops a patina, becoming more aesthetically pleasing as it ages.

Although leather is a renewable material, its production is associated with significant environmental and ethical challenges, such as greenhouse gas emissions and biodiversity loss linked to livestock farming. Additionally, tanning and dyeing processes often involve harmful chemicals that harm ecosystems. Companies are now exploring alternative plant-based processes to mitigate these impacts [41][42][43].

There is a growing effort to replace leather with alternative materials, such as mycelium-based products [44]. However, due to entrenched consumer expectations, these substitutes often fail to replicate the full range of leather's desirable properties.

Aluminium and Recycled Aluminium

Aluminum is widely used in product design due to its low weight and favorable mechanical characteristics. While non-renewable, aluminum is fully recyclable without quality loss, with approximately 40% of global aluminum currently recycled [53]. However, primary aluminum production is energy-intensive, accounting for 2% of global human-induced emissions. It also generates toxic by-products and pollution during the chemical processing of bauxite [54][55].

Due to high demand and the long lifespan of many aluminium products, the volume of primary aluminium will remain significantly larger than that of recycled aluminium in the foreseeable future [56].

Plastics and the Post-War Era

Alongside moulded plywood, plastics began showcasing their potential. Derived from non-renewable fossil sources, early plastics like Bakelite were introduced [57]. Injection moulding technology propelled plastics into prominence, enabling designers like Verner Panton to create fluid, organic shapes, exemplified by the *Panton Chair*. These new materials catered to the post-war consumer culture, prioritizing comfort, accessibility, and innovation [1].

In the United States, furniture manufacturers Herman Miller and Knoll spearheaded the adoption of plastics in furniture production [1]. Various plastics are used in the furniture industry, including PVC, polyester, and polyethylene. For this analysis, polyethylene (PE) was selected, as it has been a key material in furniture manufacturing since the latter half of the 20th century, notably in components such as glides and guide rails, exemplified by the glides of the *TipTon Chair* [36].

The production of plastics has surged significantly, from 100 million tonnes annually in the early 1990s to 390 million tonnes in 2021, primarily driven by their use in packaging [64].

Furniture companies are now exploring innovative approaches to plastic use and recycled material options. For instance, Vitra employs long-lasting virgin plastics (e.g., the *EVO-C Chair*) as well as recycled variants (e.g., the *Eames Plastic Chair RE*). Vitra avoids practices like those of Kartell, which incorporates additives like finely milled wood chips into recycled plastics, rendering further recycling impossible and ending the material's lifecycle. Instead, Vitra uses technical fillers such as glass fibers. All recycled plastics used by Vitra can be 100% recycled at the end of the product's life [65][69].

SUMMARY

This study analysed the material characteristics and manufacturing technologies employed in the 20th century, examining their impact on product design. The materials selected for this analysis were evaluated based on several key criteria: recyclability, depletion of primary resources, energy intensity of production, processability, and future potential (Fig. 2). The assessment was conducted using a 1–3 scale, where 1 represents a low value, while 3 indicates a high value.

The findings provide a comprehensive insight into how material and technological innovations influenced the design of iconic single-seating furniture pieces in the 20th century. They also highlight the environmental sustainability of contemporary design using these materials and technologies. The evolution of these innovations significantly shaped aesthetics, manufacturing processes, and sustainability in the global context of furniture design. Leading designers of their time successfully integrated these changes into their creations, inspiring subsequent generations of designers and manufacturers.

The study emphasizes that the environmental impact of furniture design is closely linked to material selection and technological processes. Achieving genuine sustainability requires re-evaluating traditional and modern materials and optimizing their life cycles.

For designers who traditionally prioritized furniture's visual and functional aspects, this entails a shift towards careful aesthetic consideration and a deeper understanding of the environmental impacts associated with material choices. Sustainability must be embedded from the beginning of the design process, necessitating close collaboration between designers, material specialists, and environmental experts.

DISCUSSION

Selected iconic furniture pieces represent specific time periods and aesthetic movements, but do not encompass the full breadth of material and technological innovations in furniture design. Another limitation is that some environmental and

	recyclability	threats to primary raw materials	energy requirements for production	shaping energy	the potential for future use
WOOD	●●●	●●	●	●	●●
PLYWOOD	●●	●●	●●	●	●●
LEATHER	●	●●	●	●	●
STEEL	●●●	●	●●	●●	●●●
ALUMINIUM	●●●	●●	●●●	●●	●●
RE ALUMINUM	●●●	●	●●	●●	●●●
POLYETHYLENE	●●●	●●	●○	●	●●
RE POLYETHYLENE	●●	●●	●	●	●●●

● Low value
●● Average value
●●● High value

2: *Parameters of selected used materials [40, 41, 45, 50, 51, 58, 59, 62, 63, 77–83]* technological data were obtained from secondary sources, which may impact the accuracy and timeliness of the findings.

The analysis showed that materials with low energy processing requirements, particularly those from sustainable sources such as certified forests (FSC, PEFC, EUTR) and recycled material, ranked highest. The study suggests gradually replacing certain traditional materials, such as reducing the use of leather and virgin plastic. Sustainable alternatives include materials with a lower environmental impact, such as substituting MDF with carbon-negative materials like HONEXT [70].

Despite efforts to reduce its use, plastic remains the most suitable material for industrial furniture production, and it has been utilized extensively since the 1960s with increasing intensity. The projected compound annual growth rate (CAGR). for plastic furniture sales from 2023 to 2033 is 5.9% [71]. However, excessive use of plastics, including furniture, results in “spread” of microplastics within the environment, impacting human health. While their presence and potential risks have been confirmed, the exact exposure from furniture contact or inhalation in indoor environments remains unclear. Little is known about which chemicals may adhere to these microplastics and nano-plastics indoors [72][73][76].

These findings underscore the importance for designers and manufacturers of maintaining an updated critical approach to material selection and addressing environmental impacts when creating new products.

Hemp-based materials could be a viable alternative to plastics and wood, offering excellent mechanical features. Hemp requires less water to grow and is harvested in shorter cycles than traditional wood cultivation [74].

Another aspect closely linked to material selection is the manufacturing technologies that vary in energy intensity. Materials with high energy demands during production were rated negatively, with one pathway to improvement being the adoption of renewable energy sources in the manufacturing process [48].

Design can no longer be judged solely on aesthetic grounds; it must incorporate sustainability and ethical considerations in material engineering. In this context, it is essential to design products based on circular economy principles, where product recyclability should be a standard and clear choice, not merely an option.

An innovative approach to the circular economy is demonstrated by Dutch designer Ineke Hans with her deposit-based chair, REX. This model is built on the concept that furniture is often replaced not due to wear but because of a desire for change. Her Circuform project enables customers to return furniture for resale, either in its original form or with replaced components [75].

CONCLUSION

The analysis reveals that the development of materials and manufacturing technologies in single-seating furniture reflects broader trends in design, culture, and technological innovation. From the use of tubular steel in modernist designs to the introduction of molded plywood and the mid-20th-century rise of plastics, each technological breakthrough has enabled designers to push the boundaries of form, comfort, and functionality.

Contemporary technologies now facilitate unconventional designs using single-material constructions that can be easily recycled at the end of their lifecycle. A notable example is the impressive advancements in processing recycled plastics.

The analysis underscores that designers are primarily responsible for improving material usage today. Just as some designers historically shaped new trends, those who adapt their approaches and embrace emerging technologies will lead the way today. The role of the designer continues to evolve. One hundred fifty years ago, Michael Thonet introduced innovations that enabled the mass production of chairs in shorter timeframes. Seventy years ago, Verner Panton sought to realize his visions by pioneering the technologies needed to achieve them. At the end of the 20th century, Bořek Šípek became a designer-artist, defying ergonomic norms with his glass chairs while expanding the creative possibilities of design processes.

Today, Ineke Hans focuses not only on product design but also on the social dimensions of design and architecture, including the processes that accompany them. Contemporary designers must consider the growing potential of new materials and the adoption of more environmentally friendly manufacturing techniques. Trends suggest that the future of the furniture industry will continue to be shaped by technological progress with a strong emphasis on sustainability.

REFERENCES

[1] KOLESÁR, Zdeno; MÁLKOVÁ, Kateřina. 2004. *Kapitoly z dějin designu.* Praha: Vysoká škola umělecko-průmyslová. ISBN 80-868-6303-4

[2] EMECO. 2024. *Emeco for US Navy.* EMECO. [Accessed: 2024-11-04] https://www.emeco.net/about/design/how-it-started-emeco-alcoa-for-us-navy..

[3] RIPPLE, William, J.; WOLF, Christopher; NEWSOME, Thomas M.; BARNARD, Phoebe; MOOMAW, William R., 2020. World Scientists' Warning of a Climate Emergency. Online. *BioScience.* 70(1), 8–12. https://doi.org/10.1093/biosci/biz152

[4] TON. 2024. *Chair n.14* [in Czech: *Židle 14: Nadčasová ikona*] TON [Accessed: 2024-11-04] https://www.ton.eu/zidle-14-nadcasova-ikona

[5] M H FURNITURE HOLDINGS LTD. 2024. *The Hill House Chair.* Iconic Interiors. [Accessed: 2024-11-04] https://www.iconicinteriors.com/designer_furniture/category/chairs/hill_house_chair

[6] M H FURNITURE HOLDINGS LTD. 2024. *The Red and Blue Chair.* Iconic Interiors. [Accessed: 2024-11-04] https://www.iconicinteriors.com/designer_furniture/category/chairs/red_and_blue_chair#photo-1

[7] DESIGNPROPAGANDA. 2024. KNOLL *Wassily Chair* [in Czech: *KNOLL křesla Wassily Chair, přirodní tkanina*]. Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produktv/knoll-kresla-wassily-chair-prirodni-tkanina

[8] CLASSICFACTORY24. 2024. *S33: Cantilever.* ClassicFactory24. [Accessed: 2024-11-04] https://www.classicfactory24.com/en/Chairs/Mart-Stam-Cantilever-Chair-S33.html

[9] BAUHAUS 2 YOUR HOUSE. *Marcel Breuer Cesca Cane Side Chair.* 2024. bauhaus2yourhouse [Accessed: 2024-11-04] https://www.bauhaus2yourhouse.com/products/marcel-breuer-cesca-cane-chair

[10] M H FURNITURE HOLDINGS LTD. 2024. *Le Petit Confort Armchair LC2.* Iconic Interiors. [Accessed: 2024-11-04] https://www.iconicinteriors.com/designer_furniture/category/chairs/le_petit_confort_armchair

[11] DESIGNPROPAGANDA. 2024. *KNOLL Barcelona Chair.* 2024. Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produktv/knoll-kresla-barcelona-chair-kuze-kategorie-y

[12] DESIGNPROPAGANDA. 2024. *TOLIX Chaise A.* Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt2/designove-zahradni-zidle-tolix-chaise-a

[13] AMBIENTE DIRECT. 2024. *ZigZag Chair.* Ambiente Direct. [Accessed: 2024-11-04] https://www.ambientedirect.com/en/cassina/zigzag-rietveld-chair_pid_38124.html

[14] DESIGNPROPAGANDA. 2024. *Vitra Standard Chair SP.* 2024. Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt/vitra-zidle-standard-chair-sp-designove-zidle/?utm_source=biano.cz&utm_medium=cpc-biano&utm_content=202021579&utm_campaign=biano%2Bjidelni-zidle&utm_term=11ef9a9f-584a-cb70-9b15-4a5703672a53

[15] DESINGBUY. 2024. *EMECO 1006 Navy Chair.* Deingbuy. [Accessed: 2024-11-04] https://www.designbuy.cz/emeco-zidle-1006-navy-chair-matna

[16] DESIGNPROPAGANDA. 2024. *VITRA DCW chair.* Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt/vitra-zidle-dcw-designove-zidle

[17] DESIGNPROPAGANDA. 2024. *VITRA La Chaise.* Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt2/designova-kresla-vitra-la-chaise

[18] DESIGNVILLE. 2024. *Eames DAW chair.* Designville [Accessed: 2024-11-04] https://www.designville.cz/zidle-eames-daw?gad_source=1

[19] BEUT. 2024. *Fritz Hansen The Ant chair.* Beut. [Accessed: 2024-11-04] https://www.beut.co.uk/fritz-hansen-the-ant-chair-clear-lacquer.html

[20] DESIGNPROPAGANDA. 2024. *Lounge chair & Ottoman.* Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/skupina/vitra-designova-kresla-lounge-chair-ottoman

[21] DSIGNHAUS. 2024. *Tulip Side Chair.* Dsignhaus. [Accessed: 2024-11-04] https://dsignhaus.com/TULIP-SIDE-CHAIR

[22] M H FURNITURE HOLDINGS LTD. 2024. *The Egg Chair.* Iconic Interiors. [Accessed: 2024-11-04] https://www.iconicinteriors.com/designer_furniture/category/chairs/egg_chair

[23] PRUNELLE. 2024. *The Drop Chair.* Prunelle [Accessed: 2024-11-04] https://prunelle.ca/en/products/chaise-drop-chair-arne-jacobsen?variant=23183601223

[24] DESIGNPROPAGANDA. 2024. *VITRA Aluminium Chair EA 117.* Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt/vitra-kancelarske-zidle-alu-group-ea-117

[25] VITRA INTERNATIONAL AG. 2024. *Heart Cone Chair.* Vitra. [Accessed: 2024-11-04] https://www.vitra.com/en-cz/product/details/heart-cone-chair

[26] DESIGNPROPAGANDA. 2024. *VITRA Panton Chair.* Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produktv/vitra-designove-zidle-panton-chair-leskla-cervena

[27] M H FURNITURE HOLDINGS LTD. *2024. The Ball Chair.* Iconic Interiors. [Accessed: 2024-11-04] https://www.iconicinteriors.com/designer_furniture/category/chairs/the_ball_chair

[28] MUEBLE DESIGN. 2024. *The Bubble Chair.* Nestmobel. [Accessed: 2024-11-04] https://www.nestmobel.de/cs/start/moderni-kreslo/zavesna-zidle-bubble-chair-vyrobena-z-pruhledneho-akryloveho-plastu

[29] DESIGNPROPAGANDA. 2024. *Vitra Wiggle Side Chair.* Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt/vitra-zidle-wiggle-side-chair

[30] DESIGNPROPAGANDA. 2024. *Magis Proust Chair*. Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt/designove-zahradni-kresla-magis-kreslo-proust

[31] DESIGNPROPAGANDA. 2024. *Kartell Louis Ghost Chair.* Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt/kartell-zidle-louis-ghost-designove-zidle

[32] DESIGNPROPAGANDA. 2024. *Magis Chair One*. 2024. Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produktv/magis-designove-zidle-chair-one-cerna

[33] MUEBLES. 2024. *Poly. Karim Rashid de Bonaldo*. 2024. Muebles. [Accessed: 2024-11-04] https://www.muebles.com/silla-poly-karim-rashid/

[34] DESIGNPROPAGANDA. 2024. *Kartell Papyrus*. Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt/kartell-zidle-papyrus-designove-zidle

[35] CASAMANIA. 2024. *Her Matt.* Casamania [Accessed: 2024-11-04] https://www.casamania.it/en/design-furniture/him-her-outdoor-chair/

[36] KONSEPTI. 2024. *TipTon/TipoTonRE*. Konsepti. [Accessed: 2024-11-04] https://www.konsepti.com/tip-ton-re/

[37] DESIGNPROPAGANDA. 2024. *Vitra Stool-Tool*. 2024. Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt/vitra-designove-zidle-stool-tool

[38] DESIGNPROPAGANDA. 2024. *DRIADE Roly Poly Armchair*. Designpropaganda. [Accessed: 2024-11-04] https://www.designpropaganda.cz/produkt2/designova-kresla-driade-roly-poly-armchair

[39] BIANO. 2024. *Vitra EVO-C*. Biano. [Accessed: 2024-11-04] https://www.biano.cz/produkt/v/103942225-vitra-designove-zidle-evo-c

[40] APA – THE ENGINEERED WOOD ASSOCIATION. 2024. *History of APA, Plywood, and Engineered Wood.* APA. [Accessed: 2024-11-04] https://www.apawood.org. https://www.apawood.org/apas-history

[41] GILLAN, Kevin; MURRAY, Jason. 2019. *Comprehensive Guide to Leather Repair and Restoration: Leather Repair Training Manual*. Advanced Leather Solutions. [Accessed: 2024-11-04] https://books.google.cz/books?id=SSOsDwAAQBAJ&hl=cs&source=gbs_navlinks_s

[42] VITRA. 2024. *Leather*. Vitra. [Accessed: 2024-11-04] https://www.vitra.com/en-cz/about-vitra/sustainability/leather

[43] VITRA. 2024. *Vegetable-Tanned Leather*. Vitra. [Accessed: 2024-11-04] https://www.vitra.com/en-gb/about-vitra/sustainability/vegetable-tanning

[44] JONES, Mitchell *et al*. 2021. Leather-like material biofabrication using fungi. *Nature Sustainability*. 4, 9–16. https://doi.org/10.1038/s41893-020-00606-1

[45] HEAVY METAL & TUBES LTD. 2016. The First Methods for Producing Steel Pipe were introduced in the early 1800s. *Medium*. Jul 23, 2016. [Accessed: 2024-11-04] https://medium.com/@hmtl.social/the-first-methods-for-producing-steel-pipe-were-introduced-in-the-early-1800s-16fb48c979c9

[46] Bureau of International Recycling. 2019. *World Steel Recycling in Figures 2015 – 2019.* [Accessed: 2024-11-04] https://www.bir.org/images/BIR-pdf/Bi2001_05a-Ferrous-report-2019.pdf

[47] GRAEDEL, T. E.; ALLWOOD, Julian; BIRAT, Jean-Pierre; BUCHERT, Matthias; HAGELUKEN, Christian *et al*. 2011. *Recycling rates of Metal – A status report*. UNEP. ISBN 978-92-807-3161-3. [Accessed: 2024-11-04] https://www.resourcepanel.org/sites/default/files/documents/document/media/e-book_metals_report2_recycling_130920.pdf

[48] DE LEEUW, Georgia; VOGL, Valentin. 2024. Scrutinising commodity hype in imaginaries of the Swedish green steel transition. *Environment and Planning E: Nature and Space*. 7(4), 1844–1867. ISSN 2514-8486. https://doi.org/10.1177/25148486241238398

[49] SLUNEČKOVÁ, Eva. 2022. Legandární design: Stam vs. Breuer a velký spor o konzolovou židli. Kdo byl první a kdo kopíroval? *Earch.cz* [Accessed: 2024-11-04] https://www.earch.cz/design/clanek/velky-spor-o-konzolovou-zidli-stam-vs-breuer-kdo-byl-prvni-a-kdo-kopiroval

[50] VITRA. 2024. *Aluminium*. Vitra. [Accessed: 2024-11-04] https://www.vitra.com/en-cz/about-vitra/sustainability/aluminium

[51] A LINE AUTOMATION. 2024. *A Brief History and Future Potential of Aluminum Extrusions*. Online. www.alineautomation.com. [Accessed: 2024-11-04] https://www.alineautomation.com/a-brief-history-and-future-potential-of-aluminum-extrusions/

[52] PRINCE, Sharma. 2022. A brief account of man, material and manufacturing: On the timeline. Online. *ScienceDirect*. 66(8), 3572–3577. https://doi.org/https://doi.org/10.1016/j.matpr.2022.07.016. [accessed 2024-11-11].

[53] GRAEDEL, T. E.; ALLWOOD, Julian; BIRAT, Jean-Pierre; BUCHERT, Matthias; HAGELUKEN, Christian *et al*. 2011. *Recycling rates of Metal: A status report.* ISBN 978-92-807-3161-3. https://wedocs.unep.org/bitstream/handle/20.500.11822/8702/Recycling_Metals.pdf

[54] VAN HEUSDEN, Renée; HARRY, Morrison; PULEO, Mary. 2020. *Why addressing the aluminium industry's carbon footprint is key to climate action*. World Economic Forum.

[55] HAVEL, Adam; PHAM, Huy. 2022. *Towards sustainability: Design nábytek + Elektronika.* Nov 3, 2022 10:22 Prague Bratislava [ZOOM Meeting]. https://us02web.zoom.us/rec/play/ZURUcDlynTIQM64emUp-c8a0BIiAoTH1StODe9JBEQ8AggTCjF6Ko5niBAFa0iNvMXXdpWSCH1ERQLOI9.5kkh6C2reTh-WxXyn?hasValidToken=false&canPlayFromShare=true&from=share_recording_detail&continueMode=true&componentName=rec-play&originRequestUrl=https%3A%2F%2Fus02web.zoom.us%2Frec%2Fshare%2FFxncLsvb7Zr1OFFt-CZ85ViDuuN05otcygNrfGYuCLaf5fbJvz45b-CIdIYqWWB-j.NWzB6t_3jzC0P_Uu

[56] VAN HEUSDEN, Renée; HARRY, Morrison; PULEO, Mary. 2020. *Why addressing the aluminium industry's carbon footprint is key to climate action*. World Economic Forum.

[57] ACS CHEMISTRY FOR LIFE. 1993. *Leo Hendrick Baekeland and the Invention of Bakelite®*. 2024. [Accessed: 2024-11-04] https://www.acs.org/education/whatischemistry/landmarks/bakelite.html

[58] NÁBYTKÁŘSKÝ INFORMAČNÍ SERVER. 2013. *Rozdělení plastů.* NIS. [Accessed: 2024-11-04] https://www.n-i-s.cz/cz/rozdeleni-plastu/page/324/

[59] VAN HEUSDEN, Renée; SANDSTRÖM, Jörgen; CHAU, Shaun; PULEO, Mary. 2021. *The answer to the aluminium industry's emissions issue? Aluminium's infinite recyclability*. World Economic Forum. [Accessed: 2024-11-04] https://www.weforum.org/stories/2021/12/aluminium-emissions-recycling-circular-economy/

[60] BUUR, Stine Liv. 2019. *Fiberglass A Materials Exploration*. [Accessed: 2024-11-04] https://www.vitra.com/en-cz/magazine/details/fiberglass

[61] PU FOAM: 2024. *The history of polyurethane*. PO foam. [Accessed: 2024-11-04] https://www.pu-schaum.center/en/facts-worth-knowing/the-history-of-polyurethane

[62] ENCYCLOPEDIA BRITANICA. 2024. Polyethylene. In: *Britanica*. [Accessed: 2024-11-04] https://www.britannica.com/science/polyethylene

[63] LI, Xiaomeng; MAHADAS, Nagarjuna A.; ZHANG, Mengxue; DEPODESTA, Jacquelyn; STEFIK, Morgan *et al*. 2024. Sustainable high-density polyethylene via chemical recycling: From modification to polymerization methods. *Polymer*. 295(1), 126698. https://doi.org/10.1016/j.polymer.2024.126698

[64] STATISTA. 2024. Annual production of plastics worldwide from 1950 to 2023. In: *Statista*. https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950

[65] VITRA. 2024. *Recycled Plastics*. VITRA. [Accessed: 2024-11-04] https://www.vitra.com/en-cz/about-vitra/sustainability/recycled-plastic

[66] HINDLE, Colin. 2024. *Polypropylen.* Online. www.bpf.co.uk. https://www.bpf.co.uk/plastipedia/polymers/PP.aspx. [accessed 2024-11-11].

[67] BRITISH PLASTIC FEDERATION. 2024. *Polycarbonate.* BPF.[Accessed: 2024-11-04] https://www.bpf.co.uk/plastipedia/polymers/Polycarbonate.aspx

[68] KULA, Daniel; TERNAUX, Elodie; HIRSINGER, Quentin. 2012. *Materiology: průvodce světem materiálů a technologií pro architekty a designéry*. Praha: Happy Materials. ISBN 978-80-260-0538-4

[69] KARTELL. 2024. *Sustainable Growth And Development in View of the Agenda for 2030 Kartell*. [Accessed: 2024-11-04] https://www.kartell.com/dk/en/ktdk/corporate/kartell-loves-the-planet

[70] HONEXT. 2024. *Circulat by Desing.* HONEXT. [Accessed: 2024-11-04] https://honextmaterial.com/circularbydesign/

[71] FACT.MR. 2024. Plastic Furniture Market Outlook (2023 to 2033). *Fact MR*. [Accessed: 2024-11-04] https://www.factmr.com/report/3574/plastic-furniture-market

[72] CAMPEN, Matthew; NIHART, Alexander; GARCIA, Marcus a spol. 2024. Bioaccumulation of Microplastics in Decedent Human Brains Assessed by Pyrolysis Gas Chromatography-Mass Spectrometry. *ResearchSquare*. https://doi.org/https://doi.org/10.21203/rs.3.rs-4345687/v1

[73] HALFAR, Jan; ČABANOVÁ, Kristína; VÁVRA, Karel ***et al.*** 2023. Microplastics and additives in patients with preterm birth: The first evidence of their presence in both human amniotic fluid and placenta. *Chemospehere*. 343, 140301. https://doi.org/https://doi.org/10.1016/j.chemosphere.2023.140301

[74] FOUR ELEMENTS CONSULTING & OMNI TECH INTERNATIONAL. 2022. *Life Cycle Assessment of HempWood® Natural Flooring*: *Third-Party Verified Report in Preparation for an Environmental Product Declaration.* [Accessed: 2024-11-04] https://5po4a0.p3cdn1.secureserver.net/wp-content/uploads/2023/02/HempWood%C2%AE-Organic-Flooring-LCA.pdf

[75] INEKE HANS. 2021. *REX the first Dutch deposit chair2021, with circuform (not Ahrend)*. [Accessed: 2024-11-04] https://www.inekehans.com/studio/work/rex
[76] VIANELLO, Alvise; JENSEN, Rasmus Lund; LIU, Li; VOLLERTSEN, Jes. 2019. Simulating human exposure to indoor airborne microplastics using a Breathing Thermal Manikin. *Sci Rep.* 9, 8670. https://doi.org/10.1038/s41598-019-45054-w
[77] BEY, Niki. 2000. *The Oil Point Method: A tool for indicative environmental evaluation in material and process selection.* Disertation Thesis. DK - 2800 Lyngby, Denmark: Department of Manufacturing Engineering, IPT Technical University of Denmark. ISBN 87-90855-09-4. [Accessed: 2024-11-04] https://polynet.dk/lenau/niki_bey_phd_thesis.pdf
[78] MINISTRY OG HOUSING, SPATIAL PLANNING AND ENVIRONMENT NETHERLANDS. 2000. *Eco-indicator 99 Manual for Designers: A damage oriented method for Life Cycle Impact Assessment*. [Accessed: 2024-11-04] https://pre-sustainability.com/files/2013/10/EI99_Manual.pdf
[79] PUETTMANN, Maureen; KAESTNER, Dominik; TAYLOR, Adam. 2016. *CORRIM REPORT – Module D2 Life Cycle Assessment of Softwood Plywood Production in the US Southeast*. [Accessed: 2024-11-04] https://corrim.org/wp-content/uploads/Module-D2-SE-Plywood.pdf
[80] KILIÇ, E.; MCLAREN, S. J.; HOLMES, G. *et al* 2023. Product environmental footprint of New Zealand leather production. Online. *The International Journal of Life Cycle Assessment*. 28, 349–366. https://doi.org/10.1007/s11367-023-02143-3
[81] GANDHI, Neeti; FARFARAS, Nicholas; LINDA WANG, Nien-Hwa and CHEN, Wan-Ting. 2021. Life Cycle Assessment of Recycling High-Density Polyethylene Plastic Waste. Online. *Journal of Renewable Materials.* 9(8), 1463–1483. ISSN 2164-6341. https://doi.org/10.32604/jrm.2021.015529
[82] LIPTOW, Christin; TILLMAN, Anne-Marie. 2009. *Comparative life cycle assessment of polyethylene based on sugarcane and crude oil*. Chalmers University Of Technology Report No. 2009:14, ISSN 404-8167. [Accessed: 2024-11-04] https://research.chalmers.se/publication/107576/file/107576_Fulltext.pdf
[83] PUETTMANN, Maureen E.; WILSON, James B. 2005. Lifecycle Analysis of Wood Products: Cradle-To-Gate Lci of Residential Wood Building Materials. Online. *Wood and Fiber Science.* 37 Corrim Special Issue, 18–29.

Reviewer
Dr. Eva Haviarova – Purdue university Indiana (U.S.A.)

Contact information
Michaela Ošťádalová: michaela.ostadalova@mendelu.cz

JOINING SOLID WOOD WITH EPOXY RESINS

Petr Pacas[1], Daniela Tesařová[1]

[1] Ústav designu a nábytku, Lesnická a dřevařská fakulta, Mendelova univerzita v Brně, Zemědělská 1, 613 00 Brno, Czech Republic

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0050

Abstract

The paper deals with the analysis of the suitability of selected woods (acacia, oak, meranti) for bonding with casting epoxy resin. The main objective is to evaluate the influence of the thickness of the cast joint on the strength properties of the formed joints. The investigated wood species differ in their physical and mechanical properties, which can significantly affect the resulting cohesion and strength of the joint. In addition to the interaction between the wood and the epoxy resin itself, the cohesive strength of the cured resin, which plays an important role in the mechanical behaviour of the joint, was also investigated. The experiments focused on measuring the strength at different cast joint thicknesses, which provided valuable information on the optimum parameters for joint formation. The results of this study provide new insights for the structural and design applications of epoxy resins in conjunction with natural materials such as wood and contribute to the development of efficient methods for producing strong and reliable joints.

Keywords: casting epoxy resin, joint width, shear strength, tensile load, impact strength, acacia, oak, meranti

INTRODUCTION

For centuries, wood has been the basic material for furniture production. However, in recent years, with the development of technology and the search for new aesthetic and functional solutions, there has been a shift towards modern materials and innovative production processes. These new trends include composites, which are created by combining solid wood and cast epoxy resin. This approach enables the creation of unique and unconventional furniture designs that are gaining popularity not only among craftsmen but also in the wider industry.

Initially, this method of using composites was popular mainly overseas, but gradually found its way to Europe, where it began to be applied in medium and large enterprises. However, the successful application of epoxy resin in conjunction with solid wood requires not only precise working procedures, but also thorough surface preparation of both materials, which is key to achieving a strong and durable bond.

Despite the growing popularity of these materials and technologies, there is still a lack of research into their long-term behaviour, both in terms of exposure to different stresses and climatic conditions. This paper presents the results of an experimental study that aims to increase the knowledge in this area and provide insight into the stress-strain behaviour of these joints, and to observe the effect of the cast joint thickness on the strength of.

Epoxy Resins

Epoxy resins are polymeric materials from the group of reactive plastics, characterized by the presence of epoxy (oxirane) groups with high reactivity. These groups allow a crosslinking process that produces strong and durable structures without by-products and with minimal shrinkage. Due to these properties, epoxy resins find a wide range of applications, for example as adhesives, potting compounds, laminates or protective coatings [1][2]. Cured epoxy resins have high adhesion to a variety of materials including metals, glass, ceramics and wood. They are also resistant to mechanical stress, chemicals, corrosion and extreme temperatures. Exceptional electrical and insulating properties remain constant even with environmental changes [2][3].

Thanks to these properties, epoxy resins have become a key material for modern applications in industrial and craft manufacturing, especially where durability, strength and resistance are required.

Curing of Epoxy Resins

The curing of epoxy resins is a key process that fundamentally affects the final material properties. This process involves a chemical reaction between the resin and hardener molecules that results in the formation of a three-dimensional cross-linked structure. Depending on the curing system used, three main curing methods can be distinguished: polyaddition, polymerisation and polycondensation [4][5].

Polyaddition is an exothermic process that uses amines - primary, secondary or tertiary - and is known for its speed. Polymerization uses organic or inorganic peroxides and is associated with the release of heat during the reaction. Polycondensation, on the other hand, is a slow process in which the resin molecules react with, for example, acid anhydrides or phenol formaldehyde resins, with no heat being released [6][7].

The choice of hardener depends on the requirements of the final product. Amines are popular for their fast cure and strong adhesion, peroxides provide high temperature resistance, acid anhydrides offer excellent chemical and thermal properties, while phenol formaldehyde resins excel in mechanical resistance [8][9].

Modifications

The modification of epoxy resins is carried out to improve their properties such as toughness, flame retardancy and thermal stability. Common techniques include the addition of fillers, pigments and plasticizers to the epoxy matrix. Current trends are not only to improve properties for specific applications, but also to promote sustainability and waste recovery [10][11].

One innovative approach is the use of carbon fibres derived from recycled hemp fibres, which opens up new possibilities for environmentally friendly composites. Another important aspect is the development of affordable and efficient fillers that can improve the properties of epoxy systems without substantially increasing production costs [12][13].

The use of Casting Epoxy Resins in Furniture

In recent years, joining solid wood with cast epoxy resins has seen a significant increase in popularity, particularly in the creation of tables, lamps, cutting boards and storage furniture. Originating in Canada and the USA, this trend quickly spread to Europe and is now commonly presented at major furniture fairs. The resulting products are prized for their aesthetic appeal and unique combination of natural wood with translucent or pigmented resin.

For these applications, modified casting epoxy resins are used, which are adapted for larger casting widths and provide sufficient joint strength. In addition, the use of pigments eliminates the visibility of air bubbles, which can still occur even with highly sophisticated manufacturing techniques. The complexity of the process involves not only the preparation of the wooden parts and moulds, but also the casting itself, which is both time-consuming and costly.

Despite the higher material and production costs, these products have found their place in the market thanks to their unique aesthetics and ability to compete with traditional furniture. The most popular applications are conference and writing tables that combine functionality with modern design [14].

MATERIALS AND METHODS

Materials Used

Three wood species were used for testing: oak, acacia and meranti. While oak and acacia represent common domestic woods, meranti was chosen to represent tropical woods. All samples had a moisture content in the range of 7–8%, which ensures stable properties during casting and curing.

A two-component primer from a domestic manufacturer, commonly used to close the pores of the wood and reduce the risk of air bubbles, was used to prepare the surface. The penetrating compound is mixed at a ratio of 100 (A) : 26 (B) and further diluted with water at a ratio of 100 (compound) : 50 (water). After mixing, the mixture is workable for 60 minutes and cures within 24 hours.

A low viscosity system, also from a domestic manufacturer, was used as the casting epoxy resin. The resin is mixed with amine hardener in a ratio of 100 : 30 and allows casting up to 50 mm thickness or 10 litres volume. The processing time is less than 60 minutes at 25 °C, with a minimum curing time of 2 days. This system has been chosen for its suitability in handling larger volumes and its precision in achieving the required mechanical properties.

Samples

For this research, special samples and moulds were designed to create these samples. Due to material availability and variability, wooden moulds separated by PP adhesive tape were used. The basic dimensions of the sample were 12 × 20 × 90 mm. The specimens were placed in the mould to match the required thickness of the poured joint (5, 10 and 20 mm), with the length of the poured joint being 30 mm. This procedure allowed the creation of specimens with different joint widths for testing their mechanical properties. The dimensions of the base specimen and the final cast specimen are shown in Fig. 1.

Sample Preparation

The preparation of the samples started with grinding the basic dimensions of the samples using P80, P120 and P150 roughness sandpaper. After sanding, a primer was applied and allowed to cure. The samples were then sanded again with a P150 grit. The specimens were then placed in the mould, fixed, sealed and cast with casting epoxy resin. The mixed resin/hardener mixture was left in an ultrasonic cleaner to improve viscosity and eliminate air bubbles. After curing, the samples were conditioned for 28 days under normal conditions and then formatted to a thickness of 12 mm. The deposition of the samples in the mould is shown in Fig. 1.

Measurement Methodology

The shear strength test was carried out according to the principles of the test ČSN EN 1465 Adhesives - Determination of shear strength under tensile stress of refastened bonded assemblies. The specimens were placed in clamps so as to correspond exactly to the actual stresses of the products in use. The moisture content of the wood was also determined for all specimens according to ČSN EN 322 Wood panels - Determination of moisture content. This procedure was carried out to ensure the accuracy of the measurements and the correctness of the results [15][16].

RESULTS

Evaluation of the Shear Strength Test

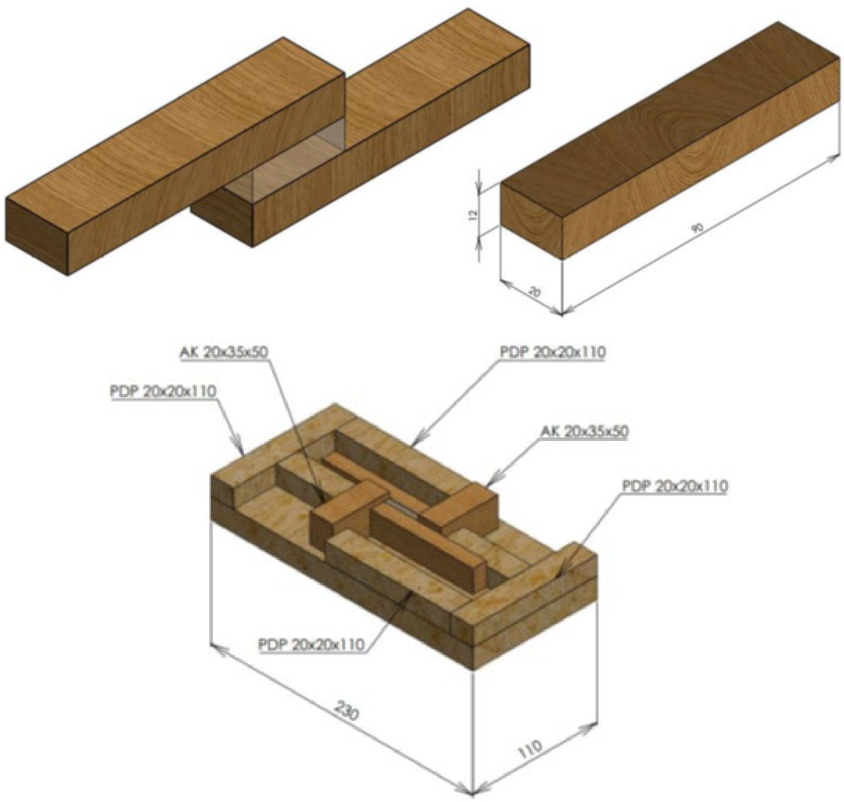
The investigation of the effect of the thickness of the cast joint on the shear strength showed that for all tested timbers the shear strength decreased with increasing joint thickness. For acacia, the average shear strength values were found to be 5.13 MPa at 5 mm joint thickness, 3.35 MPa at 10 mm thickness and 1.90 MPa at 20 mm thickness. This decrease was statistically confirmed and the results are graphically shown in Fig. 2.

A similar trend was also observed for oak, where the average shear strength values were 4.85 MPa at a joint thickness of 5 mm, 3.47 MPa at 10 mm and 2.13 MPa at 20 mm. We also observe a larger scatter in the measured data compared to acacia. The test results are clearly shown in Fig. 3.

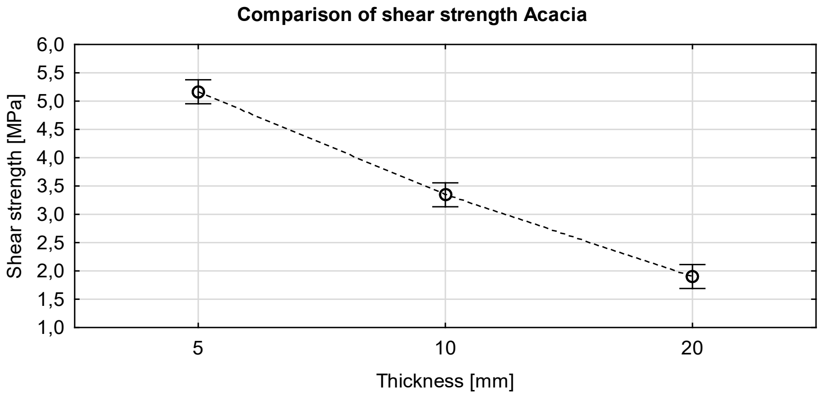
Meranti also shows a decrease in shear strength with increasing thickness of the cast joint. The average strength values are 5.30 MPa at 5 mm joint thickness, 3.48 MPa at 10 mm thickness and 2.06 MPa at 20 mm thickness. If we focus on the scatter of the measured data, the scatter is the largest observed for meranti wood. All of the above is shown graphically in Fig. 4.

Link Quality Evaluation

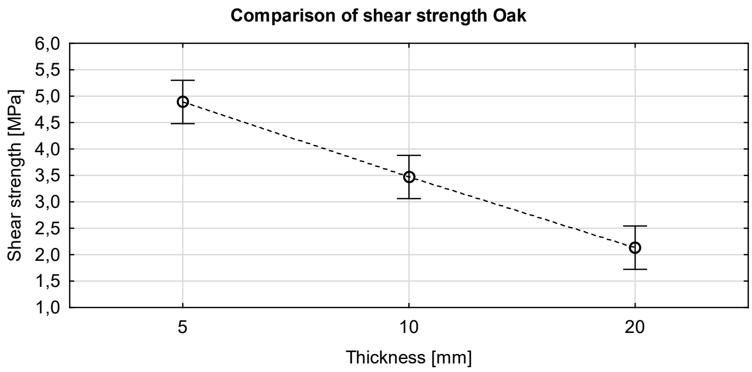
In the evaluation of the quality of the bond between the casting epoxy resin and the solid wood, it was found that the highest percentage of defective joints was found in acacia, where a defective bond was recorded in 86.67% of cases. This result points to the problematic compatibility of this wood with the casting resin used. On the contrary, the lowest percentage of defective joints was observed in meranti, where the ratio of joints without defects prevailed, namely in 56.67% of cases. The results can be observed in Fig. 5.



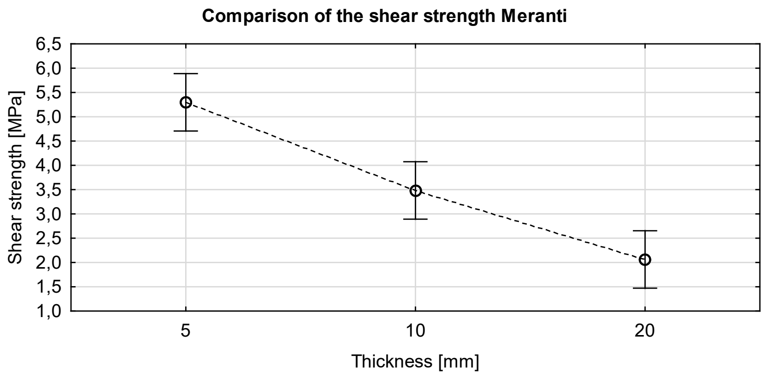
1: *Samples*



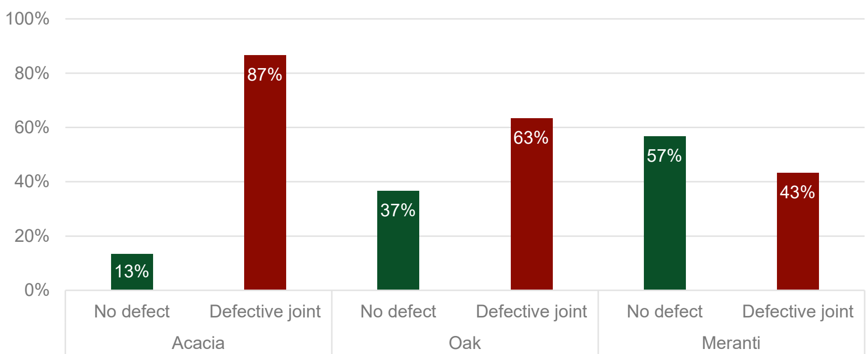
2: *Comparison of shear strength Acacia*



3: *Comparison of shear strength Oak*



4: *Comparison of shear strength Meranti*



5: *Comparison of the percentage of defective connections*

CONCLUSION

The measurements show that the thickness of the cast joint significantly affects the strength of the shear-stressed joint, with a decrease in strength with increasing cast joint thickness. This negative effect was demonstrated for all tested timbers, indicating that careful selection of the thickness of the cast joint is crucial to maintain the desired mechanical properties of the joint. In addition to the effect of thickness, the percentage of defective joints was also evaluated, suggesting that acacia wood is not ideal for epoxy resin casting technology. Oak and, among the exotic woods, meranti were found to be more suitable due to their specific structure. Overall, the joints produced by this technology achieve adequate shear strength values that are applicable in the furniture industry. However, it is essential that the preparation and application procedures recommended by the manufacturer are followed precisely in order to maintain the aesthetic and mechanical properties of the joints. This technology therefore represents an interesting alternative to traditional bonding, particularly for design and visually attractive applications.

REFERENCES

[1] LIDAŘÍK, M. 1983. *Epoxidové pryskyřice*. 3rd Editon. Praha: SNTL, Makromolekulární látky.

[2] MLEZIVA, J. 1993. *Polymery – výroba, struktura, vlastnosti a použití*. Praha: Sobotáles. ISBN 80-901570-4-1

[3] PHAM, H. Q.; MARKS, M. J. 2002. Epoxy Resins. In: HERMAN, M. F. (Ed.). *Encylopedia of Polymer Science and Technology*. John Wiley & Sons. ISBN 9781118633892

[4] DOMINIGHAUS, H. 1993. *Plastics for engineers: Material, Properties, Applications*. Munich: Hansen Publisher. ISBN 344615239

[5] RYBNIKÁŘ, F. 2000. *Makromolekulární chemie*. Brno: VUT v Brně. ISBN 80-214-1556-8

[6] PROKOPOVÁ, I. 2007. *Makromolekulární chemie*. 2nd Edition. Praha: Vydavatelství VŠCHT. ISBN 978-807-0806-623

[7] KALENDOVÁ, A.; TAMCHYNOVÁ, P. 2003. Studium nátěrových systémů pro korozní ochranu kovových materiálů z hlediska výběru pojiv a pigmentů. *CHEMagazín*. XIII, 28–31.

[8] LIU, Z; KRAUS, G. 2015. *Green Materials from Plant Oils*. Royal Society of Chemistry. ISBN 978-1-84973-901-6

[9] JIN, F.-L.; LI, X.; PARK, S.-J. 2015. Synthesis and application of epoxy resins: A review. *Journal of Industrial and Engineering Chemistry*. 29, 1–11. ISSN 1226-086X. https://doi.org/10.1016/j.jiec.2015.03.026

[10] KUBEŠ, T. 2020. *Možnosti modifikace epoxidové směsi nanometrickým plnivem*. Diploma Thesis. Plzeň: Západočeská univerzita v Plzni, Fakulta elektrotechnická.

[11] MOHAN, P. 2013. A Critical Review: The Modification, Properties, and Applications of Epoxy Resins. *Polymer-Plastics Technology and Engineering*. 52(2), 107–125. https://doi.org/10.1080/03602559.2012.727057

[12] BARTOLI, M.; DURACCIO, D.; FAGA, M.; PIATTI, E.; TORSELLO, D.; GHIGO, G.; MALUCELLI, G. 2022. Mechanical, electrical, thermal and tribological behavior of epoxy resin composites reinforced with waste hemp-derived carbon fibers. *Journal of Materials Science*. 57, 14861–14876. https://doi.org/10.1007/s10853-022-07550-9

[13] SZEWCZAK, A., SZELĄG, M. 2019. Modifications of Epoxy Resins and their Influence on their Viscosity. *IOP Conf. Ser.: Mater. Sci. Eng*. 471(2), 022038.

[14] PACAS, P. 2022. *Vliv střídání klimatických podmínek a mechanického namáhání na pevnostní vlastnosti spojů licích pryskyřic a masivního dřeva*. Diploma Thesis. Brno: Mendelova univerzita v Brně, Lesnická a dřevařská fakulta.

[15] ČSN EN 1465. 1997. *Lepidla – Stanovení pevnosti ve smyku při tahovém namáhání přeplátovaných lepených sestav*. Česká agentura pro standartizaci.

[16] ČSN EN 322. 1994. *Dosky z dreva. Zisťovanie vlhkosti.*

Reviewer
Dr. prof. Bekir Cihad – BAL Kahramanmaraş Sütçü İmam University (Turkey)

Contact information
Petr Pacas: petr.pacas@mendelu.cz

THE RESPONSE OF SCREW CORNER JOINTS MANUFACTURED OF HONEYCOMB PANELS TO CHANGES IN RELATIVE AIR HUMIDITY

Smardzewski Jerzy[1,2], Tokarczyk Maciej[1], Giedrius Pilkis[2]

[1] Poznan University of Life Sciences, Faculty of Forestry and Wood Technology, Wojska Polskiego 28, Poznan, Poland
[2] Vilnius Academy of Arts, Maironio g. 3, LT-01124 Vilnius, Lithuania

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0055

Abstract

Honeycomb panels are an attractive material for furniture production. However, their usefulness in industrial practice depends on the technological quality of corner joints and the effect of temperature and relative humidity changes on the stiffness and strength of these joints. This work made corner joints from 37 mm thick honeycomb panels. A screw confirmat type was used for the connection. It was experimentally determined to what extent a change in air relative humidity from 40% to 85% will affect the strength and stiffness of corner joints. Numerical models were developed to predict the behavior of joints in variable climatic conditions. It was shown that an increase in air humidity reduces the stiffness and strength of joints. However, in conditions of extreme humidity of 85%, the stiffness and strength of joints are still acceptable compared to dry conditions (40%). Numerical models allow for correct estimation of the quality of joints.

Keywords: honeycomb, screw joint, air humidity, strength, stiffness, FEM

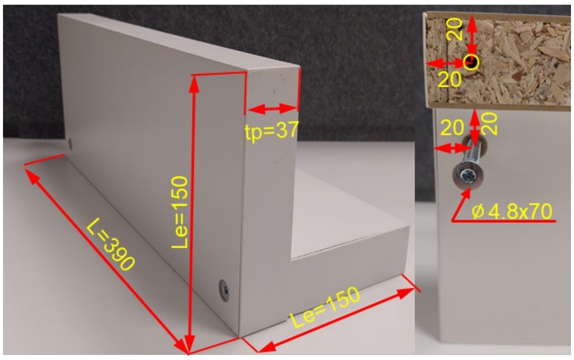
INTRODUCTION

An important reason for using lightweight panels in the furniture industry is to protect the environment and reduce production costs (Feifel, Poganietz, Schebek, 2013; Nordvik, Broman, 2005). Popular wood materials such as PB particleboard, medium-density MDF, and high-density HDF are widely used in practice due to their favorable strength-to-low density ratio (Smardzewski, Slonina, Maslej, 2017). More competitive, however, are lightweight panels. Their low weight is their most significant asset (Librescu, Hause, 2000; Shalbafan *et al.*, 2012), especially in furniture manufacturing (Allen, 1969; Smardzewski 2013). Wood-based cellular panels, however, are more vulnerable to climatic conditions changes at their sites of use (Smardzewski, Slonina, Maslej, 2017; Nilsson, Ormarsson, Johansson, 2017). This is due to the function of the rooms, such as the kitchen, bathroom or living room, and also the world's climatic zones. In order to make effective use of this raw material, their suitability for designing durable and long-lasting furniture joints must be carefully considered (Carll, Wiedenhoeft, 2009; Smardzewski, Łabęda, 2018). To date, the stiffness and strength of cellular board joints have been tested under residential conditions, that is, at a relative humidity and air temperature of approximately 65% and 21˚C (Kasal *et al.*, 2008; Tankut, 2009; Kasal *et al.,* 2014).

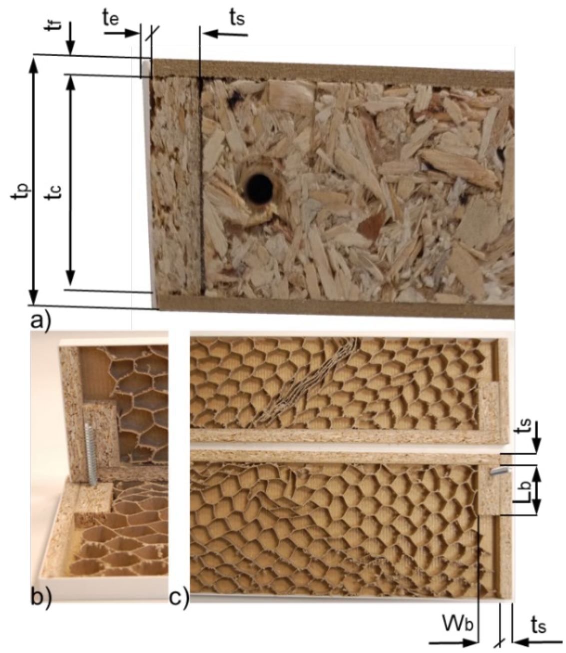
This study aimed to increase knowledge of the effect of climate change (relative humidity and air temperature) on the strength and stiffness of corner joints of lightweight panels assembled with confirmat bolts. In addition, the study aimed to determine the failure mode of the connections using the finite element method. This knowledge can be used to optimise the design of lightweight furniture.

MATERIALS AND METHODS

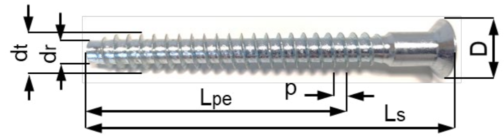
For the tests, corner joints were made of lightweight panels with a thickness of t_p =37 mm (Fig. 1). The length of the joint arms L_e was equal to 150 mm, and the joint width L = 390 mm. The facings were made of high-density fibreboard (HDF) with a thickness of t_f = 2.5 mm, while the core was made from particle board (PB) and paper honeycomb (PP) with a thickness of t_c = 32 mm. The core had a frame structure (Fig. 2). The frame around the perimeter of the specimen was made from strips of particleboard with a thickness of t_s = 12 mm. Reinforcing blocks with a width of W_b = 24 mm and length L_b =50 mm. The thickness of the block corresponded to the thickness of the cellular board core. The core filling was a honeycomb made from Testliner-2 paper (HM Technology, Brzozowo, Poland)) with a thickness of t = 0.23 mm. The hexagonal cells of the core were characterised by a length of L_c =31 mm, width S_c = 26 mm, double wall length h_c = 8 mm and free wall length l_c = 13 mm. The average value of the cell wall angle was equal to φ = 39.4 degrees (0.688 rad). The cladding and core elements were glued together using PVAc Woodmax FF 12.47 class D2 adhesive applied at approximately 110 g/m^2 (Synthos Adhesives, Oświęcim, Poland). The table top was edged on narrow surfaces with ABS edging (Acrylonitrile Butadiene Styrene, Rehau Sp. z o.o. Baranowo, Poland) using Jowat 280.30 hot-melt adhesive (Jowat Sp. Z o.o., Sady, Poland). The edge banding used was t_e = 1 mm.



1: *Samples dimensions*



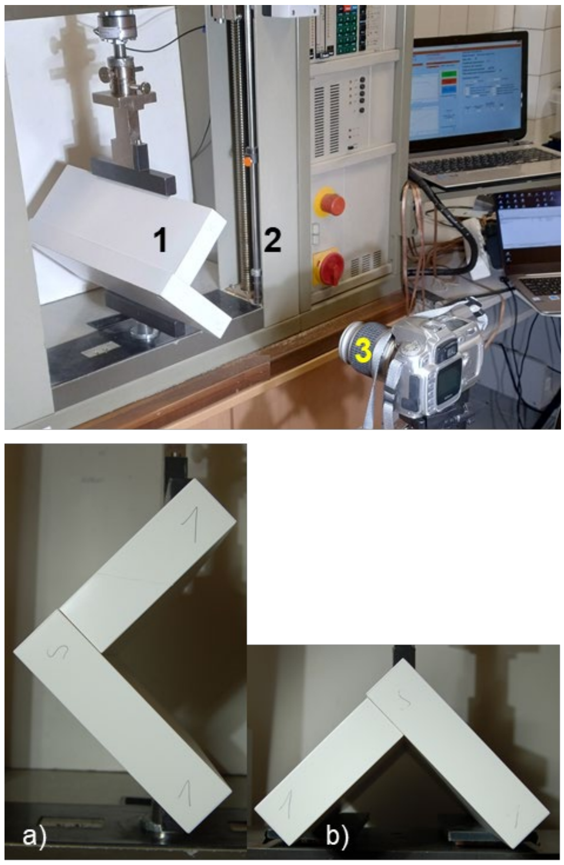
2: *Cross section of joint*



3: *Screw dimensions*

The joints were connected using confiirmate screws with a length of L_s = 70 mm, thread diameter d_t = 7 mm, core diameter d_r = 4.8 mm and a thread length embedded in the plate to a depth of L_{pe} = 32 mm. The pitch of the thread was p_e =2.4 mm, and the head diameter D = 9 mm (Fig. 3). The joints were decided to be subjected to compressive and tensile loading under varying climatic conditions. For this purpose, a laboratory test rig was prepared to determine the stiffness and strength of the corner joints of box furniture in the shortening and opening test (Fig. 4). A climate chamber was also prepared to simulate dry conditions (D) (temperature 26˚C and relative humidity 40%) and wet conditions (W) (temperature 28˚C and relative humidity 85%). Ten joints were prepared for each sample, for a total of forty samples.

The prepared specimens were short-circuited and pulled apart (Fig. 4) on a Zwick 1445 universal testing machine. During loading, the displacements



4: *Universal testing maschine: 1) sample, 2) test machine, 3) digital camera. Compression a) and tension b) test* were recorded with an accuracy of 0.01 mm, and the force was measured with a resolution of 0.01 mm. δP were recorded with an accuracy of 0.01 mm and the force with an accuracy of 0.01 N. P with an accuracy of 0.01 N. Testing continued until the specimen failed with a load drop of at least 100 N or until a displacement of 10 mm was achieved.

The strength of the joints was determined by comparing the maximum bending moments that caused the failure of the joint. For joints subjected to compression, the strength M_c is given by the formula:

$$M_c = P\alpha'$$

and for tensiled joints, the strength M_T is determined by the formula:

$$M_T = Pe'$$

In the compression (closing) test, the joint stiffness K_C was calculated from the equation:

$$K_C = \frac{M_C}{\Delta\varphi} = \frac{P\alpha'}{\Delta\varphi}\ \text{[Nm/rad]}$$

where:

$$\Delta\varphi = \frac{\pi}{90}\left(\alpha tg\left(\frac{\frac{\sqrt{2}}{2}L_e}{\alpha'}\right) - \alpha\sin\left(\frac{\frac{\sqrt{2}}{2}L_e - \delta P_{0.4}P_{max}}{\sqrt{t_p^2 + (L_e - t_p)^2}}\right)\right)$$

$$\alpha' = \frac{\sqrt{2}}{2}L_e - \sqrt{2t_p}$$

In the tension (opening) test, the stiffness of the joint K_T was calculated from the equation:

$$K_T = \frac{M_T}{\Delta\varphi} = \frac{Pe'}{\Delta\varphi}\ \text{[Nm/rad]}$$

where:

$$\Delta\varphi = \frac{\pi}{90}\alpha tg\left(\frac{\sqrt{\frac{1}{2}(L_e - t_p)^2(L_e + t_p)^2 - \left((L_e + t_p) - \delta P_{0.4}P_{max}\right)^2}}{(L_e + t_p) - \delta P_{0.4}P_{max}}\right)$$

$$-2\alpha tg\left(\frac{(L_e - t_p)}{(L_e + t_p)}\right)$$

$$e' = \frac{\sqrt{2}}{2}(L_e - t_p)$$

Numerical Model

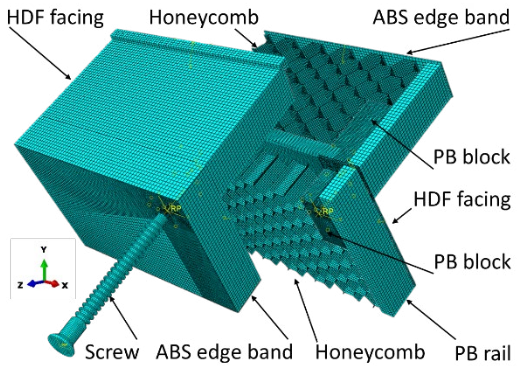
It was also decided to determine the strength of the joint by numerical calculations using the finite element method. The structure of the model corresponded to the structure shown in Fig. 2. First, realistic computer models of the connections were made in Autodesk Inventor (Autodesk, Warsaw, Poland). Then, taking into account the symmetry of the structure, numerical models of the screw connections were developed (Fig. 5).

An 8-node linear brick, reduced integration, hourglass control element type C3D8R was used for PB, HDF, PP, ABS materials (mesh density from 0.1 mm to 3 mm). For the screw and thrust, A4-node 3-D bilinear rigid quadrilateral elements type R3D4 (mesh density from 0.83 to 3 mm) were used. Between the surfaces of the facings, slats (rails) and cores, a „tie“ type interaction was used (Smardzewski, Tokarczyk 2024). A contact with a friction coefficient of 0.15 and 0.13, respectively, was used between the surface of the screw and the surfaces of the holes in the PB particleboard and HDF board. A contact with a friction coefficient of 0.23 was used for the contact surfaces of the joint arms.

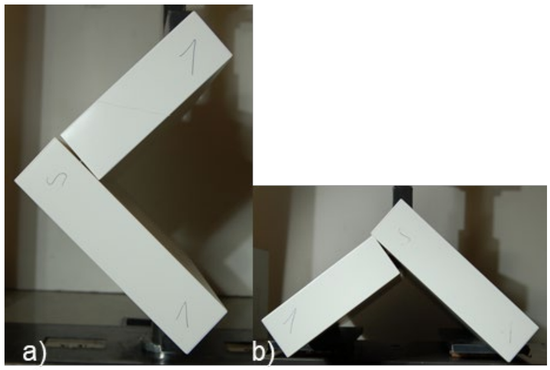
Based on the results of our own research, Tab. I summarises the physical and mechanical properties of the materials used to create the joints under dry conditions, temperature and relative humidity of 20C, 40% respectively (Krzyżaniak, Smardzewski, 2021; Kasal *et al.*, 2023). It was assumed that

I: *Physical-mechanical properties of the materials used for the joints. Standard deviation in brackets, MC (%) moisture content, D (kg/m³) density, υ Poisson's ratio, G (MPa) shear modulus, E (MPa) linear modulus, R (MPa) static yield strength (Lay et al., 2019; Krzyżaniak, Smardzewski, 2021; Kasal et al., 2023)*

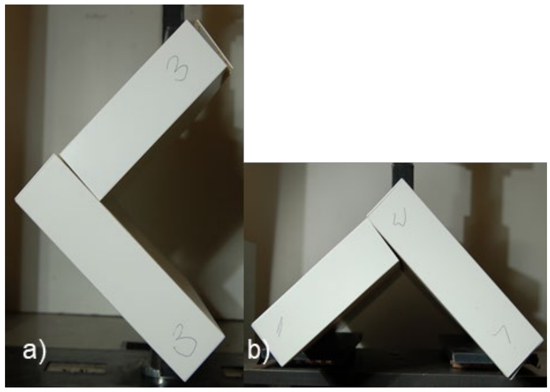
Property	Unit	PB			HDF	ABS	Steel
		t = 32	t_{top} = 3	t_{mid} = 26	tf = 2.5	t_e = 1.0	-
MC	%	6.18 (0.08)	5.2 (0.09)	6.54 (0.1)	5.07 (0.11)	-	-
D	kg/m³	649 (7)	882 (4.8)	541 (5)	966 (62)	1 100 (-)	70 860 (-)
υ			0.29		0.30	0.30	0.30
G	MPa	991 (112)	1298 (85)	682 (72)		*E*/2(1 + *υ*)	
E	MPa	2 556 (290)	3 350 (220)	1 760 (185)	5 190 (67)	16 000 (-)	210 000 (-)
R	MPa	10.9 (1.8)	14.1 (2.1)	7.8 (1.7)	32.3 (1.83)	58.0 (-)	430 (-)



5: *Mesh model of joint*



7: *Damage of dry joints under a) compression, b) tension*



8: *Damage of wett joints under a) compression, b) tension*

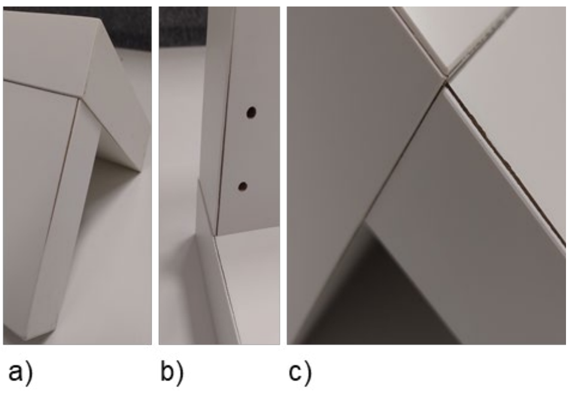
particleboards are three-layer systems. Therefore, the elastic properties of the outer layers with a thickness of t_{top} =3 mm and middle layers with a thickness of t_{mid} = 26 mm. The properties of ABS edging strips are given based on the work of (Lay *et al.*, 2019).

All numerical computations were performed at the Poznań Supercomputing and Networking Center (PSNC) using the Eagle computing cluster. The finite element analysis was conducted using Abaqus/Explicite v.6.14-2 (Dassault Systemes Simulia Corp., Waltham, Ma, USA).

RESULTS AND DISCUSSION

Experimental Part

As the samples were divided into two groups, air-conditioned in dry conditions of the production hall (D) and conditions with increased temperature and relative humidity (W), they were visually inspected, and the most common air-conditioning-induced damages were selected (Fig. 6). The most common damages to the furniture joints included peeling off of the edging on the narrow surfaces of the panel elements. The peeling off caused exposure of the particleboard and penetration of water vapour deep into the core of the particleboard.

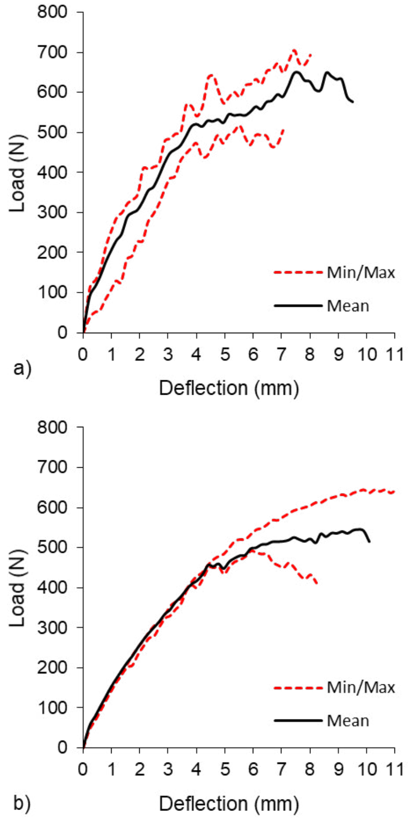


6: *The most common cases of damage of panels after wetting: a,b) butt member, c) butt and face members*

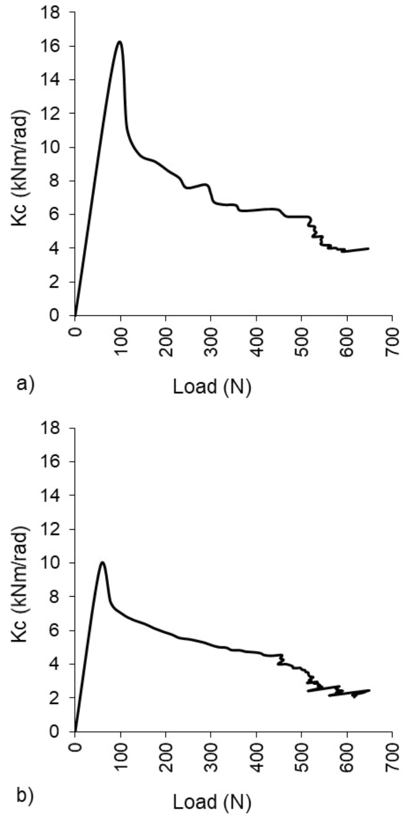
During the tests of furniture connections, the force value was recorded P with an accuracy of 0.01 N and the displacement δP in the direction of force application P with an accuracy of 0.01 mm. The stiffness K_C, K_T of the joints was determined moistened under dry conditions (D) T = 26C and H = 40%, and the stiffness of the joints K_C, K_T conditioned under wet conditions (W) T = 28C and H = 85%. Characteristic failures of dry joints are shown in Fig. 7, and failures of wet joints in Fig. 8.

Fig. 9 shows the average failure forces of the joints in the closing test. The maximum failure force for dry-conditioned joints (D) was 648 N, while for wet-conditioned joints (W) it was 541 N, respectively, at a similar displacement. It was noted here that the dry joints (D) were not homogeneous and provided different force values throughout the closing test (Fig. 9a). Wet joints (W) in the displacement range up to 4 mm showed regularity of results (Fig. 9b). Beyond a displacement of 4 mm, the force values started to vary and at a maximum displacement of about 10 mm, the force differences were as high as 244 N.

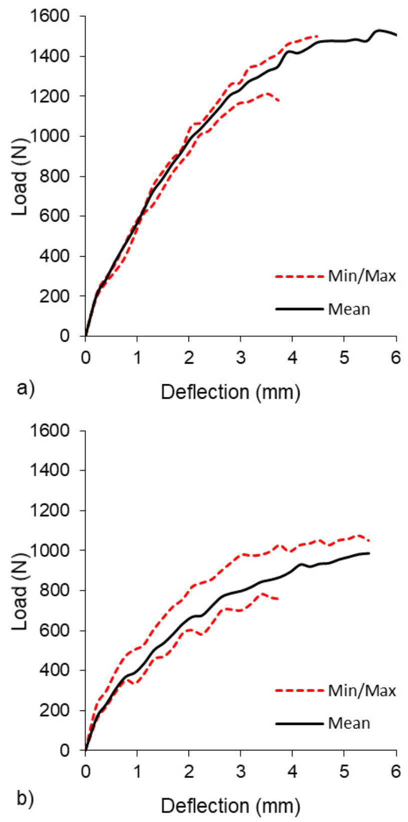
The joints also differed in the slope of the curve relative to the horizontal axis. This resulted in a change in the stiffness of these joints. Fig. 10 shows that the maximum stiffness of the dry joints (D) subjected to a closing force of about 80 N was equal to 15.8 Nm/rad, while the maximum stiffness of the wet joints (W) was 9.8 Nm/rad. However, it should



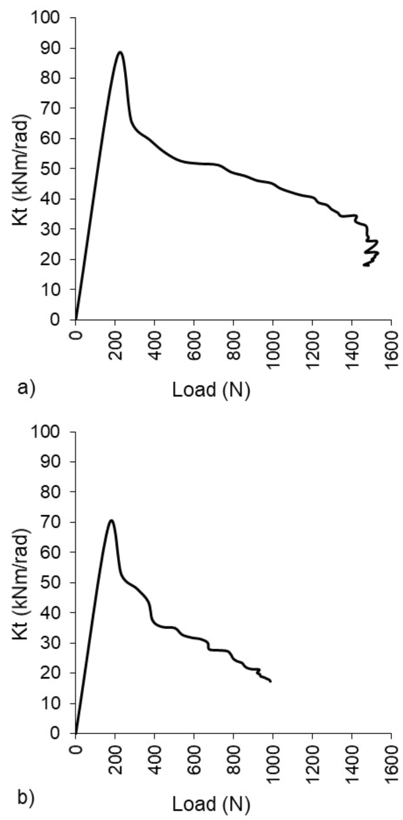
9: *Compression test a) dry, b) wetted*



10: *Compression test a) dry, b) wetted*



11: *Tension test a) dry, b) wetted*



12: *Tension test a) dry, b) wetted*

be noted that as the load increased, the stiffness of both connections decreased. For forces of 200 N, 300 N and 400 N, the ratios were equal to 8.6 and 5.9, 7.2 and 5.1, 6.2 and 4.6 (Nm/rad) respectively.

Fig. 11, on the other hand, shows the average failure forces of the joints in the opening test. In the case of dry-conditioned joints (D), the maximum failure force was 1 524 N, while in the case of wet-conditioned joints (W) it was 986 N, respectively, at a similar displacement. It was noted here that the wet joints (W) were not homogeneous this time and provided different force values throughout the dilation test (Fig. 9b). Dry joints (D) in the range of displacements up to 3 mm showed a high repeatability of results (Fig. 11a). Beyond a displacement of 3 mm, the force values started to vary, and at a maximum displacement of about 4.5 mm, the force differences were as high as 320 N. As in the case of tension, the joints also differed in the slope of the curve relative to the horizontal axis. This resulted in a change in the stiffness of these joints.

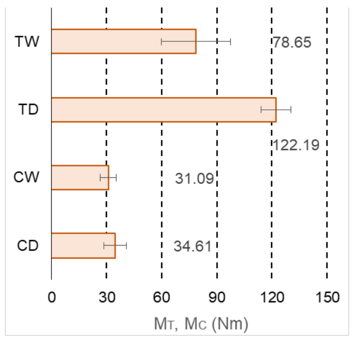
Fig. 12 shows that the maximum stiffness of the dry joints (D) subjected to a force of about 190 N was equal to 86.3 Nm/rad, while the maximum stiffness of the wet joints (W) was 68.8 Nm/rad. It should also be noted here that as the load increased, the stiffness of both joints decreased. The ratios for 400 N, 600 N, and 800 N forces were 77.5 and 37.5, 51.7 and 31.8, 48.9 and 24.8 (Nm/rad), respectively.

It can also be seen from Fig. 10 and 12 that wet conditioning reduces the stiffness of the diverging joint (T) from 86.31 Nm/rad to 68.64 Nm/rad. The change is from 15.9 Nm/rad to 9.8 Nm/rad during closing.

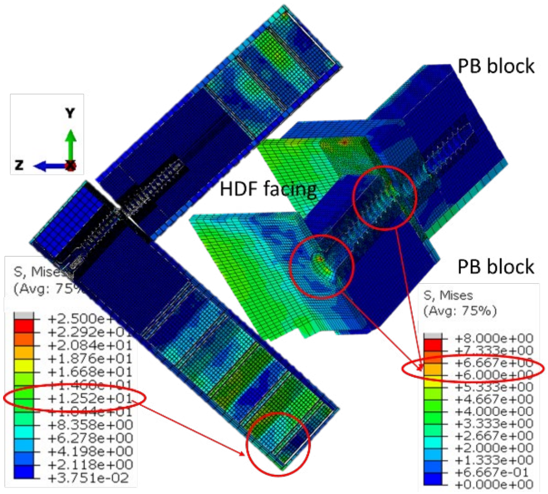
The differences in the strength and stiffness of the joints are illustrated in Fig. 13, which shows that changing the conditioning conditions of the joints significantly affects their strength in the dilation test (T). In this case, the strength of the connections decreases from 122.19 Nm to 78.65 Nm. For joints subjected to compression (C), the strength of the connections decreases from 34.61 Nm to 31.09 Nm.

Numerical Part

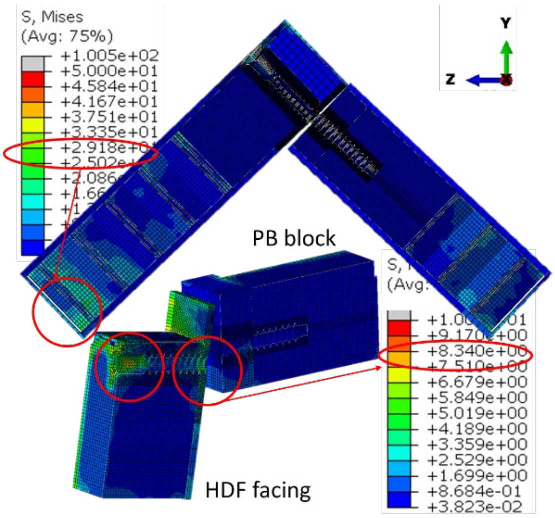
The numerical calculations were designed to show the characteristic damage at the screw and socket contact points in the particleboard. It can be seen



13: *Strength (M_T, M_C) a) and stiffness (K_T, K_C) b) of joits, W - wett, D - dry, T - tension, C - compression*



14: *Mises stresses in compressed joints*



15: *Mises stresses in tensiled joints*

from Fig. 14 that during short-circuiting, the highest stresses, with a value of 12.52 MPa, are concentrated on the edges at the point of load application and the point of support. These stresses do not exceed the strength of the weakest material in the structure at 14.1 MPa (Tab. I). At the bolt and chipboard block junction, the stresses reach a value of 6.67 MPa. These values do not exceed the strength of the central part of the particleboard of 7.8 MPa.

Fig. 15 illustrates the stresses in joints subjected to tension. The highest stresses, with a value of 29.18 MPa, are concentrated on the edges at the point of load application and the point of support. The value of these stresses exceeds the chipboard strength of 14.1 MPa. At the joint between the screw and the particleboard blocks, the stresses reach a value of 8.34 MPa. These values exceed the strength of the central part of the particleboard 7.8 MPa.

Numerical tests have shown that the strength of the connections is sufficiently effective for use in industrial solutions.

CONCLUSION

The experimental study involved determining the effect of temperature and relative humidity changes on the stiffness and strength of corner joints made from 37 mm thick lightweight panels. Confirmat screws were used for the joints. Experimentally, it was shown that changing the temperature and relative humidity of the air from 26C, 40% to 28C, 85% significantly affected the strength and stiffness of the corner joints. When the specimens are humidified, their strength decreases by 10.2% in the short-circuit test. During dilation, the strength decreases by 35.6%. Moistening the specimens also reduces the stiffness of the joints by 38.4% and 20.5% for short-circuited and open-circuited joints, respectively. However, the numerical models developed confirm that the strength of the connections is still acceptable under extreme loading conditions. Slight failures only occur in non-visible areas at the interface between the screw and the thread formed in the chipboard.

Acknowledgements

This project has received funding from the Research Council of Lithuania (LMTLT), agreement No: S-A-UEI-23-3.

REFERENCES

[1] ALLEN, Howard Georg. 1969 *Effect of cell-wall angle on the uniaxial crushing behaviour of paper hexagonal honeycombs*. New York: Pergamon Press. ISBN 9789532920314

[2] CARLL, Charles; WIEDENHOEFT, Alex C. 2009. Moisture-related properties of wood and the effects of moisture on wood and wood products. In: *Moisture Control in Buildings: The Key Factor in Mold Prevention*. ASTM Manual. 2nd Edition. West Conshohocken, PA: ASTM International, c2009. Chapter 4, p.54–79.

[3] FEIFEL, Silke, POGANIETZ, Witold-Roger; SCHEBEK, Liselotte. 2013. The utilization of light weight boards for reducing air emissions by the German wood industry - a perspective? *Environmental Sciences Europe*. 25, 5. https://doi.org/10.1186/2190-4715-25-5

[4] HARKATI, A. *et al.* 2020. In-plane elastic constants of a new curved cell walls honeycomb concept. *Thin-Walled Structures*. 149, 106613. https://doi.org/10.1016/j.tws.2020.106613

[5] KASAL, A. *et al.* 2008. Effects of screw sizes on load bearing capacity and stiffness of five-sided furniture cases constructed of particleboard and medium density fiberboard. *Forest Products Journal*. 58(10), 25–32.

[6] KASAL, A. *et al.* 2014. Effect of material properties and anchorage location on load-bearing capacity of screw-connected and hung cabinets. *Wood and Fiber Science*. 46(1), 1–10.

[7] KASAL, Ali *et al.* 2023. Analyses of L-Type Corner Joints Connected with Auxetic Dowels for Case Furniture. *Materials*. 16(13), 4547. https://doi.org/10.3390/ma16134547

[8] KRZYŻANIAK, Łukasz; MARDZEWSKI, Jerzy. 2021. Impact damage response of L-type corner joints connected with new innovative furniture fasteners in wood-based composites panels. *Composite Structures*. 255, 113008. https://doi.org/10.1016/j.compstruct.2020.113008

[9] LAY, Makara *et al.* 2019. Comparison of physical and mechanical properties of PLA, ABS and nylon 6 fabricated using fused deposition modeling and injection molding. *Composites Part B: Engineering*. 176, 107341. https://doi.org/10.1016/J.COMPOSITESB.2019.107341

[10] LIBRESCU, Liviu; HAUSE, Terry. 2000. Recent developments in the modelling and behavior of advanced sandwich constructions: A survey. *Composite Structures*. 48(1-3), pp. 1–17. https://doi.org/10.1016/S0263-8223(99)00068-9

[11] NILSSON, Jonaz, ORMARSSON, Sigurdur; JOHANSSON, Jimmy. 2017. Moisture-related distortion and damage of lightweight wood panels-experimental and numerical study. *Journal of the Indian Academy of Wood Science*. 14(2), 99–109. https://doi.org/10.1007/s13196-017-0193-y

[12] NORDVIK, Enar; BROMAN, N. Olof. 2005. Visualizing wood interiors: a qualitative assessment of what people react to and how they describe it. *Forest Products Journal.* 55(2), 81–86.

[13] SHALBAFAN, A. *et al.* 2012. Comparison of foam core materials in innovative lightweight wood-based panels. *European Journal of Wood and Wood Products*. 70(1–3), 287–292. https://doi.org/10.1007/s00107-011-0552-0

[14] SMARDZEWSKI, J. 2013. Elastic properties of cellular wood panels with hexagonal and auxetic cores. *Holzforschung*. 67(1), 87–92. https://doi.org/10.1515/hf-2012-0055

[15] SMARDZEWSKI, J.; ŁABĘDA, Karol. 2018. Mechanical and Hygroscopic Properties of Longitudinally- Laminated Timber (LLT) Panels for the Furniture Industry. *BioResources*. 13(2017), 2871–2886. https://doi.org/10.15376/biores.13.2.2871-2886

[16] SMARDZEWSKI, Jerzy; MAJEWSKI, Adam. 2015. Mechanical properties of auxetic honeycomb core with triangular cells. In: *25th International Scientific Conference New materials and technologies in the function of wooden products*, pp. 103–112. ISBN 9789532920345

[17] SMARDZEWSKI, Jerzy, SŁONINA, Michał; MASLEJ, Michał. 2017. Stiffness and failure behaviour of wood-based honeycomb sandwich corner joints in different climates. *Composite Structures*. 168, 153–163. https://doi.org/10.1016/j.compstruct.2017.02.047

[18] SMARDZEWSKI, Jerzy; TOKARCZYK, Maciej. 2024. Lightweight honeycomb furniture panels with discreetly located strengthening blocks. *Composite Structures*. 331, 117927. https://doi.org/10.1016/J.COMPSTRUCT.2024.117927

[19] TANKUT, Nurgul. 2009. Effect of various factors on the rigidity of furniture cases. *African Journal of Biotechnology*. 8(20), 5265–5270.

Reviewer
Dr. Manja Kitek Kuzman, PhD – University of Ljubljana (Slovenia)

Contact information
Smardzewski Jerzy: jsmardzewski@up.poznan.pl

ANALYSIS OF SHIPPING CONTAINERS, THEIR EVOLUTION AND THE PATH TO CONTAINER ARCHITECTURE

Andrea Vokřálová[1], Richard Sovják[1]

[1] Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic

Link to this article: https://doi.org/10.11118/978-80-7701-044-3-0063

Abstract

The paper analyses the historical development of shipping containers, the change of their use from standardized shipping containers to a building element from which both a building with architectural value and a useful building for humanitarian and social housing can be constructed very quickly and cheaply. Materials, technologies and technical solutions for construction are constantly advancing and it is therefore essential to address current and future issues concerning our planet. After the supply-chain crisis, production of shipping containers is on the rise again due to the worldwide increasing demand for international transport of goods. Retired containers need to be disposed of in a meaningful way and given an alternative use as a building block. This paper summarizes the information necessary to create an ergonomic manual for the rapid construction of cities with all the social amenities. It is also important to take into account the impact on people through the quality of interior comfort, the speed and sustainability of production and the social convergence between the population and nature. To evaluate the efficiency of use, to explore its further progression for the benefit of the population of our planet and beyond.

Keywords: container, transport, ships, architecture, living, sustainable, humanitarian, office

INTRODUCTION

The paper deals with the development of the shipping container, its function as a box for transporting products and later recycling for use in the construction industry. The standardization of dimensions has enabled the stacking of containers and caused a global flow of trade. However, this stroke of genius has also seen its further application in architecture as a building element to create very attractive, economical and sustainable buildings, popular not only among the young population.

The aesthetic design of modern container housing must flawlessly integrate the individual parts into a functional whole. The great advantage of this type of housing is the unification for production and assembly worldwide.

It must be stressed that shipping containers are environmentally friendly and sustainable with regard to the extraction and production of raw materials contrasted with the bulky amount of materials used in traditional construction. Construction using shipping containers can take place off-site without the need for technological interruptions in the construction process. The advantage is especially the speed and reduction of additional waste during construction. Containers in different levels of wear (one way or discarded due to damage) can be widely used for the construction of private or public buildings (vaccination centres, schools, alternative housing during emergency situations, etc.) [1].

If we summarize all the available information we come to the conclusion that containers serve excellently for the rapid and sustainable construction of various types of architectural use. Thanks to the standardisation of dimensions, they are easy to transport to the site and quick to assemble. Such a construction system is ideal in dealing with crisis situations for various humanitarian and social projects, as well as luxury and economic housing.

Historical Development of Shipping Containers

The forerunner of the first shipping container was designed by James Brindley in 1766. This container was part of the Starvationer and was used in England to transport coal from the mines. In 1795, Englishman Benjamin Outram designed the first container made of wood for transporting coal, which was hauled by horses from the mines to ships in port. By the 1830s, containers were being transported by rail on some continents. Up to 4 containers could fit on one car. These were then transported by horse-drawn carriages, one container at a time. Later, metal containers were produced, and by the beginning of the 20th century, they were already being produced enclosed [2].

As a result of the advent of the Industrial Revolution, there was a demand for efficient transportation without unwanted time gaps.

The American merchant Malcolm McLean realized the need for unification of shipping containers and began to investigate different variants. He adopted a 35‘ (about 11 m) container model that is still known today as the shipping/storage container. Today's modern containers have established length dimensions of 20‘ and 40‘. They are a standardized, durable, stackable, easy to load and lock solution that allowed for transloading between train, ship and truck [3].

Revolution in Transport

Shipping containers were one of the key elements that enabled the globalisation of modern trade. Their adoption and standardisation have revolutionised logistics and business processes around the world, not only in the transport sector, but also in construction and other industries. Today, approximately 90% of all world goods are transported in containers [4].

Standardised Container Dimensions

Shipping containers are manufactured in standardized sizes according to ISO 668 international standards and may vary slightly depending on the manufacturer.

These containers are referred to as ISO Class 1 and consist of several types. The most common types seen are the 20‘ (1C) and 40‘ (1A) containers, which allow up to 6 containers to be stacked on top of each other. Standardization has also made good use of internal dimensions for efficient transport. The container can accommodate 3 Euro pallets per width.

The width of the container has a constant dimension, but the length and height of the containers vary according to the types. The basic models 1A and 1C are 2,438 mm high, but there are also elevated models 1AA and 1CC with a height of 2,591 mm and a tall container 1AAA with a height of 2,896 mm (Tab. I) [5].

I: *Standardized container dimensions [3] [5]*

Container size		External dimensional (mm)	Interior dimension (mm)
20'	length	6,058	5,898
	width	2,438	2,352
	height	2,591	2,393
40'	length	12,192	12,032
	width	2,438	2,352
	height	2,591	2,393
45'	length	13,716	13,556
	width	2,438	2,152
	height	2,591	2,698

Container Support Material and Surface

The supporting structure of the shipping containers is made of high-strength corten steel (composition Fe, Cr, Cu, Ni and P). This steel has high corrosion resistance, excellent mechanical properties, but above all, it has a long service life.

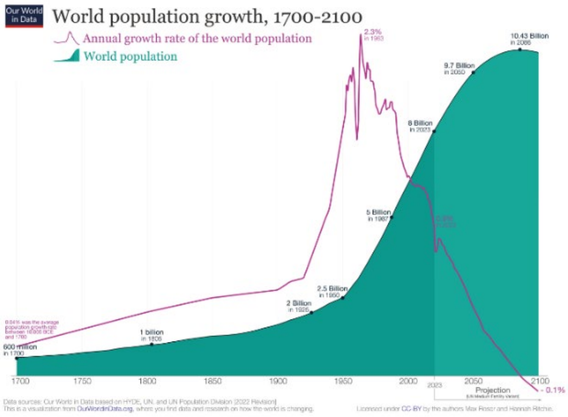
Corrosion forms a patina/rust layer which prevents further rusting. For this reason, it is not necessary to apply protective coatings to the containers, but for operational and aesthetic reasons these treatments are carried out [6].

The advantage of using Corten steel without surface treatment is the characteristic oxidation of the steel (Fig. 1), which finds application in building facades, bridge construction and other civil engineering structures [7].

1: *Corten surface [8]*

Population Growth

According to the information and graphs available in the Our World in Data articles, it is certain that the world's population is still growing. In recent years, the increase has not been as marked as in the second half of the 20th century, when the population grew by about half, from 2.5 billion to 5 billion. This year, the population has exceeded 8 billion,



2: *World population growth [9]*

3: *Cointainer hotel in Quepos, Costa Rica*

and growth forecasts estimate that we will reach 10 billion in 2058 (Fig. 2), [9].

Important questions arise in the redesign of shipping containers that focus on their benefits to society, the purpose of their construction, the possibility of disrupting the advantages of modularity (non-traditional architecture) and aesthetic treatment.

Methodology

This paper uses a qualitative approach for evaluation based on primary and secondary sources, research on the history of container housing and research on the existence of construction companies in the market that are already working with containers.

It analyses the production of shipping container manufacturing in recent years and the developments that have taken place since the beginning of the 20th century. It describes the current direction of container housing construction and its possible prediction for the future.

Developing a SWOT analysis of container housing with respect to current use and prospects for future applications, including interpretation of the results from this analysis.

Results

Shipping containers were initially used by companies for quick solutions to accommodation problems of their employees, mostly construction workers, etc. In the early 21st century, shipping containers began to be widely used by architects/designers for the construction of hotels (Fig. 3), schools, offices, holiday housing and glamping. Today, however, these buildings are even more popular due to their low purchase price, low environmental burden on nature, sustainable living, as well as low energy consumption in their operation.

Containers are now commonly used to build various types of „box houses“, schools, nurseries (Fig. 8), offices and Even doctors' surgeries. London-based Container City (Fig. 4), founded in 1998, is a major player in this type of construction. As an example, the Container City™ project, located at Trinity Buoy Wharf in the heart of London's Docklands, was completed in five months in 2001. Container City I was initially three-storeys providing 12 work studios on 446 m². A fourth floor was added in 2003 to accommodate three additional live/work apartments. The actual installation of the prefabricated containers on site took 2 days.

Another project that followed on from Container City I is one of the most famous buildings in the world (Fig. 4), Container City II. The colourful and distinctive building has five storeys and occupies 8,208 m². It took 15 days to assemble the ready-made boxes [10].

A Breakthrough in the Development of Container Architecture

The first ideas of converting shipping containers into housing were pioneered by Phillip C. Clark in 1987, who registered US patent US4854094A „Method for converting one or more steel shipping containers into a habitable building at a building site and the product thereof“ [11].

4: *Container City I, London [10]*

5: *Watter Hub, New York, 2013 [12]*

6: *House design Carroll House, California [12]*

A single-family house in Brooklyn by the architectural firm LOT-EK (Fig. 5 and Fig. 6). The house was designed by Italian architects Ada Tolla and Giuseppe Lignano in 1993 [12].

An as-yet-unrealized 2017 design for a single-family home in California's Joshua Tree National Park by English architect James Whitaker (Fig. 7), [13].

When the Costa Mesa Waldorf School in California decided to expand, they chose to use shipping containers due to their sustainability. The school used shipping containers to create a new wing of eco-conscious buildings. The project utilized 32 shipping containers to create an additional 4 buildings on their campus. In addition to extra classroom space, the new additions include a library, 2-story auditorium, and a science lab. (Fig. 8), [14].

8: *Waldorf Costa Mesa School, California [14]*

Adam Kalkin

Adam Kalkin is a prominent American architect working on container buildings. He tries to combine the function and aesthetics, but also the economic side of these buildings. Among his most notable projects is the Illy Push Button House, which is a revolution in the perception of building technology.

He designed this building in collaboration with the coffee company Illy and presented it at Art Basel in Miami. Kalkin has combined aesthetics, design, sustainability and the enjoyment of good coffee. The shipping container opens like a flower at the push of a button (Fig. 9). The motorised walls use hydraulic struts to open all the side walls and a coffee bar is created [15].

Many construction companies and architects are involved in the construction of shipping container buildings. We mainly encounter design aesthetic buildings for living. However, this building element offers a very wide range of building applications for: schools, hospitals, cultural houses, factories, studios, housing for the homeless and, above all, buildings for humanitarian and emergency situations.

7: *Design of Family House, California [13]*

9: *Push Button House, Adam Kalkin [15]*

The bonus is its recycling reuse for another purpose from a sustainable material and that is corten steel. To make such a building fully sustainable it is essential to address its internal wall and floor design, i.e. insulation and materials for furniture production.

Completely Independent Box on Utility Networks

Nowadays, it is possible to build a completely independent house from utilities quickly and easy to implement and cheaper than conventional buildings made of other materials. A bonus is the simple composition of standardised container sizes, differently stacked to create visually aesthetic buildings.

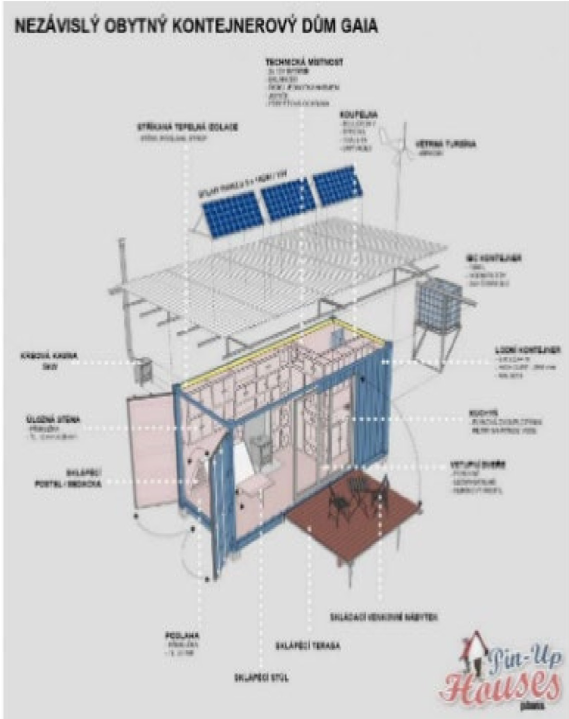
If the carbon footprint is reduced as much as possible with their handling and the use of building insulation, etc., the residential container box will be fully eco-friendly and sustainable.

The current options for building independence from utilities is based on the principles of:

- electricity generated by photovoltaics or wind power;
- rainwater harvesting and recycling using filtration units;
- ecological composting toilet [16].

Off-Gridd House Gaia

Shipping Container House Gaia is a project of experimental self-sufficient house, it is a so-called Off-Grid House (Fig. 10, 11). The house is equipped with solar panels and a wind turbine that recharges the batteries at night and during the winter months when the solar panels are less powerful. Battery status, consumption, recharging and other factors can be monitored using a mobile app. The house retains rainwater, which is filtered and distributed to the bathroom and kitchen. It is equipped with a refrigerator, a water boiler for heating water and other appliances at 12 and 24V. At the same time, a higher voltage of 110V to 230V can be created using an inverter. Clever storage space, a folding bed/sofa, furniture and table is standard. The outdoor patio can be folded using a winch to close the container.



11: *Gaia living container (Vojtěch Valda) [16]*

The main building materials are a marine HC 20‘/6m container, wooden KVH prisms and wrapping spruce plywood which defines the entire interior space. The inner walls of the container are insulated with sprayed thermal insulation. The steel roof structure is covered with galvanised corrugated sheet. The generous roof overhang increases the catchment area for rainwater, which is collected in a 1,000 litre IBC container.

Kebin

KEBIN is a mobile container with dimensions of (2.6–7.0) m and a height of 2,780 mm and works on the OFFGRID principle (Fig. 12). It is therefore self-contained and without the need for connection to utilities. The project authors, architect Jan Bek and builder Stanislav Líkař, designed the container to be as comfortable as possible, to have a practical use and to blend in with its surroundings [17].

10: *Gaia living container (Ing. Arch. Vojtěch Valda) [16]*

12: *OFFGRID house Kebin, 14.2 m² [17]*

II: *SWOT Analysis of shipping containers [1]*

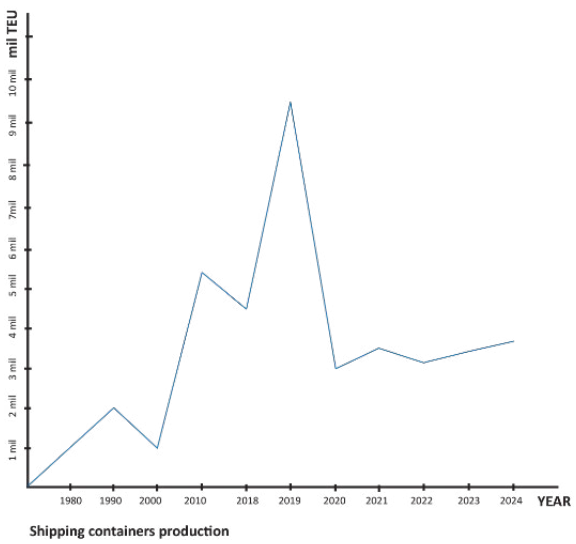
	ADVANTAGES	DISADVANTAGES
Internal	Reduction of the price for transport of products (materials bricks, ...)	High carbon footprint during transport
	Easy maintenance and pest resistance (wooden buildings)	
	Modularity and speed of construction (Reduction of construction energy)	
	Possibility of non-traditional architectural solutions	
External	Recycling requirements and reuse	Energy intensity of modifications (change in energy prices)
	Reducing the consumption of input materials (reducing the environmental burden associated with mining, production of building materials)	Health and safety aspects (necessary control of decontamination of shipping containers due to transport of unknown goods)
	Mobility (easily relocatable - reducing the environmental burden associated with demolition and construction of new buildings)	Lacle of shipping containers (crisis in the steel industry, excessive demand for shipping containers)
	Attractiveness of housing (speed and cost of construction)	
	Modularity of transport	

SWOT Analysis

SWOT developed from a redevelopment perspective of shipping containers to container housing (Tab. II).

DISCUSSION

Container architecture brings significant benefits and is applicable both in urban areas and in more remote locations where rapid and efficient construction is needed. Typical examples are student halls of residence, emergency shelters, commercial and office space.



13: *Chart of containers production (1 TEU is equivalent to one 20' container) [18] [19] [20]*

The production of standardized containers is again on the rise (Fig. 13). Containers have a lifespan of 10–15 years for transportation needs, resulting in the accumulation of large quantities of discarded containers [21]. Containers can, however, continue to serve an ecological purpose in the construction industry and change the established approach in urban development.

Shipping containers can be the basis for sustainable construction, provided that the prerequisites for minimising the negative environmental impacts associated with their handling and transport are met. It is important to ensure that their reuse respects modern building requirements with regard to the use of natural insulation/environmentally friendly materials for energy efficient housing. Important aspects in the construction of container housing are the location and also the purpose of the construction. In the case of construction in locations with favourable climatic temperatures, it will not be necessary to ensure perfect insulation against installations in cold/very warm climates. What is essential is the use of container housing, namely seasonality or permanent housing.

Increasing urbanisation, the high cost of traditional housing, sustainability and design flexibility also play a significant role. Containers are used for both low-cost housing and luxury modern projects.

- Global population growth is increasing the demand for housing, underlining the importance of sustainable and low-cost solutions such as container architecture.

- A number of construction companies around the world specialise in projects based on container architecture, from emergency shelters to luxury homes.
- Innovations in the 21st century, such as Adam Kalkin's pioneering designs, have accelerated the construction of container buildings with an emphasis on lower costs and speed of construction.
- The public's changing preferences are leaning towards smaller, more efficient living spaces with modern design, due in part to economic factors.
- Environmental factors such as climatic conditions significantly influence the feasibility and popularity of container architecture.
- Clustering, modularity of shipping containers and finishes (cladding) aesthetically enhance the architectural design of container housing

CONCLUSION

The analysis presents a path for the conversion of shipping boxes from wood to steel containers of standardized dimensions. Its enormous impact on the world globalization in transportation and the change in the perception of shipping containers as an essential building element that has changed the perception of architecture. The advantage of these containers is the use for transportation as well as eventually for use in construction. This makes it a fully sustainable building element ready for quick and cheap housing construction, not only because of the unification of dimensions (building in modules).

The production of containers is fully dependent on the economic and political situation in the world. This fact can be seen in the chart (Fig. 13) which records the production of shipping containers since the beginning of the 21st century.

The forecast for containers as a building element is increasing. They are gradually being integrated into the construction industry and stand out primarily as design buildings, but containers offer far more extensive social possibilities such as the creation of buildings for the homeless, refugees, victims of natural disasters, etc. Examples include building London firms such as Container City, Modulus Homes, SG Block and New York's Lot-ek.

Container architecture is a revolutionary approach to construction that combines sustainability, efficiency and flexibility in construction. A major advantage is the ability to quickly address global housing needs with adapted shipping containers, especially in crisis situations. Further research and innovation is needed to improve container reuse, optimise insulation and reduce the environmental impact of construction. The future of container architecture promises speed of construction, but above all both social and environmental benefits, from affordable housing to luxury design.

REFERENCES

[1] HZ KONTEJNERY. 2024. *Bydlení z kontejnerů*. HZ containers.com [Accessed: 2024-11-23] https://hz-containers.com/cs/bydleni-z-kontejneru/

[2] TUONG HOA. 2023. *The history of container shipping*. 20/9/2023. [Accessed: 2024-11-23] https://tuonghoa-imex.com/en/logistics-knowledge/the-history-of-container-shipping.html

[3] LEVINSON, Marc. 2016. The Box. In: *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger*. Princeton University Press, p. 191–196. ISBN 9780691170817

[4] HZ KONTEJNERY. 2024. *Historie lodních kontejnerů*. HZ containers.com [Accessed: 2024-11-23] https://hz-containers.com/cs/historie-lodnich-kontejneru/

[5] NOVÁK, Jiří. 2020. *Rozměry a stohování lodních kontejnerů*. Obalové Materiály. 13. 2. 2020. [Accessed: 2024-11-23] https://www.obalove-materialy.cz/o-nas/clanky/rozmery-a-stohovani-lodnich-kontejneru

[6] KUMARAVEL, D.; RAJA, V. K. Bupesh; BALTHASER, Kabasker; ANANDAN, Jayaganthan; SAHAS, S. *et al*. 2022. Investigation on Wear and Corrosion Behavior of Cu, Zn, and Ni Coated Corten Steel. *Advances in Materials Science and Engineering*. 2022, 7341201. https://doi.org/10.1155/2022/7341201

[7] ABRA SERVICE. 2024. *Cor-ten*. Abra Service. [Accessed: 2024-11-23] https://www.abraservice.com/cs-cz/materialy/ocel-odolna-vuci-povetrnostnim-vlivum/corten

[8] MONAGHAN, Aidan. Grillagh Water House/Patrick Bradley Architects [photography]. In: *Archdaily*. [Accessed: 2024-11-23]https://www.archdaily.com/593806/grillagh-water-house-patrick-bradley-architects/54d01ae0e58ece5c5e0003de-6_am_-no_water-jpg?next_project=no

[9] ROSER, Max; RITCHIE, Hannah. 2023. *How has world population growth changed over time?* Our World in Data. [Accessed: 2024-11-23] https://ourworldindata.org/population-growth-over-time

[10] CONTAINER CITY. 2022. *Container City 1*. [Accessed: 2024-11-23] http://www.containercity.com/container-city-1

[11] BLANFORD, Mike; BENDER, Stephen. 2020. Upcycling Shipping Containers for Houses. Cityscape. 22(2), 95–100. [Accessed: 2024-11-23] https://www.huduser.gov/portal/periodicals/cityscpe/vol22num2/ch7.pdf
[12] BRIGHT, Danny. 2016. CARROLL HOUSE [photography]. LOT-EK. [Accessed: 2024-11-23] https://lot-ek.com/CARROLL-HOUSE-1
[13] ŠTECH, Adam. 2021. Modulární architektura aneb když se z kontejneru stane dům. *CAMP Magazine*. 10. 3. 2021. [Accessed: 2024-11-23] https://praha.camp/magazin/detail/modularni-architektura-aneb-kdyz-se-z-kontejneru-stane-dum
[14] CONTAINER TECHNOLOGY INC. 2023. *Build a School Out of Shipping Containers*. CTI. Published 12. 10. 2023. [Accessed: 2024-11-23] https://containertech.com/articles/shipping-container-schools/
[15] ANAKIN. 2009. Push Button House by Adam Kalkin. In: *Luxuo*. 26. 5. 2009. [Accessed: 2024-11-23] https://www.luxuo.com/culture/art/push-button-house-adam-kalkin.html
[16] VALDA, Vojtěch. 2021. *Off-Grid Dům "Gaia" z Námořního Kontejneru*. Publikováno 1 února 2021. Vojtěch Valda. [Accessed: 2024-11-23] https://vojtechvalda.cz/off-grid-dum-gaia-z-namorniho-kontejneru/
[17] KEBIN. 2024. *Luxusní obytný kontejner*. KEBIN. [Accessed: 2024-11-23] https://kebin.cz/
[18] COSCO SHIPPING. 2023. *CSR*. Cosco Shipping. [Accessed: 2024-11-23] https://lines.coscoshipping.com/home/About/socialResponsibility/sustainabilityReport
[19] TEU Volumes. [Accessed: 2024-11-23] https://containerstatistics.com/
[20] RODRIGUE, J.-P. 2024. *World Container Throughput, 1980–2021*. The Geography of Transport Systems. [Accessed: 2024-11-23] https://transportgeography.org/contents/chapter5/intermodal-transportation-containerization/world-container-throughput/
[21] HZ KONTEJNERY. 2024. *Námořní kontejnery ISO*. HZ containers.com. [Accessed: 2024-11-23] https://hz-containers.com/cs/namorni-kontejnery-iso/

Reviewer
Dr. Manja Kitek Kuzman, PhD – University of Ljubljana, Slovenia

Contact information
Andrea Vokřálová: andrea.vokralova@mendelu.cz

Title: Trends in Furniture and Living 2024
Proceedings of the International Scientific Conference

Editor: edited by Petr Čech et al.

Publisher: Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
Edition: 1st Edition, 2025

ISBN 978-80-7701-044-3 (online ; pdf)
https://doi.org/10.11118/978-80-7701-044-3