

VET providers training programme

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CONTENTS

INTRODUCTION.....	3
1. ROLES & RESPONSIBILITIES	4
2. REQUIREMENT & PREREQUISITES.....	4
3. STRATEGY & APPROACH	5
3.1 Training Sources	5
3.2 Delivery Method	6
3.3 Dependencies and Limitations	6
4. TRAINING RESOURCES	7
4.1 Materials.....	7
4.2 Staffing.....	7
4.3 Equipment	8
4.4 Environment	8
5. TRAINING SCHEDULE	9
6. TRAINING EVALUATION	9
7. TRAINING SECURITY & UPDATES	10
7.1 Access to Training Material	10
7.2 Access to Training Environment	10
7.3 Updating Training Resources.....	10
APPENDIX A: TRAINING CURRICULUM	11
Curriculum One	11
Curriculum Two.....	12
Curriculum Three	13
Curriculum Three	14
APPENDIX B: TRAINING MATERIALS FOR TRAINING CURRICULUM.....	15

INTRODUCTION

This Training programme outlines a learning intervention that SUSFUR consortium determines is necessary to support new staff, to enable existing staff performance or to accompany the introduction of an unfamiliar process related to sustainable furniture production and use of reclaimed wood in Western Balkan.

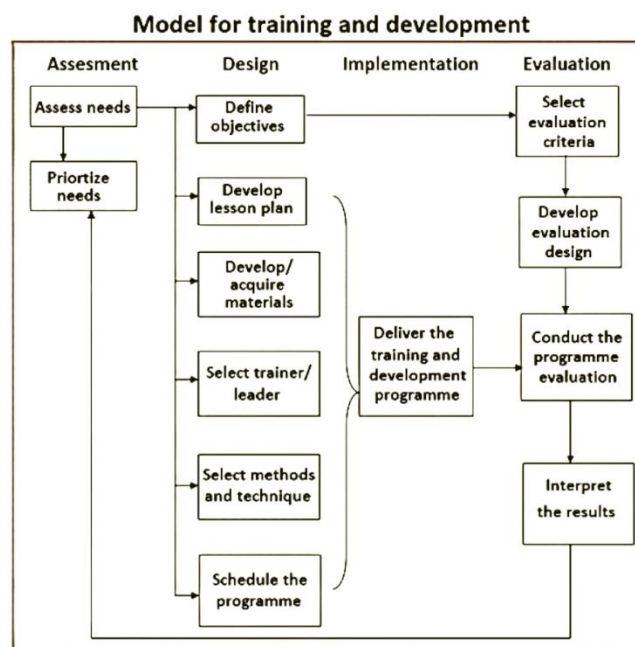


Figure 1: Flowchart of SUSFUR provider training program (development, implementation and assessment)

The document follows the training requirements outlined in the project proposal and builds learning content based on needs identified on the Research report document (D2.1).

This format is intended for vocational education and training (VET) professionals and stakeholders engaged in the SUSFUR project. It provides a structured approach to understanding how training requirements in sustainable furniture production—particularly in the context of circular economy practices—will be addressed and how learning outcomes will be achieved. This document represents the second phase of the SUSFUR learning intervention, supporting capacity building among VET providers and learners across the Western Balkan region.

The programme covered five modules: sustainable material sourcing, design for sustainability, sustainable manufacturing processes, technological advancements, and furniture waste management. Participants gained hands-on experience by creating prototypes from reclaimed wood and by visiting best-practice sites (the Ljubljana Reuse Center and the company M SORA). The above-mentioned modules were delivered by different experts and approached from various professional perspectives. The training materials are provided in APPENDIX B of this document and are also available on the project website.

1. ROLES & RESPONSIBILITIES

Project Coordinator (University of Ljubljana)

- Lead the design, development, and delivery of the training programme.
- Provide technical knowledge and expertise in the field of sustainable furniture production, the use of reclaimed wood, and the introduction of circular economy principles into practice.
- Host practical training sessions, workshops, and facility tours at Department of wood science and technology, University of Ljubljana.
- Ensure quality assurance of training materials and content.

Modules Development Team (All Partners)

- Conduct Training Needs Analysis (TNA) and identify priority skills for VET providers
- Develop training materials including presentations and case studies from home countries.
- Disseminate results and ensure knowledge transfer to broader VET communities.

VET Trainer(s) (selected from consortium or invited experts)

- Deliver theoretical and practical sessions to VET providers.
- Apply pedagogic strategies suitable for adult learning and vocational contexts.
- Facilitate hands-on workshops (selection of reclaimed materials and products, conduct and assist by planning of new product, development of a prototype product made from reclaimed wood).
- Mentor participants during Work-Based Learning (WBL) activities.

Quality Manager (MP)

- Oversee the training evaluation process in line with the Quality Plan (D1.3).
- Monitor participant satisfaction, knowledge uptake, and practical competencies.
- Collect and analyse feedback to inform continuous improvement.

2. REQUIREMENT & PREREQUISITES

Organisational Requirements (University of Ljubljana)

- Secure training venues (classrooms, laboratories, or on-site facilities at Department of wood science and technology).
- Fully equipped training facilities (furniture workshop, laboratories, technicians).
- Organization of a study visit showcasing good practices in the implementation of circular economy principles in the furniture industry at two companies: Ljubljana Reuse Center and M Sora.
- Assign administrative staff to manage participant registration, attendance tracking, and certification procedures.

Training Content & Format (All Partners)

- Modules developed in line with the Research Report (D2.1).
- Learning resources adapted for mixed delivery (theoretical, practical, and digital).
- Training Format draft (Deliverable 2.2) finalised before the start of implementation.

Prerequisites for VET Trainers (University of Ljubljana)

- Experts with prior experience in sustainable furniture production and circular economy practices have been identified and committed to lead the workshops.
- Trainers will be briefed on pedagogical strategies, including adult learning methods and evaluation techniques tailored to vocational education.
- They will be available to deliver both theoretical sessions and hands-on practical modules, including prototype development using reclaimed wood and eco-design principles.

Prerequisites for VET Providers (All Partners)

- Basic understanding of furniture production processes or strong motivation to engage in sustainable design and circular economy practices.
- Commitment to complete both theoretical and practical training modules, including prototype development using reclaimed wood.
- Willingness to transfer acquired knowledge and skills to VET learners and peers within their institutions, supporting the green transition in the furniture sector.

3. STRATEGY & APPROACH

The SUSFU training programme adopts a blended approach that combines lectures, demonstrations, study visits, and practical workshops. This strategy ensures that VET providers acquire the technical, pedagogical, and entrepreneurial skills necessary to train learners and connect them with the sustainable furniture industry labour market.

The schedule consists of 5 working days from **September 22nd to 26th**, each dedicated to a specific thematic area related to circular economy principles and sustainable practices in the furniture sector (see APPENDIX A: TRAINING CURRICULUM). Daily sessions will last approximately 6 to 8 working hours, including lectures, hands-on activities, and study visits.

Locations are set at the Biotechnical Faculty, Department of Wood Science, and selected partner sites, due to their advanced facilities and expert staff, ensuring participants gain practical experience in sustainable design, reuse, and recycling of furniture materials.

3.1 Training Sources

The training programme will be **developed in-house** by the SUSFUR project team in close collaboration with the **Department of Wood Science and Technology** at the Biotechnical Faculty. This approach leverages internal expertise in sustainable furniture production, circular economy principles, and vocational education.

Associated Development Activities

Curriculum Design (July – August 2025)

- Define learning objectives aligned with SUSFUR goals.
- Structure modules covering circular economy, sustainable materials, reuse practices, and practical workshops.

- Engage multiple faculty members and researchers from the Department of Wood Science and technology to contribute their specialized knowledge in material science, design, and production technologies.
- Prepare study visit plans and identify partner companies.

Content Development (August – early September 2025)

- Create lecture materials, case studies, and practical workshop guidelines.
- Develop supporting resources (presentations, handouts, evaluation forms).
- Validate content through internal peer review by department experts.

Logistics & Resource Preparation (early September 2025)

- Secure training facilities at the Biotechnical Faculty and partner sites.
- Prepare tools and materials for practical workshops.
- Finalize participant information packages.

Delivery of Source Materials (by September 22, 2025)

- Upload finalized training materials to the SUSFUR shared platform.
- Provide trainers with facilitator guides and participant manuals.

3.2 Delivery Method

The SUSFUR training programme will use a **blended learning approach**, combining:

- Classroom-based **lectures and demonstrations** at the Biotechnical Faculty (Department of Wood Science and technology).
- **Hands-on practical workshops** focused on creating new products from reclaimed wood and furniture.
- **Study visits** to external sites (Ljubljana Reuse Center and M Sora) to observe real-world applications of circular economy principles.
- **Interactive discussions** and case studies to reinforce theoretical concepts.

This mix ensures participants gain both **theoretical knowledge** and **practical skills** relevant to sustainable furniture production and circular economy practices.

3.3 Dependencies and Limitations

Dependencies

Trainer Availability

The program relies on the confirmed participation of subject matter experts from the Biotechnical Faculty. Any changes in their availability could impact the schedule and content delivery.

Facility and Equipment Access

Training rooms, laboratories, and workshop tools must be available on the planned dates. Study visits depend on confirmed access to partner sites (Ljubljana Reuse Center and M Sora).

Material Supply for Workshops

Timely procurement of reclaimed wood, tools, and safety equipment is essential for practical sessions.

Digital Infrastructure

Access to the shared platform (e.g., SharePoint/Teams) for distributing materials and communication is required.

Limitations**Time Constraints**

The program is limited to five consecutive days (22–26 September 2025), requiring strict adherence to the schedule.

Budgetary Restrictions

Financial limits may affect the scope of study visits, quality of materials, or participant capacity.

Health and Safety Compliance

Workshops involving tools and external visits are not allowed to use these tools. Carpenter from Biotechnical faculty, have to be present and work according to participant instructions.

External Dependencies

Delays in confirming study visits or logistical services could disrupt the overall timeline.

4. TRAINING RESOURCES

4.1 Materials

To support effective learning, participants will receive comprehensive training materials, including:

- **Instructor Guides:** Detailed facilitator manuals with session objectives, timing, and instructions.
- **Presentation Materials:** PowerPoint slides for all modules.
- **Visual Aids:** Diagrams, charts, and case study visuals.
- **Handouts:** Quick reference sheets, checklists, and process flows.
- **Demonstration Materials:** Samples of reclaimed wood, tools, and finished products for practical sessions.
- **Evaluation Tools:** Pre- and post-training assessments, as well as feedback forms.

4.2 Staffing

Lead Trainers / Subject Matter Experts

- Dr. Boštjan Lesar (Program Lead)
- Dr. Miha Humar, Dr. Sergej Medved, Dr. Marko Petrič, Dr. Gorazd Fajdiga, Dr. M. Kariž

All trainers involved in the SUSFUR program possess strong knowledge and practical experience in the field of wood science and technology. They are recognized experts who already teach and lead courses on circular economy in the wood and furniture sector. Collectively, they cover a wide range of topics included in the training program, such as service life of wood products, sustainable materials, recycling practices, and innovative design using reclaimed resources.

Workshop Facilitators and Technical Support

- Assistants for practical sessions and equipment setup, work in workshop

Administrative Staff

- Coordination of logistics, participant communication, and documentation, foto documentation

Quality Assurance Team

- Review of training content and evaluation tools

4.3 Equipment

The SUSFUR training program requires a Microsoft Windows environment for all presentation and collaboration activities, including laptops or desktops with MS Office (PowerPoint, Word, Excel) and access to Microsoft Teams/SharePoint. A multimedia projector, screen, and audio system are needed for lectures, supported by stable Wi-Fi connectivity. In addition to classroom facilities, a fully equipped woodworking workshop is essential, including carpentry machines (saws, planers, drills, sanding machines), workbenches, and safety equipment, to enable participants to develop prototypes during practical sessions.

4.4 Environment

Training rooms and workshops must be large enough to accommodate the entire participant group comfortably, ensuring safe and effective delivery of both lectures and practical sessions. In cases where this is not possible due to space or equipment limitations, participants will be divided into smaller groups to complete the activities in rotation. Adequate lighting, ventilation, and a stable indoor temperature should be maintained to provide a conducive learning environment.

5. TRAINING SCHEDULE

SUSFUR Project – Training Program					
Date	22.09.2025	23.09.2025	24.09.2025	25.09.2025	26.09.2025
Time	First Day	Second Day	Third Day	Fourth Day	Fifth day
08:30 – 09:00		Lecture: Recycled Wood in Wood-Based Composites	Study visit: Departure (08:30)	Practical workshop: Introduction	Practical workshop: Third part
09:00 – 10:00			Visit Ljubljana Reuse center		
10:00 – 11:00		Caffe Break		Caffe Break	Caffe Break
		11:00 – 12:00		Contemporary sustainable materials for the surface treatment of wood and for products in the wood industry	Depart from Reuse Center (11:00)
12:00 – 13:00	Introduction	Lunch	Visit of the company M sora	Lunch	Lunch
	Lecture: Service life of different furniture and wooden products				
13:00 – 14:00		Lunch	Practical workshop: Second part		
14:00 – 15:00	Break				
	15:00 – 16:00	Tour of the laboratories at the Department of Wood Science and Technology, Biotechnical Faculty			Lecture: Designing Furniture from Reused Materials - How to repair furniture with new techniques
16:00 – 17:00	Lecture: Cascading Use of Wood and Characterization of Recycled Wood on the European Market	Lecture: Materials in furniture production - sustainable materials utilization: wood and other biobased materials recycled materials and sustainably sourced wood			
17:00 – 18:00					Summary of Day One

6. TRAINING EVALUATION

The effectiveness and quality of the VET providers training program will be measured through a structured evaluation process. This process ensures that the training objectives are met, and that continuous improvements are integrated into future iterations of the program. The primary evaluation tool will be a [standardized questionnaire](#) designed under the Quality Plan document (D1.3).

The questionnaire will capture both quantitative and qualitative data regarding:

- Knowledge and skills gained (up-skilling achievements).
- Satisfaction with training delivery methods, materials, and practical exercises.
- Relevance of the course content to professional practice and market needs.
- Perceived applicability of the acquired skills in a furniture sector.

Both digital and paper-based formats will be made available to ensure inclusivity. The Quality Manager will oversee distribution, collection, and analysis of the questionnaires, supported by the consortium members.

Open discussions and debriefs at the end of modules will capture real-time impressions and suggestions for improvement. Feedback will inform the refinement of learning objectives, training methods, and the balance between theory and practice.

Trainers will assess participant engagement, ability to apply circular economy principles in the wood and furniture sector, and overall competency development throughout the program. Evaluation results will inform continuous improvement by updating training manuals, case studies, and the design of practical exercises to ensure alignment with industry needs and project objectives.

7. TRAINING SECURITY & UPDATES

7.1 Access to Training Material

All training materials—including instructor guides, participant workbooks, presentation slides, handouts, and evaluation tools—will be stored on a secure **Microsoft Teams** platform, ensuring controlled access for trainers and participants. Materials will be available in **Microsoft Office formats** (Word, PowerPoint, Excel). Participants will receive printed handouts for key sessions and practical exercises.

7.2 Access to Training Environment

The SUSFUR training environment will run on a Microsoft Windows platform with MS Office (Word, PowerPoint, Excel) and Microsoft Teams/SharePoint for collaboration. Trainers and participants will receive role-based access credentials before the program, with any changes managed by the system administrator upon request. Lecture rooms and workshops must be prepared with AV equipment, stable internet, and adequate space for group activities. A fully equipped woodworking workshop with carpentry machines, workbenches, and safety gear will be set up for practical sessions. All training materials and data will be uploaded to SharePoint in advance, and printed handouts will be provided for exercises.

7.3 Updating Training Resources

The SUSFUR training program, curriculum, and supporting materials will be updated as needed based on participant feedback, trainer evaluations, and industry developments. Required or requested changes will be collected through post-training evaluations and trainer reports. Proposed updates will be reviewed by the project team, prioritized according to relevance and impact, and incorporated into future iterations of the program. All revised documents will include a clearly marked **revision history with the issue date** to ensure version control and traceability.

APPENDIX A: TRAINING CURRICULUM

Curriculum One

Course Name	Topics	Location	Date	Duration
Service life of different furniture and wooden products (functional and aesthetic service life, decay,)	Service life of different products and what influence to aesthetic and functional service life. Q&A and interactive reflection with participants Instructor: prof. dr. Miha Humar	Department of wood science and technology	<Oct 22nd/ 12:15-13:45>	1,5 hr
Tour of the laboratories at the Department of Wood Science and Technology	Presentation of What the Department of Wood Science Can Offer on the Topic of Circular Economy and the Use of Reclaimed Wood Q&A and interactive reflection with participants	Department of wood science and technology	Oct 22nd/ 14:45-16:15	1,5 hr
Cascading Use of Wood and Characterization of Recycled Wood on the European Market	What is cascading use of wood and how reclaimed wood is sorted and what contaminants can be expected Q&A and interactive reflection with participants Instructor: assist. prof. dr. Boštjan Lesar	Department of wood science and technology	Oct 22nd/ 16:15-17:45	1,5 hr

Curriculum Two

Course Name	Topics	Location	Date	Duration
Recycled Wood in Wood-Based Composites	Which are the most important wood based composites for furniture production and how to use recycled wood in wood based composites. Q&A and interactive reflection with participants Instructor: prof. dr. Sergej Medved	Department of wood science and technology	<Oct 23nd/ 8:30-10:00>	1,5 hr
Contemporary sustainable materials for the surface treatment of wood and for products in the wood industry	Sustainable, bio-based surface treatments for wood, including coatings made from liquefied wood, natural oils, and biopolymers. How these innovations support circular economy principles by enabling the reuse and recycling of coated wood and improving durability, environmental safety, and functionality. Q&A and interactive reflection with participants Instructor: prof. dr. Marko Petrič	Department of wood science and technology	Oct 22nd/ 10:30-12:00	1,5 hr
New production Technologies for Furniture Production	Presentation of new technologies used in the furniture industry, including CNC and robotics, ... Q&A and interactive reflection with participants Instructor: prof. dr. Gorazd Fajdiga	Department of wood science and technology	Oct 22nd/ 13:00-14:30	1,5 hr
Designing Furniture from Reused Materials - How to repair furniture with new techniques	A presentation of how modern furniture design is carried out using new and/or reused materials with the help of advanced techniques such as 3d scanning and modelling Q&A and interactive reflection with participants Instructor: assist. prof. dr. Mirko Kariž and prof. dr. Manja Kitek Kuzman.	Department of wood science and technology	Oct 22nd/ 13:45-16:15	1,5 hr

Course Name	Topics	Location	Date	Duration
Materials in furniture production - sustainable materials utilization:	<p>Presentation of wood-based and other natural materials for the production of modern furniture according to circular economy principles</p> <p>Q&A and interactive reflection with participants</p> <p>Instructor: assist. prof. dr. Boštjan Lesar and prof. dr. Sergej Medved</p>	Department of wood science and technology	Oct 22nd/ 16:15-17:45	1,5 hr

Curriculum Three

Course Name	Topics	Location	Date	Duration
Study Visit Ljubljana Reuse center	<p>Gain insight into how reuse centres operate in Slovenia, including the processing and refurbishment of furniture items</p> <p>Q&A and interactive reflection with participants</p> <p>Instructor: Nathalie MACCAGNAN</p>	Ljubljana Reuse centre	Oct 24nd/ 9:00-11:00	2 hr
Visit of the company M sora	<p>Tour joinery production with a focus on circular economy principles. Learn the principles of implementing circular economy in the production of wooden windows, including the processing and use of production residues, sorting of waste, and recycling principles for windows and doors.</p> <p>Q&A and interactive reflection with participants</p> <p>Instructor: Barbara Šubic, director</p>	M sora, company, Žiri, Slovenia	Oct 24nd/ 12:00-14:00	2 hr

Curriculum Three

Course Name	Topics	Location	Date	Duration
Practical Workshop: Part 1	Selection of reused materials and planning of new products. Work will be performed in groups.	Department of wood science and technology	Oct 25nd/ 8:30-12:30	4 hr
Practical Workshop: Part 2	The initial phase of producing items from reclaimed wood: material cleaning and start of production	Department of wood science and technology	Oct 25nd/ 13:30-17:30	4 hr
Practical Workshop: Part 3	Finalization of new products and presentation to other workshop participants, including a discussion of challenges faced during the process	Department of wood science and technology	Oct 26nd/ 08:30-12:30	4 hr

APPENDIX B: TRAINING MATERIALS FOR TRAINING CURRICULUM

Content: The training material covered five modules as explained in training program above some of the modules were covered from different experts and form different perspectives:

1. Service life of different furniture and wooden products
2. Cascading Use of Wood and Characterization of Recycled Wood on the European Market
3. Recycled Wood in Wood-Based Composites
4. Contemporary sustainable materials for the surface treatment of wood and for products in the wood industry
5. New production Technologies for Furniture Production
6. Designing Furniture from Reused Materials - How to repair furniture with new techniques
7. Materials in furniture production - sustainable materials utilization
8. Sustainable and circular practices in M sora company

All training materials are available on the project website or via the [provided link](#).

APPENDIX B

TRAINING MATERIALS FOR TRAINING CURRICULUM

Content: The training material covered five modules as explained in training program above some of the modules were covered from different experts and form different perspectives:

1. Service life of different furniture and wooden products (prof. Miha Humar)
2. Cascading Use of Wood and Characterization of Recycled Wood on the European Market
3. Recycled Wood in Wood-Based Composites
4. Contemporary sustainable materials for the surface treatment of wood and for products in the wood industry
5. New production Technologies for Furniture Production
6. Designing Furniture from Reused Materials - How to repair furniture with new techniques
7. Materials in furniture production - sustainable materials utilization
8. Sustainable and circular practices in M sora company

Service life of different furniture and wooden products

Miha Humar

University of Ljubljana, Biotechnical Faculty

Univerza v Ljubljani
Biotehniška fakulteta



1

Service life

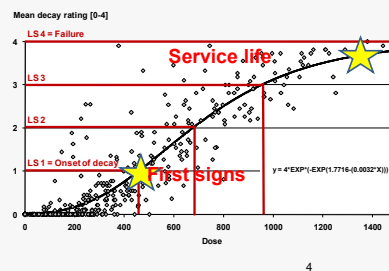


2



3

Service life



4

Service life

→ aesthetic



5

New facility



6

New building - house



7

After 2 years



8

After three years



9

October 2013



October 2016

10

	Oct 2013	Dec 2013	Mar 2014	May 2014	Aug 2014	Oct 2014	Apr 2015	Oct 2015	Apr 2016	Oct 2016	May 2017	Oct 2017
PA	7.36	10.48	15.04	17.80	22.27	29.76	34.24	34.83	35.55	36.16	36.07	
PA-NW	5.89	11.24	10.77	12.06	16.20	24.55	24.53	28.76	27.22	33.30	33.28	
PA-AC	3.87	7.67	2.92	3.85	5.23	11.40	13.70	13.81	16.53	19.27	20.24	
PA-CE	5.03	2.27	5.00	3.74	2.85	5.49	10.08	10.77	15.05	17.50	18.25	
PA-CE-NW	5.57	6.53	10.12	10.45	10.44	6.74	7.73	9.51	8.58	10.72	12.62	
PA-TM	8.90	10.82	12.88	15.12	18.01	18.90	16.02	15.19	13.97	15.46	16.40	
PA-TM-NW	2.87	4.27	4.48	4.36	8.55	9.17	8.36	12.51	10.10	12.93	13.54	
PA-TM-CE	2.84	7.61	11.83	11.14	8.97	9.54	8.92	10.28	9.20	10.83	12.07	
LD	8.25	0.82	1.27	3.74	8.94	18.97	22.34	25.07	26.96	30.93	32.60	
LD-TM	9.40	6.40	5.26	8.85	9.94	10.63	10.53	11.12	9.55	10.18	10.08	
FS	4.17	7.54	5.52	7.48	11.17	15.35	21.03	22.96	17.11	22.08	23.05	
Q	9.61	3.45	5.79	10.39	11.94	16.48	16.87	21.91	23.11	24.82	25.27	

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12



13



14



15



16



17



18

Aesthetic SL



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Table



21

Perception



22

Perception



23

Service life

→ Resistance to water performance



24

24



25

25



26

26



27

27

Water performance - dimensional stability



28

28

Dimensional stability



29

Moisture - Composites



30

Moisture CLT - 2013



31

2013



32

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2014



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2015



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2018



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The wrong adhesives?



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Experiment



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Results



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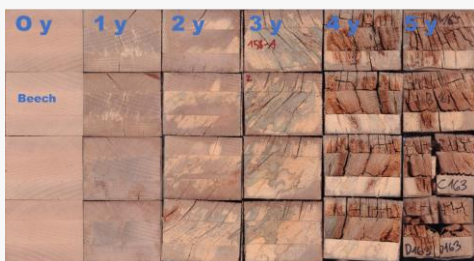
Results - decay - Spruce



40

41

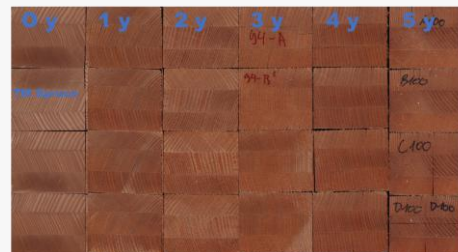
Results - decay - Beech



41

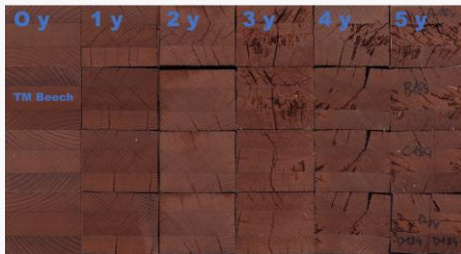
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Results - decay - TM spruce



42

43

Results - decay - TM Beech

43

Service life

→ Resistance/Durability/Functionality



44

44

Service life

45

45

Service life - arboretum

46

Functionality

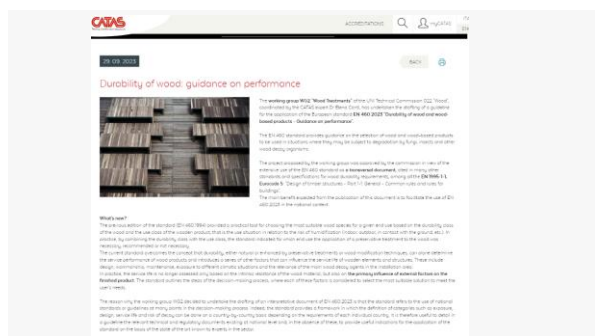
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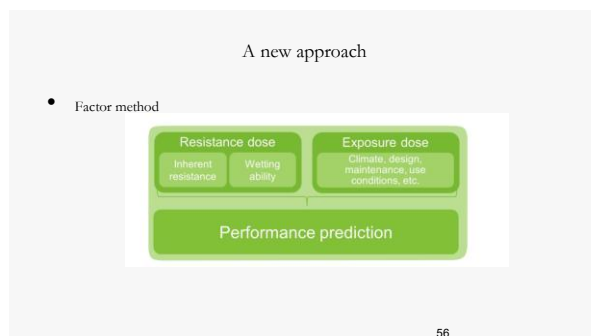
Functional Service life

48

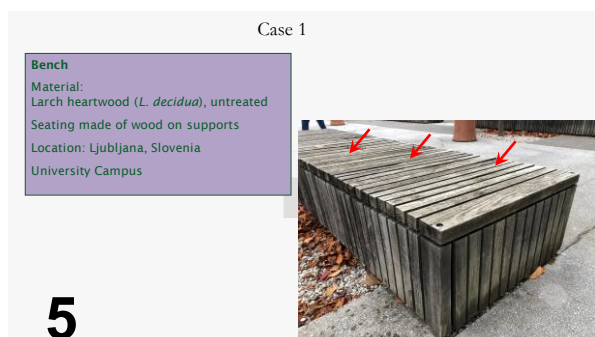
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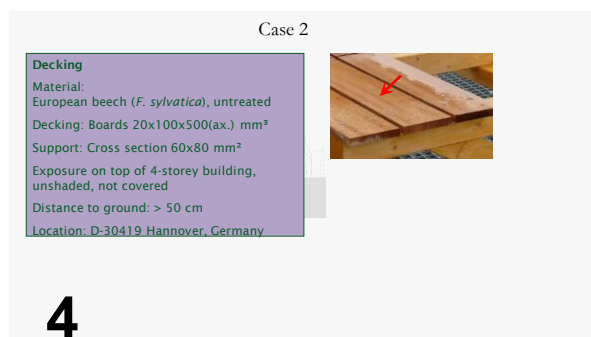
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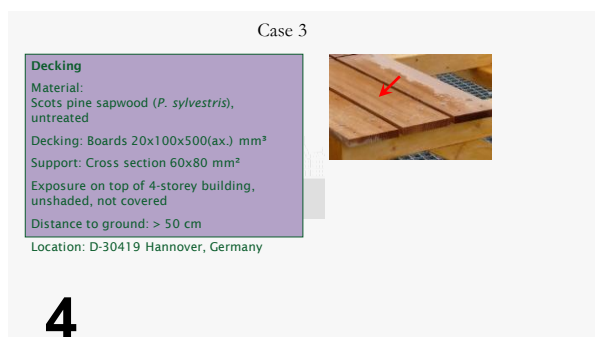
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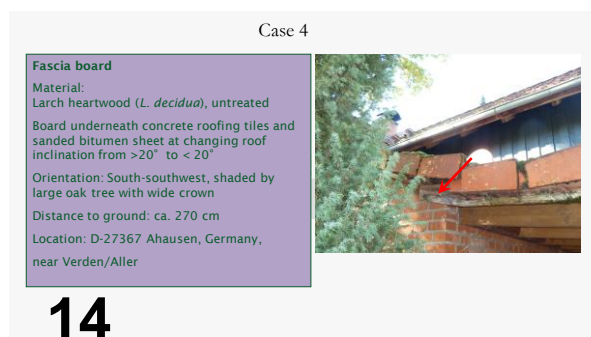
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Case 5

Board-on-board cladding

Material:
Norway spruce (*P. abies*), untreated

Board-on-board cladding: Boards planed 20x100x500(ax.) mm³

Overlap: ca. 20 mm

Exposure on top of 4-storey building, unshaded

Distance to ground: > 50 cm

North oriented, not ventilated, but air space behind boards

Location: D-30419 Hannover, Germany



6

61

Pedestrian bridge - Pillar

Material:
Norway spruce (*P. abies*)
glulam
surface treated with
'wood protection primer',
'wood protection stain' &
'weather protection stain'

V-pillars made from glulam elements shear-resistantly connected by bolts and nail plates

Location: D-93343 Essing, Altmühl valley, Germany

Case 6



16

62

Case 7

Pedestrian bridge - Trusses

Material:
Norway spruce (*P. abies*)
glulam
surface treated with
'wood protection primer',
'wood protection stain' &
'weather protection stain'

Main trusses, connectors are bolts and nail plates

Drainage of rain water from bridge flooring via metal sheets

Location: D-93343 Essing, Altmühl valley, Deutschland



9

63

Case 8

Decking

Material:
European beech (*F. sylvatica*), untreated

Decking: Boards 20x100x500(ax.) mm³

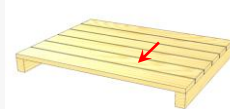
Gaps between boards: 20 mm

Support: Cross section 60x80 mm²

Exposure at half-shaded garden area, underground: gravel

Distance to ground ~ 20 cm

Location: D-30419 Hannover, Germany



1

64

Case 9

Decking

Material:
Norway spruce (*P. abies*), untreated

Decking: Boards 20x100x500(ax.) mm³

Gaps between boards: 20 mm

Support: Cross section 60x80 mm²

Exposure at half-shaded garden area, underground: gravel

Distance to ground ~ 20 cm

Location: D-30419 Hannover, Germany



3

65

Case 10

Cycling track

Material:
Merbau heartwood (*Intsia spp.*), untreated

Velodrome track
Fully exposed

Planks notched, but installed without gaps

Substructure: preservative treated Norway spruce

Location: Novo mesto, Slovenia
(ca. 60 km south of Ljubljana)



22

66

Case 11

Balcony decking

Material:
Douglas fir heartwood
(*P. menziesii*), untreated, surface
coated

Planks' cross section: 20 x 120 mm²

Location: Reinhausen, Germany,
near Göttingen

**5**

67

Case 12

Road bridge

Overspanning the Ljubljana
Beam covered by preservative
treated board

Location: Ljubljana, Slovenia

Material:
Norway spruce glulam
(*P. abies*), untreated, coated

**9**

68

Case 13

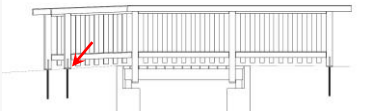
Railing of wooden bridge

N-S-oriented, shaded by trees

Railing post without distance to concrete
fundament

Location: D-30519 Hannover-Kirchrode, Germany

Material:
English oak heartwood (*Q. robur*), untreated

**5**

69

Case 14

Inclined climbing wall on children playground

Partly shaded

Boards screwed onto each other

Location: Ljubljana, Slovenia

Material:
Norway spruce (*P. abies*),
impregnated with
copper-chromium-boron preservative
(Retention: 6 kg /m³)

**28**

70

Case 15

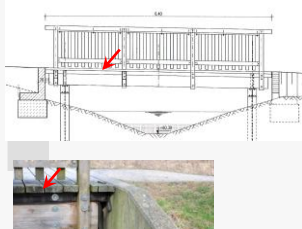
Bridge flooring

Material:
Larch heartwood (*L. decidua*),
untreated

Not shaded

Flooring separated from
underconstruction by foil

Location: Hannover-Kirchrode,
Germany

**6**

71

Case 16

Screen

Material:
Oil-heat treated Norway spruce
(*P. abies*)

Overgrown by smartweed

Distance to ground: ca. 20 cm

Location: D-27367 Ahausen,
Germany

near Verden/Aller

**14**

72

Case 17

Outside trim of hunting cabin

Material:
Norway spruce (*P. abies*), untreated

Unshaded, not covered

Distance to ground: ca. 200 cm

Location: Ny Ålesund, Svalbard, Norway



85

Case 18

Covered window board

Material:
Norway spruce (*P. abies*),
untreated, but partly painted

Unshaded

Roof overhang: ~ 15 cm

Distance to ground: ca. 150 cm

Location: Ås, Southern-Norway

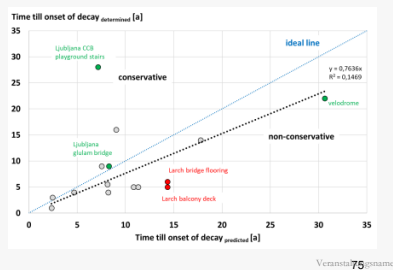


16

73

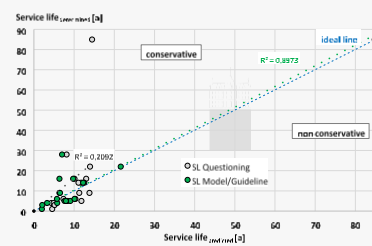
74

Use of expert opinion



Veranst76gname

Use of model

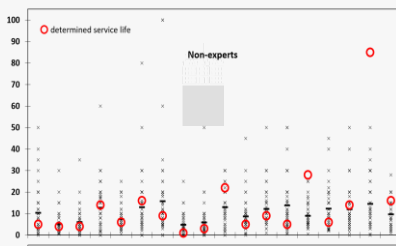


Veranst76gname

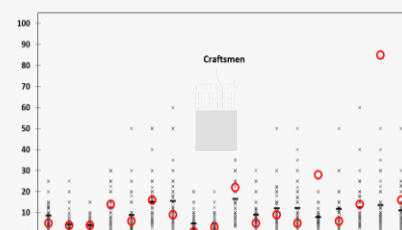
75

76

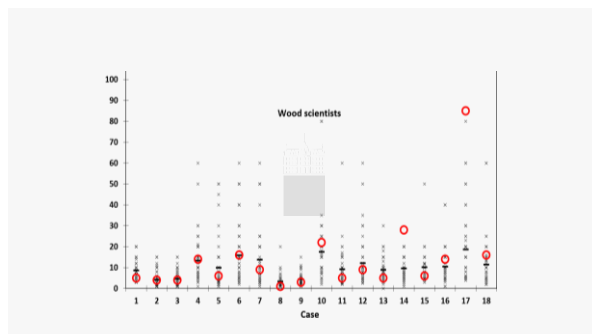
Estimated service life [a]



77



78



79

Wood as building material



80

Wood as building material



81

Is wood protection still required?



82

Wood and decay



83



Vyhádková trasa Aichelburg - Horní Mladá

84



<http://www.blesk.cz/>

85



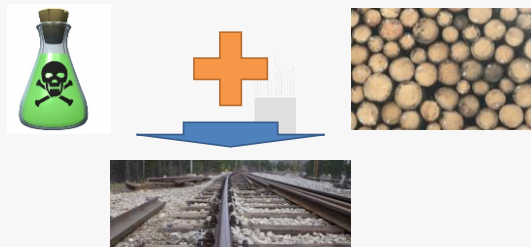
<http://www.blesk.cz/>

86



87

What is wood protection? - Yesterday



88

Changes in Europe 1998 – 202X

- Legislation (BPD, BPR, REACH ...)
 - Ban of classic biocides in EU
 - 50 out of 98 biocides for wood protection were banned. Trend is continuing.
- Protection of tropical forests
- „Eco, bio“ trends
- Development of wood modification
- **Increased importance of domestic wood species.**

www.greenpeace.org



89

What is wood protection today?

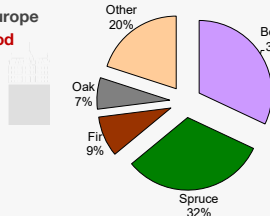
- **Selection of wood**
 - Better understanding of wood
- **Protection of wood**
 - Biocides
 - Modification
- **Protection by construction**
- **Maintenance**



90

Domestic (Slovenia, Europe) wood species

- 90% of wood species in Europe does not have **durable wood**



91

Climate changes

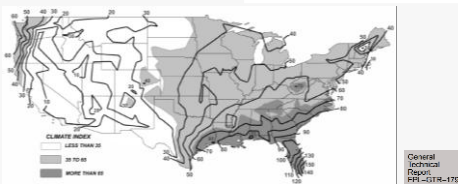


<https://www.aveine.paris/blog/en/climate-change-and-wine-impacts-and-consequences/>

92

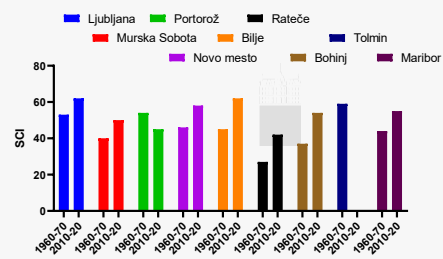
Scheffer climate index

$$\text{Index} = \frac{\sum_{\text{Jan}}^{\text{Dec}} [(T - 2)(D - 3)]}{16.7}$$



93

Scheffer climate index



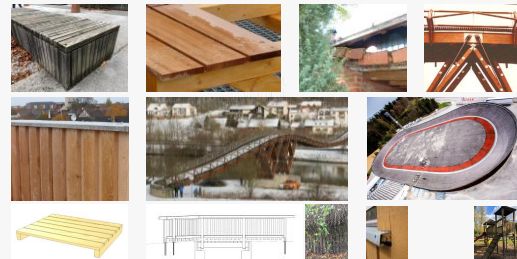
94

Can we rely on expert opinion?



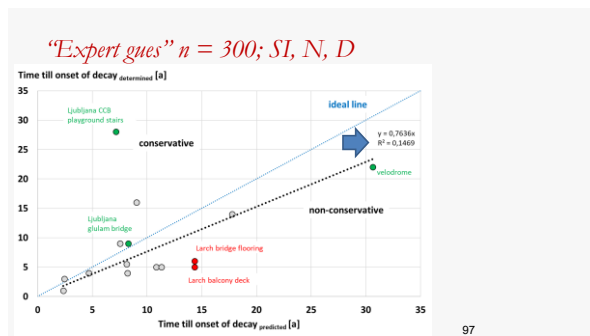
95

"Questionnaire" n = 300; SI, N, D

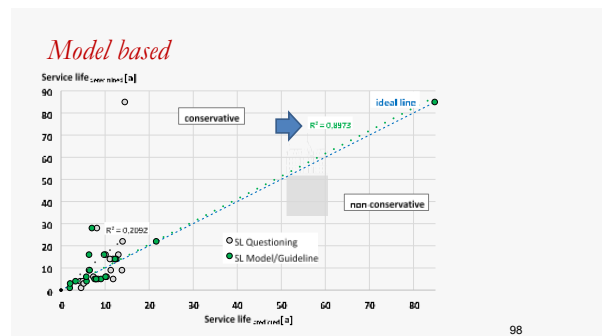


96

96



97



98

We should rely on models

- How to test all of the materials to get reliable results to be used for model?



99

Model house (2013 -2023 ...)

Wood species	Treatment
Norway spruce	Untreated
	Treated with montan wax
	Surface coated with acrylic coating
	Treated with copper-ethanolamine s
	Thermally modified
European larch	Thermally modified and impregnates
	Thermally modified and impregnates
	Thermally modified and coated with
	Thermally modified
Beech	Untreated
Swiss chestnut	Thermally modified and impregnates
Scotts pine sawwood	Untreated
Scotts pine heartwood	Untreated
Black poplar	Thermally modified
Ash	Untreated
	Thermally modified



100

Model house 2021



101

Monitoring

- Color changes
- Fungal disfigurement
- Corrosion
- Moisture content (160 MC sensors), Scantronik Gigamodule
- Temperature



102

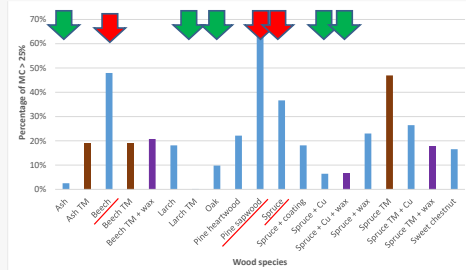
Decay

- Service life of wood in above-ground applications is a function of
 - Inherent durability (extractives ...)
 - Water exclusion efficacy



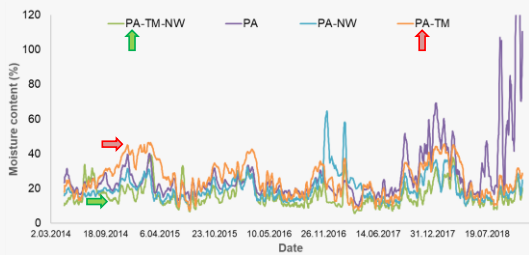
103

Decking, percentage of MC > 25% (n = 5900) 2013-21



104

MC of spruce based materials on decking of model house



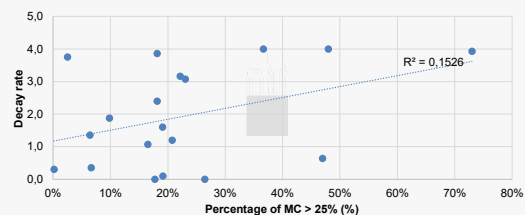
105

Decking, decay after 9 years (EN 252)

	2014	2015	2016	2017	2018	2019	2020	2021	2022
Spruce	0,0	1,0	2,4	3,7	4,0	4,0	4,0	4,0	4,0
Beech	0,0	1,0	2,2	3,1	3,7	3,9	4,0	4,0	4,0
Ash	0,0	0,0	1,0	1,4	2,1	3,3	3,8	4,0	4,0
Spruce + coating	0,0	0,0	0,8	1,6	3,0	3,6	3,9	3,9	4,0
Pine sapwood	0,0	0,6	1,2	2,2	3,1	3,6	3,9	3,9	4,0
Spruce + Wax	0,0	0,0	0,2	1,1	1,9	2,7	3,1	3,1	3,5
Pine HW	0,0	0,0	0,6	1,5	2,3	2,6	3,2	3,3	3,3
Spruce + CuEA	0,0	0,0	0,0	0,0	0,0	1,4	1,7	2,9	
Beech TM	0,0	0,0	0,0	0,0	0,6	1,6	1,8	2,8	
Larch	0,0	0,0	0,6	1,3	1,6	2,2	2,4	2,5	2,7
Oak	0,0	0,0	0,0	0,5	0,9	1,4	1,9	1,9	2,2
Sweet chestnut	0,0	0,0	0,0	0,0	0,0	1,1	1,4	1,8	
Beech TM + wax	0,0	0,0	0,0	0,0	0,0	1,2	1,4	1,6	
Ash TM	0,0	0,0	0,0	0,0	0,0	0,1	0,5	1,6	
Spruce TM	0,0	0,0	0,0	0,0	0,2	0,4	0,6	0,6	1,1
Spruce + CuEA + Wax	0,0	0,0	0,0	0,0	0,0	0,4	0,6	0,9	
Spruce TM + Wax	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,8	
Larch TM	0,0	0,0	0,0	0,0	0,1	0,1	0,3	0,3	0,5
Spruce TM + CuEA	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	

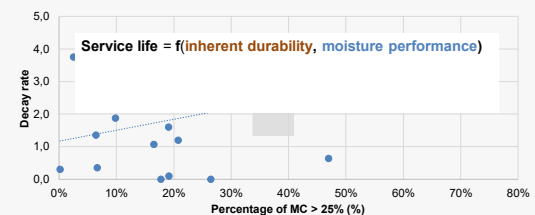
106

Decking, decay vs MC



107

Decking, decay vs MC



108

Factor approach to quantify the resistance dose (Veltrup-Meyer et al. 2017)

- Corresponding lab test data for k_{inh} and k_{wa}

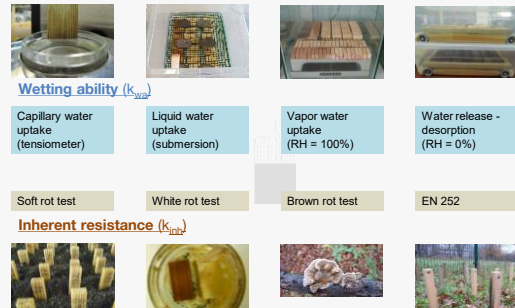
Wetting ability (k_{wa})

Capillary water uptake (tensiometer)	Liquid water uptake (submersion)	Vapor water uptake (RH = 100%)	Water release - desorption (RH = 0%)
--------------------------------------	----------------------------------	--------------------------------	--------------------------------------

Inherent resistance (k_{inh})

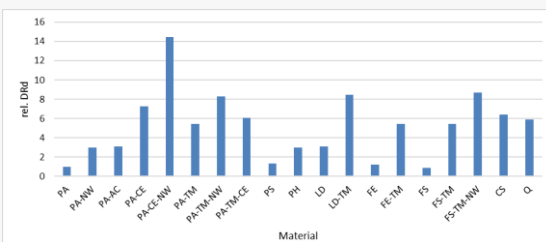
Soft rot test	White rot test	Brown rot test
---------------	----------------	----------------

109



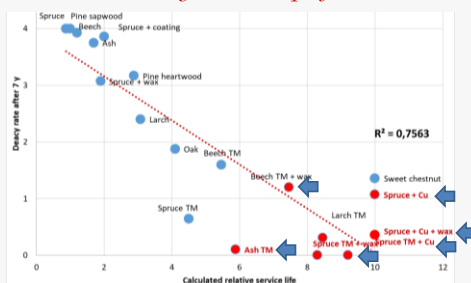
110

Relative durability – material resistance - factor



111

Relative durability vs actual performance



112

Validation

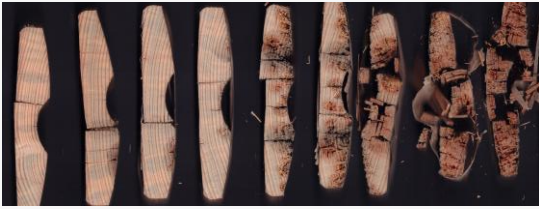


113

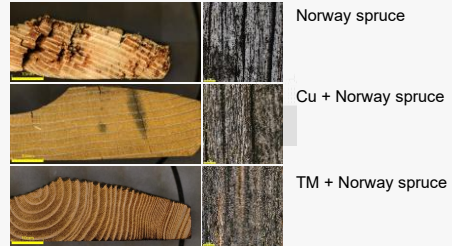
Roof



114

Spruce shingles

115

Shingles

116

Shingles

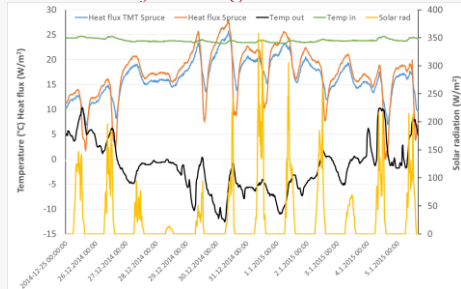
117

Windows

118

Thermal conductivity - windows

119

Results - Heat flux through window

120

Modified wood – few examples



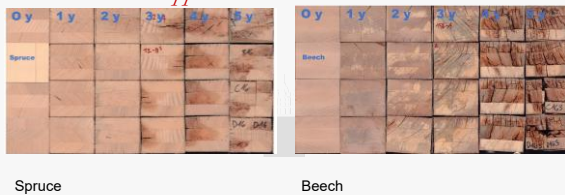
121

What are other potential applications?



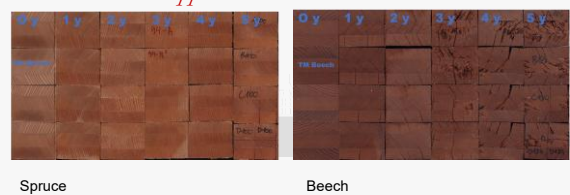
122

Beams – visual appearance



123

Beams – visual appearance



124

Demo object 2.0 – Mozirje



- First object made of TM wood in Slovenia
- Made of TM modified spruce wood
- House located in the park
- **Finished in 2008**
- Monitoring: March 2015
- 8 MC measurements

125

Demo object



<https://grof.eu/>

126

Technical equipment

- Scanntronik equipment
 - Gigamodule – MC
 - RH and temperature sensors
 - Themofox – data logger



127

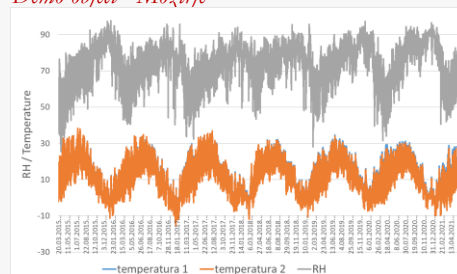


128



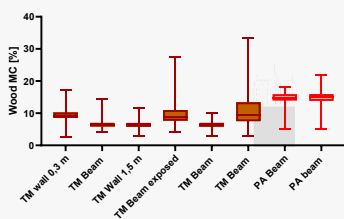
129

Demo object - Mozirje



130

Demo object – Mozirje (n = 4500)



131

Demo object 3.0 – Ljubljana - 2015



132

Visual appearance

2008



2018



133

Visual appearance



134

Colour changes of the facade of the model object

	Oct 2013	Dec 2013	Mar 2014	May 2014	Aug 2014	Oct 2014	Apr 2015	Oct 2015	Apr 2016	Oct 2016	May 2017	Oct 2017
PA	1.98	10.46	15.04	17.80	22.27	26.76	34.24	34.83	35.55	36.16	39.07	
PA-NW	6.05	11.24	10.77	10.06	16.30	24.05	24.93	26.76	27.22	33.30	33.28	
PA-AC	3.67	7.67	2.92	3.85	5.23	11.40	13.70	13.81	16.53	19.27	20.24	
PA-CE	5.03	2.27	5.80	3.74	2.89	5.49	10.08	13.77	15.65	17.50	19.25	
PA-CE-NW	8.57	5.53	10.12	10.45	10.44	5.74	7.73	9.51	8.58	10.72	12.62	
PA-TM	8.80	10.82	12.88	15.12	16.25	16.30	16.02	15.79	13.97	15.48	16.40	
PA-TM-NW	2.67	4.27	4.46	4.36	8.05	8.17	9.36	12.51	15.10	12.93	13.64	
PA-TM-CE	2.84	7.61	11.83	11.14	8.97	9.54	8.92	10.28	9.20	10.83	12.07	
LD	8.25	6.62	7.21	5.74	8.94	16.97	22.34	25.07	26.96	30.93	32.60	
LD-TM	9.40	6.40	6.26	8.85	9.04	10.83	10.93	11.12	9.55	10.18	10.08	
FS	8.17	2.64	5.50	2.48	11.17	16.36	21.03	22.96	17.11	22.08	23.00	
Q	9.83	5.45	6.78	10.39	11.84	16.48	18.87	21.91	23.31	24.82	25.27	

135



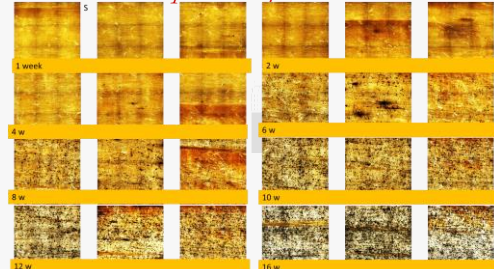
136

Why do color change, how to simulate weathering?

	Control	1 st EN152	100 h of AW	200 h of AW	300 h of AW	400 h of AW	500 h of AW	2 nd EN152	Natural weathering
PA	1.98	10.46	15.04	17.80	22.27	26.76	34.24	34.83	Oct 2016: 35.55, May 2017: 36.16, Oct 2017: 39.07
PA-NW	6.05	11.24	10.77	10.06	16.30	24.05	24.93	26.76	Oct 2016: 27.22, May 2017: 33.30, Oct 2017: 33.28
PA-AC	3.67	7.67	2.92	3.85	5.23	11.40	13.70	13.81	Oct 2016: 16.53, May 2017: 19.27, Oct 2017: 20.24
PA-CE	5.03	2.27	5.80	3.74	2.89	5.49	10.08	13.77	Oct 2016: 15.65, May 2017: 17.50, Oct 2017: 19.25
PA-CE-NW	8.57	5.53	10.12	10.45	10.44	5.74	7.73	9.51	Oct 2016: 8.58, May 2017: 10.72, Oct 2017: 12.62
PA-TM	8.80	10.82	12.88	15.12	16.25	16.30	16.02	15.79	Oct 2016: 13.97, May 2017: 15.48, Oct 2017: 16.40
PA-TM-NW	2.67	4.27	4.46	4.36	8.05	8.17	9.36	12.51	Oct 2016: 15.10, May 2017: 12.93, Oct 2017: 13.64
PA-TM-CE	2.84	7.61	11.83	11.14	8.97	9.54	8.92	10.28	Oct 2016: 9.20, May 2017: 10.83, Oct 2017: 12.07
LD	8.25	6.62	7.21	5.74	8.94	16.97	22.34	25.07	Oct 2016: 26.96, May 2017: 30.93, Oct 2017: 32.60
LD-TM	9.40	6.40	6.26	8.85	9.04	10.83	10.93	11.12	Oct 2016: 9.55, May 2017: 10.18, Oct 2017: 10.08
FS	8.17	2.64	5.50	2.48	11.17	16.36	21.03	22.96	Oct 2016: 17.11, May 2017: 22.08, Oct 2017: 23.00
Q	9.83	5.45	6.78	10.39	11.84	16.48	18.87	21.91	Oct 2016: 23.31, May 2017: 24.82, Oct 2017: 25.27

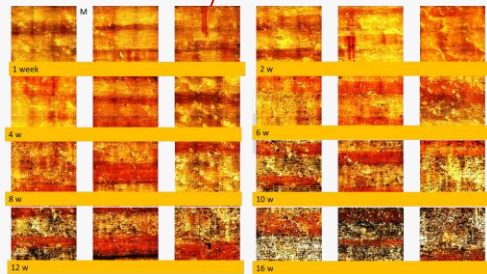
137

Blue stain development - Spruce



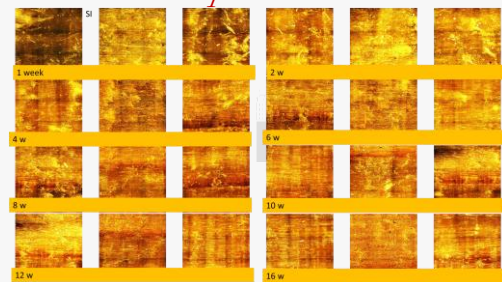
138

Blue stain development - Larch



139

Blue stain development - CuEA



140

Prediction of service life is possible



141

Acknowledgement

ARRS (P4-0015, L4-7547, IC LES-PST)

Woolf, Wintherwax

Durasoft

ReWinUse

MKGP (CRP: V4-1818, V4-2017)

OneForest



142

Questions

- Miha.humar@bf.uni-lj.si



143

Cascading use of wood and Characterization of recycled wood on the European market

Assoc. Prof. Boštjan Lesar

Ljubljana, 24.09.2025

1

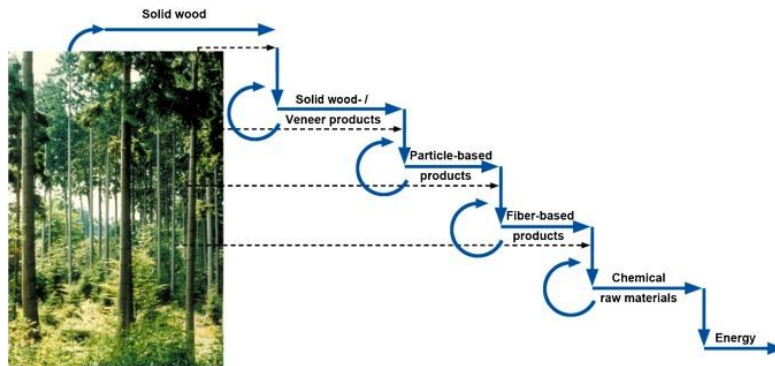
UL | BF

Content

Cascading use of
woodCase studies use
of recycled woodSorting systems
for recycling woodCharacterization of
recycled wood on
European market

2

Cascading use of wood



Höglmeier et al. 2017

28/09/2025

3

3

Cascading use of wood

Wood is material with at list two or three use cycles

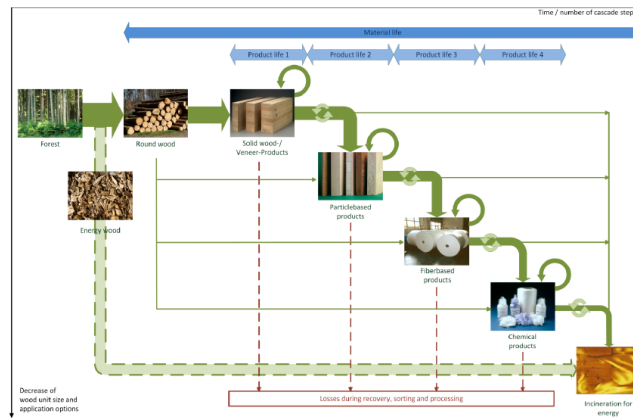
1. **Product** (solid wood, Sawn wood, construction wood, furniture)
2. **Material in recycle process** (wood based composites, paper,...)
3. At the end of cascading, use for **green energy**

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4

4

Cascading use of wood



(Höglmeier 2014)

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5

5

Way to use wood in cascades

- **Demand** for wood and wood based products from natural forest resources **is increasing**
 - population growth
 - political changes
 - increased environmental awareness and a shift of EU policies to the circular- and bio-economy



28/09/2025

6

6

Way to use wood in cascades

Forest resources are limited

Challenge:

from 2020 to 2030 the demand will exceeds supply of wood



Need for use of wood in cascades

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7

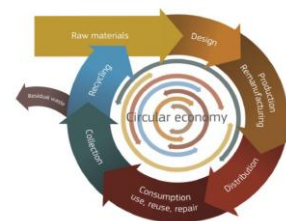
7

Benefits of cascading use

- Increased added value of wood
- Protection of forest resources
- More green jobs
- Opportunity - circular economy



Added value for use of wood only for energy supply is very low.

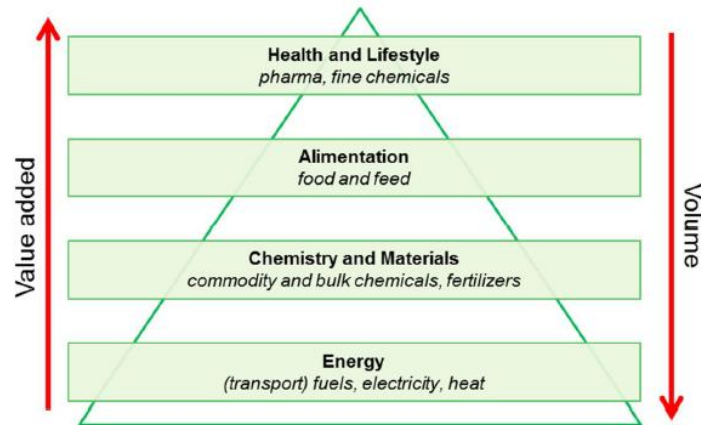


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8

8

The value pyramid used to classify biomass application



Based on Ministerie van LNV, 2007

Odegard et al. 2012

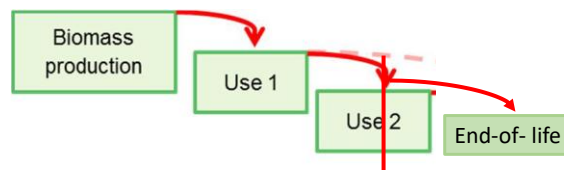
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9

9

Cascading factor in EU

- 1.00 when only wood directly from trees is used
- The total cascading factor in Europe (EU27) is 1.57 (2010)



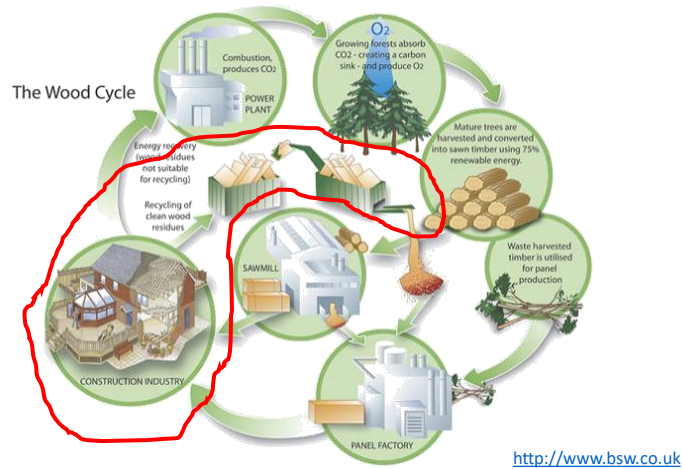
Source: Mantau 2012

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10

10

Wood cycle



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11

11

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Waste wood in EU in 2010

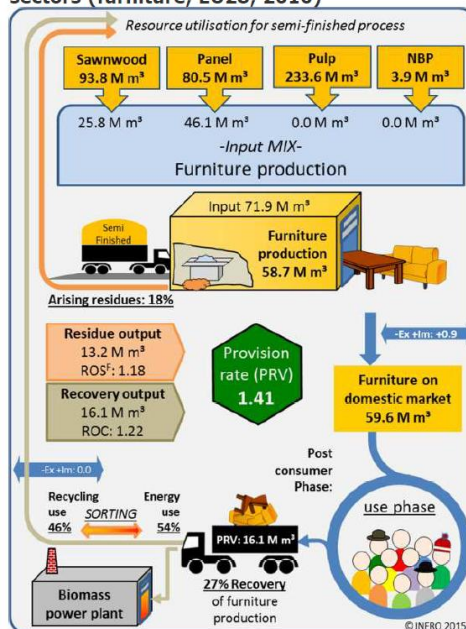
- In the EU in 2010, 52.3 million m³ of waste wood was available, of which 36.4 million m³ was collected:
- **32%** for material use,
- **37%** for energy,
- **30%** still ended up in landfills.
- **The paper industry** has the highest recycling rate (97% of collected paper goes back into the industry).

Source: VIS at al, 2016 doi: 10.2873/827106

12

12

Figure 8: Calculation scheme for the end-use sectors (furniture; EU28; 2010)



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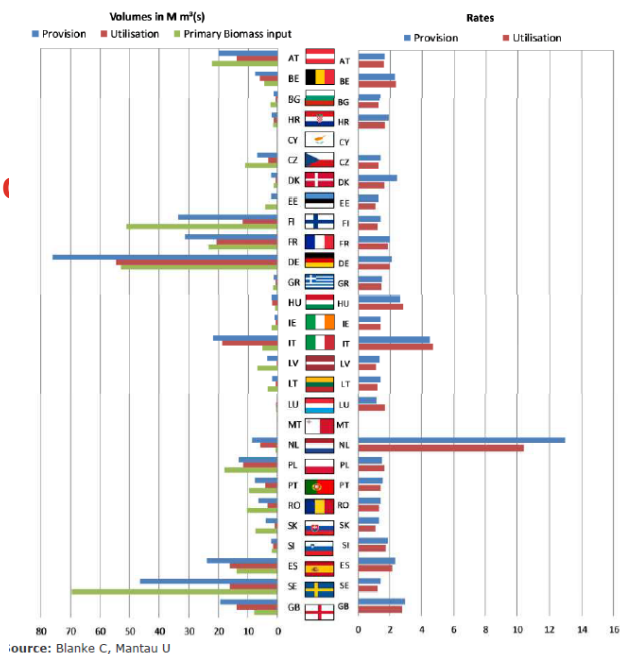
Source: Blanke C, Mantau U 2016

13

13

Provision and utilisation volumes and rates of cascading materials in the EU28

<http://ec.europa.eu/DocsRoom/documents/18081/attachments/1/translations/en/renditions/pdf>



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14

14

Main barriers to cascading use

- technical (contamination of waste wood, difficulties in separation and cleaning),
- market (dependence on primary products, low price of fresh wood compared to the costs of collecting and cleaning waste wood),
- governance (different legislation, lack of standards, separate collection not mandatory in all countries).
- The greatest potential for improvement** lies in increasing the use of industrial residues for material purposes (instead of energy) and in better utilization of waste wood.

Source: VIS at al, 2016 doi: 10.2873/827106

15

15

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Recycled wood

Recycled wood is wood that has already gone through at least one utilisation stream

Synonyms:

- Recovered wood
- Recycled waste wood
- **Post consumed wood**
- Altholz (DE)

Recycled wood **≠ wood residues**



16

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16

Recycled wood

- Construction wood
- Old furniture
- Packaging material
- ...



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17

17

Recycled wood is not

- Industry wood residues
- Forestry residues



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18

18

Recycled wood

- Quality is uniform
- Dimensions
- Age
- Decay
- Surce
- **Pollutants**



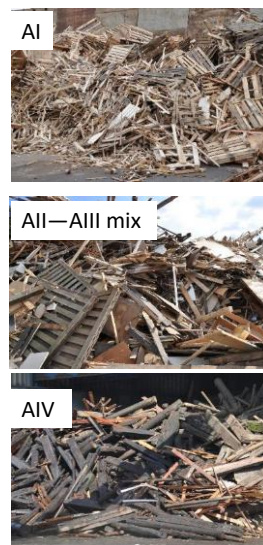
19

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19

Recycled wood - clasification

- In Europe is no common classification ordinance for RW
- Altholzverordnung – German ordinance
 - **AI** - only mechanically treated
 - **AII** - surface treated without halogenated organic compounds
 - **AIII** - surface treated with halogenated organic compounds
 - **AIV** – treated with biocides
 - **PCB Altholz** - RW treated with PCB



20

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20

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A I recycled wood (RW)



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21

21

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A II recycled wood (RW)



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22

22

A III recycled wood (RW)



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23

23

A IV recycled wood (RW)



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24

24

Intended use

Class	Intended application
A I	Material use (energy possible)
A II	Material use (energy possible)
A III	Energy use (material use only with prior processing)
A IV	Energy use in large-scale combustion facilities
PCB	Non-hazardous disposal

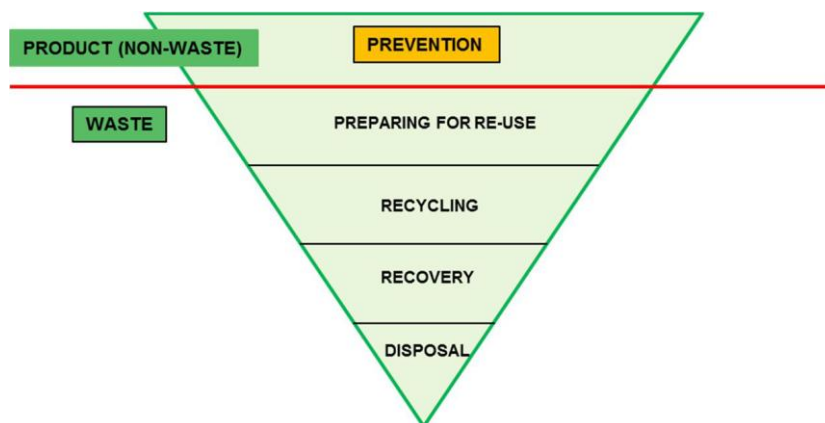
K. Höglmeier et al. / Resources, Conservation and Recycling 78 (2013) 81– 91

25

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25

The waste hierarchy according to the Waste Framework Directive

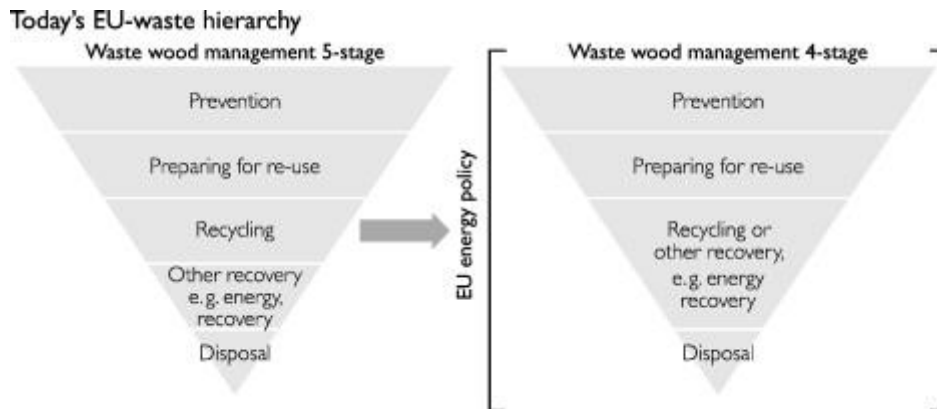


26

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26

The waste hierarchy – EU energy policy



<http://dx.doi.org/10.1016/j.forpol.2014.12.003>

28/09/2025

27

27

Consumption of woody biomass in Germany

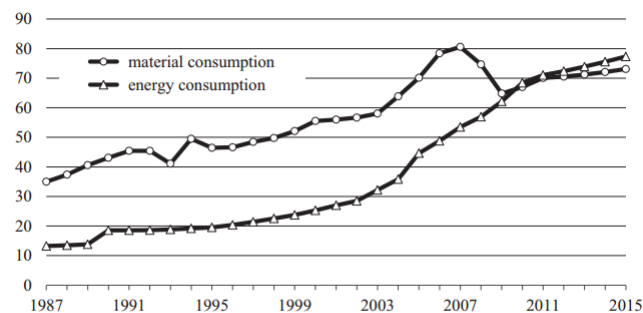


Fig. 2 – Consumption of woody biomass for material and energy uses in Germany in hm^3 [14].

Source: Mantau, 2015

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28

28

Recycled wood used for material and energy

Table 13: Material application, energy application and disposal of used wood in Member States (thousands m³) in order of decreasing disposal.

Country	Material	Energy	Disposed	Country	Material	Energy	Disposed
United Kingdom	2,194	2565	2,748	Lithuania	51	60	172
Poland	363	424	2,667	Austria	463	541	136
Spain	1,016	1188	1,962	Netherlands	1,076	1,258	123
Italy	2,047	2393	1,761	Estonia	32	37	107
Romania	247	289	1,199	Croatia	91	106	95
Germany	3,489	4079	1,141	Denmark	551	644	89
France	2,522	2949	825	Slovakia	59	69	88
Greece	124	144	599	Sweden	438	513	70
Portugal	98	115	515	Cyprus	23	27	67
Czech Republic	119	139	479	Finland	515	603	51
Hungary	76	89	371	Bulgaria	44	52	46
Ireland	161	188	238	Slovenia	48	56	27
Belgium (Flanders)	856	1000	234	Malta	5	5	13
Latvia	36	42	174	Luxembourg	8	9	3
				EU28	16,753	19,587	15,999

Source: Leek (2010)

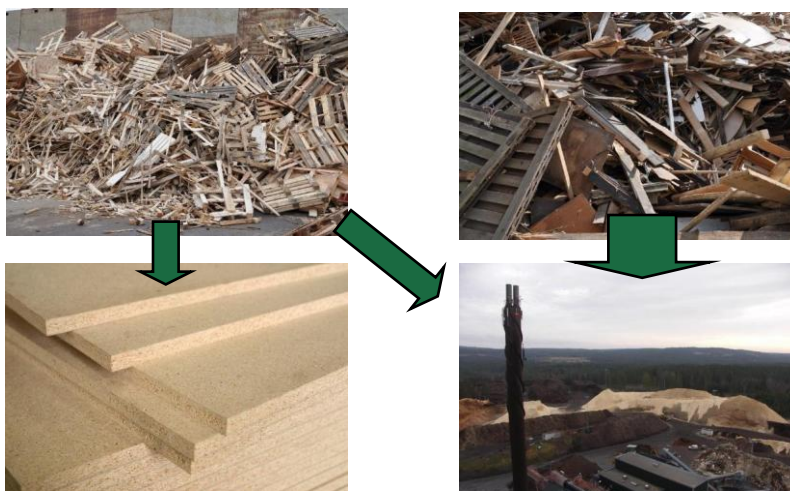
29

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29

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Use of recycled wood - today

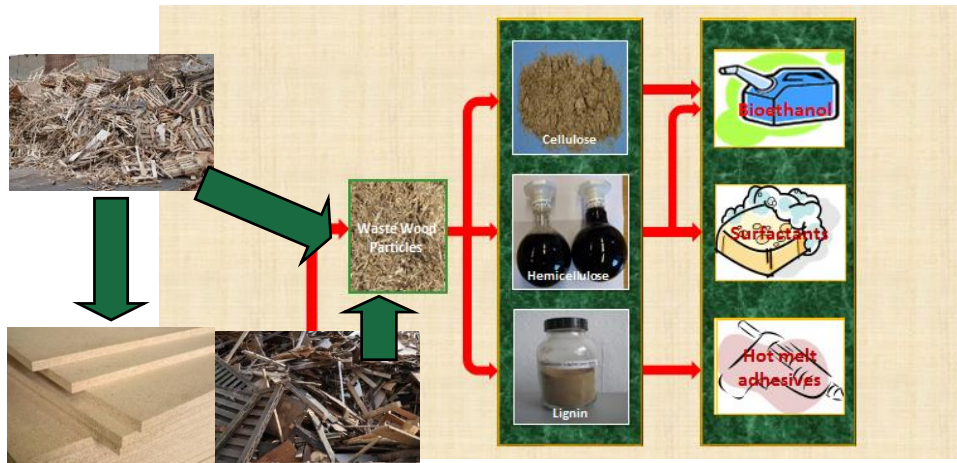


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30

Use of recycled wood – tomorrow

- Today use + biorafineries



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31

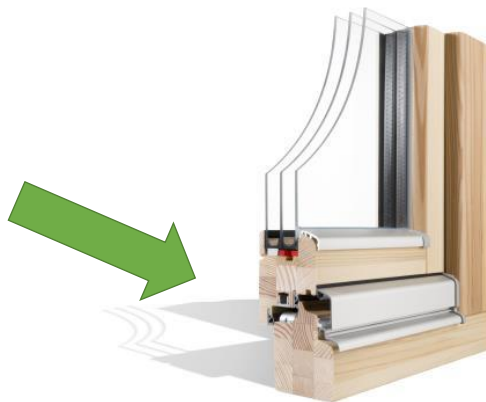
Case studies

32

32

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New window from old windows



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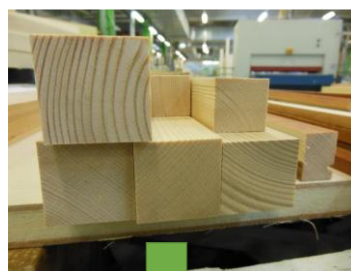
Foto: A. Ugovšek, M SORA d.d.

33

33

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New window from old windows



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Foto: A. Ugovšek, M SORA d.d.

34

34

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New window from old windows



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Foto: A. Ugovšek, M SORA d.d.

35

35

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Prototypes from recycled woodn windows



Foto: A. Ugovšek, M SORA d.d.

36

36

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Shelters from recycled wood -Denmark



37

<https://www.naeste.dk/boligselskaber>

37

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Shelters from recycled wood - Denmark



38

<https://www.naeste.dk/boligselskaber>

38

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Re use case in Albania



39

39

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From old to new

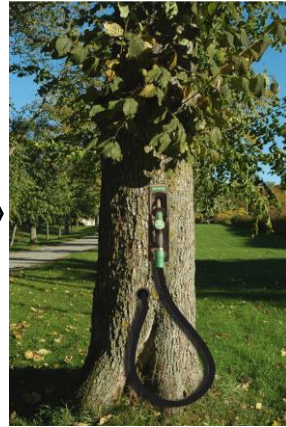


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40

Other options

- Use of Recycled wood in biorafineries for products with high added



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41

41

Colection and sorting of recycled wood

42

42

Collection and sorting of RW in Slovenia



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43

43

Recycled wood from household



<https://www.moja-dejavnost.si/odvoz-smeti-logatec/komunalno-podjetje-logatec-doo>

44

44

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Recycled wood from household



<https://old.delo.si/>

45

45

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Collection center



46

46

Sorting systems for RW

- Big companies - sortig line
- Small companies only mill



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47

47

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Milling of RW


<https://www.tisa.si/>

48

48

Sorting system in German recycling company for AI an AI-AIII RW



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49

49

Sorting system in German recycling company 2



28/09/2025

50

50

Sorting system in German recycling company manual sorting



28/09/2025

51

51



28/09/2025



52

52

Second hammer mill



28/09/2025

53

53

Sieves and dust removal system



28/09/2025

54

54

Fine fraction removing and electrical magnets



28/09/2025

55

55

Storage of RW



28/09/2025

56

56

Transport of RW



28/09/2025

57

57

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Characterization of recycled wood (AI and AI-III mixture) on European market

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58

58

Material and methods

- Sampling of RW from September 2014 - October 2015

Mark	Country of origin	Type of company	Annual process capacity (t)	Quality*	Sampling schedule
GA	Germany	recycling	100.000	A I	2 w
GB	Germany	recycling		A I - A III mix	2 w
S1A	Slovenia	recycling	30.000	A I	2 w - 4 w
S1BS	Slovenia	recycling		A I - A III mix S	2 w - 4 w
S1BB	Slovenia	recycling		A I - A III mix B	2 w - 4 w
S1CS	Slovenia	recycling		Softwood chips	8 w
S1CH	Slovenia	recycling		Hardwood chips	8 w
S2B	Slovenia	communal	10.000	A I - A III mix	2 w - 4 w
EA	UK	recycling	~ 300.000	A I	-
EB	UK	recycling		A I - A III mix	-
FA	Finland	recycling	40.000 –	AII	-
FB	Finland	recycling	60.000	AIII	-

28/09/2025

59

59

Sampling in German recycling company

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60

60

Sampling in Slovenian recycling company



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61

61

Sampling in Slovenian communal company



AI and AIII mix – big chip size



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62

62

Methods: Visual assessment of samples

- Wood species
- Composition of samples
- Presence of metals and other non wood materials



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63

63

Results: Visual assessment of samples – Wood species

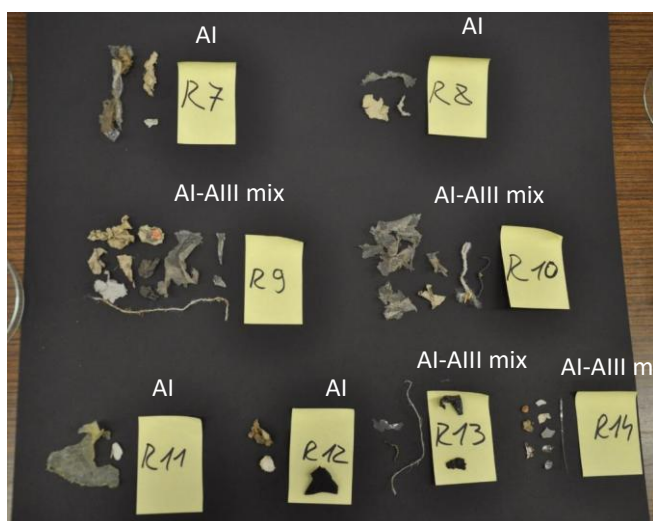
- **AI samples**
 - Norway spruce, pine, poplar, beech, oak, ...
- **AI - All mix samples**
 - Particle boards (cca. 60 % - 80 %)
 - MDF and HDF boards
 - Norway spruce,
 - Beech,
 - Pine,
 - Oak,
 - Robinia

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64

64

Content of non-wooden materials in recycled wood



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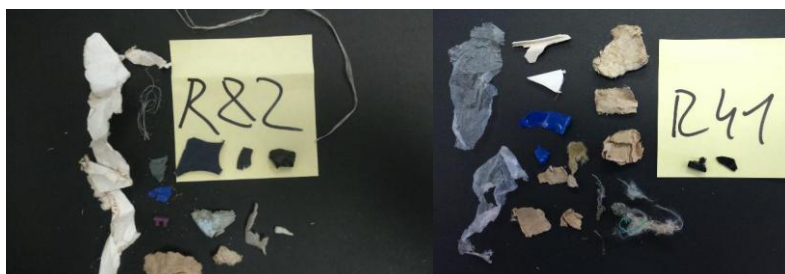
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65

Content of non-wooden materials in samples from German company (GA and GB) (%)

Category	Glass	Metals	Plastic	Fabric	Paper	Stones	Other	Average of total	Max of total	Min of total
Al	0,00	0,00	0,10	0,00	0,09	0,02	0,03	0,22	1,53	0,00
Al-All mix	0,06	0,17	0,35	0,03	0,31	0,03	0,19	1,04	5,58	0,00

114 samples were analyzed



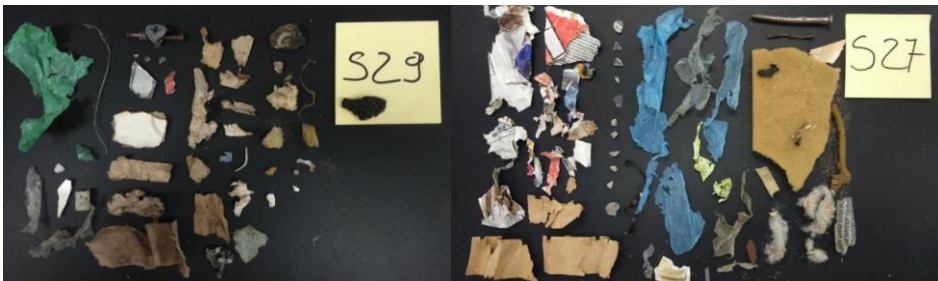
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66

66

Content of non-wooden materials in samples from Slovenian communal company (S2) (%)

Category	Glass	Metals	Plastic	Fabric	Paper	Stones	Other	Average of total	Max of total	Min of total
AI - AIII B	0,16	1,16	0,45	0,44	0,14	0,08	0,21	2,96	6,51	0,85



28/09/2025

67

67

XRF analysis of recycled wood samples



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68

68

Limit values of pollutants - Altholz and EPF

Element/Compounds	Altholz (mg/kg)	EPF, 2004* (mg/kg)
As	2	25
Cu	20	40
F	100	100
Cd	2	50
Cl	600	1000
Cr	30	25
Pb	30	90
Hg	0,4	25
PCP	3	ND
PCB	5	ND

* European panel federation

28/09/2025

69

69

Matrix of waste wood material characteristics

RECYCLED WOOD CATEGORY	Concentration/Number/Percentage	CHEMICAL ELEMENTS IN WASTE WOOD SAMPLES									NON-WOOD MATERIALS IN SAMPLES	
		Cl	Cr	Cu	Fe	Zn	Br	Pb	Ni	Hg	Plastic (%)	Total non wood material (%)
AI*	MIN (mg/kg)	6	0	0	58	5	0	1	0	0	0,0	0,0
	MAX (mg/kg)	708	63	30	751	168	4	15	2	3	0,8	4,3
	AVERAGE (mg/kg)	308	5	4	203	16	0	4	0	0	0,1	0,2
	No. of samples	77	77	77	77	77	77	77	77	77	95	95
	No. above AltholzV limit	2	2	0	-	-	-	0	-	-	-	-
	No. above EPF limit	0	3	0	-	-	-	0	-	-	-	-
	No. above PAS limit	-	0	0	-	-	-	0	-	-	-	-
	% above AltholzV limit	3	3	0	0	0	0	0	0	-	-	-
	% above EPF limit	0	4	0	0	0	0	0	0	-	-	-
	% above PAS limit	0	0	0	0	0	0	0	0	-	-	-
AI-AIII MIX**	MIN (mg/kg)	0	0	0	97	12	0	3	0	0	0,0	0,0
	MAX (mg/kg)	1843	367	193	6855	824	80	155	9	10	4,2	8,4
	AVERAGE (mg/kg)	702	32	15	461	122	2	21	1	0	0,2	1,2
	No. of samples	123	123	123	123	123	123	123	123	123	109	109
	No. above Altholz limit	77	38	27	-	-	-	16	-	-	-	-
	No. above EPF limit	17	52	6	-	-	-	4	-	-	-	-
	No. above PAS limit	-	5	0	-	-	-	0	-	-	-	-
	% above Altholz limit	63	31	22	0	0	0	13	0	-	-	-
	% above EPF limit	14	42	5	0	0	0	3	0	-	-	-
	% above PAS limit	0	4	0	0	2	0	0	0	-	-	-

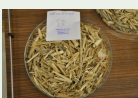

28/09/2025 * AI according to Altholzverordnung, or A - UK classification and AI according to Slovenian companies classification

** AI-AIII according to Altholzverordnung, or B - C UK classification and AI - AIII according to Slovenian companies classification

70

70

Summary Analysis of recycled wood samples – German recycling company


Vzorec	Koncentracija/število/ Procenti	Anorganska onesnažila v odsluženem lesu							
		Cl	Cr	Cu	Fe	Zn	Br	Pb	
 Al	MIN	66	0	0	58	5	0	1	
	MAX	708	39	30	322	168	4	10	
	Povprečje	314	3	3	157	15	0	3	
	Št. vzorcev	64	64	64	64	64	64	64	
	Št. nad AltholzV M.V.	2	1	0	-	-	-	0	
	Št. nad EPF M.V.	0	2	0	-	-	-	0	
	% nad AltholzV M.V.	3	2	0	-	-	-	0	
	% nad EPF M.V.	0	3	0	-	-	-	0	
 Al-All mix	MIN	391	1	0	138	18	0	4	
	MAX	1630	114	82	624	213	1	155	
	Povprečje	802	33	18	284	73	0	27	
	Št. vzorcev	54	54	54	54	54	54	54	
	Št. nad AltholzV M.V.	43	23	18	-	-	-	11	
	Št. nad EPF M.V.	11	31	3	-	-	-	3	
	% nad AltholzV M.V.	80	43	33	-	-	-	20	
	% nad EPF M.V.	20	57	6	-	-	-	6	

28/09/2025

71

71

Summary Analysis of recycled wood samples – Slovenian utility company



Vzorec	Koncentracija/število/ Procenti	Anorganska onesnažila v odsluženem lesu							
		Cl	Cr	Cu	Fe	Zn	Br	Pb	
 Al-All mix B	MIN	82	0	0	140	48	0	4	
	MAX	1843	167	84	531	538	80	38	
	Povprečje	707	22	9	266	191	6	16	
	Št. vzorcev	30	30	30	30	30	29	30	
	Št. nad AltholzV M.V.	19	4	2	-	-	-	3	
	Št. nad EPF M.V.	3	6	1	-	-	-	0	
	% nad AltholzV M.V.	63	13	7	-	-	-	10	
	% nad EPF M.V.	10	20	3	-	-	-	0	

28/09/2025

72

72

Summary Analysis of recycled wood samples – Slovenian recycling company

Samples	Concentration/Number /Percentage	Chemical elements in waste wood samples							
		Cl	Cr	Cu	Fe	Zn	Br	Pb	
 Al-AIII mix B	MIN	0	0	0	97	12	0	3	
	MAX	720	29	27	1296	824	2	29	
	AVERAGE	410	15	7	411	138	0	11	
	No. of samples	16	16	16	16	16	16	16	
	No. above AltholzV limit	2	0	1	-	-	-	0	
	No. above EPF limit	0	2	0	-	-	-	0	
	% above AltholzV limit	13	0	6	-	-	-	0	
	% above EPF limit	0	13	0	-	-	-	0	
 Al-AIII mix S	MIN	148	9	0	204	55	0	6	
	MAX	1555	367	193	6855	396	0	31	
	AVERAGE	725	59	25	1503	173	0	16	
	No. of samples	16	16	16	16	16	14	16	
	No. above AltholzV limit	11	9	4	-	-	-	1	
	No. above EPF limit	1	11	1	-	-	-	0	
	% above AltholzV limit	69	56	25	-	-	-	6	
	% above EPF limit	6	69	6	-	-	-	0	

28/09/2025

73

73

Source of pollutants in wood

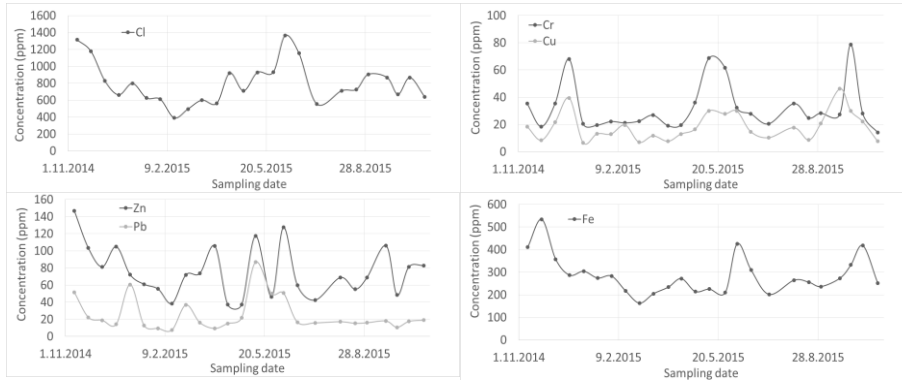
prCEN/TS 14961, 2004

28/09/2025

Pollutant	Origin*
Cl	Biocides Contamination with NaCl during storage, transport... Chlorinated water PVC residues
Ca	Construction materials residues
Cr	Component of wood preservatives Antioxidant in surface coatings Motor oil residues Metal residues after milling, machining
Fe	Corrosion of steel Metal residues after milling, machining
Ni	Motor oil residues Metal residues after milling, machining
Cu	Biocides
Zn	Additive of surface coatings
As	Biocides
Br	Flame retardants
Mo	Motor oil residues
Sn	Biocides
Cd	Additives in plastics, laminates Additive of surface coatings
Ti	Additive of surface coatings
Pb	Additive of surface coatings Contamination during transport Additives in plastics, laminates

74

Seasonal influence on contamination



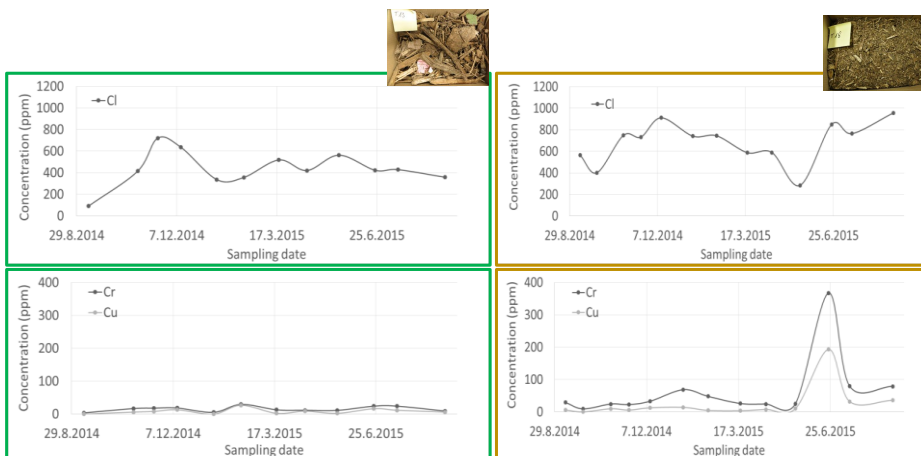
- No seasonal influence on contamination
- Variation are from different sources of RW

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75

75

Seasonal influence on contamination – samples - **S1BB** in **S1BS**



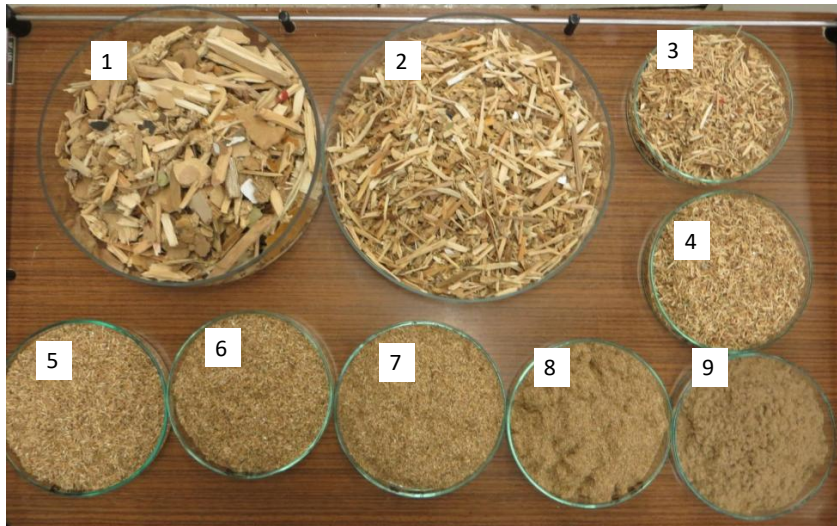
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76

76

Fraction analysis

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77

77

Fraction analysis

- AI – AIII mix RW cca. 20 kg – German company
 - Sampling 22.6.15
- $\frac{1}{2}$ with non wood material and $\frac{1}{2}$ without non wood material



28/09/2025

78

78

Fraction analysis - 2

- 9 fractions
- Sample cca. 10 x 2 kg
- 10 min cca. 250 g

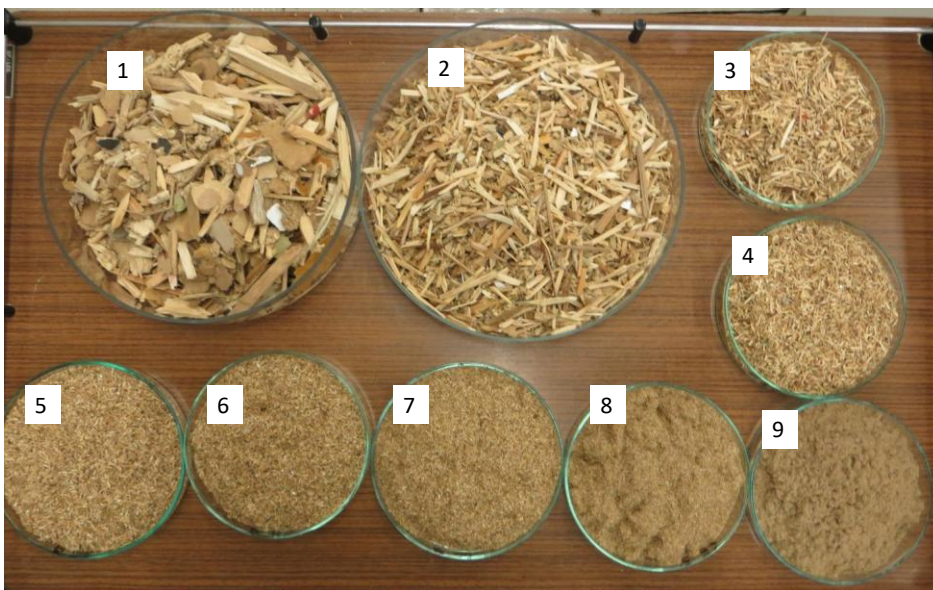
number	fractions
1	>6,14 mm
2	4,0 - 6,14 mm
3	2,0 - 4,0 mm
4	1,5 - 2,0 mm
5	1,27 - 1,5 mm
6	1,0 - 1,27 mm
7	0,60 - 1,0 mm
8	0,237 - 0,6 mm
9	0,0 - 0,237 mm

28/09/2025



79

79



28/09/2025

80

80

Extraction – Soluble part

- 5 g of dry milled samples from fraction analysis
- 3 stage extraction (3 x 20h)
 1. Cyclohexane : Ethanol = 2:1
 2. Ethanol
 3. Water



28/09/25

81

81

Lignin content (Klason)

- 1g of extracted sample
- 2 h - 72 % H_2SO_4 , room temperature
- 4 h - 3 % H_2SO_4 , boiling

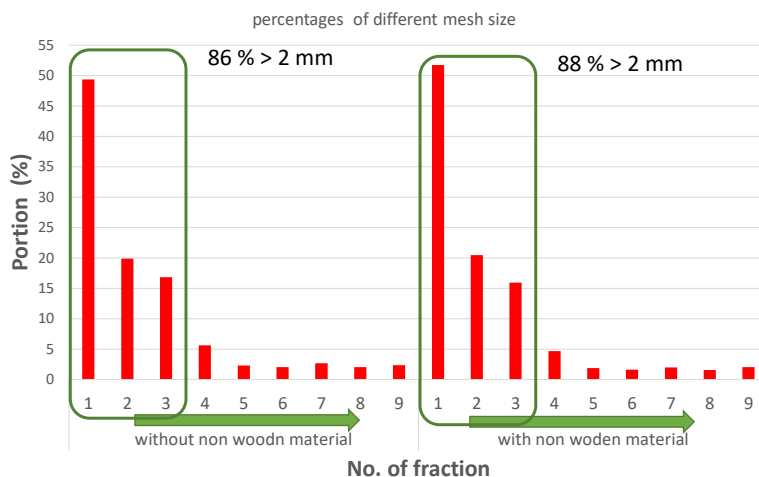


28/09/25

82

82

Fraction analysis - percentages of different mesh sizes

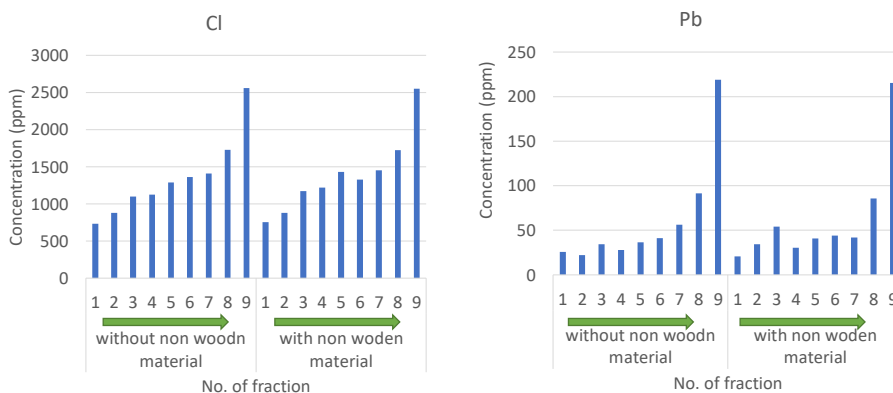


28/09/2025

83

83

Fraction analysis - concentration of Cl and Pb in Al – AlIII mix sample



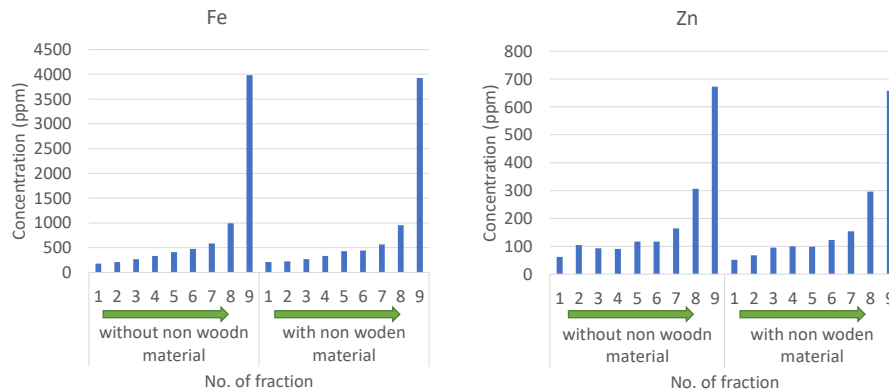
28/09/2025

84

84

Fraction analysis - concentration of Fe and Zn in Al –AIII mix sample

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85

85

Soluble part and lignin content in samples from fraction analysis (Al-AIII mix)

No. of fraction	without non wooden material		with non wooden material	
	Extractives (%) (soluble part)	Lignin (%)	Extractives (%) (soluble part)	Lignin (%)
1	8,9	28,5	8,5	29,1
2	7,0	28,4	9,0	25,8
3	8,0	29,0	7,0	25,8
4	8,3	28,0	7,5	28,0
5	7,8	28,7	9,3	28,3
6	8,0	29,8	8,4	29,5
7	11,1	30,9	9,5	30,5
8	11,7	31,3	10,3	32,3
9	12,8	35,6	14,5	36,0

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86

86

Conclusions 1

- AI recycled wood has low portion of non wooden material in average 0,2% on dry mass
- AI-AIII recycled wood has 6 times higher portion of non wooden material than AI wood in average 1,2%
- Samples from companies with sophisticated sorting systems have lower portion of non wooden materials.
- Only 3% of AI recycled wood samples analyzed exceed limit values according to Altholz
- The most critical inorganic elements (they exceed limit values according to Altholz and EPF) are Cl, Cr, Cu and Pb
- 63 % of samples exceed Altholz limits values for Cl and 31 % for Cr, and even more

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87

87

Conclusions 2

- Results of fraction analysis show that in first three fractions (mesh sizes > 2 mm) was more than 85 % of mass regarding all sample
- Concentrations of all analyzed inorganic pollutants increase with lower mesh size (more fine material)
- New sorting system will be needed for RW which will be used in biorefineries

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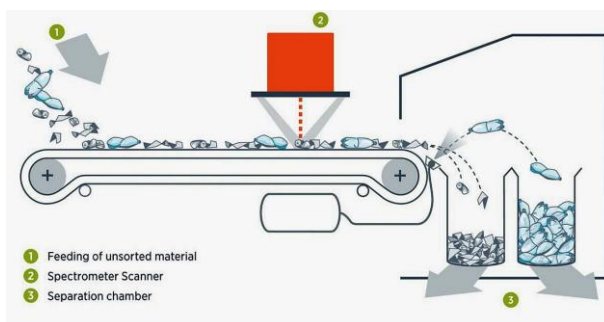
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To the end

New sorting system will be needed for RW for more cascading cycles of wood

- Infrared sorting technology
- XRF
- ...



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89

Main references

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- Vis M., U. Mantau, B. Allen (Eds.) (2016) Study on the optimised cascading use of wood. No 394/PP/ENT/RCH/14/7689. Final report. Brussels 2016. 337 pages http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8906&lang=en
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- Mantau U., 2015: Wood flow analysis: Quantification of resource potentials, cascades and carbon effects, Biomass and bioenergy 79 (2015) 28-38.

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Thank you for your attention

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92

RECYCLED WOOD IN WOOD – BASED COMPOSITES

prof. dr. Sergej Medved

*University of Ljubljana, Biotechnical Faculty,
Department of Wood Science and Technology*

1

Introduction

UL | BF

- Recycling: What is it? What do we understand under recycling?
 - Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes (Source: Waste Framework Directive, 2025)
 - Upcycling (also creative reuse): turning (recycled) materials into new products of higher quality or value compared to the source material (original)
 - Downcycling: turning (recycled) materials into new products of lower quality or value compared to the source material (original); also breaking down (recycled) material into new product (usually lower quality or value)
 - Status quo: turning (recycled) material into same material
- Important part of circular economy

Source: Waste Framework Directive, 2025

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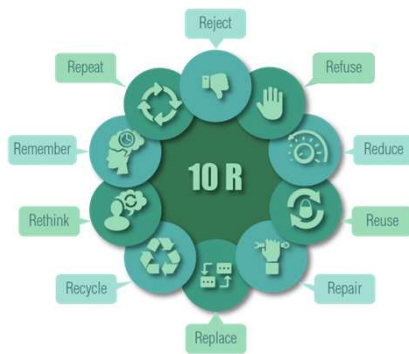
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Introduction

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→ Recycling rules: 10R's of circularity



Source: Eco Friendly Volunteers, 2025

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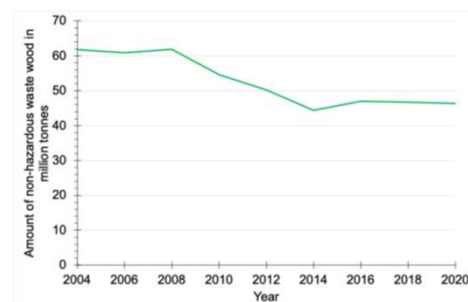
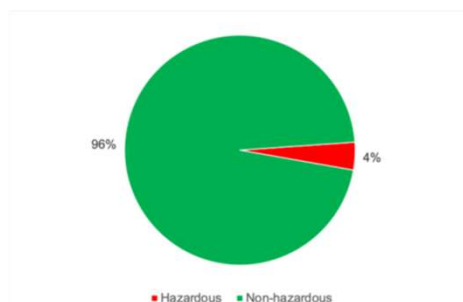
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Waste wood

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→ Waste wood generation in EU27

→ Total: 48,240,000 tonne



Source: EuroStat, 2025

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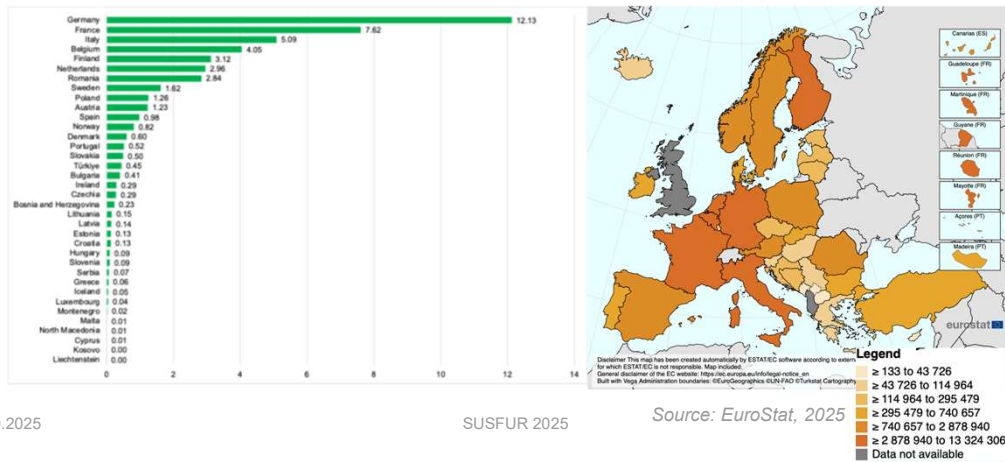
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Waste wood

UL | BF

→ Waste wood generation in EU27



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5

5

Waste wood

UL | BF

→ Types of waste wood

- Category A: clean, untreated, solid wood (poles, beams, pallets, sawdust, ...)
- Category B: industrial wood (wood contaminated with adhesive, varnish, coating systems, surfacing materials, furniture, wooden material obtained at demolition sites, ...)
- Category C: mixed/municipal waste (wood treated or impregnated with protective agents, ...)
- Category D: hazardous (treated with hazardous preservatives, contains harmful contaminants, or is heavily mixed with other hazardous waste, e.g. railway sleepers)



Source: Moore Recycling Ltd, 2025; EuWid, 2025; Rawlings Manufacturing, 2025; Railway supply, 2025

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6

6

Waste wood

UL | BF

→ Where it is generated?

- By-products from wood processing industries
 - Sawmilling industry
 - Solid wood processing
 - Panel production
 - Furniture production
 - Production of construction products
- Post-consumer wood
 - Furniture
 - Construction (at demolition)

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7

7

Waste wood

UL | BF

→ Shape of waste wood

- Poles (log)
- Slabs
- Beams
- Panels
- Particles
- Sawings
- Fibres
- Sawdust



Source: ASTM, 2025; Creveling Sawmill, 2025; Globalwood, 2025; CBS, 2025

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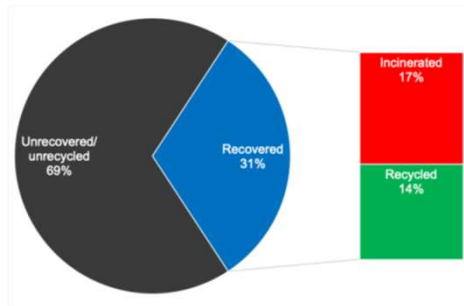
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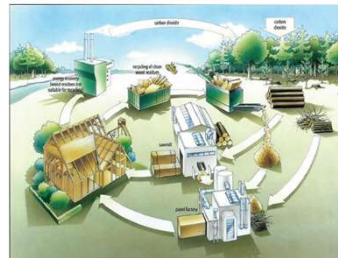
Waste wood

UL | BF

→ Utilisation of waste wood: Are we (in EU) successful in exploitation of waste wood?



Is this in accordance with sustainability and cascade use principles?



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Source: Ikenze et al. (Wood2Wood), 2024; EPF, 2025
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Recycling

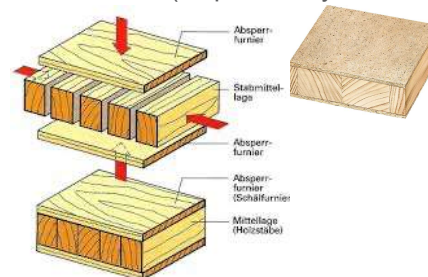
UL | BF

→ Wood-based panels / Wood-based composites

→ CLT (long lamellas, mostly softwood)



Blockboard (strips, mostly softwood)



Aufbau einer Stabsperholzplatte

Source: Lightwood, 2025; Stora enso, 2025; Grower, 2025; Luhmann, 2025

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10

10

Recycling

UL | BF

→ Wood-based panels / Wood-based composites

→ Plywood (veneer, mostly beech, poplar, birch, also softwood)



Source: Lightwood, 2025

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11

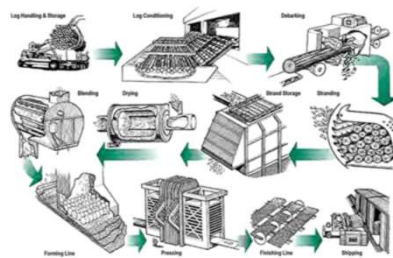
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Recycling

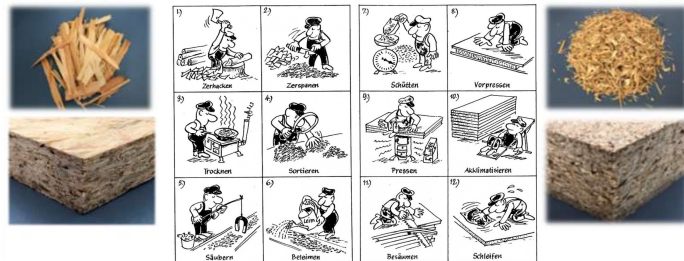
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→ Wood-based panels / Wood-based composites

→ OSB (strands, mostly softwood)



Particleboard (particles, chips)



Source: Weyerhouser, 2025; Hoechsmann, 2024

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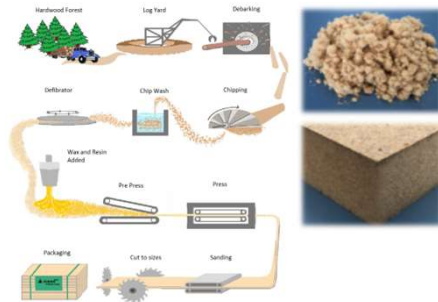
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Recycling

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- Wood-based panels / Wood-based composites
- Fibreboard (MDF, hardboards, softboards) (fibres)



Source: Fomex, 2025

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13

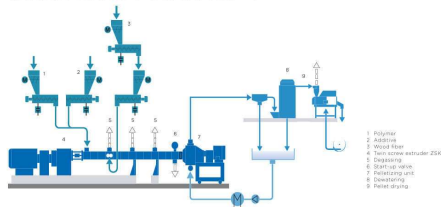
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Recycling

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- Wood-based panels / Wood-based composites
- Wood-plastic composites (fibres, fines)

Typical set-up for the production of wood plastic composites WPC



Source: Coperion, 2025; MRS Woodcraft

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14

14

Recycling

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- For which/what WBP or WBC can waste wood be used?
 - CLT
 - Blockboard
 - Plywood
 - OSB
 - Particleboard
 - Fibreboard
 - WPC

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15

Recycling

UL | BF

- Why only those WBP/WBC? What are the limitations?
 - Type of waste wood (what WBP/WBC is made of)
 - Size of waste wood
 - Contaminants
 - Metal
 - Nails, screws, hinges, ...
 - Non-metal
 - Surface coating system
 - Liquid
 - Paper, film, foil, laminate (CPL, HPL)
 - Adhesive

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16

16

Recycling

UL | BF

- Why only those WBP/WBC? What are the limitations?
 - Moisture content
 - Size of constituents obtainable at cleaning (removal of contaminants) or breakdown

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17

17

Recycling

UL | BF

- What WBP/WBC is ideal for implementation of recycled material (waste wood)?
 - History
 - 1887 – introduction of concept
 - 1935 – first plant
 - 1932 – patented a proces where constituents were not fully impregnated with adhesive
 - Initially single-layer afterwards three-layer

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18

18

Recycling

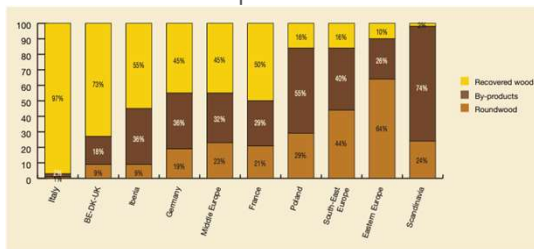
UL | BF

→ What WBP/WBC is ideal for implementation of recycled material (waste wood)?

→ Nowadays

→ Production: > 30 Mm³/year

→ Raw material consumption



Source: EPF, 2023

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19

19

Particleboard

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→ Waste wood (recovered wood) is an important source for PB production (average across EU ≈ 43 %)

→ Fact

→ Almost all types of waste wood (grade A, B and partially C) can be broken down into particles (downcycling or status quo)

→ Fibreboards can not be broken down into particles

→ Size of particles depends on numerous factors

→ Type of waste (recovered) wood

→ MC

→ Level of contamination

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20

20

Particleboards

UL | BF

- Downsides of using waste (recovered) wood, challenges and ways of removal
 - Metals → magnet, sieve, water
 - Non-metals → during break down process followed by sieving, steaming, sieving
- Limited usability → morphology of particles (increasing number of break down procedure results in size reduction)

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21

21

Particleboards

UL | BF

- Impact on properties
 - Mechanical properties: slightly lower due to the irregular nature of recycled particles and potential contaminants
 - Dimensional stability and moisture resistance: good
 - Formaldehyde emission
- To consider
 - Target density
 - Type of resin
 - Resin load & resin distribution

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22

22

Fibreboard

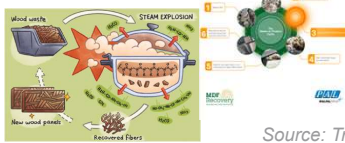
UL | BF

→ What about fibreboard and its recyclability?

- At breakdown irregular shape of constituents is achieved



- Recovery of fibres (MDF Recovery): Fibres gently separated without compromising integrity



Source: Troilo et al., 2023; Zimmer & Lunelli Bachmann, 2023; MDF Recovery, 2025; EcoReFibre, 2025; ESB, 2025

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23

23

Fibreboard

UL | BF

→ Impact on properties

- Mechanical properties: depends on fibre length and panel density
- Dimensional stability and moisture resistance: good
- Formaldehyde emission

→ To consider

- Target density
- Type of resin
- Resin load & resin distribution
- Limited numbers of recycling process due possible decrease in fibre length

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24

24

WPC

UL | BF

→ Composition

- Matrix: plastic (PP, PE, PLA, ...)
- Fibrous elements: particles, fibres, fines
- Matrix envelopes fibrous elements
- At compression moulding and extrusion compression occurs (increase in wood density)



Source: Binhussain & El-Tonsy, 2013

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25

25

WPC

UL | BF

→ Impact on properties

- Mechanical properties
- Dimensional stability and moisture resistance: good
- Formaldehyde emission

→ To consider

- Compatibility with plastic
- Primer
- Filler or reinforcement

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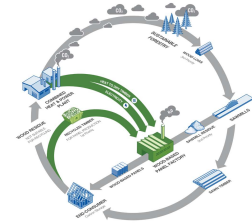
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...for the end...

UL | BF

- Using waste/recovered wood
 - Abundancy: ≈ 48 Mtonne $\rightarrow \approx 68$ Mm³ PB
 - Costs
 - Environment/sustainability
 - Circular economy



- ***Wood burns...but...we should incinerate wood as last resort, when it loses all its technical value***

Source: Woodknowledge Wales, 2025

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27

27

Thank you for your attention!

Q & A session

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28

28

CONTEMPORARY SUSTAINABLE MATERIALS FOR THE SURFACE TREATMENT OF WOOD
AND FOR PRODUCTS IN THE WOOD INDUSTRY

BY MARKO PETRIČ, UNIVERSITY OF LJUBLJANA, BIOTECHNICAL FACULTY,
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LJUBLJANA, SLOVENIA, 23RD SEPTEMBER 2025

SUSTAINABLE, ENVIRONMENT FRIENDLY SOLUTIONS

- WATER-BORNE COATINGS – STILL CONTAIN PETROLEUM BASED INGREDIENTS
- HIGH SOLID COATINGS – STILL CONTAIN PETROLEUM BASED INGREDIENTS
- THE IMPORTANCE OF CIRCULAR ECONOMY OR AT LEAST CASCADE USE – WOOD COATINGS?
- COATINGS ON THE BASIS OF BIO-BASED RESINS
- FORMULATIONS WITH NATURAL ADDITIVES AND FILLERS



**Development of Water-Resistant, Functional, Regulation
Compliant Water-borne Wood Coating**

FP7-SME-2008-2-243603

May 2010 - April 2013

A very old example of the project on
development of a new polyurethane coating:

A new wearable, functional, regulation
compliant water-borne WOOD coating from
vegetable oils.

HOW TO REUSE COATED WOOD?

- TO DISMANTLE PRODUCTS MADE OF COATED WOOD AND MANUFACTURE NEW ITEMS FROM THE COMPONENTS OBTAINED THROUGH DISASSEMBLY
- BUT: EXPENSIVE AND SLOW
- WHAT SHOULD BE DONE WITH THE OLD COATINGS—HOW CAN THEY BE RESTORED?
- **M-SORA** D.D., ŽIRI, SLOVENIA: **ICON 2.0** (SIMPLIFIED REPLACEMENT OF COMPONENTS AND RECYCLING AT THE END OF THE PRODUCT'S SERVICE LIFE); **REWINNUSE** (FOCUSED ON THE USE OF RECLAIMED WOOD AND ALTERNATIVE WOOD SPECIES, AND THE DEVELOPMENT OF FULLY DEMOUNTABLE WOODEN WINDOWS); **LESNI FENIKS** (A PILOT PROJECT ON THE USE OF WOOD RESIDUES AND WASTE WOOD FROM WHICH NEW PRODUCTS WILL EMERGE); **REWIN** (TO DEVELOP AND PROMOTE THE SALES OF WOODEN WINDOWS MADE OF OLD, DISCARDED WOOD)

HOW TO REUSE COATED WOOD – MAYBE A WOOD COATING COULD BE REMOVED?



Progress in Organic Coatings

journal homepage: www.elsevier.com/locate/porgcoat



Thermal debonding on demand for wood coatings via nitrocellulose-based primer

Thomas Höfer^a, Albert Rössler^b, Oliver I. Strube^{a,*}

^a Universität Innsbruck - Institute for Chemical Engineering, Innsbruck, Austria

^b ADLER-Werk Lackfabrik Johann Berghofer GmbH & Co KG, Schwaz, Austria

- NITROCELLULOSE BASED PRIMERS HAVE BEEN FOUND TO BE CAPABLE TO INTRODUCE DEBONDING (160–170 °C) ON DEMAND PROPERTIES TO STANDARD WOOD COATING SYSTEMS

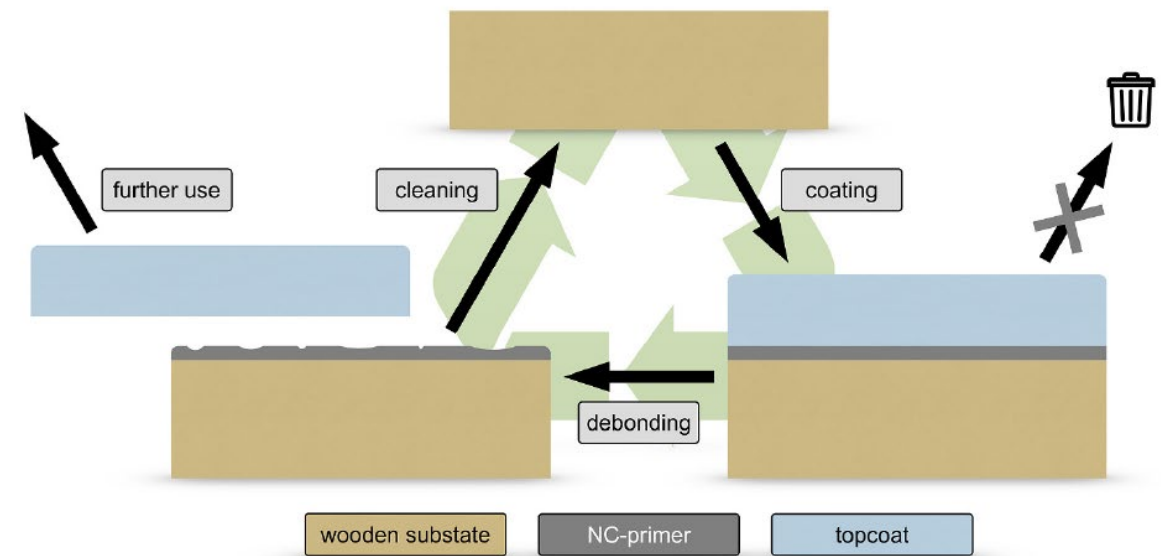


Fig. 1. Schematic process for circular reuse of wood with a NC-based DoD-coating.

Recent Advances in Bio-Based Wood Protective Systems: A Comprehensive Review

Massimo Calovi * , Alessia Zanardi and Stefano Rossi 

BIO-BASED WOOD PROTECTIVE SYSTEMS



Figure 1. Graphical illustration of the bio-based materials employed in wood protective systems.

BIO-BASED BINDERS: LIQUEFIED WOOD

What is liquefied wood



Wood constituents:
lignin, cellulose,
hemicelluloses, other

Formation of resins for
wood adhesives or
coatings, curing

Depolymerisation of wood constituents, their reaction with
the reactive solvent

Reaction of depolymerised fragments
between themselves, with the solvent, **with
various curing agents**

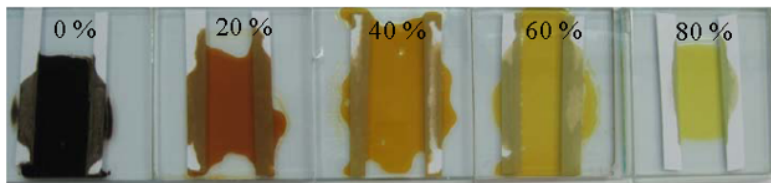
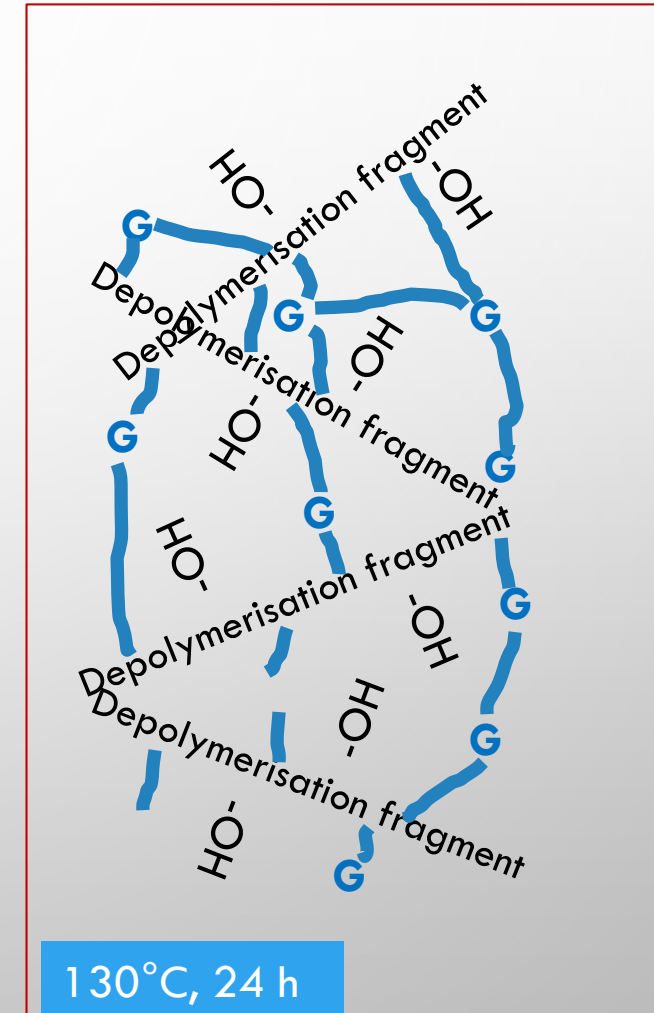
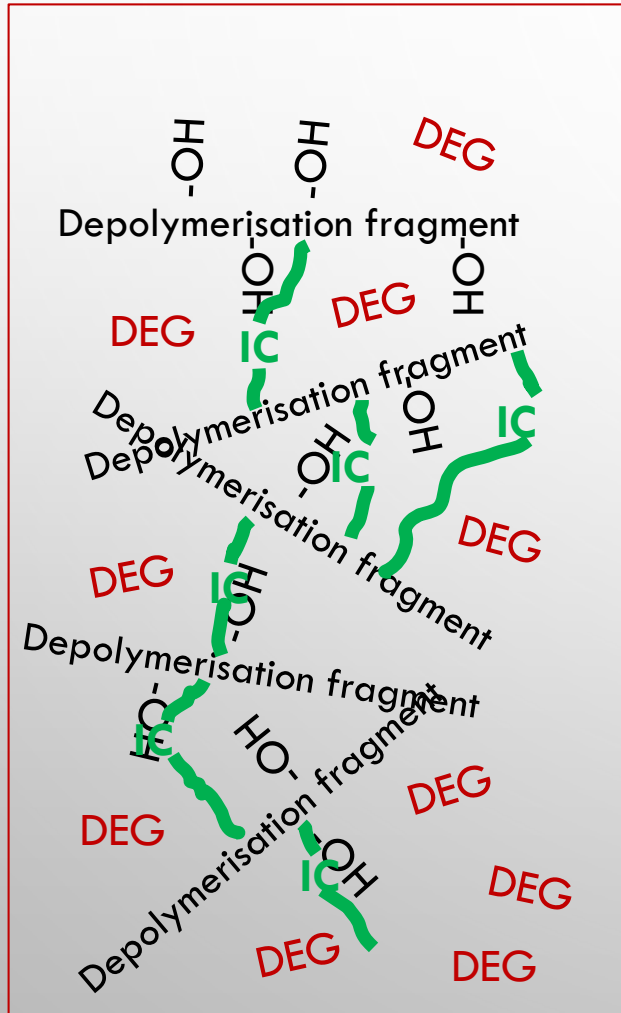


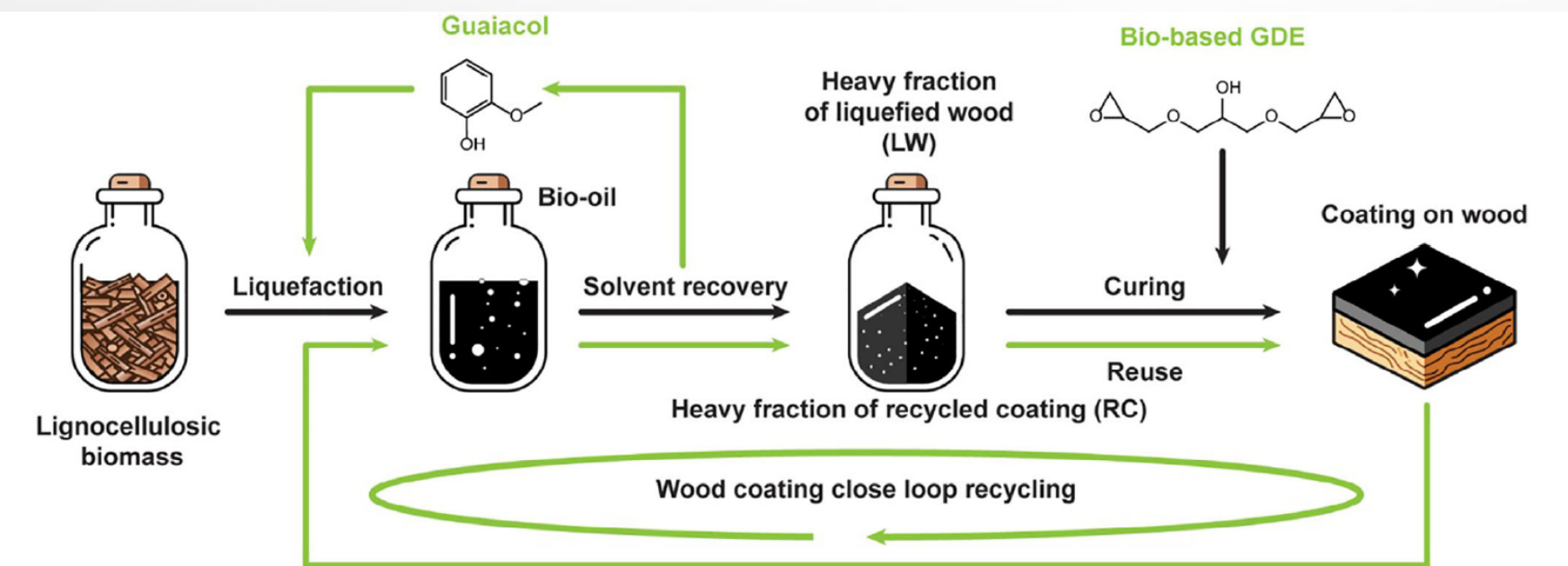
Fig. 2. Colour change of liquefied wood during manganese sulphate/sodium bicarbonate activated hydrogen peroxide oxidation as a function of the quantity of hydrogen peroxide applied.

GENERAL CONCEPTS OF CURING MECHANISMS TO OBTAIN SOLID COATING FILMS



Fully Bio-Based Epoxy Resins from Liquefied Wood for Chemically Recyclable Wood Coatings

Qisong Hu, Ricardo P. Martinho, Suna Azhdari, Jean-Paul Lange, Martin van Drongelen, M. Pilar Ruiz, and Frederik R. Wurm*



- LW, DERIVED FROM PINE WOOD LIQUEFACTION, EXHIBITS A HIGHLY PHENOLIC STRUCTURE SIMILAR TO LIGNIN, ENABLING ITS REACTION WITH EPOXIDES TO FORM DURABLE COATINGS
- THESE COATINGS CAN BE CHEMICALLY RECYCLED THROUGH THE SAME LIQUEFACTION PROCESS USED TO GENERATE LW

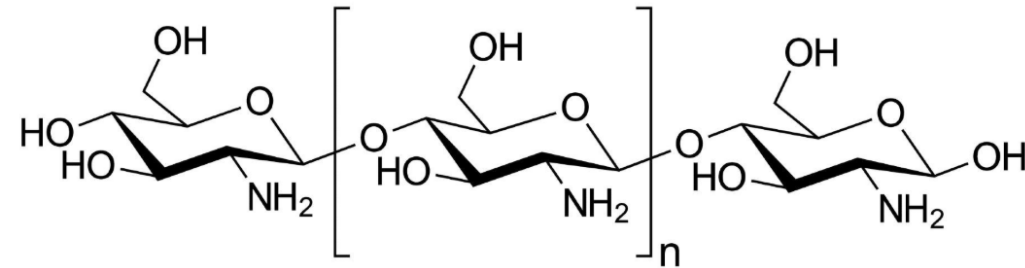
Figure 1. Schematic concept of this study. The heavy fraction of liquefied wood (LW) is produced through the liquefaction of lignocellulosic biomass (pine wood). Wood coatings are synthesized by crosslinking LW with bio-based glycerol diglycidyl ether (GDE) on wood tiles. These wood coatings are subsequently recycled via liquefaction, yielding the heavy fraction of recycled coating (RC), which is reused in the production of new wood coatings.

BIO-BASED BINDERS ON THE BASIS OF NATURAL OILS

- VEGETABLE OILS AND THEIR DERIVATIVES: LINSEED AND TUNG OIL + ADDITIVES AND/OR PIGMENTS (HEMP-DERIVED BIOCARBON, PIGMENTS EXTRACTED FROM WOOD-DECAY FUNGI, NANOFIBRILLATED CELLULOSE, BEESWAX, MICRONIZED SODIUM CHLORIDE (NaCl) PARTICLES, ETC.
- OILS OF NATURAL ORIGIN AS A STARTING BASE FOR THE SYNTHESIS OF RESINS AND COATINGS (A BIO-BASED EPOXIDE AMINE NANOCOATING OIL, ACRYLATED VEGETABLE OILS, EPOXIDIZED SOYBEAN OIL WAS MIXED WITH CASTOR OIL MALEIC ANHYDRIDE ADDUCT, HYPERBRANCHED ALKYD RESIN FROM CASTOR OIL, SOYBEAN OIL MODIFIED WITH ACRYLIC ACID, EPOXIDIZED SOYBEAN OIL, PEANUT OIL AS A PRECURSOR FOR THE SYNTHESIS OF POLYURETHANE, ETC.)

BIO-BASED BINDERS – NATURAL BIOPOLYMERS

- CHITOSAN, CELLULOSE (NC), LIGNIN



- LIGNIN-BASED POLYURETHANE COATINGS
- TANNINS (+LIGNIN)
- POLYLACTIC ACID (IN COMBINATION WITH NANOCELLULOSE))
- VANILLIN-BASED POLYURETHAN
- HYPERBRANCHED POLYESTER–URETHANE–ACRYLATE ON THE BASIS OF CITRIC ACID



Cite this: *Soft Matter*, 2021, 17, 5231

A self-healing, recyclable, and degradable fire-retardant gelatin-based biogel coating for green buildings†

BASED ON CHITOSAN

Lei Zhang,^{‡ab} Yubin Huang,^{‡ab} Ping Sun,^{ab} Yun Hai^{ab} and Saihua Jiang^{id} *^{ab}

 **polymers**



Article



Synthesis and Characterizations of Eco-Friendly Organosolv Lignin-Based Polyurethane Coating Films for the Coating Industry

Sara Bergamasco^{id}, Swati Tamantini *^{id}, Florian Zikeli *^{id}, Vittorio Vinciguerra, Giuseppe Scarascia Mugnozza^{id} and Manuela Romagnoli *^{id}



Article

Bioinspired Living Coating System in Service: Evaluation of the Wood Protected with Biofinish during One-Year Natural Weathering

Faksawat Poohphajai ^{1,2}, Jakub Sandak ^{1,3,*}, Michael Sailer ⁴, Lauri Rautkari ² , Tiina Belt ⁵ and Anna Sandak ^{1,6} 

	reference	3 monts	6 months	9 months	12 months
CIE L*	23.4	24.0	23.1	23.5	23.2
CIE a*	0.6	0.2	0.3	0.4	0.5
CIE b*	1.4	0.2	0.4	1.0	0.4
Gloss ⊥	1.7	1.6	1.0	1.4	1.2
Gloss //	1.2	1.2	0.8	1.2	0.9

Figure 2. Surface texture, CIE L*a*b* colour coordinates and glossiness parameters altered during weathering progress of biofinish-coated Scots pine samples.

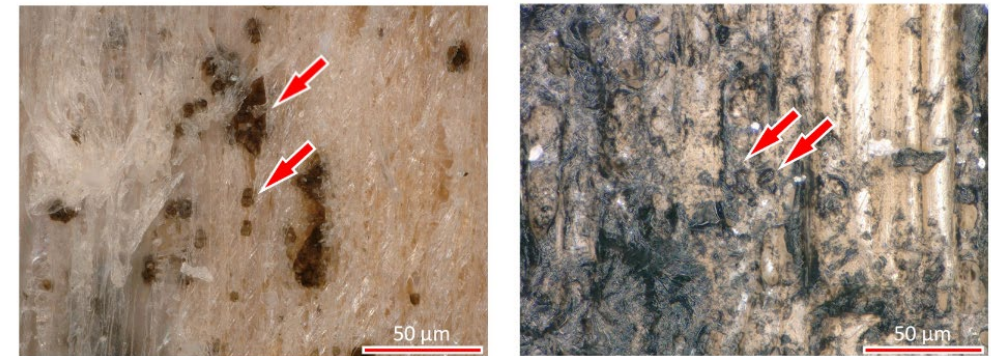
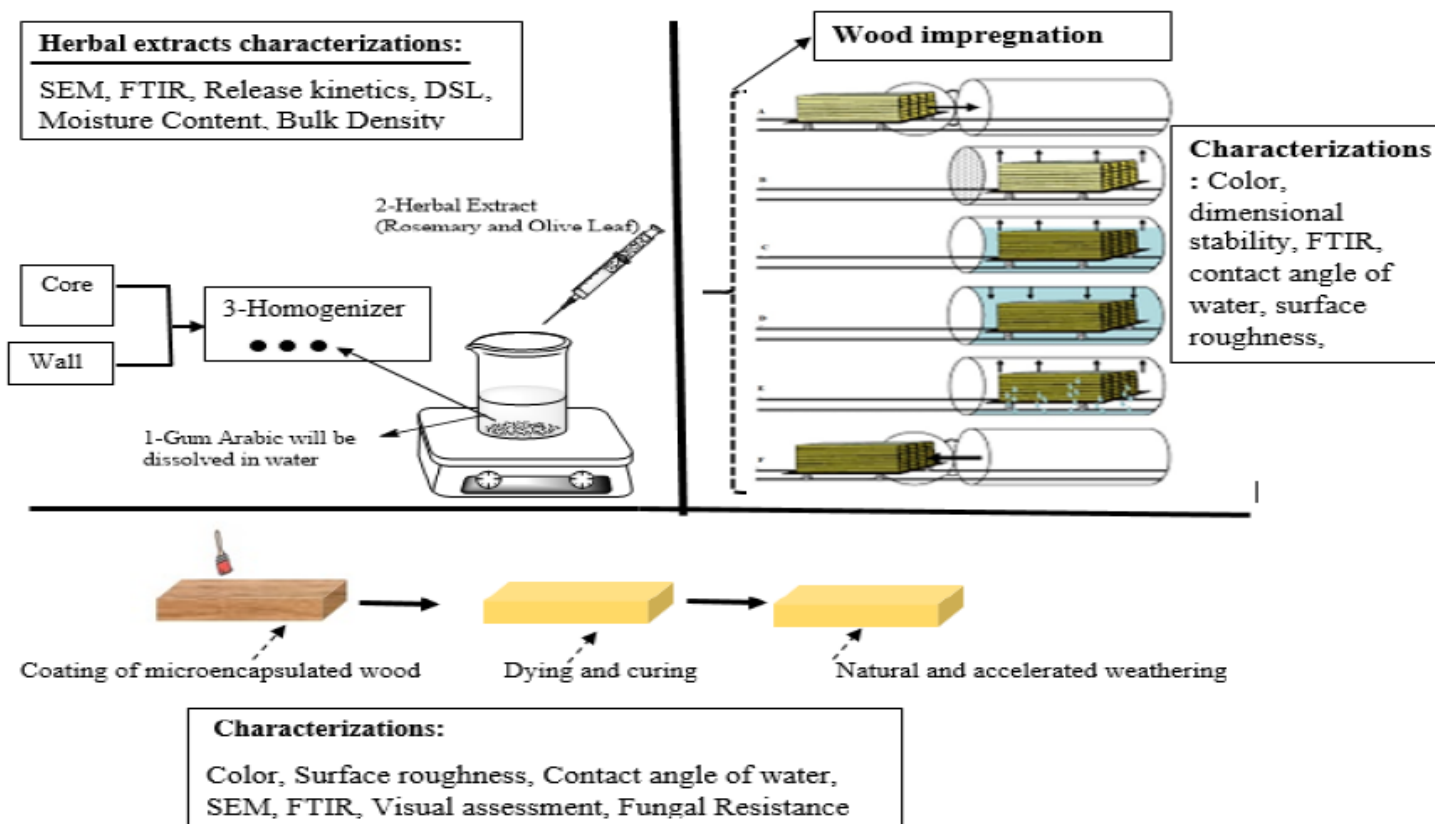


Figure 8. Chlamydospores of *A. pullulans* on the surface of uncoated Scots pine after 9 months of exposure (a) and a biofinish-coated reference sample not exposed to natural weathering (b), observed under microscope with ×1000 magnification.

OTHER BIO-BASED CONSTITUENTS (E.G. FILLERS, PIGMENTS, DYES)

- HEMP-BASED BIOCARBON (BC)
- **OLIVE LEAF EXTRACT AS A SUPPLEMENT IN POLYACRYLATE COATINGS**
- **WOOD COATING DEVELOPED THROUGH THE CURING OF LEVULINIC ACID SERVED AS AN INNOVATIVE BIO-DERIVED SOLVENT FOR THE MILD SOLVOLYSIS LIQUEFACTION OF WOOD**
- LIGNIN FROM WOOD WASTE AS AN ADDITIVE
- TANNINS, DERIVED FROM WOOD, O ENHANCE THE PROTECTIVE QUALITIES OF COATINGS
- CARNAUBA WAX COMBINED WITH ZINC OXIDE NANOPARTICLES WITHIN MULTI-LAYER COATINGS TO EXTEND THE LIFESPAN OF WOOD
- REINFORCING BIO-BASED FILLERS (NANOCELLULOSE,



European Journal of Wood and Wood Products
<https://doi.org/10.1007/s00107-021-01712-3>

ORIGINAL ARTICLE

Weathering performance of thermally modified wood coated with polyacrylate containing olive leaf extract as a bio-based additive

Zahra Nowrouzi¹ · Behbood Mohebbi¹ · Morteza Ebrahimi² · Marko Petrič³

Biomass Conversion and Biorefinery
<https://doi.org/10.1007/s13399-023-03858-x>

ORIGINAL ARTICLE

Thermochemical conversion of wood in levulinic acid and application in the preparation of wood coatings

Arnaud Maxime Cheumani Yona^{1,2} · Dušan Žigon³ · Jure Žigon¹ · Alexis Ngueteu Kamlo² · Matjaž Pavlic¹ · Sebastian Dahle¹ · Marko Petrič¹

Protection of wood against weathering with microencapsulated olive leaf and rosemary extracts and a natural drying linseed oil

PLASMA AND ITS APPLICATIONS IN WOOD SCIENCE & TECHNOLOGY



- PLASMA IS „THE FOURTH STATE OF MATTER“. IT IS A HIGHLY IONIZED GAS COMPOSED OF POSITIVELY CHARGED IONS, FREE ELECTRONS, AND NEUTRAL PARTICLES.

From: <https://sullivanplate.com/news/tag/states-of-matter/>

TYPES OF PLASMAS

- NATURAL: STELLAR AND INTERSTELLAR PLASMAS (SOLAR WIND), EARTH'S IONOSPHERE, AURORA BOREALIS, THUNDER, **FLAME**
- ARTIFICIAL – MAN MADE
 - WITH REGARDS TO TEMPERATURE: THERMAL PLASMAS (OVER 1000 °C), **NON-THERMAL OR COLD PLASMAS** (NEAR ROOM TEMPERATURE)
 - WITH REGARDS TO GAS: **ATMOSPHERIC PLASMAS**, VACUUM PLASMAS, PLASMA GENERATED IN VARIOUS GASSES (INCLUDING POLYMER PRECURSORS (E.G. ETHYLENE), SILICON COMPOUNDS, NITROGEN,...)
 - WITH REGARDS TO PRESSURE: LOW AND HIGH PRESSURE PLASMAS, AT **ATMOSPHERIC PRESSURE**
 - WITH REGARDS TO THE ENERGY SOURCE: CORONA AND ELECTRICAL DISCHARGE, AC DISCHARGE, RF DISCHARGE, MW DISCHARGE , **DIELECTRIC BARRIER DISCHARGE**, LASER PLASMAS, THERMAL PLASMAS (ELECTRIC ARCS, FLAMES, INDUCTION HEATING, PARTICLE BEAM PLASMAS,...)

PLASMA TREATMENT OF WOOD

- TO ACTIVATE WOOD, TO MAKE IT MORE POLAR – HYDROPHILIC, IN ORDER TO IMPROVE ADHESION OF WOOD ADHESIVES AND WOOD COATINGS
- TO MAKE WOOD HYDROPHOBIC
- TO CREATE THIN POLYMERIC FILMS ON WOOD SURFACES (E.G. POLYETHYLENE FILMS)
- FUNCIONALIZATION OF WOOD, FOR EXAMPLES WITH SILANES
- TO IMPROVE ADHESION OF NANOPARTICLES ON WOOD SURFACES
- TO REMOVE FILMS OF OLD COATING LAYERS
- TO REMOVE DAMAGED SURFACE LAYERS FROM WOOD SURFACES
- TO DISINFECT AND CLEAN WOOD SURFACES
- EVEN AS A REPLACEMENT FOR CLASSICAL SANDING

PLASMA TREATMENT OF WOOD – SOME EXAMPLES FROM OUR INVESTIGATIONS

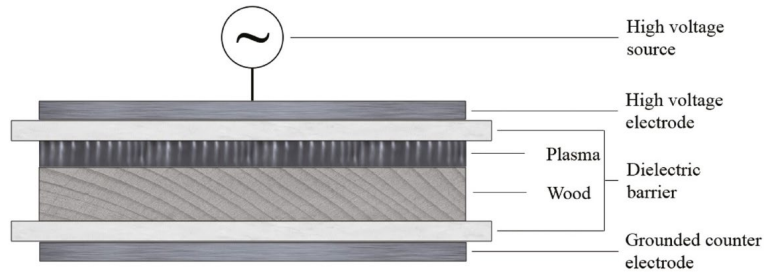


Figure 1:

Schematic presentation of a DBD plasma applied on a wood surface (based on [Rehn and Viöl 2003](#); [Viöl et al. 2012](#))

ŽIGON, Jure, PETRIČ, Marko, DAHLE, Sebastian. Dielectric barrier discharge (DBD) plasma pretreatment of lignocellulosic materials in air at atmospheric pressure for their improved wettability : a literature review. *Holzforschung*. 2018, vol. 72, iss. 11, str. 979-991.

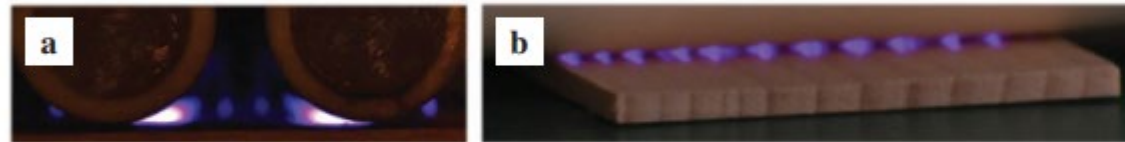
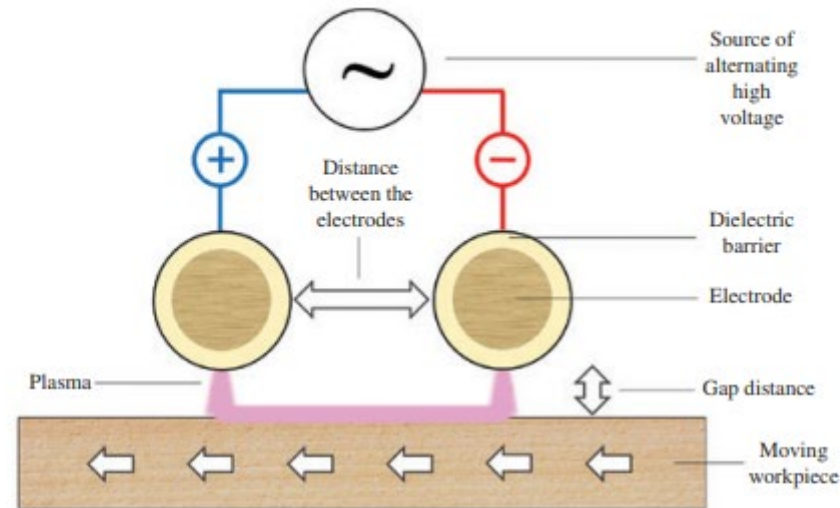


Figure 1: Schematics and photos of FE-DBD plasma wood surface treatment.

Schematic presentation of wood surface treatment with FE-DBD plasma and appearance of plasma during treatment of wood surfaces: (a) side view, (b) front view.

ŽIGON, Jure, PETRIČ, Marko, DAHLE, Sebastian. Dielectric barrier discharge (DBD) plasma pretreatment of lignocellulosic materials in air at atmospheric pressure for their improved wettability : a literature review. *Holzforschung*. 2018, vol. 72, iss. 11, str. 979-991.

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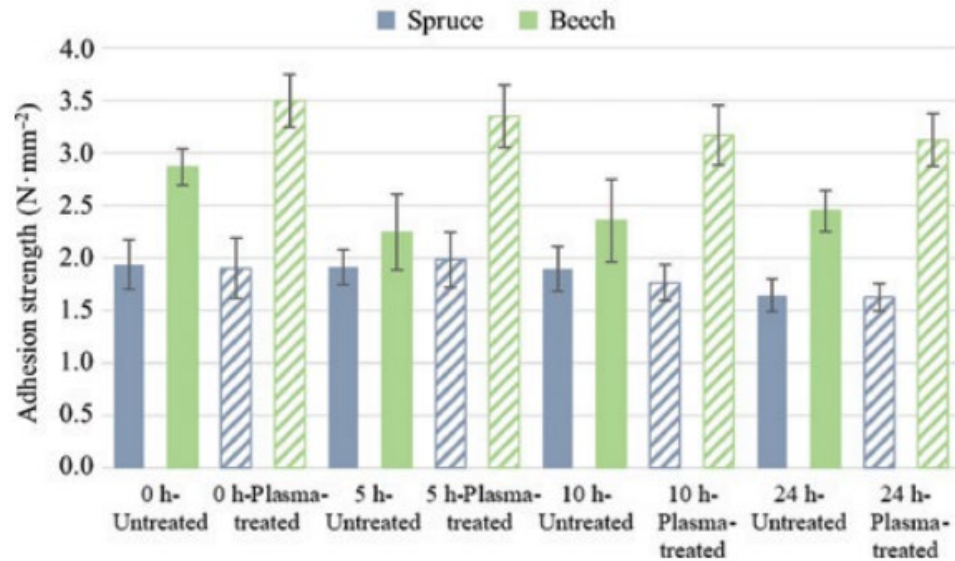


Figure 10: Adhesion pull-off strength of coating system on coated wood samples.

For all measurements performed on coated beech wood surfaces, a predominant adhesive type of fracture occurred between the substrate and the coating film. PT prior to coating application contributed to an increase in the adhesion strength of the cured film by over 20% compared to the corresponding untreated specimen.

ŽIGON, Jure, PETRIČ, Marko, DAHLE, Sebastian. Dielectric barrier discharge (DBD) plasma pretreatment of lignocellulosic materials in air at atmospheric pressure for their improved wettability : a literature review. *Holzforschung*. 2018, vol. 72, iss. 11, str. 979-991.

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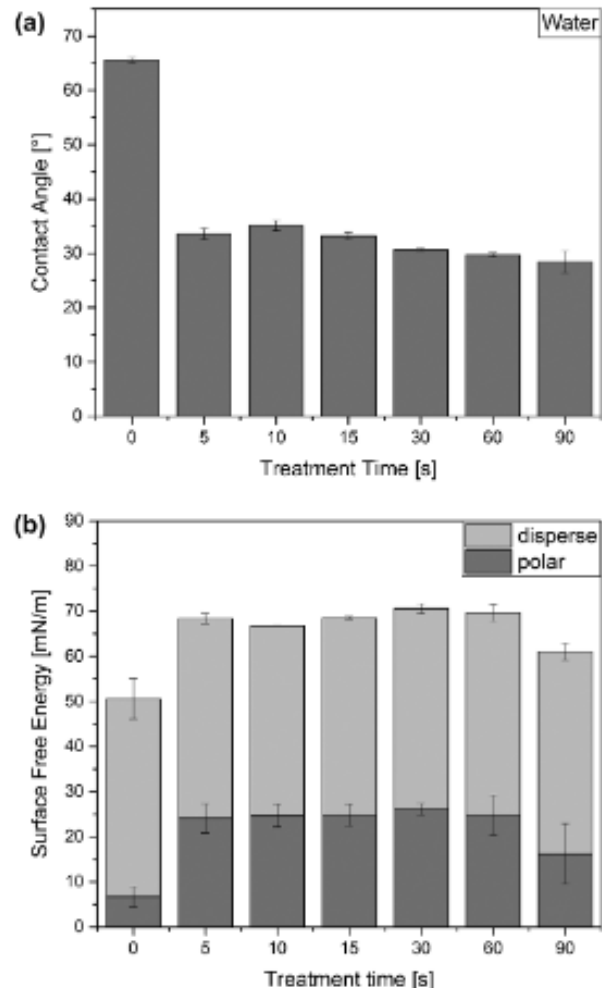


Figure 2. Water contact angles (left) and surface free energies (right) as determined by Fowkes' method from contact angles of water, diiodomethane, bromonaphthalene and glycerol.

VOVK, Matej, WALLENHORST, Lena M., KALDUN, Christian, MEUTHEN, J. N., ARENDT, A. L., ŠERNEK, Milan, ŽIGON, Jure, KAUFMANN, D. E., VIÖL, Wolfgang, DAHLE, Sebastian. **Air plasma treatment of aluminium trihydrate filled poly(methyl methacrylate).** *Journal of adhesion science and technology*. 2018, vol. 32, no. 12, str. 1369-1391.

PLASMA TREATMENT OF WOOD – SOME EXAMPLES FROM OUR INVESTIGATIONS

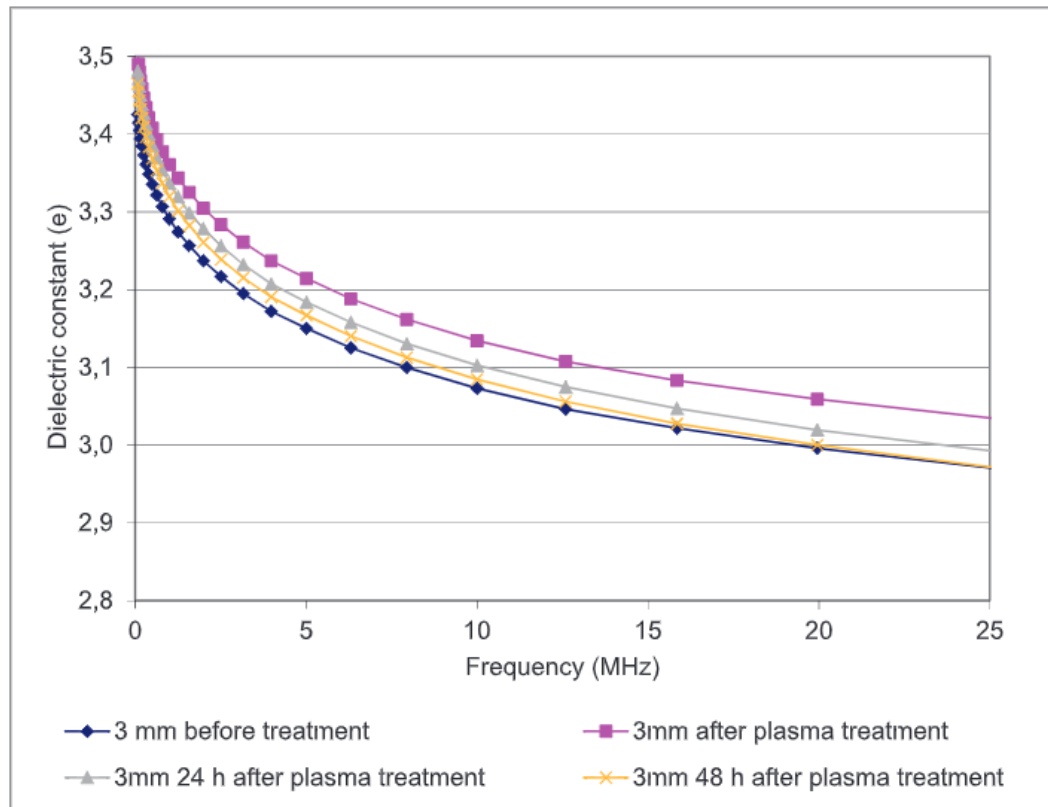


Figure 3. Dielectric constant of spruce discs, thickness 3 mm
Slika 3. Dielektrična konstanta smrekovih diskov debeline 3 mm

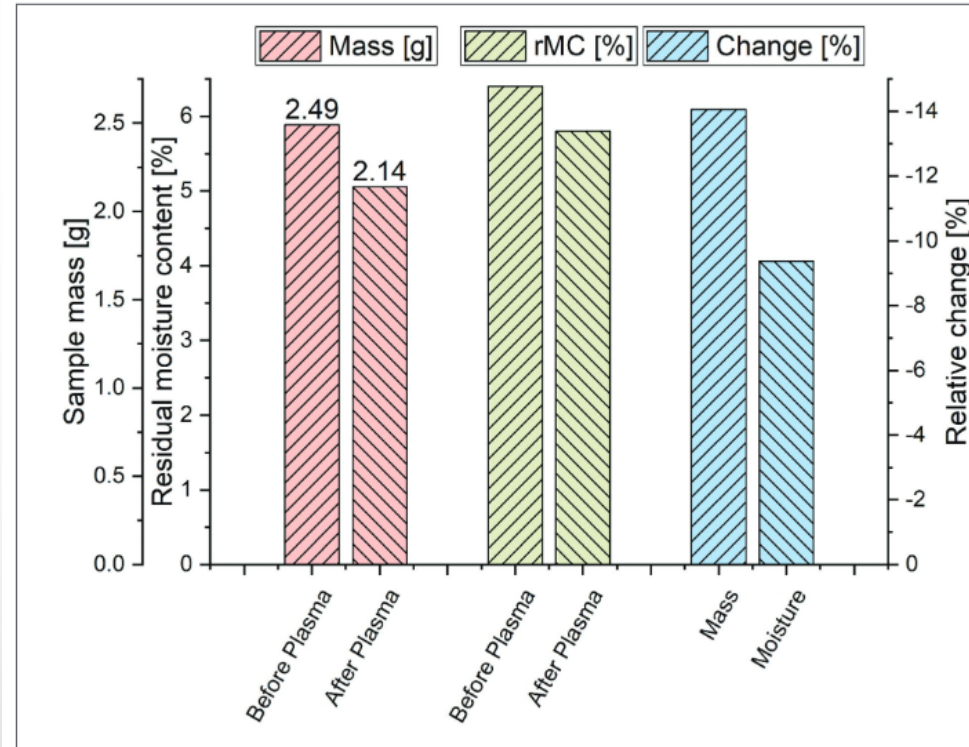


Figure 6. Mass and residual moisture content (rMC) of a spruce lamella with a thickness of 3 mm before and after plasma treatment, as well as the relative changes of mass and rMC



















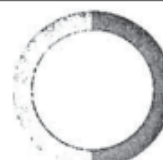
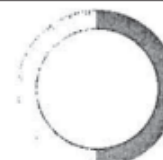
Slika 6. Masa in vlažnost smrekove lamele debeline 3 mm pred obdelavo s plazmo in po njej ter relativne spremembe mase in vlažnosti.

DAHLE, Sebastian, ŽIGON, Jure, PETRIČ, Marko, KARIŽ, Mirko. Plasma treatment of spruce wood changes its dielectric properties = Obdelava smrekovega lesa s plazmo spremeni njegove dielektrične lastnosti. Les. [Tiskana izd.]. 2020, letn. 69, št. 2, str. 83-95, ilustr. ISSN 0024-1067.

PLASMA TREATMENT OF WOOD – SOME EXAMPLES FROM OUR INVESTIGATIONS

Table 1 Appearance of representative samples after a specific number of revolutions in abrasion resistance test. Left side of images is shown as processed with Fiji software for grey value analysis

Tablica 1. Izgled reprezentativnih uzoraka nakon određenog broja ciklusa ispitivanja otpornosti na abraziju. Lijeva strana fotografija obrađena je *Fiji* softverom za analizu sive vrijednosti.

Sample Type <i>Vrsta uzorka</i>	Number of revolutions, appearance <i>Broj okretaja, izgled</i>				
	0	10	25	50	75
Untreated <i>neobrađen</i>					
Plasma treated <i>obrađen plazmom</i>					
	100	125	150	175	200
Untreated <i>neobrađen</i>					
Plasma treated <i>obrađen plazmom</i>					

ŽIGON, Jure, DAHLE, Sebastian, PETRIČ, Marko, PAVLIČ, Matjaž. **Enhanced abrasion resistance of coated particleboard pre-treated with atmospheric plasma** = Pojačana otpornost na abraziju premazanih iverica prethodno obrađenih atmosferskom plazmom. *Drvena industrija : Znanstveno stručni časopis za pitanja drvne tehnologije*. 2020, vol. 71, iss. 2, str. 129-137.

PLASMA TREATMENT OF WOOD – SOME EXAMPLES FROM OUR INVESTIGATIONS

Table 3 Cracking assessment on different coated and plasma pretreated sample systems after 6 and 10 months of natural weathering

Surface finish	Plasma	6 months	10 months
Uncoated	Yes	0	0
	No	0	0
Tung oil	Yes	0	0
	No	0	1.3 S1.3 a
Water-based stain	Yes	0	0.7 S0.7 a
	No	1.3 S2.3 a	3 S3.7 b
Solvent-based UV stain	Yes	0	0
	No	1.7 S2.7 b	3.7 S3.7 b

nomenclature. The first rating defines the extent of cracking (0—no, 1—less than a few, 2—a few, 3—medium, 4—medium dense, 5—dense). The second rating assesses the crack size (S1—visible only at 10 × magnification, S2—barely visible to the naked eye, S3—clearly visible to the naked eye, S4—large cracks up to 1 mm wide, S5—very large cracks with a width of more than 1 mm). The third rating evaluates the crack depths (a—the top layer is not entirely cracked, b—the top layer is completely cracked, the bottom layer remains mostly undamaged, c—the entire coating system from the surface to the substrate is cracked).

DAHLE, Sebastian, ŽIGON, Jure, ZAPLOTNIK, Rok, PETRIČ, Marko, PAVLIČ, Matjaž. An open-source surface barrier discharge plasma pretreatment for reduced cracking of outdoor wood coatings. *Cellulose*. 2021, vol. 28, iss. 12, str. 8055-8076.

3D UV CURING

- IN GENERAL, UV CURED COATINGS ARE OF A BETTER QUALITY THAN THE CONVENTIONALLY DRIED ONES (LOWER INHERENT STRESS DUE TO HIGHER DRY MATTER CONTENT, FAST, LOW ENERGY CONSUMPTION,...)
- BUT: ONLY FOR FLAT ELEMENTS
- SOLUTIONS FOR 3D UV CURING:
 - UV CURING CHAMBERS WITH INERT ATMOSPHERE
 - UV LIGHTS ON ROBOTS
 - MULTI-AXIS UV CURING SYSTEMS
 - UV CURING CONVEYORS WITH VARIABLE SPEED AND HEIGHT ADJUSTMENT
 - UV LED ARRAYS WITH CUSTOMIZABLE GEOMETRIES
 - HYBRID CURING SYSTEMS COMBINING UV AND THERMAL CURING

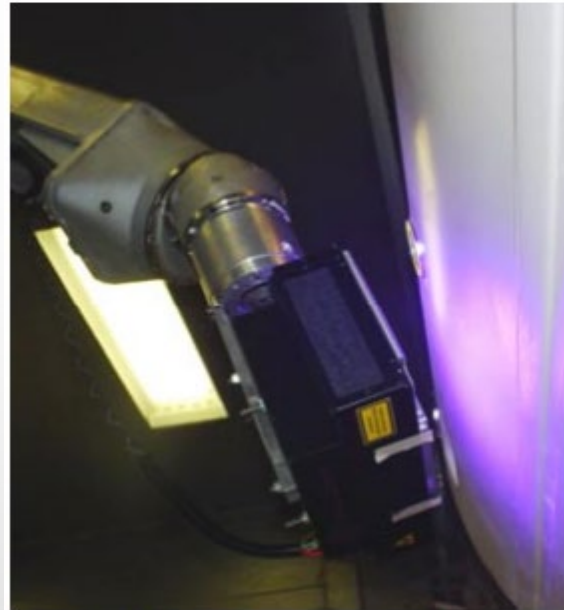
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3D UV CURING



<https://cromaiberica.com/gb/curado-uv-halogeno/357-cuv-500.html>



The UV LED source used in robot testing provides excellent promise

©RadTech e | 5 2006
Technical Proceedings

LED UV CURING

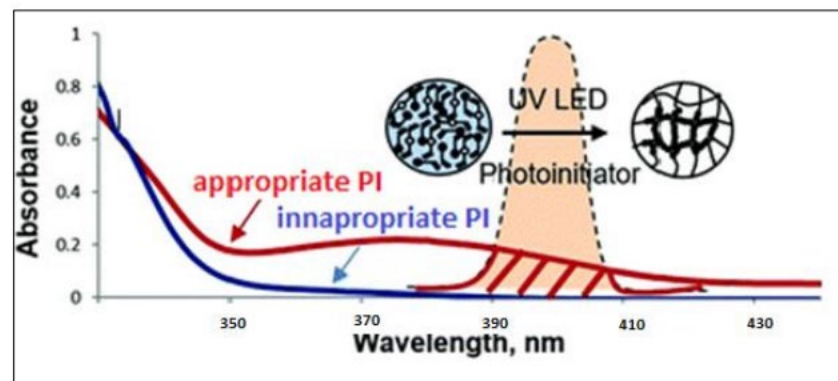
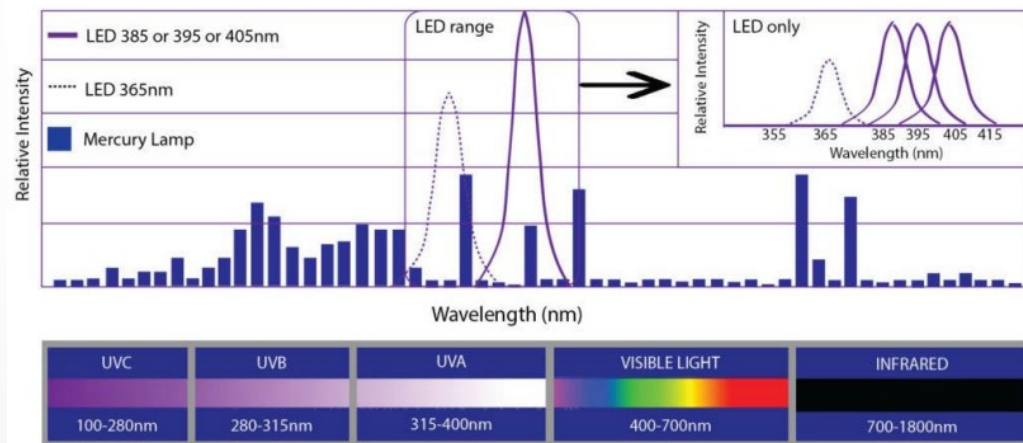
- ADVANTAGES:

- LOW ENERGY CONSUMPTION (CCA 70% LOWER OPERATIONAL COSTS THAN AT HG LAMPS)
- LONG SERVICE LIFE (UP TO 50 000 HOURS)
- CONSTANT RADIATION POWER, HIGH INTENSITY
- LOW WORKING TEMPERATURE
- VERY SUITABLE FOR TEMPERATURE SENSITIVE SUBSTRATES
- NO OZONE
- NO HG

LED UV CURING

- CHALLENGES:

- ALMOST MONOCHROMATIC SPECTRUM
- HIGH PRICE
- UNWANTED INHIBITION BY OXYGEN
- LOWER QUALITY CURING
- COATING FORMULATION MUST BE ADAPTED
- SELECTION OF THE RIGHT PHOTOINITIATOR



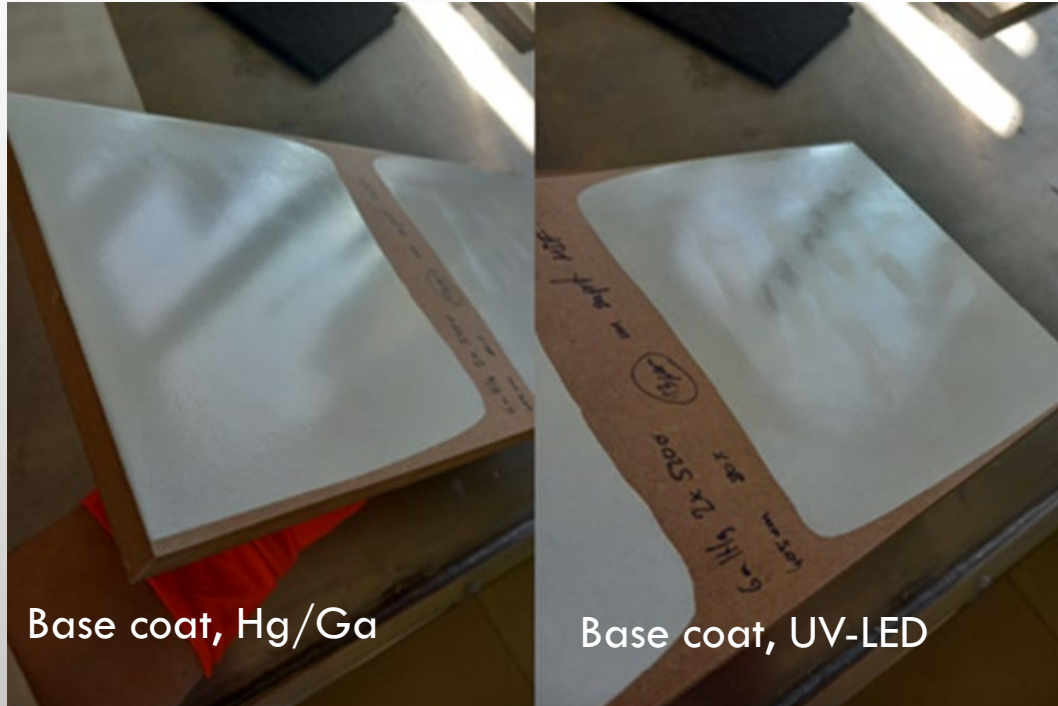
From: L.O. Jurina, „UV-LED Premazi – Prihodnost UV utrjujočih premazov za zaščito lesa“, Kansai Helios, Ljubljana

SELECTION OF PHOTOINITIATORS FOR UV-LED CURING OF WHITE PIGMENTED COATINGS: A CASE STUDY OF INDUSTRY-ACADEMIA COLLABORATION

MARKO PETRIČ^{1*}, LEON OSTANEK JURINA², MATEJA ŠLIBAR² AND KLARA PESTOTNIK¹

¹ DEPARTMENT OF WOOD SCIENCE AND TECHNOLOGY, BIOTECHNICAL FACULTY, UNIVERSITY OF LJUBLJANA, SLOVENIA

² KANSAI HELIOS SLOVENIJA D.O.O., KOLIČEVO, DOMŽALE, SLOVENIA



Base coat, Hg/Ga

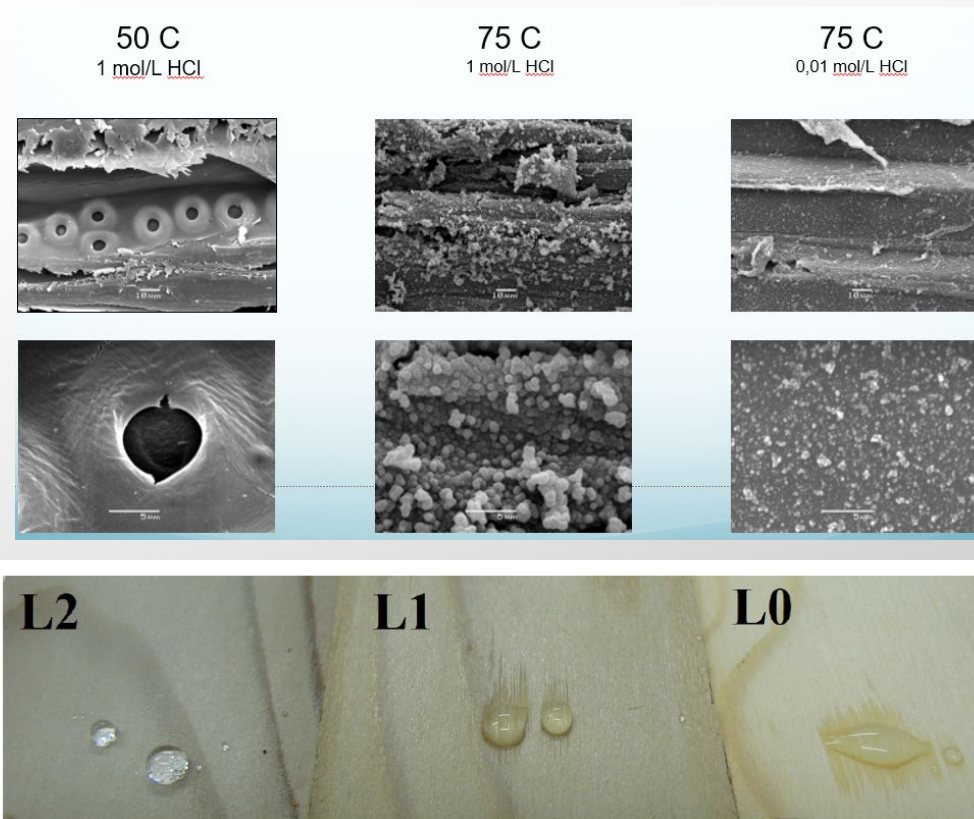
Base coat, UV-LED



YELLOWING

NANOPARTICLES IN COATINGS AND FOR WOOD TREATMENT (INCLUDING NANOCELLULOSE)

- NANOPARTICLES ON WOOD SURFACES
 - IMPROVEMENT OF MECHANICAL PROPERTIES
 - ENHANCED WATER RESISTANCE
 - INCREASED UV PROTECTION
 - ANTIBACTERIAL AND ANTIFUNGAL PROPERTIES
 - FIRE RETARDANCY
 - SURFACE MODIFICATION AND FUNCTIONALIZATION



PORI, Pavel. Zaščita lesa pred sevanjem UV s premaznimi sistemi z nanodelci : doktorska disertacija = Protection of wood against UV radiation with nano-coatings : doctoral dissertation. Ljubljana: [P. Pori], 2016. XVIII, 177 f., ilustr. <http://www.dlib.si/details/URN:NBN:SI:doc-F6B501LO>.

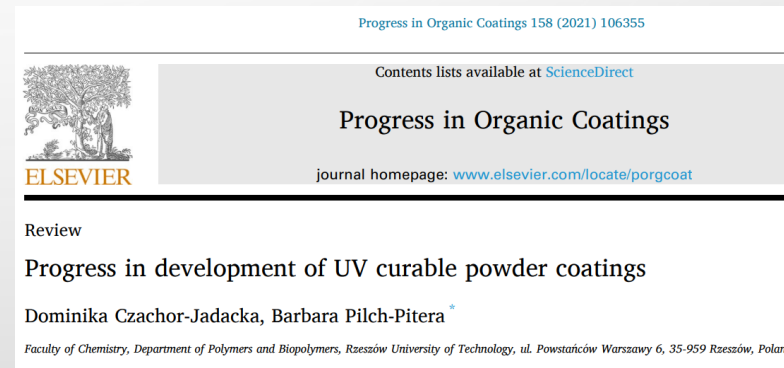
POWDER COATINGS

- HAS BEEN LONG KNOWN FOR SURFACE FINISHING OF MDFs (BUT, LOW CURING TEMPERATURES – PROBLEMS WITH POWDER COATINGS ON SOLID WOOD)

Table 6

Comparison of curing parameter in thermosetting and UV curing powder coatings [81].

Heating/curing	Curing temperature	Curing time	Substrate
Thermosetting powder coating			
Temperature convection	130–220 °C	15–30 min	Metal
IR	130–250 °C	2–15 min	Metal
UV curing powder coating			
Heating	Curing		
IR/temperature convection	UV	90–130 °C	1–3 min
			Metal, wood, plastic.



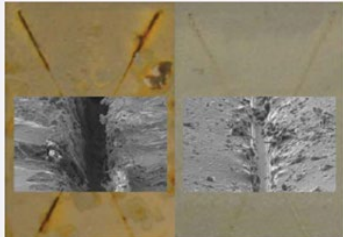
SELF HEALING COATINGS AND CAPSULES



Obnovljive prevleke za korozijsko zaščito



Korozija povzroči stroškov okoli 300 mrd USD/leto



SELF-HEALING POLYMERS

These images present the dramatic reduction in corrosion of a steel plate coated with a self-healing coating (right) as compared to a conventional coating. Both samples were scratched and placed in 5% NaCl for 5 days. The background is an optical image (2x magnification), in the foreground is an SEM image of the scratch. In the self-healing sample, the scratch has almost completely self-healed, while in the control sample, the scratch remains all the way down to the substrate, as reported by Paul Braun and co-workers on p.645.

Cho, S.H., White, S.R. and Braun, P.V., *Self-Healing Polymer Coatings*, *Advanced Materials* 21, 645-649 (2009).

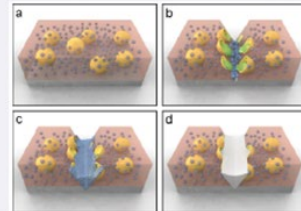
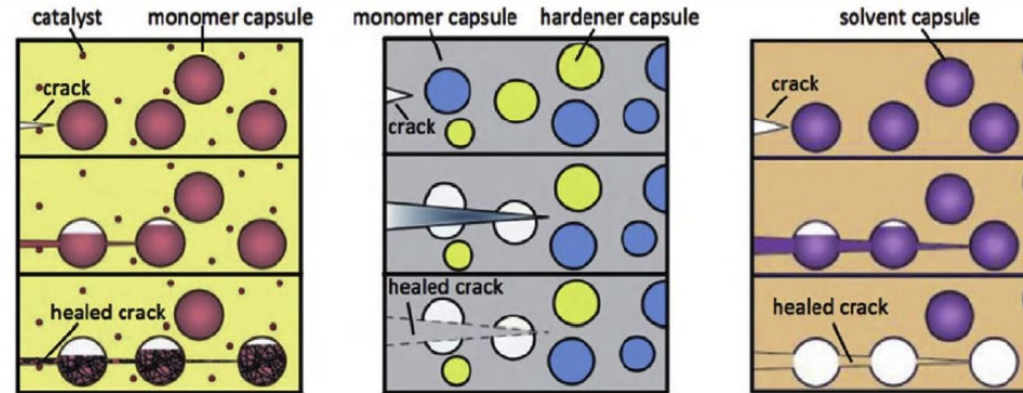
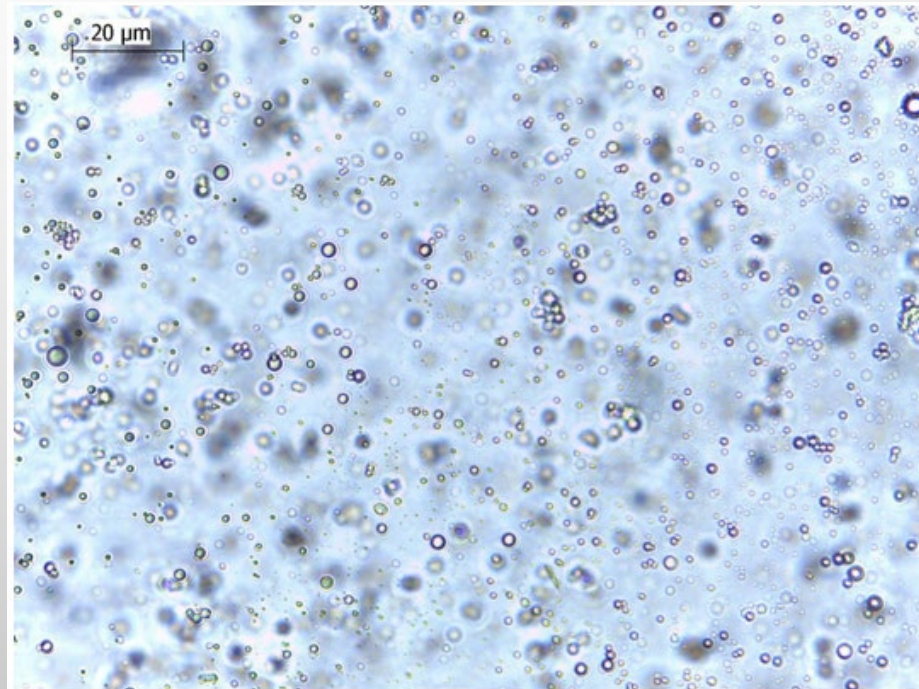


Figure 1. Schematic of self-healing process. a) Self-healing coating containing microencapsulated catalyst (yellow) and phase-separated healing agent droplets (blue) in a matrix (light orange) on a metallic substrate (grey). b) Damage to the coating layer releases catalyst (green) and healing agent (blue). c) Mixing of healing agent and catalyst in the damaged region. d) Damage healed by cross-linked POMS, protecting the substrate from the environment.



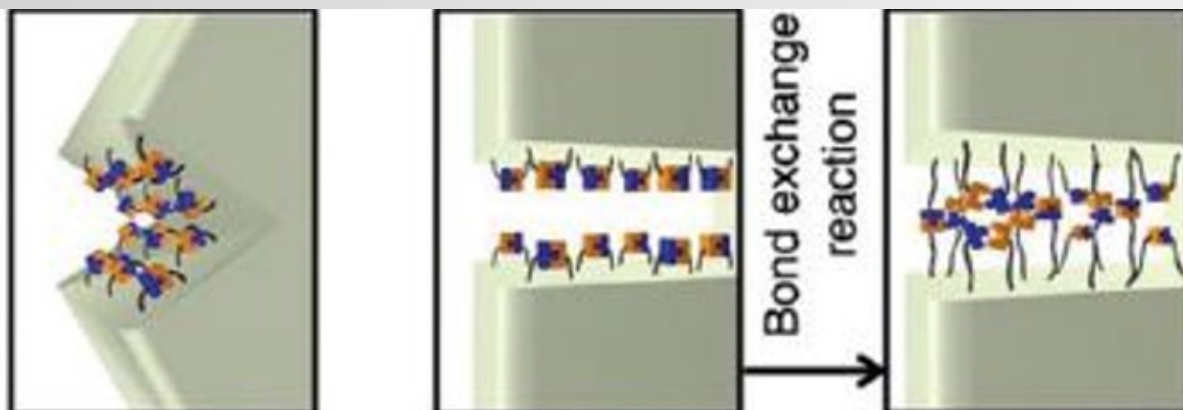
Slika 8 Različni tipi mikrokapsul in način utrjevanja (Ataei, 2019)



Slika 31 Mikrokapsule pod mikroskopom Ultratrak pri 11000 obr. min-1 in čas mešanja 60 sekund in 15 minut utrjevanja v utrjevalni raztopini (Jemec, 2020)

JEMEC, Blaž. Izdelava mikrokapsul za uporabo v samoobnovljivih premazih za les in kovino : magistrsko delo = Preparation of microcapsules for applications in self-healing wood and metal coatings : M. Sc. thesis. Ljubljana: [B. Jemec], 2020. X, 73 f., ilustr. <https://repozitorij.uni-lj.si/IzpisGradiva.php>

Source: Venturini, P., Helios group



Amaral A. J. R., Pasparakis G. 2017. Stimuli responsive self-healing polymers, gels, elastomers and membranes. *Polymer Chemistry*, 8: 6464-6484

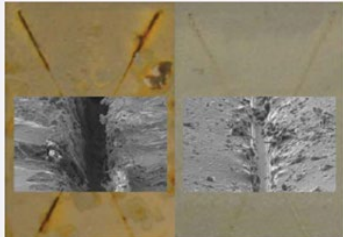
SELF HEALING COATINGS AND CAPSULES



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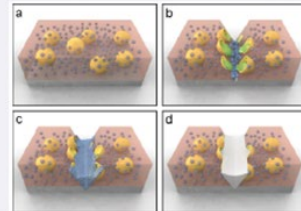
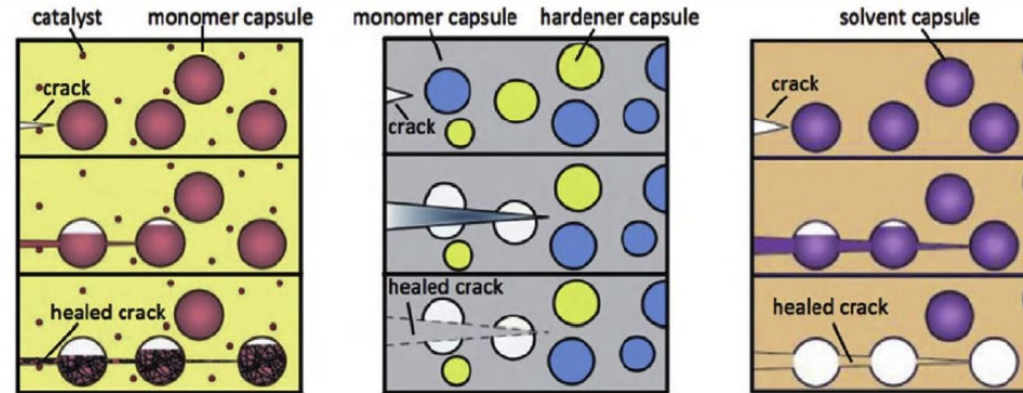
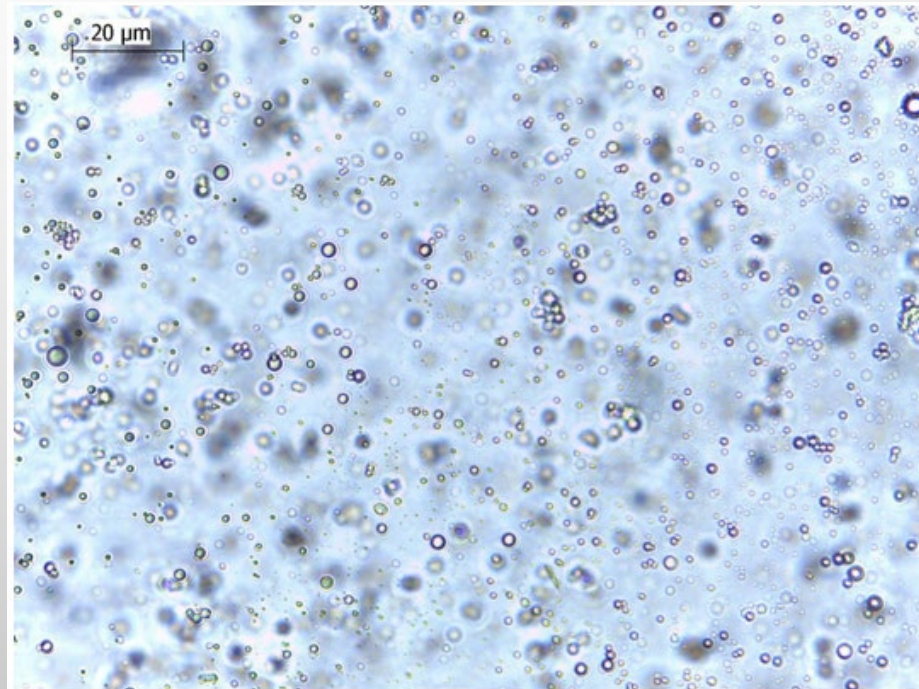


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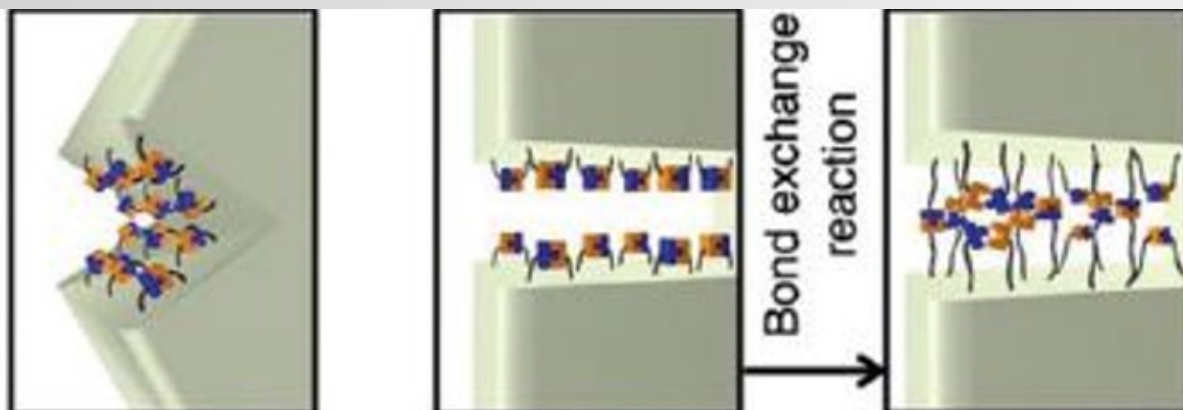
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MICROCAPSULES IN WOOD COATINGS CAN BE USED ALSO FOR OTHER PURPOSES



- CONTROLLED RELEASE OF ACTIVE INGREDIENTS; ENHANCED DURABILITY AND WEATHER RESISTANCE; COLOR AND AESTHETIC ENHANCEMENT; ODOR CONTROL AND VOC REDUCTION; SCRATCH AND ABRASION RESISTANCE; FUNCTIONAL COATINGS FOR SPECIALIZED APPLICATIONS



SUPERHYDROPHYLIC AND SUPERHYDROPHOBIC SURFACES

Surface Energy (SE)

Decrease, SE: $-\text{CH}_3 > -\text{CH}_2 > -\text{CF}_2 > -\text{CF}_2\text{H} > -\text{CF}_3$
Nano Lett. 2009, 1, 501-505

Contact Angle (CA)

(1) Young's Equation:

Valid for flat/smooth surfaces

$$\cos \theta = \frac{f_{VS} - f_{LS}}{f_{LV}}$$

where:

- f_{LV} - interfacial force of drop and vapor
- f_{LS} - interfacial force of drop and surface
- f_{VS} - interfacial force of surface and vapor

www.astb.com
<https://www.youtube.com/watch?v=27bq3o3y8Os>

(2) Wenzel's Equation:

Valid for uniformly rough surfaces³

Langmuir 2003, 19, 8343-8348.

$$\cos \theta_r = r \cos \theta$$

where:

- r - roughness factor
- θ_r - rough surface contact angle
- θ - smooth surface contact angle

$$r = \frac{\text{actual_surface}}{\text{geometric_surface}}$$

(1) Wenzel, R.N. *Ind. Eng. Chem.* 1936, 28, 8, 986-994.
 (2) Wenzel, R. N. *J. Phys. Colloid Chem.* 1949, 53, 1466-1467.
 (3) Nosonovsky, M. *Langmuir* 2007, 23, 9919-

(3) Cassie-Baxter's Equation:

Valid for heterogeneous rough (porous) surfaces³

Langmuir 2003, 19, 8343-8348.

$$\cos \theta_r = f_1 \cos \theta - f_2$$

where:

- f_1 - interfacial area of porous microstructure
- f_2 - interfacial area of air in the interspaces among the porous microstructure
- θ_r - rough surface contact angle
- θ - smooth surface contact angle

$$f_1 + f_2 = 1$$

(1) Cassie, A. B. D.; Baxter, S. *Trans. Faraday Soc.* 1944, 40, 546-551.



<https://www.properla.co.uk/lotus-effect/>



<https://phys.org/news/2016-06-lotus-leaf-scientists-world-self-cleaning.html>

PHOTOCHROMIC, THERMOCHROMIC AND ELECTROCHROMIC COATINGS

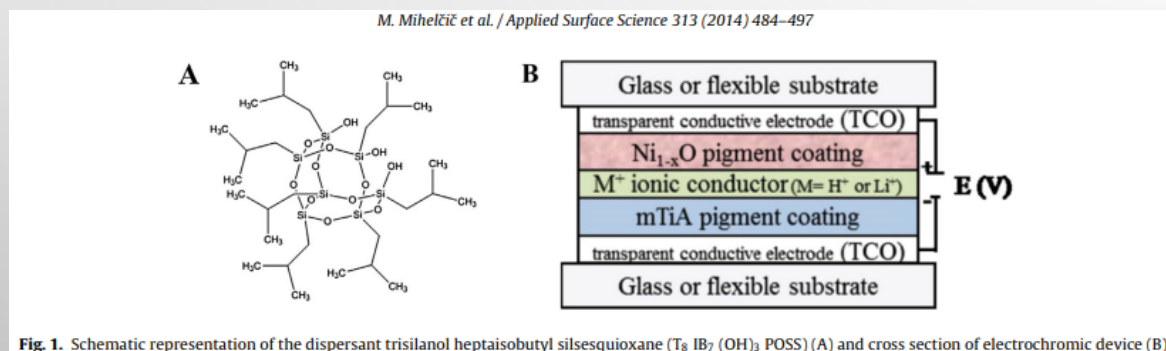
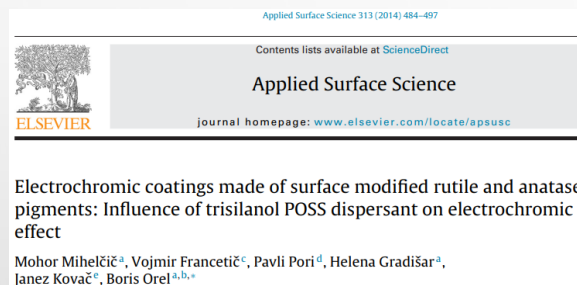


Fig. 1. Schematic representation of the dispersant trisilanol hepta(isobutyl) silsesquioxane (T₈ IB₇ (OH)₃ POSS) (A) and cross section of electrochromic device (B).

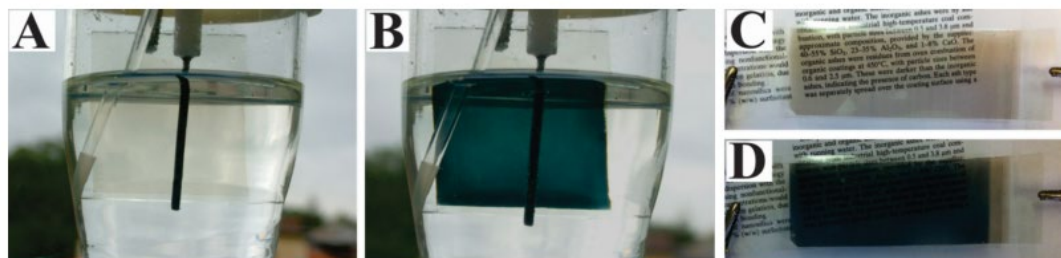


Fig. 16. Electrochromic changes of the mTiA pigment coatings mTiA01 (1 × spin-coating) deposited on FTO glass in initial (A) and charged state (B) obtained after charging for 1 min at −1.7 V (see text). EC devices on ITO PET foils in bleached (C) and coloured (D) states are also presented (for details see text).

From:

Sun *et al.* (2018). “Hydrothermal WO₃ wood,” *BioResources* 13(1), 1075-1087.



Fig. 5. Photographs of untreated wood, S-90, and S-120 before and after 6 h UV irradiation

1. Wood with photochromic and superhydrophobic properties was achieved by hydrothermally growing WO₃ nanoparticles on the surface of the wood at a low temperature. The SEM images proved that temperature played a key role in the thickness and roughness of the WO₃ layer.
2. The WO₃-coated wood was sensitive to UV light and was more sensitive at a high temperature of 120 °C.
3. Self-cleaning character was obtained after a simple fluorosilane modification of the WO₃-coated wood.
4. This study provides a simple and mild method for enhancing the visual quality of fast-growing wood. Changing the reaction conditions and photo stimulation controlled the color.

THANK YOU VERY MUCH FOR YOUR ATTENTION!

MARKO PETRIČ, UNIVERSITY OF LJUBLJANA, BIOTECHNICAL FACULTY,

marko.petric@bf.uni-lj.si



BF

UNIVERSITY
OF LJUBLJANA

Biotechnical
Faculty

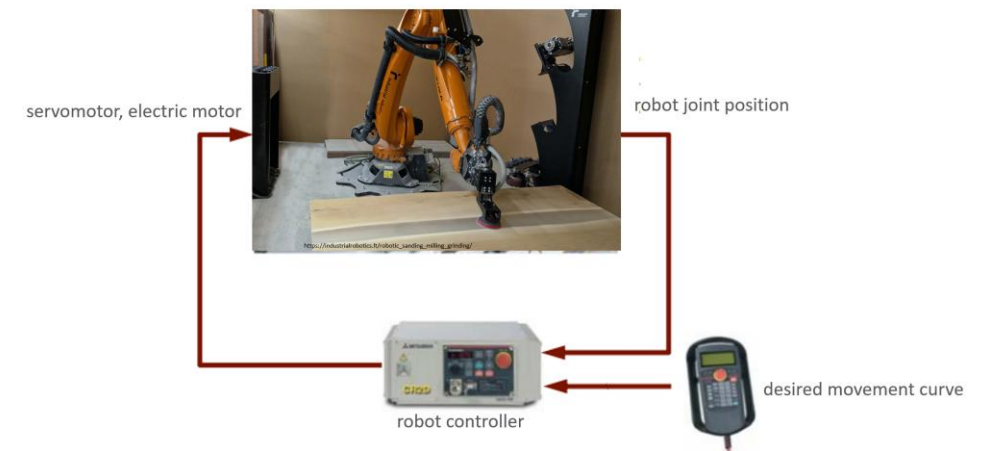
NEW PRODUCTION TECHNOLOGIES FOR FURNITURE PRODUCTION

Prof.dr. Gorazd Fajdiga

SUSFUR Project – Training Program

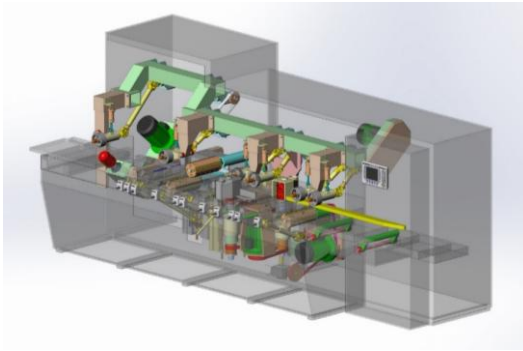
Ljubljana, 23.9.2025

- An overview of the areas we cover at the chair
- Smart factories (Industry 4.0, 5.0)
- Computer Integrated Manufacture
- Automatically controlled systems (components)
- CNC machines
 - Components
 - Mechanical parts
- Robotic automation



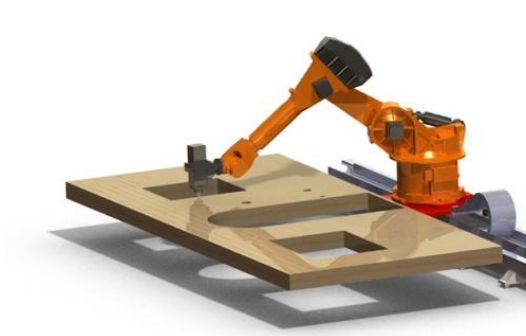
Woodworking machines, mechanical elements, ...

Development, measurements, strength analysis of elements, programming of CNC machines, maintenance of individual machine elements,...



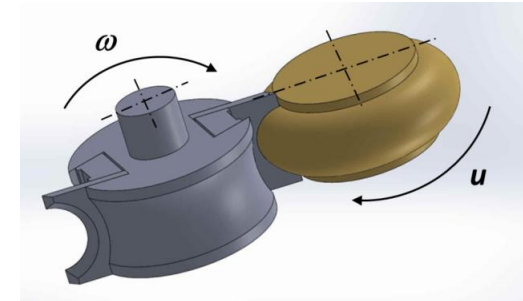
Automatisation and robotisation

Robot as a woodworking machine and as a supplying unit



Woodworking tools

Development, analysis and production of special tools



Chair of Mechanical Processing Technologies of Wood

Prof. dr. Gorazd Fajdiga (head)
Assist. prof. dr. Dominika Gornik Bučar
Assist. prof. dr. Miran Merhar
Ass. dr. Bojan Gospodarič
Drago Vidic, technical assistant
Gregor Tuta Gaberšček, PhD student

Wood biomass and wood residues processing

Production of wood chips and pellets from different tree species, analysis of properties



Woodworking processes and technologies

Technological measurements and optimization of technological processes



PEDAGOGICAL ACTIVITY RESEARCH ACTIVITY

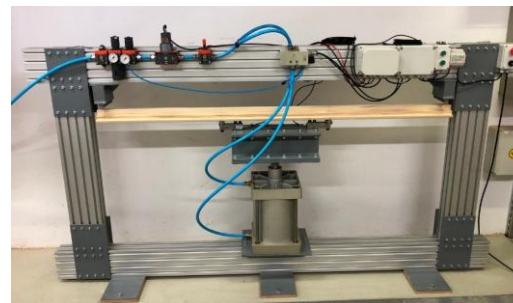
Development of new products

I profile based on veneer



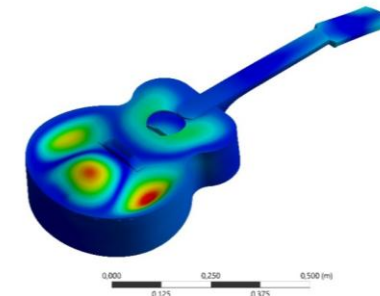
Dynamic durability of wood

Determination of durability (experimental, analytical)

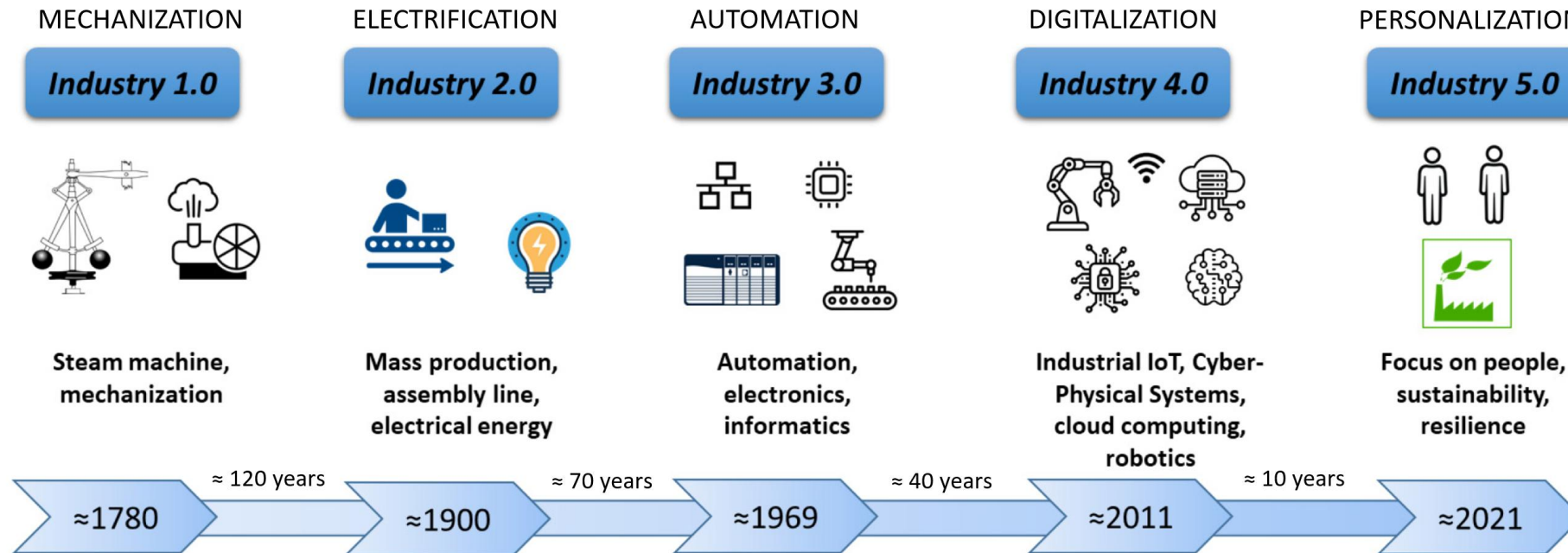


Numerical simulations and analysis

Structural (deformations, stresses), acoustic and thermal analyses



INDUSTRIAL REVOLUTIONS



<https://www.mdpi.com/2079-9292/13/4/782>

Industry 3.0: Automation (≈ 1969)

- **What it brought:** The use of electronics, computers and robots to automate production processes. Humans continued to control production.
- **Examples:** Programmable logic controllers (PLCs) and robots.

Industry 4.0: Digitalisation (≈ 2011)

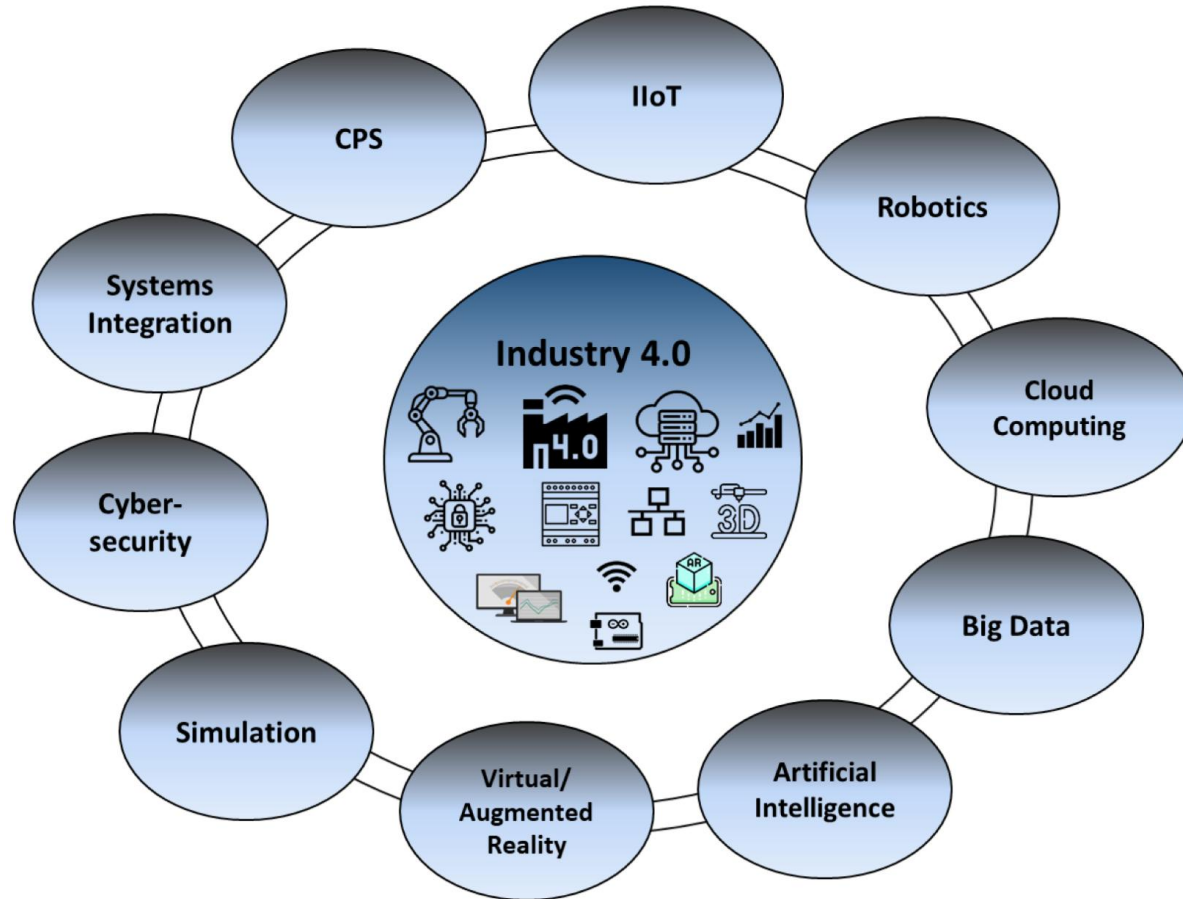
- **What it brought:** Everything was networked and digitalized. Utilization of the Internet of Things (IoT), cyber-physical systems, cloud computing and robotics. Production systems became "intelligent" and were able to communicate with each other.
- **Examples:** Smart factories that collect and analyze data in real time.

Industry 5.0: Personalisation (≈ 2021)

- **What it brought :** Industry 5.0 builds on Industry 4.0 and puts people at the centre. The focus is on human-machine collaboration (cobots), the customisation of products and the introduction of sustainability and resilience in production systems.
- **Examples:** Systems that enable customised production and robots that work together with humans in a safe environment.

COMPARISON OF INDUSTRY 4.0 AND INDUSTRY 5.0

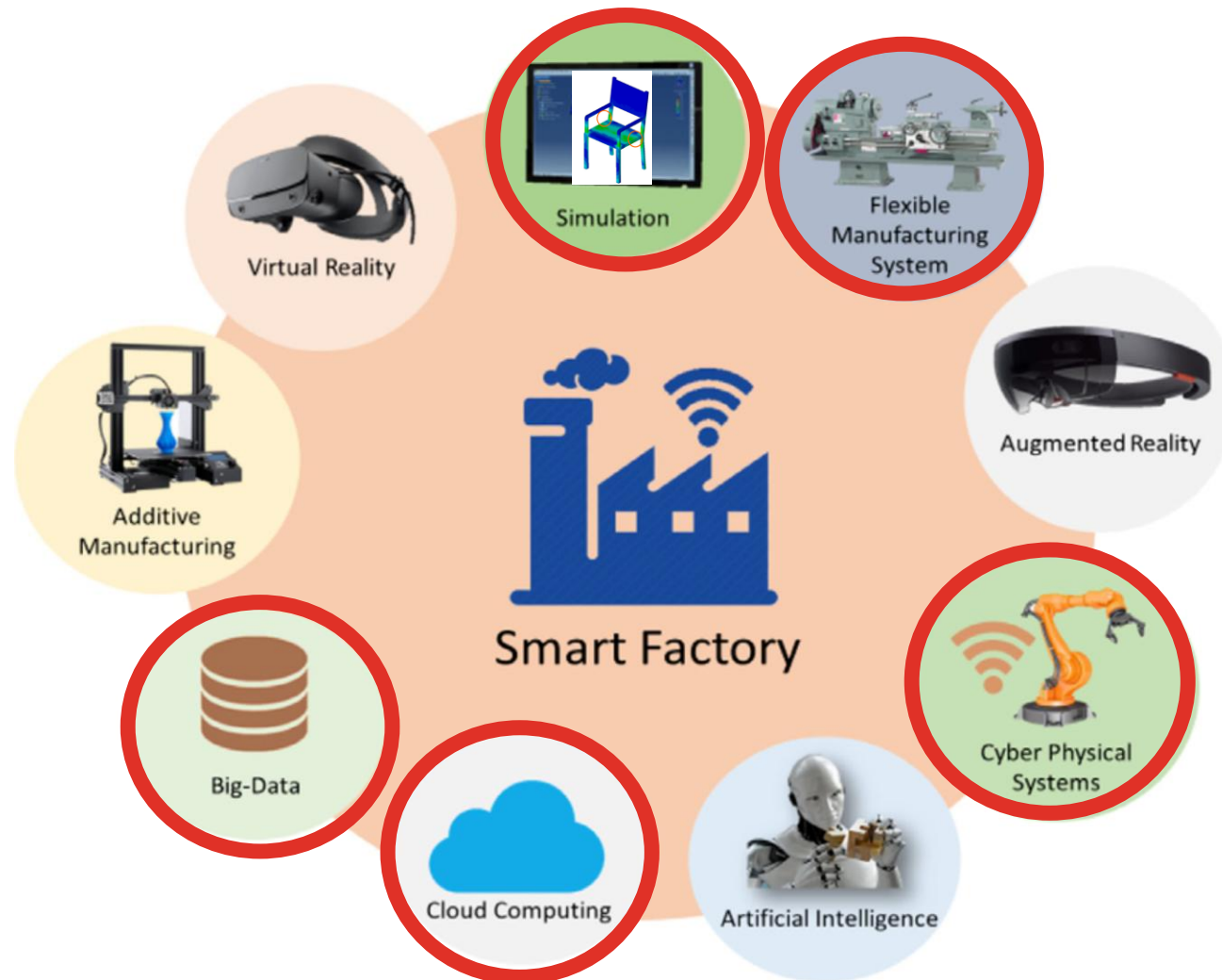
Characteristic	Industry 4.0	Industry 5.0
Main focus	Automation and efficiency	Human-machine collaboration
Goal	Increasing productivity through technology	Creating value by combining human and technological capabilities
The role of the robot	Autonomous work and replacing people	Help and support for humans (cobots)
Philosophy	"Smart factories"	"Smart people and machines"
Main concept	Digitalization, Internet of Things, Big Data	Focus on people, sustainability, resilience



- **CPS (Cyber-Physical Systems):** integration of physical machinery with computational models.
- **IIoT (Industrial Internet of Things):** network of connected devices enabling real-time data exchange.
- **Robotics:** automation of tasks with high precision and flexibility.
- **Cloud Computing:** scalable storage and processing power for industrial data.
- **Big Data:** collection and analysis of massive datasets for insights and optimization.
- **Artificial Intelligence (AI):** decision-making, predictive maintenance, and process optimization.
- **Virtual/Augmented Reality (VR/AR):** training, design visualization, and remote assistance.
- **Simulation:** digital twins and process modeling to test scenarios before implementation.
- **Cybersecurity:** protecting networks and data from digital threats.
- **Systems Integration:** seamless connectivity between machines, software, and business processes.

The Smart Factory is the „operational result“ of Industry 4.0 — a connected, automated, and intelligent production environment.

Some industries (automotive) already include all components, the furniture industry is following suit and does not yet include all areas.

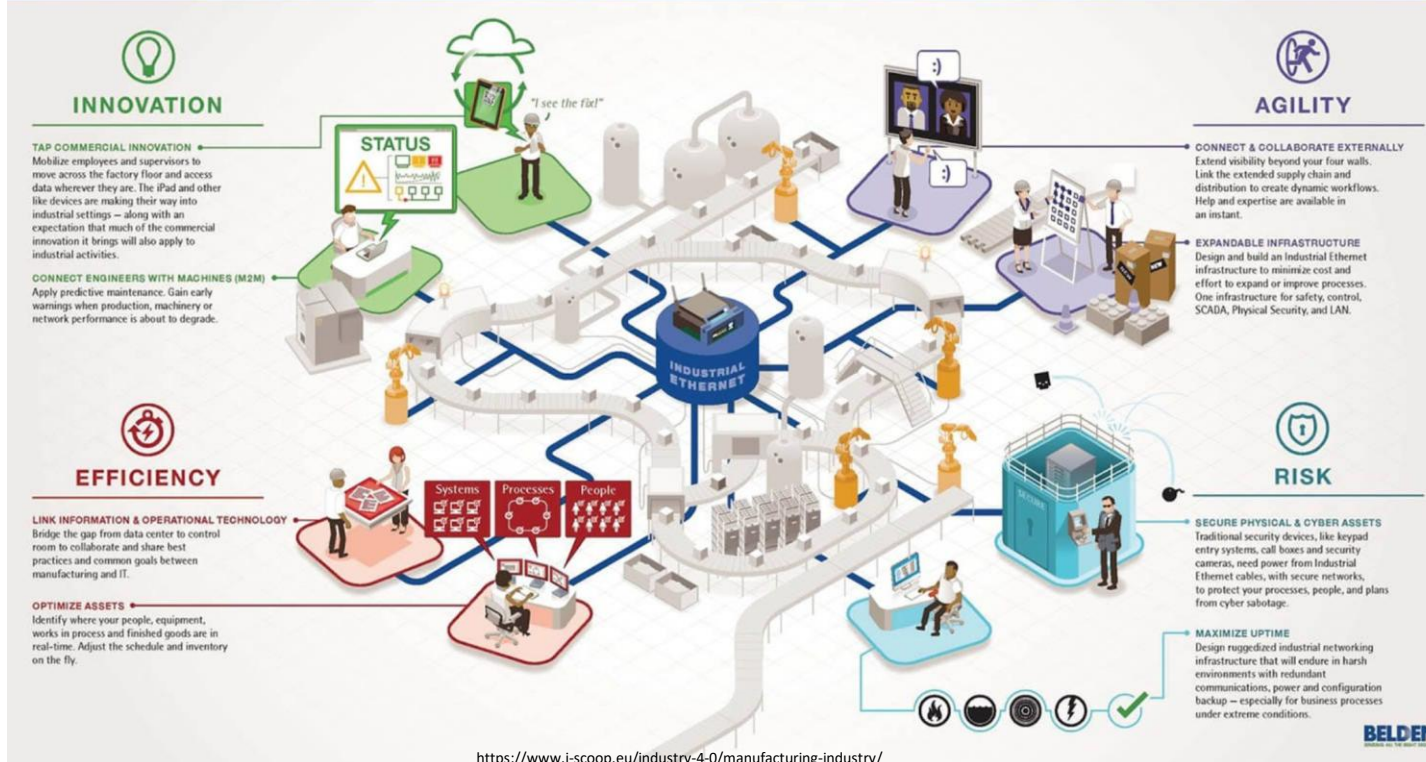


Technologies associated with Smart Manufacturing

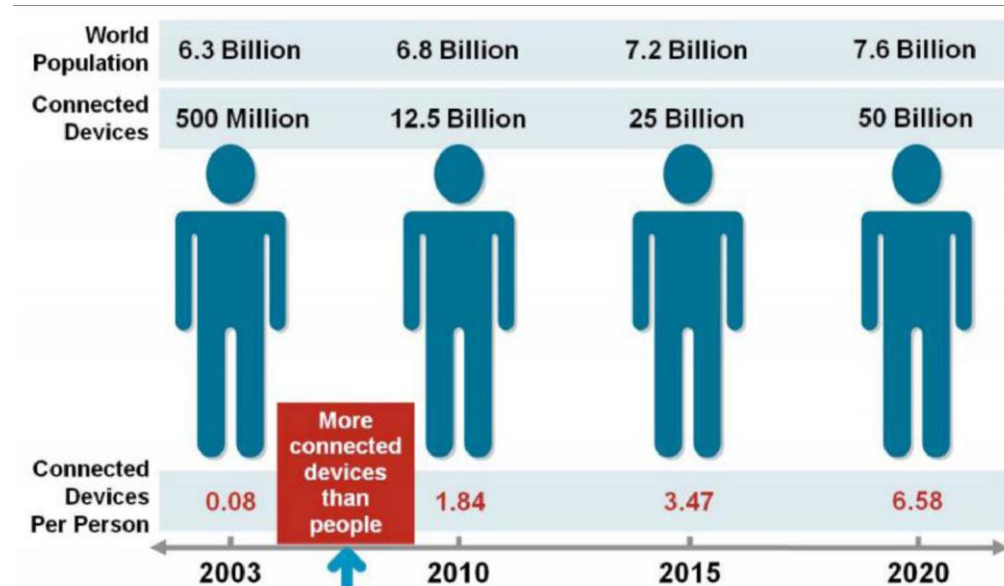
- **Virtual Reality (VR):** immersive training and design visualization.
- **Simulation:** digital modeling and testing of processes before implementation.
- **Flexible Manufacturing System:** adaptability to changing product designs and volumes.
- **Augmented Reality (AR):** real-time support for operators, assembly, and maintenance.
- **Cyber-Physical Systems (CPS):** integration of physical machines with digital controls and data.
- **Artificial Intelligence (AI):** predictive analytics, decision-making, and optimization.
- **Cloud Computing:** scalable storage and access to production data from anywhere.
- **Big Data:** analysis of large datasets to improve efficiency and predict failures.
- **Additive Manufacturing (3D printing):** rapid prototyping and customized production.

The Smart Factory is the „operational result“ of Industry 4.0 — a **connected**, automated, and intelligent production environment.

The Connected Factory in Action



Number of Connected devices per person



<https://www.sciencedirect.com/science/article/pii/S2666188820300162?via%3Dihub>

CHALLENGES OF THE FURNITURE INDUSTRY

Main trends in the furniture industry:

- shorter delivery times,
- higher quality (demand for consistent quality),
- sustainability aspects,
- lower labor costs,.....

Solutions:

- optimization of work processes,
- reduction of errors,
- faster response to demand,
-

All of this is addressed by **smart factories** (Industry 4 and 5):

- **CIM** (Computer Integrated Manufacture)
 - **CNC** machines (greater flexibility and precision)
 - **Robot** (material manipulation, grinding, assembly,...)



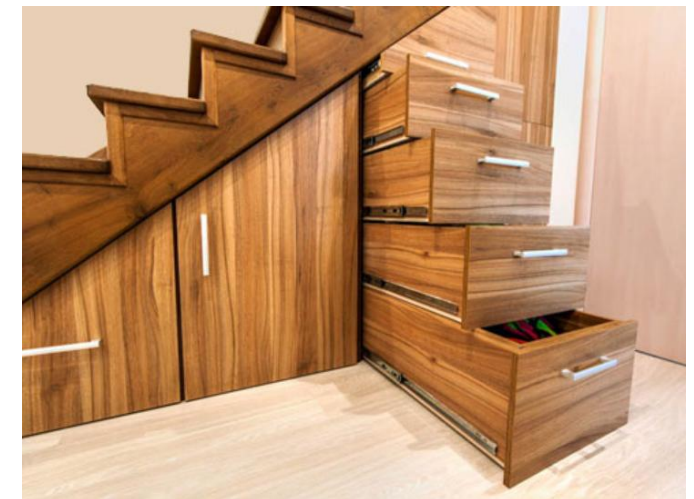
<https://www.lushome.com/eco-friendly-wooden-furniture-green-modern-interior-design/119230>



<https://frequip.com/best-furniture-brands-in-india/>



<https://thepurewood.com/wooden-furniture-manufacturers/>



CIM (Computer Integrated Manufacture)

- is a method of manufacturing in which the entire production process is controlled by a computer,
- the main goal of CIM is:
 - to **simplify** the manufacturing process,
 - **improve** efficiency, quality, and flexibility.

Benefits of CIM

Improved productivity

Improved quality

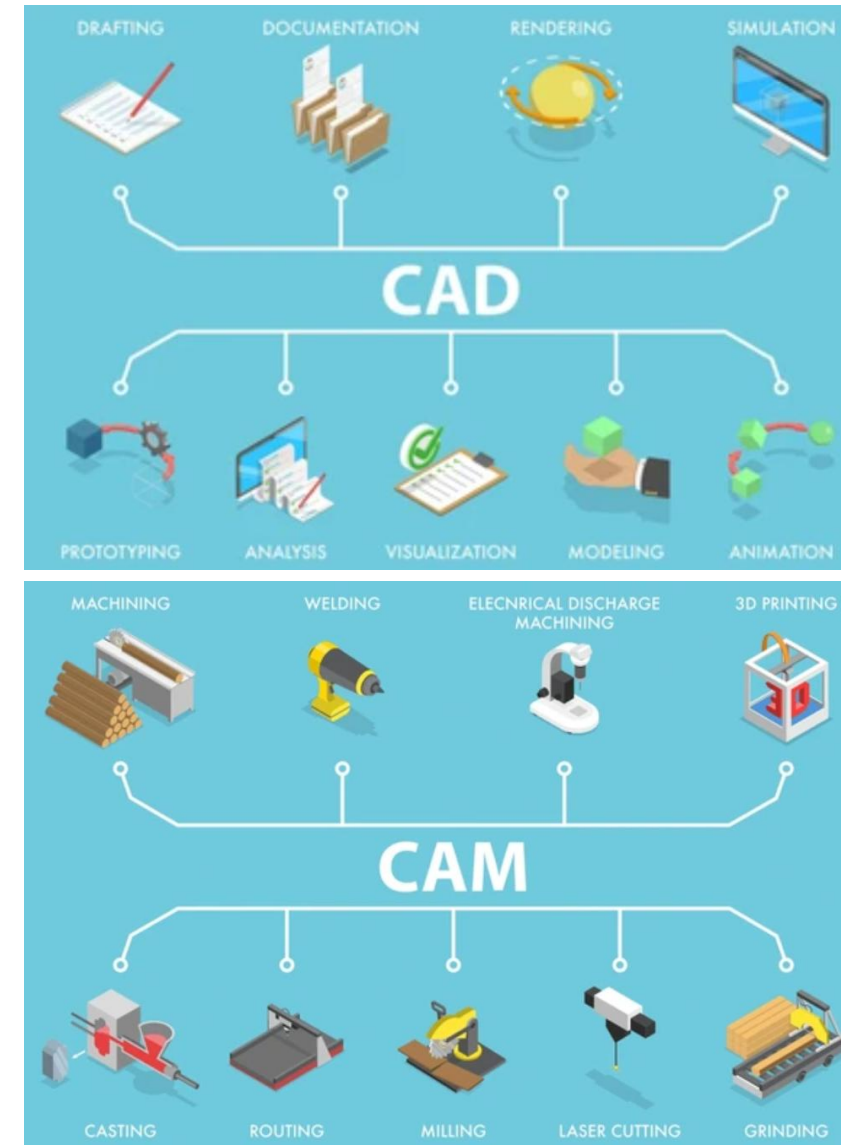


Improved customer satisfaction

Improved flexibility

CIM (Computer Integrated Manufacture)

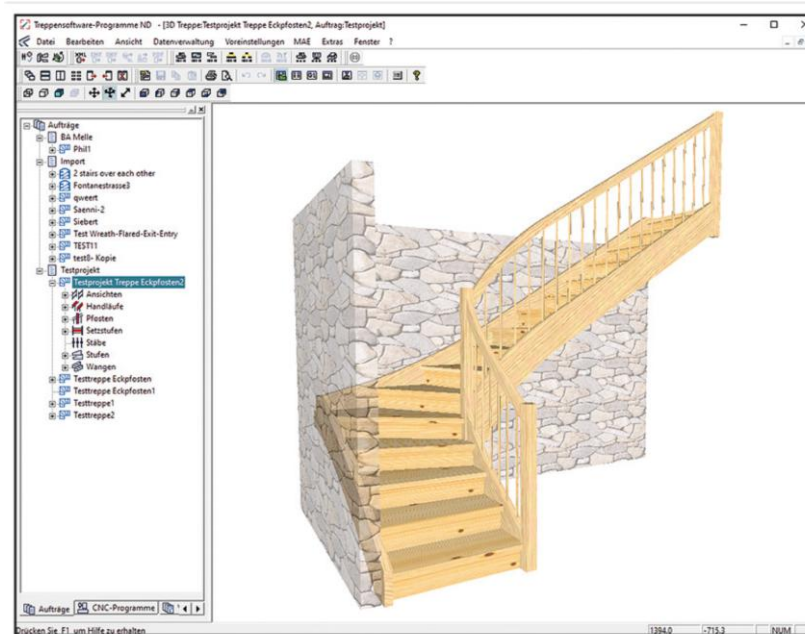
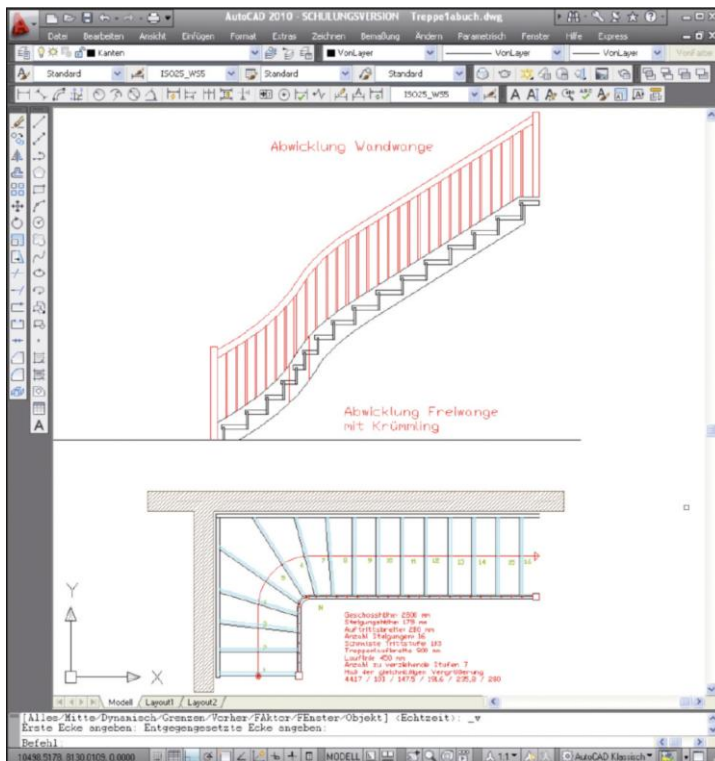
- **Computer-aided techniques:**
 - CAD (Computer-Aided Design)
 - CAM (Computer-Aided Manufacturing)
 - CAE (Computer-Aided Engineering)
 - CAPP (Computer-Aided Process Planing)
 - CAQ (Computer-Aided Quality Assurance)
 - PPC (Production Planning and Control)
 - ERP (Enterprise Resources Planning)



CIM Software

CAD – Computer-Aided Design

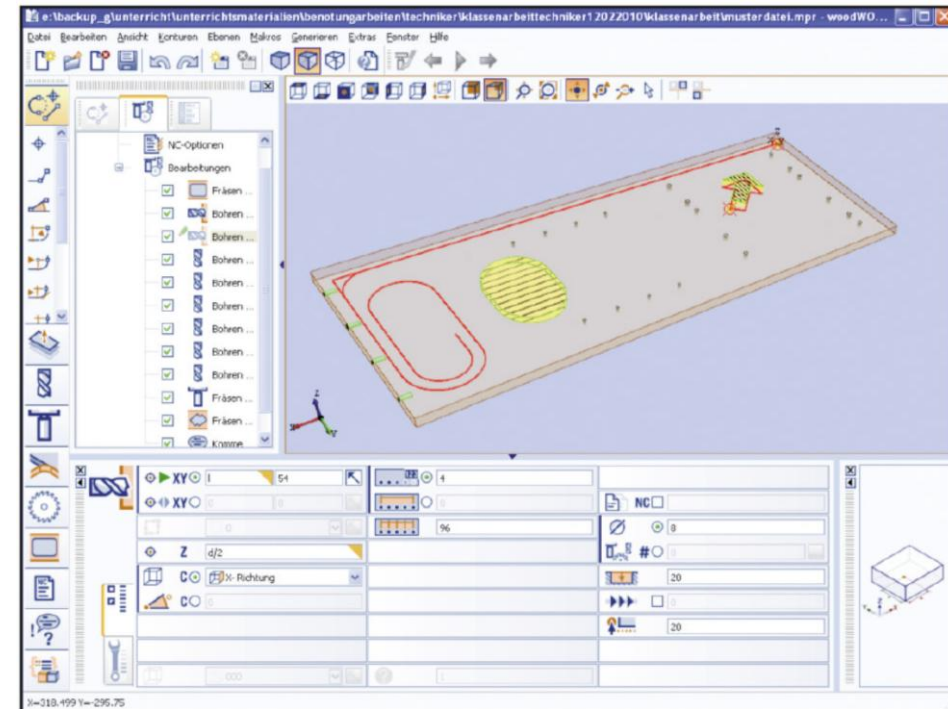
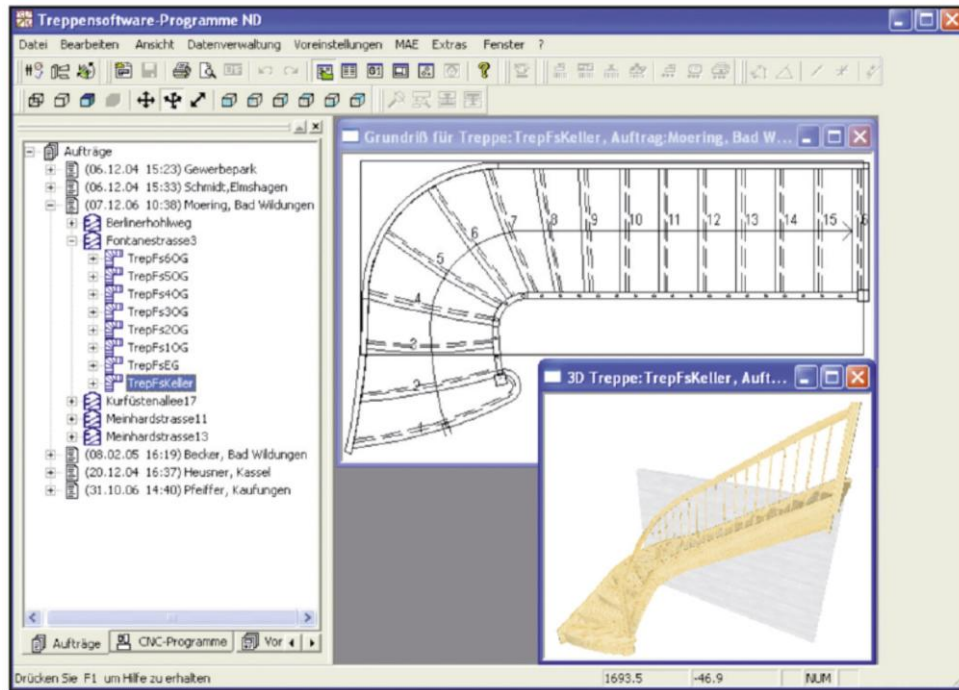
- CAD refers to any computer software that is used to produce high quality drawings and models which meet exact specifications
- CAD software is often then linked to machinery to perform a task to manufacture part of or a whole product;



CIM Software

CAM – Computer-Aided Manufacturing

- CAM allows products to be manufactured with very little effort compared to more hands on techniques where humans are controlling the machines
- CAM involves using CNC (Computer Numerical Control), whereby a machine's movement is described in exact detail by the computer program



CIM Hardware

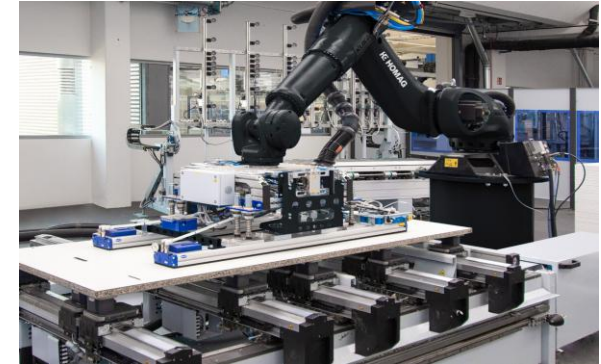
- **Manufacturing Equipment**

- task:
 - automate repetitive tasks,
 - improve precision and
 - increase production speed,
- includes:
 - CNC machines (Computer Numerical Control),
 - robots,
 - automated assembly lines and
 - material handling systems.

CNC machines



Robot



- **Sensors and Data Collection Devices**

- these devices gather real-time data on machine performance, production rates, and quality metrics, enabling manufacturers to monitor and optimize processes.

Inductive displacement sensor



<https://www.lotric.si/product/senzor-pomika-induktivni-tip-8739/>

- **Computers and Workstations**

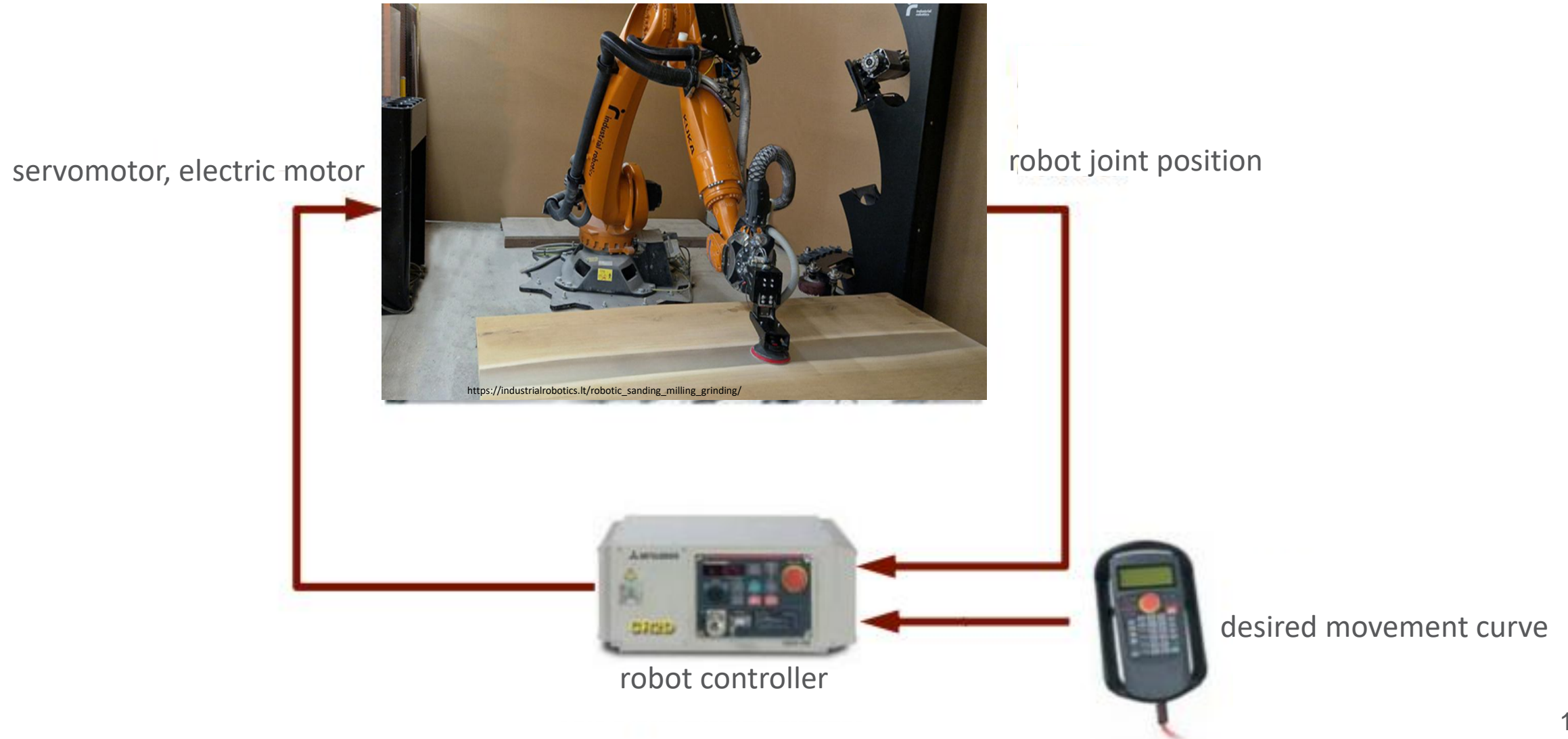
- these devices process data, execute commands, and facilitate communication between different components of the CIM system.

Industrial computer

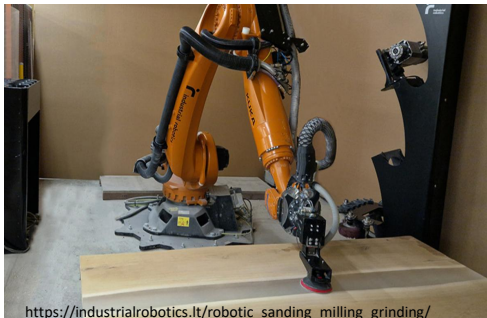
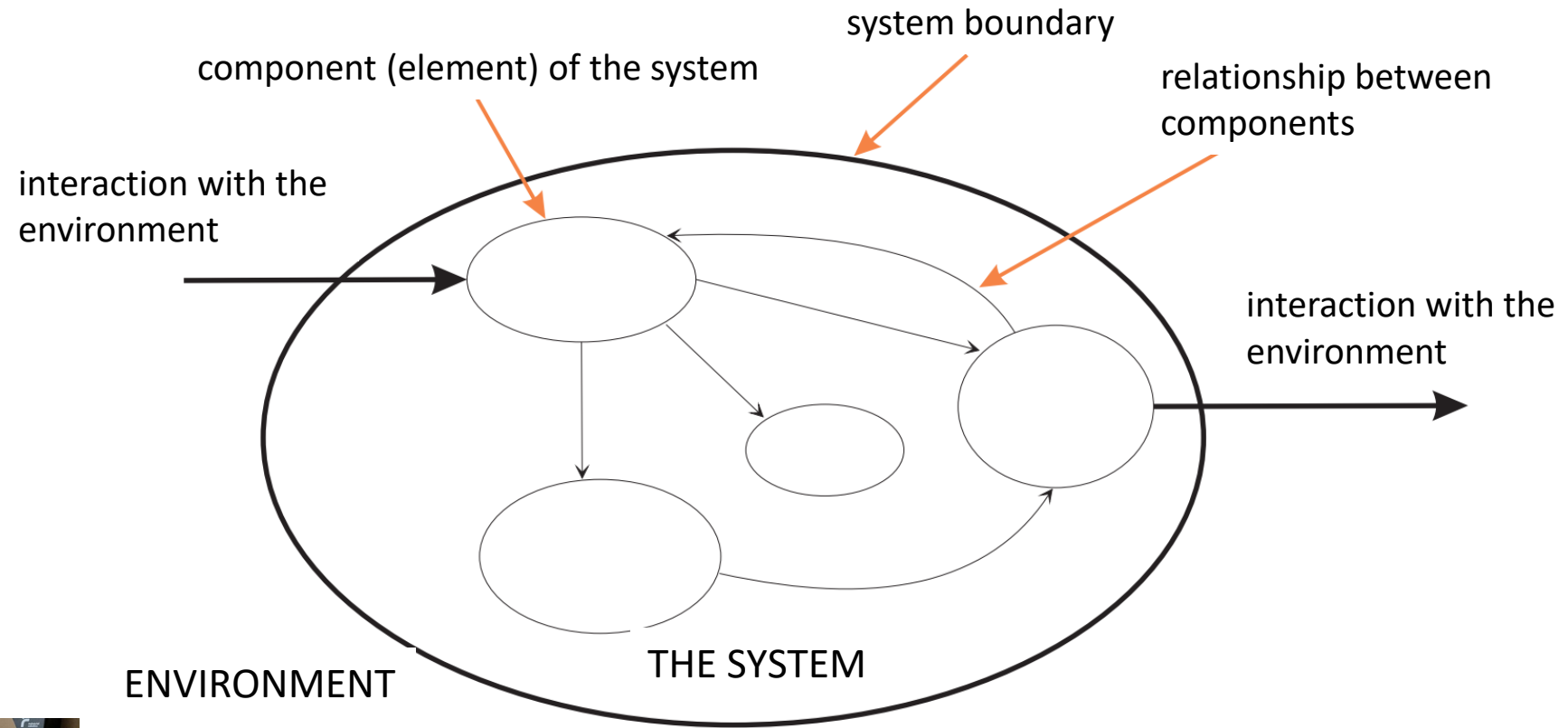


<https://tipteh.com/s/industrijski-racunalniki-mreza-oprema/modularni-industrijski-racunalnik-za-vse-aplikacije/>

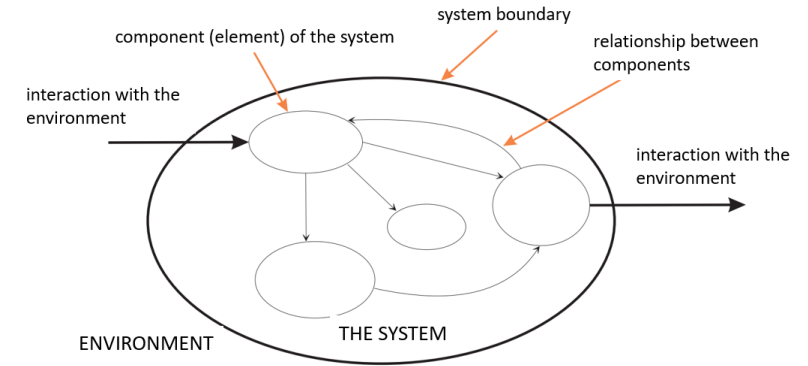
AUTOMATICALLY CONTROLLED SYSTEMS (ROBOT AS A SANDING MACHINE)



- the system is more than just the sum of its individual components

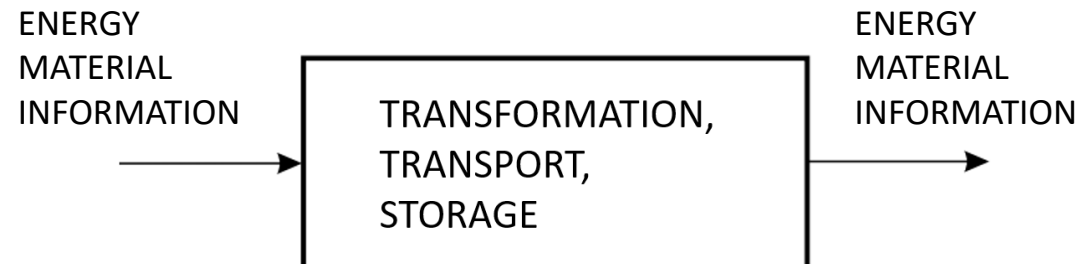


- a system is the framework in which **processes** take place,
- a **process** is the content of the system

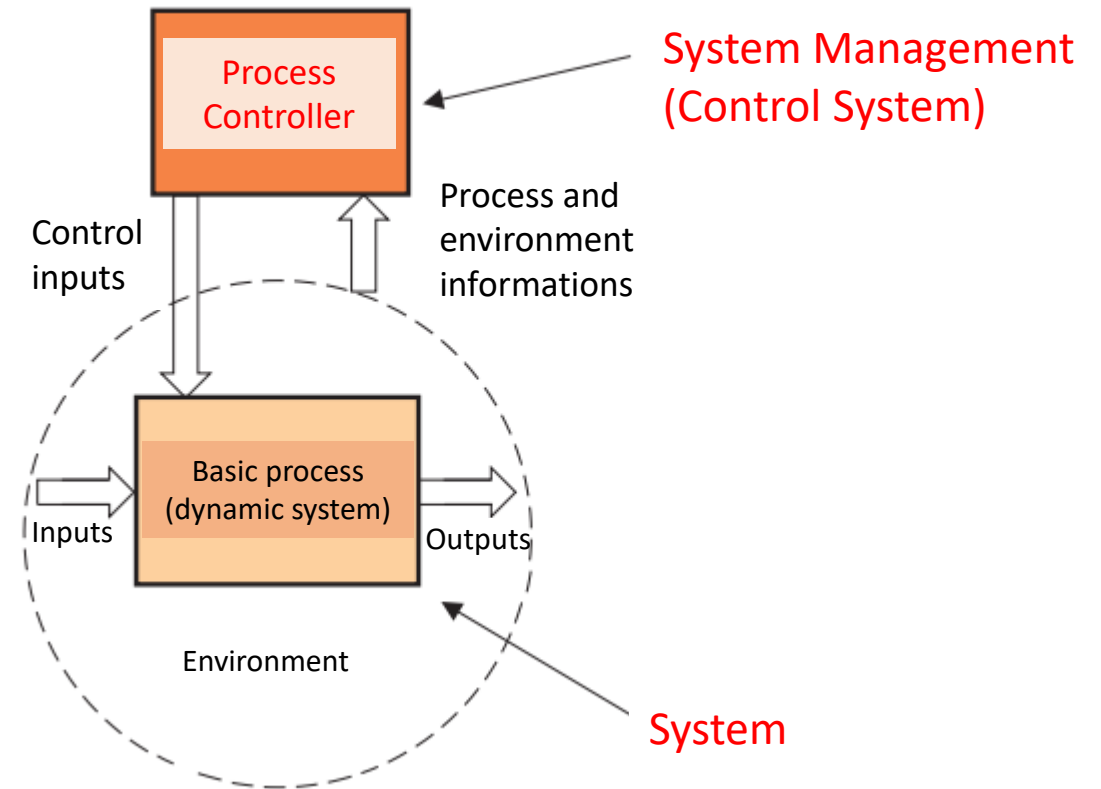
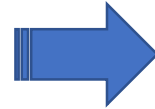
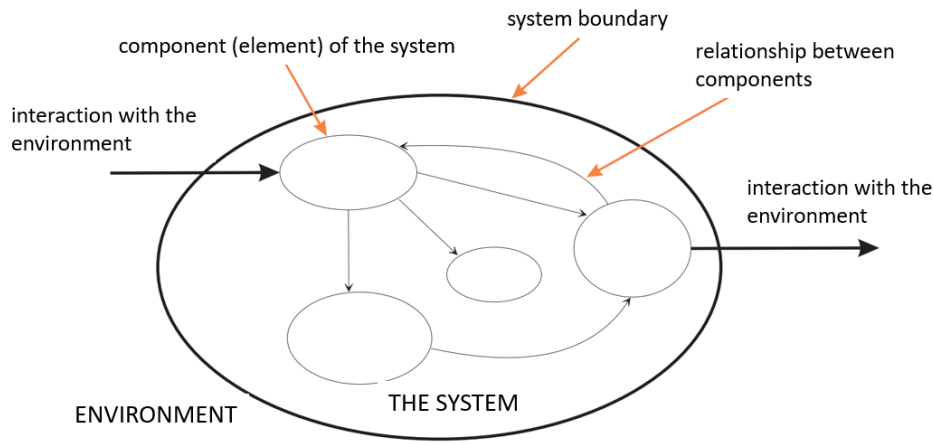


- **technical processes**

- a set of interdependent processes in a system that result in the transformation, transport, or storage of material, energy, or information.

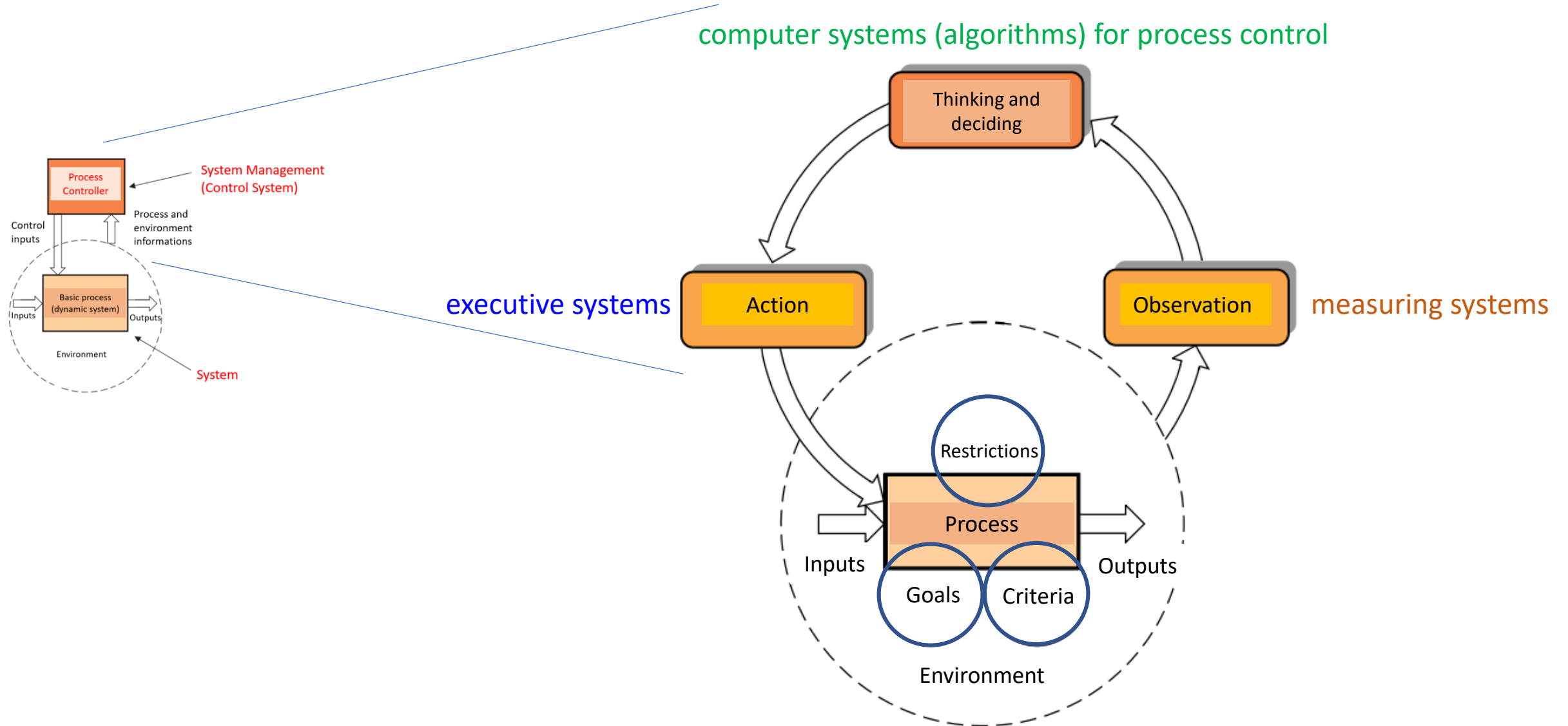


- we separate the system management from the basic process and its environment and obtain two subsystems:
 - system,
 - system management (control system).



- **System Management (Control System)** is a process within a system (manual control, automatic control, **computer control**)
- **Process Controller** is a process by which we influence the operation (behavior) of a system in order to achieve a set goal

SYSTEM MANAGEMENT (CONTROLLING SYSTEM)



- **Observation:**

- we obtain a suitable knowledge base with the help of which we **prepare measures** to lead the system to the desired goal by thinking and deciding

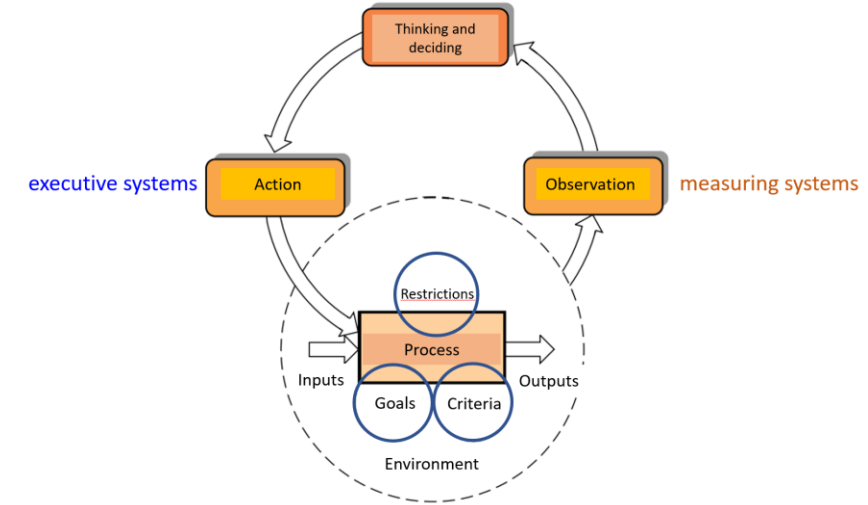
- **Thinking and deciding:**

- the **preparation and selection of measures** is the aim of system control
- the **quality of system control** undoubtedly depends largely on the quality of the measure as well as on its timeliness

- **Action:**

- decisions **must** be implemented.

computer systems (algorithms) for process control



Even a good and timely decision is pointless if we cannot implement it!

AUTOMATICALLY CONTROLLED SYSTEM

- Robot as a sanding machine

servomotor, electric motor
(action – implementation)



robot joint position
(observation - measuring systems)



robot controller
(thinking and deciding - controllers)

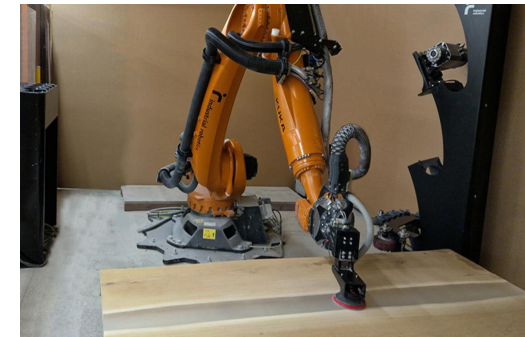


desired movement curve

- **measuring systems**

- **sensor** – converts a physical quantity into an electrical quantity of the order of magnitude [mV] in contact with the measuring medium)
- **transducer** – generates a useful signal from the sensor output (amplifies the measurement signal):
 - standard analogue signals (4-20 mA, 0-10 V),
 - digital signals (0/1, on/off, ...), communication networks.

- **displacement, speed and acceleration sensors** (potentiometers, encoders - pulse generators, etc.)



- **temperature measuring devices** (resistor, thermocouple, semiconductor ...)



- **pressure measuring devices** (absolute, differential; strain measurement with resistance plates, piezoelectric, ...)



- **flow and level metres**



- decision-making about management measures **is the most important part of the system control and management** (the "brain" of management systems),
- decision-making is based on a control algorithm (running on an embedded computer),



- **selection** according to the complexity of the tasks that the control system must fulfil:
 - **microcontroller** (simple, cheap),
 - **programmable logic controller - PLC** (more expensive, specialised in so-called discrete and/or sequential control, when binary signals predominate - on, off, ...),
 - **industrial regulator** (specialised in so-called continuous control, where continuous signals predominate - e.g. the controller regulates the opening of the mixing valve to achieve the appropriate temperature),
 - **process computers** (for particularly complex and sophisticated systems)



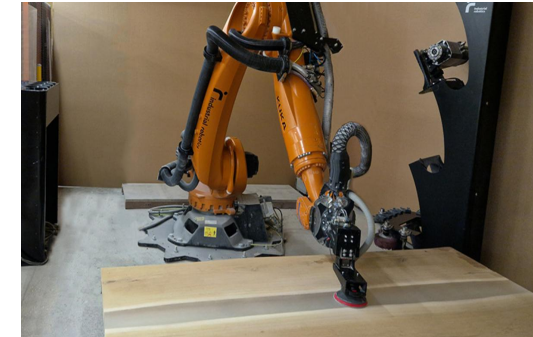
- **executive systems:**
 - **actuator** (drives the executing element, converts the control signal into a displacement or other suitable physical quantity),
 - **final execution element** (acts on the process and causes a change in the operation of the system)

- **valves with different types of actuators:**



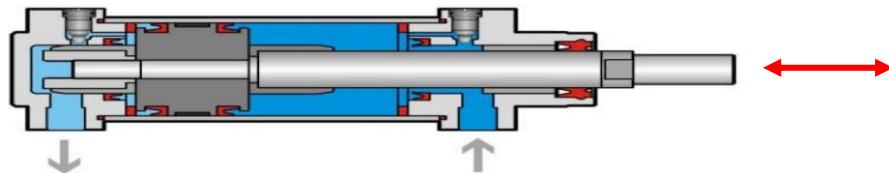
- **the actuator is the driving part of the valve** (it generates the movement with an electromagnet, an electric motor or by changing the pressure on the diaphragm, the movement is converted into a change in the flow through the valve),
- **the valve is the final executing element.**

- electric drive motors and controls for electric drive motors

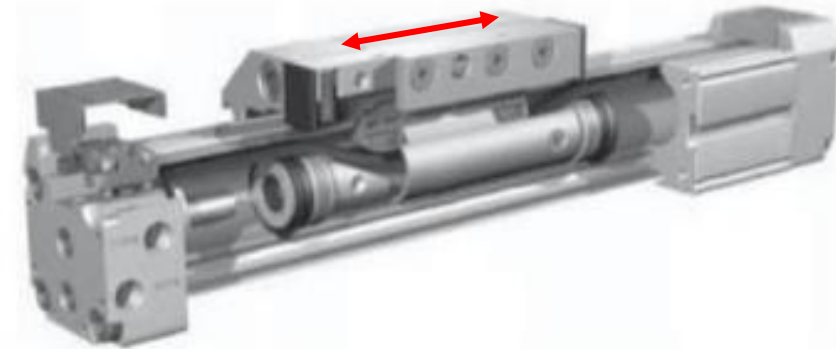


- the **output** of the actuator is not a **displacement** (here the displacement is the desired final change in the process, and the **electric current** and **voltage** at the electric motor are intermediate quantities),
- the **electric motor controller converts** the control signal into a suitable form of current and voltage,
- most often used:
 - **direct current (DC) motors** and associated power controllers,
 - **asynchronous motors** and associated frequency controllers (they allow the speed of rotation of asynchronous motors to be controlled by changing the frequency of the AC voltage applied to the motor).

- pneumatic cylinders and electro-pneumatic valves



linear actuator



- the control signals are electrical, so we need actuators that convert the signal into the corresponding pressure on the cylinder (electropneumatic valves),
- the piston moves freely in the cylindrical tube under the influence of compressed air,
- a permanent magnet is built into the piston and slide,
- the movement of the piston is transmitted to the slide by magnetic force fields (as the piston moves under the influence of compressed air, the slide also moves (synchronously)),
- application: for particularly long movements; up to 10 m,

COMPUTERIZED NUMERICAL CONTROL (CNC) MACHINES

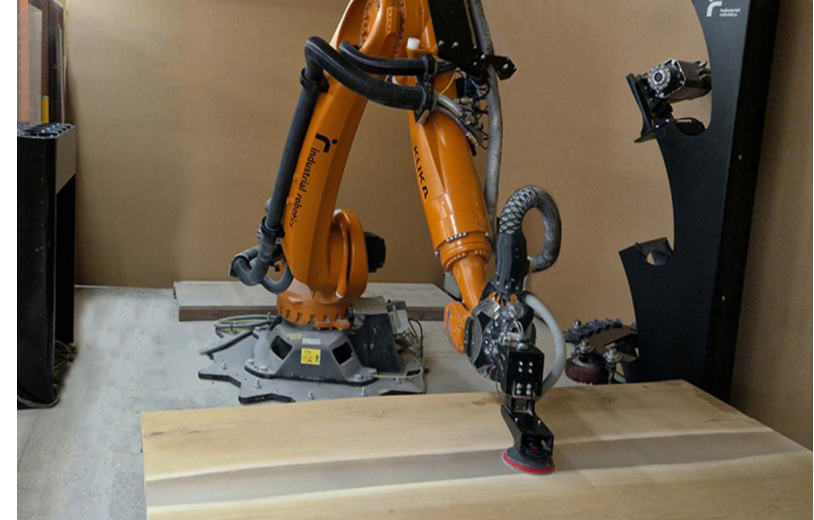
CIM Hardware

- Manufacturing Equipment
 - CNC machines (Computer Numerical Control),
 - robots,
 - automated assembly lines and
 - material handling systems.

CNC machines



Robot



Automated assembly lines



Advantages of CNC machines:

- machining **quality** is always the same,
- **low costs** for quality control (less scrap),
- **shorter production time** (6 to 10 times higher productivity than with conventional machining),
- the workpieces do **not need to be stored** between the individual machining phases,
- **adaptation** of the technological parameters between the work steps,
- possibility of machining **several different workpieces** on the same work table with one fixture,
- possibility of **upgrading** (automation),
- carrying out more **complex operations**,
- **saving** a previously created **programme** (repeatability of operations even after a long time with the same accuracy),
- **easy maintenance** (one person can maintain the entire machine),
- **high level of safety** in the workplace,
- **savings in workspace** (replacing a large number of traditional machines with a single one)

Disadvantages:

- costly setup, skilled operators
- computers, programming knowledge required
- maintenance is difficult

NC – numerical control

CNC - computerized numerical control

DNC – direct numerical control



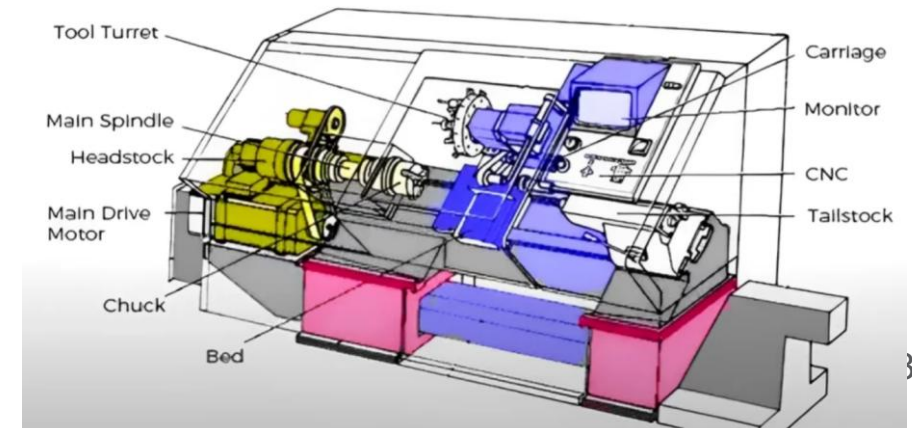
COMPONENTS OF CNC MACHINES

- **control unit - CNC controller** (controls the work of all units and receives feedback on the operation of the machine),
 - **input unit** (USB reader, keyboard, mouse - reads the programme and enables the input and correction of computer programmes),
 - **computing unit** (processes input data - computer),
 - **storage unit** (stores data),
 - **monitor**,
 - **output unit** (sends appropriately processed and converted data to the mechanical part of the machine)



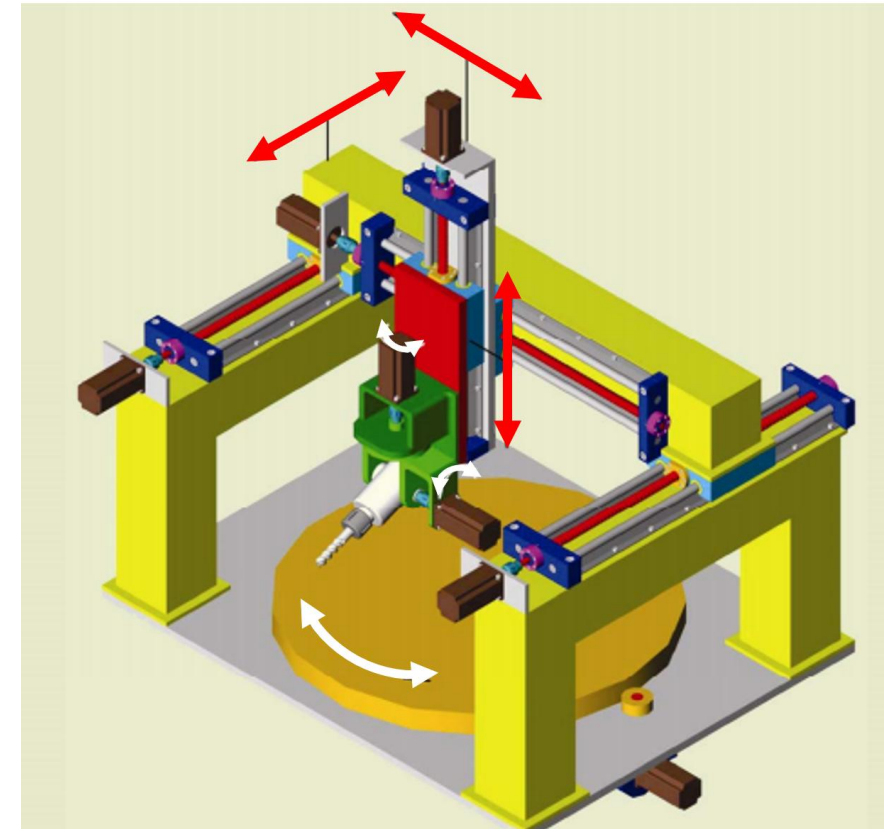
- **mechanical part - machine**
 - frame,
 - guides,
 - bearings,
 - drives,
 - spindle,
 - workpiece clamping,
 - system for a **high accuracy positioning** of tools and workbenches,
 - ...

CNC LATHE



- **control unit - CNC controller**

- input unit,
- computing unit ,
- storage unit,
- monitor,
- output unit.



- Controlled by G and M codes.
- These are number values and co-ordinates.
- Each number or code is assigned to a particular operation.
- Typed in manually to CAD by machine operators.
- G&M codes are automatically generated by the computer software.

COMPONENTS OF CNC MACHINES – MECHANICAL PART

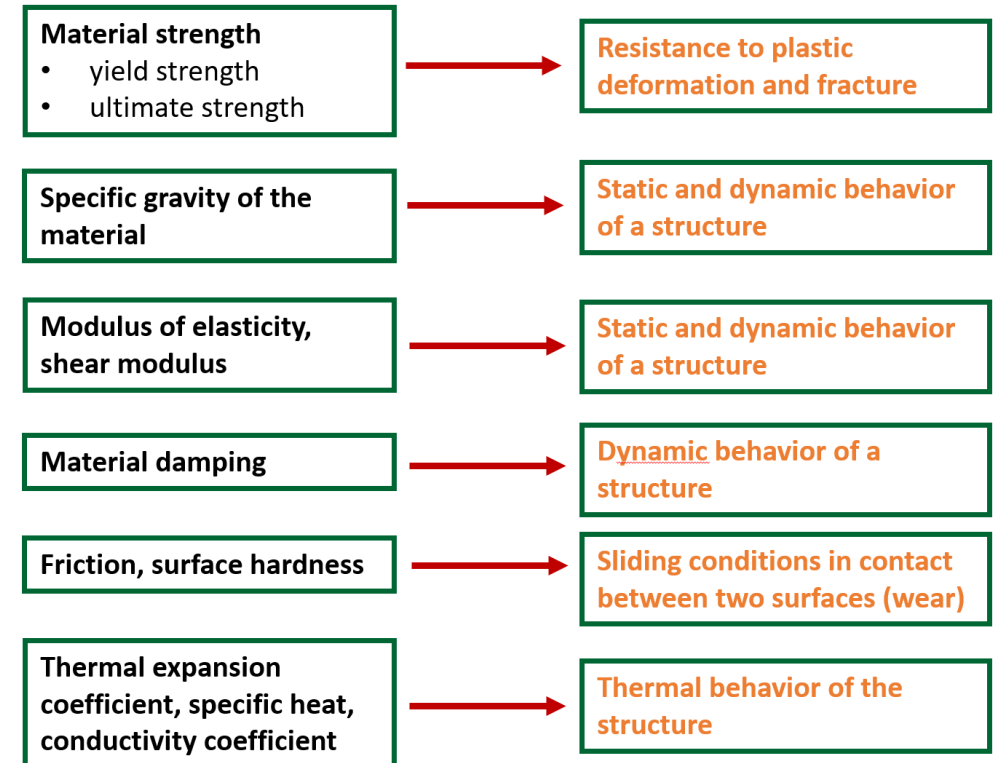
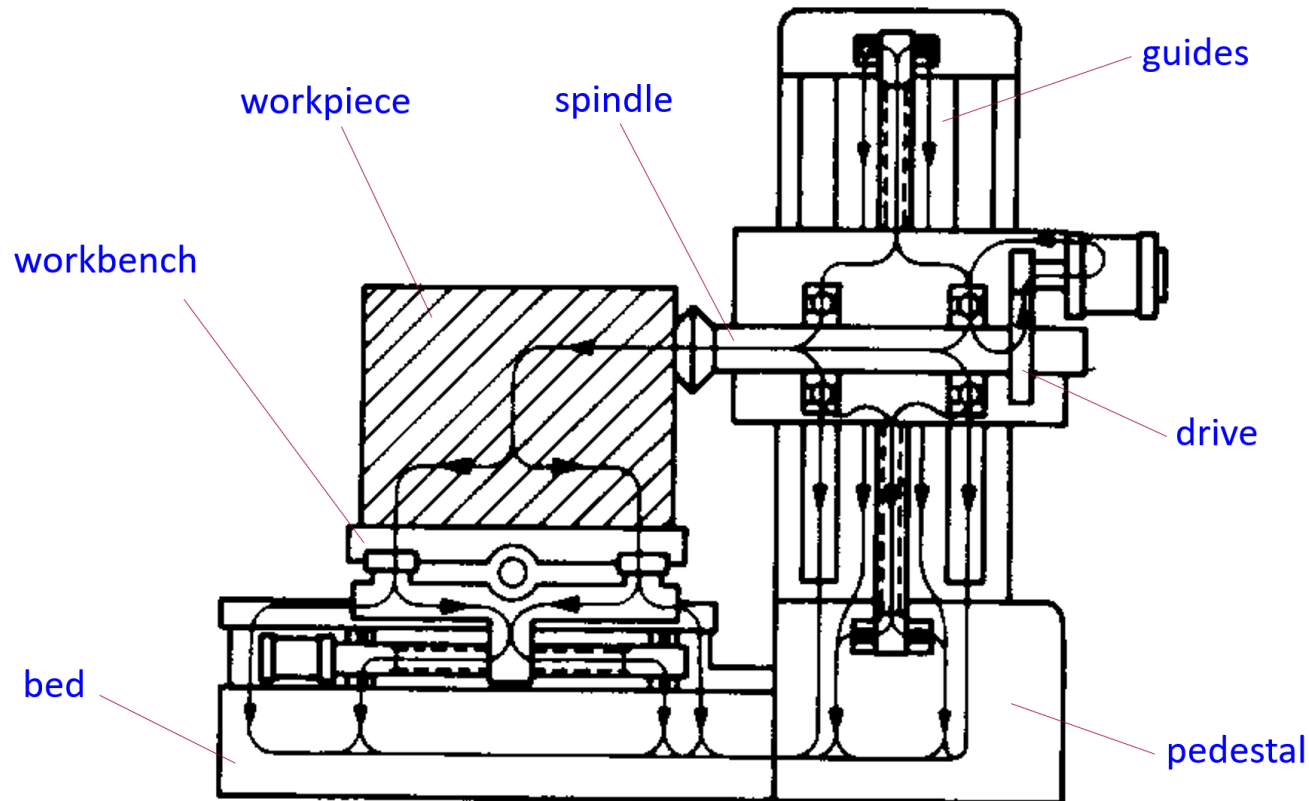
- mechanical part - machine
 - frame,
 - guides,
 - barings,
 - drives,
 - spindle,
 - system for a **high accuracy positioning** of tools and workbenches



Homag profit H500

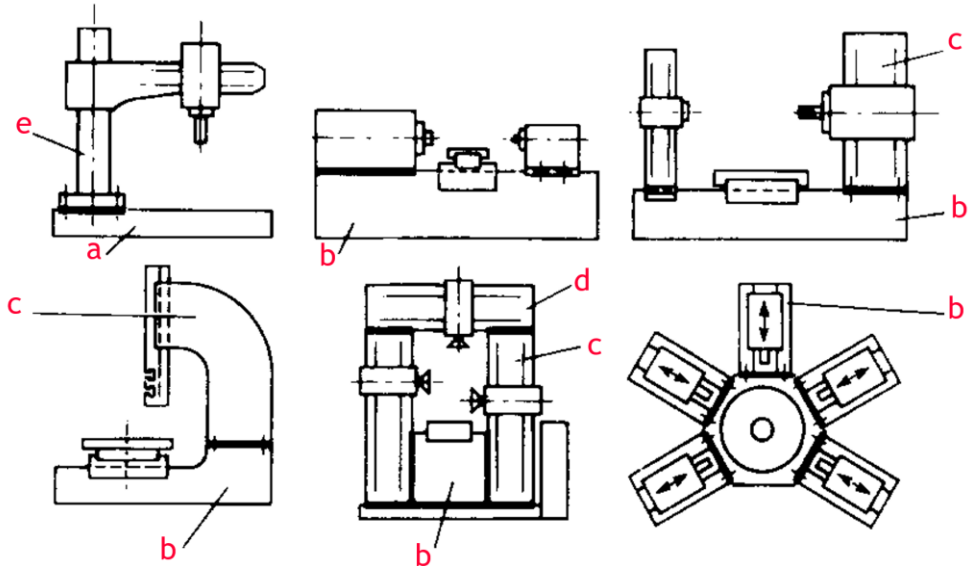
COMPONENTS OF CNC MACHINES – MECHANICAL PART

- **frame**
 - **machines** are more **rigid**, which results in lower machine vibrations and therefore higher production accuracy (depending on the material being processed)



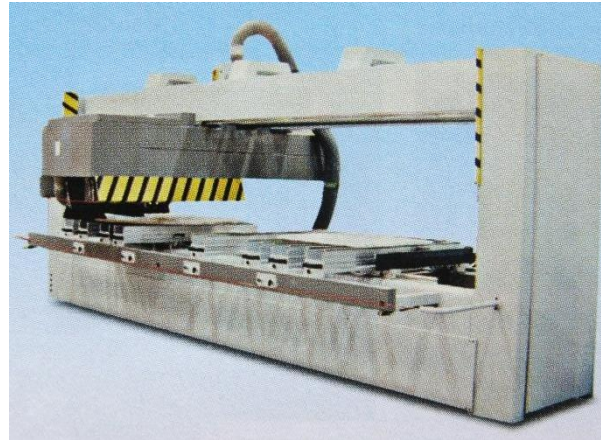
COMPONENTS OF CNC MACHINES – MECHANICAL PART

- frame

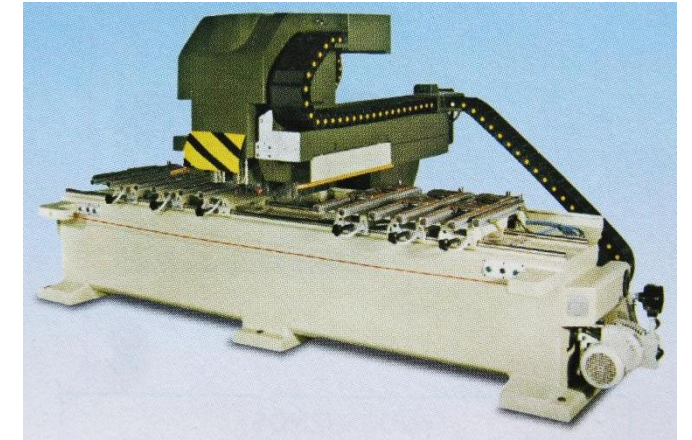


a- base, b- bed, c- stand, d- crossbar, e- pillar

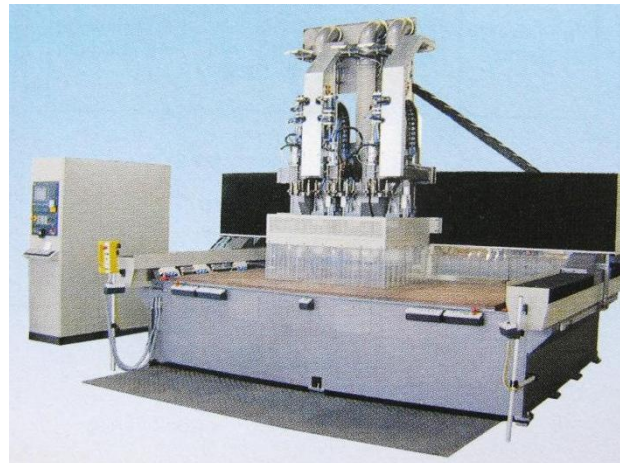
- CNC machine with movable portal



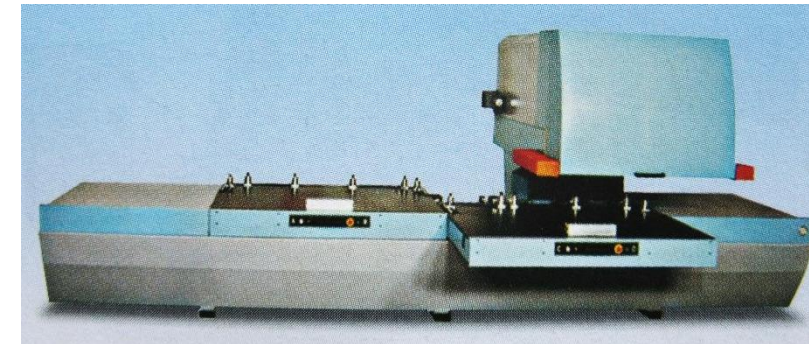
- CNC machine with movable handle



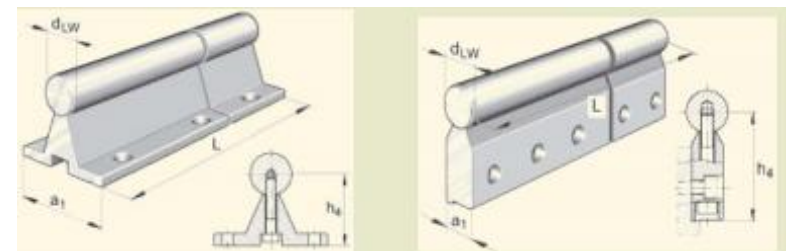
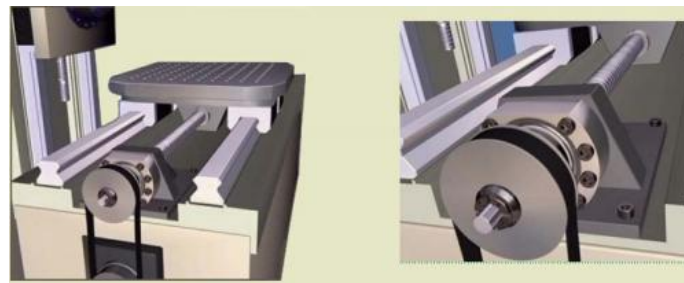
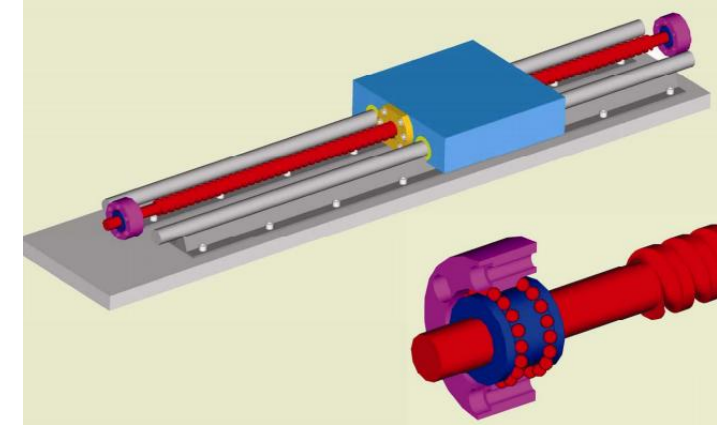
- CNC machine with fixed working table



- CNC machine with movable workbenches



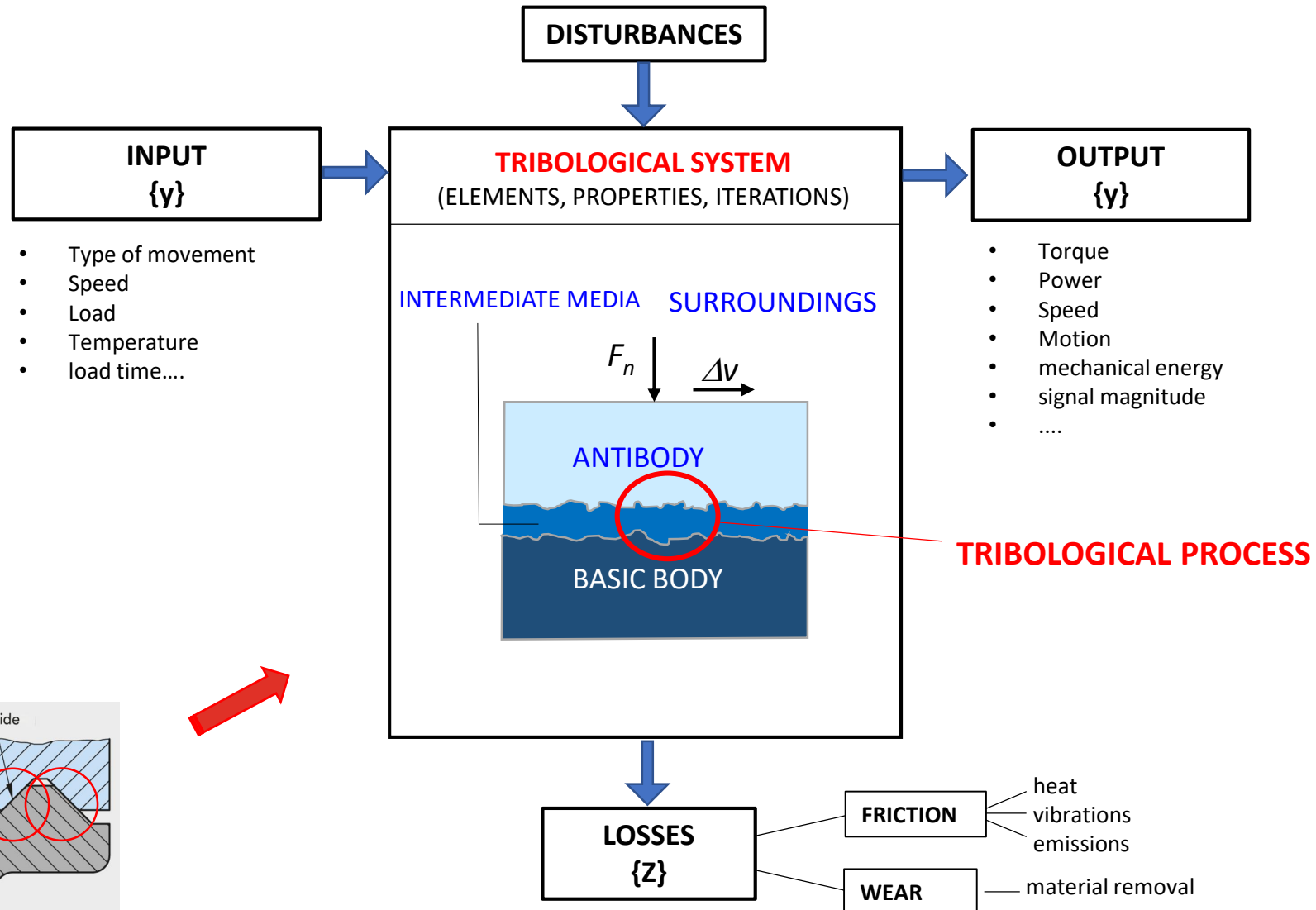
- guides (slide movement elements)
 - requirements:
 - high accuracy
 - good surface finish on slide way surface
 - low coefficient of friction
 - low wear
 - negligible stick-slip
 - high rigidity
 - good damping capacity



COMPONENTS OF CNC MACHINES – MECHANICAL PART

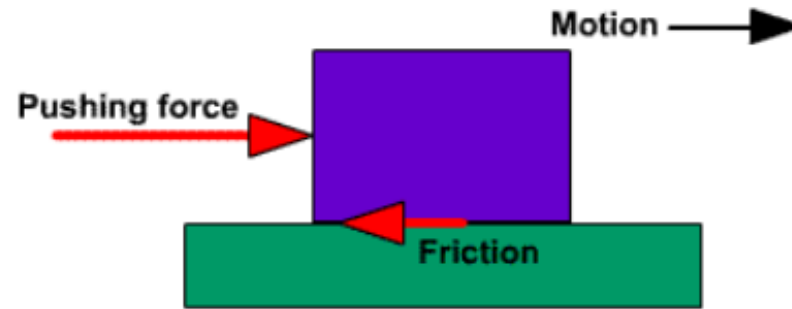
Tribology - the science of friction, wear and lubrication (the science of the interaction of surfaces in relative motion)

Tribological (tribotechnical) system



COMPONENTS OF CNC MACHINES – MECHANICAL PART

- sliding friction

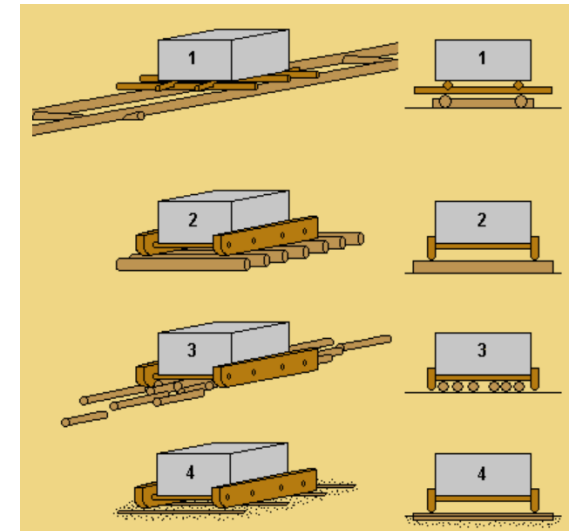
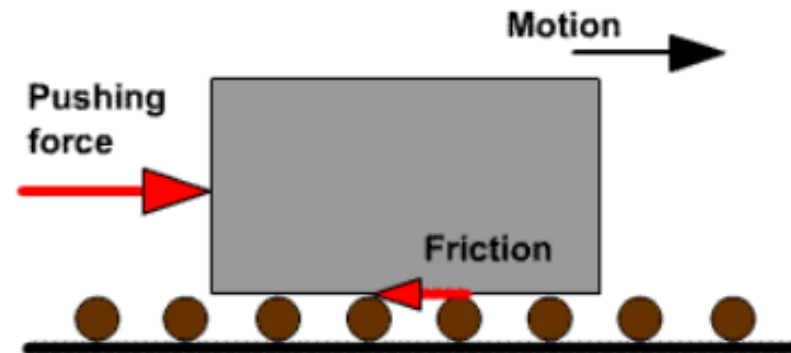


Pushing force is greater than resistive friction force



<https://www.alamy.com/ancient-egyptians-moving-stone-computer-illustration-showing-the-method-used-by-ancient-egyptians-to-move-large-blocks-of-cut-stones-to-build-structu-image334993100.html>

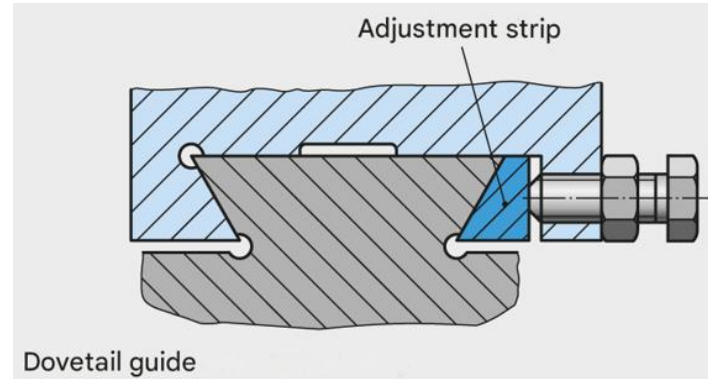
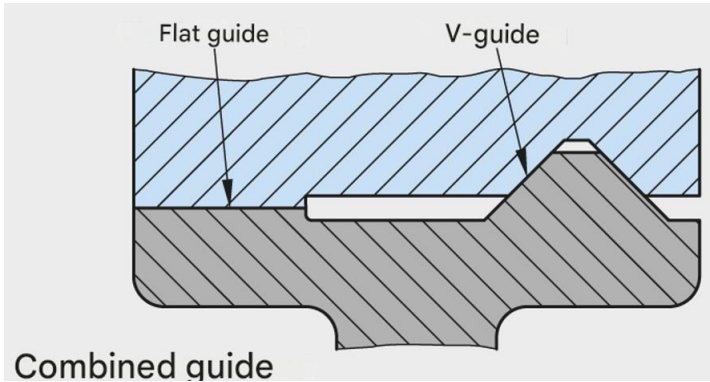
- rolling friction



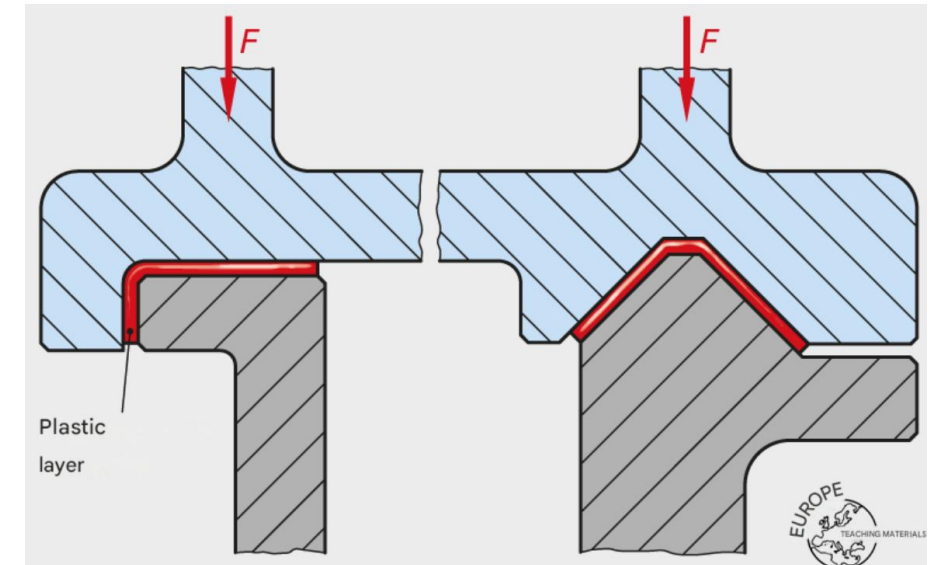
<https://www.cheops-pyramide.ch/khufu-pyramid/sledge-tracks.html>

Types of slide ways

- sliding friction type slide ways
 - V/flat/round/dove tail slide ways

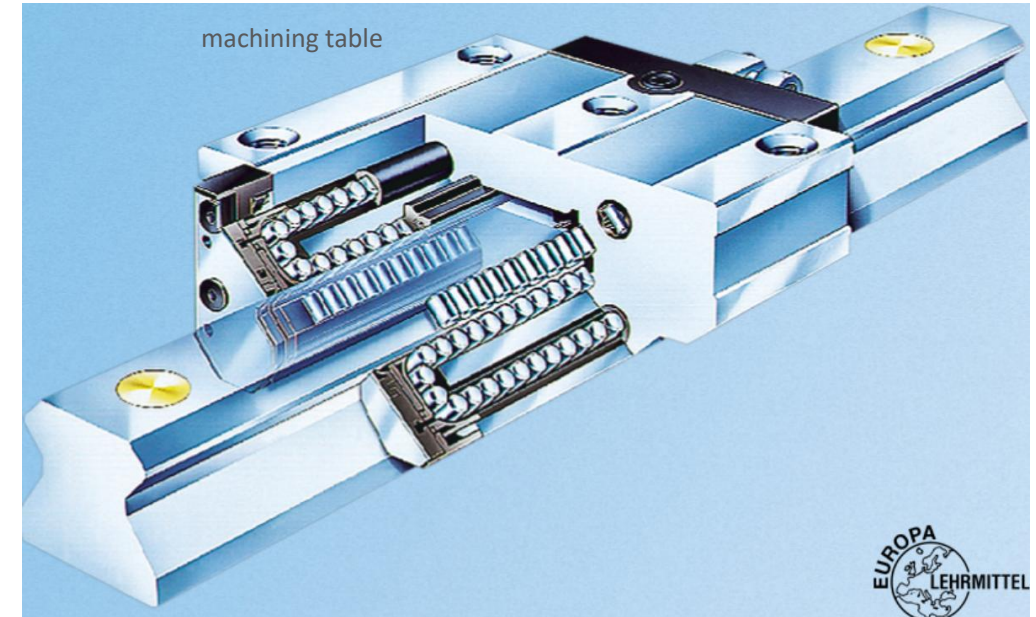
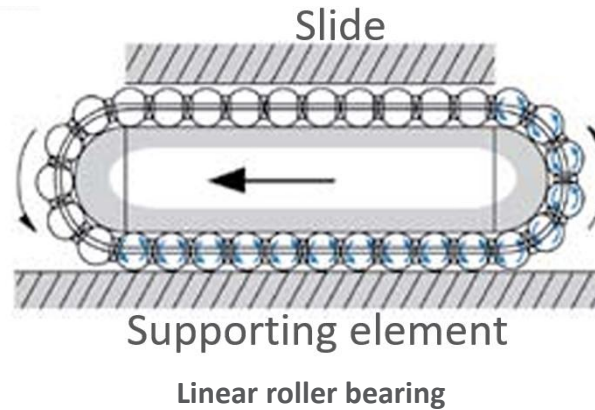
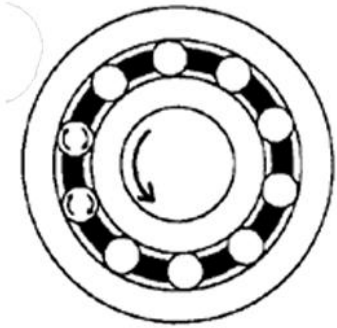


- **Plastic coated slide ways**
 - plastic or non metallic inserts are mostly used
 - they have self-lubricating property
 - these inserts reduce coefficient of friction and increase wear resistance and load bearing capacity

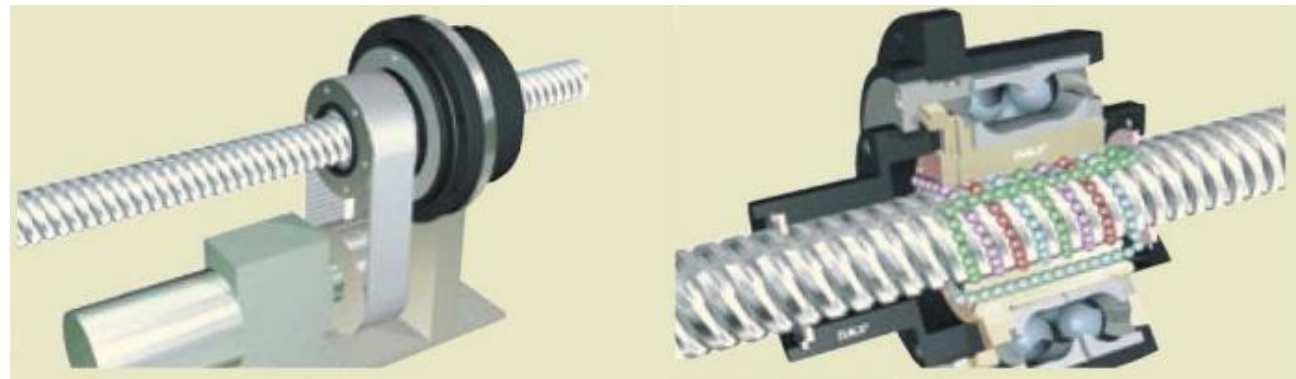


COMPONENTS OF CNC MACHINES – MECHANICAL PART

- rolling friction type slide ways
 - linear motion bearings (ball, roller)

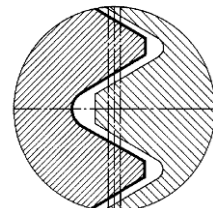
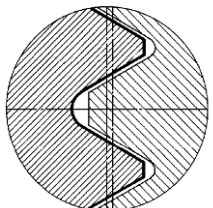


- recirculating ball screw and nut
 - Balls rotate between the screw and nut
 - It convert the sliding friction into rolling friction
 - The balls are re-circulated from one end to the other by return tubes

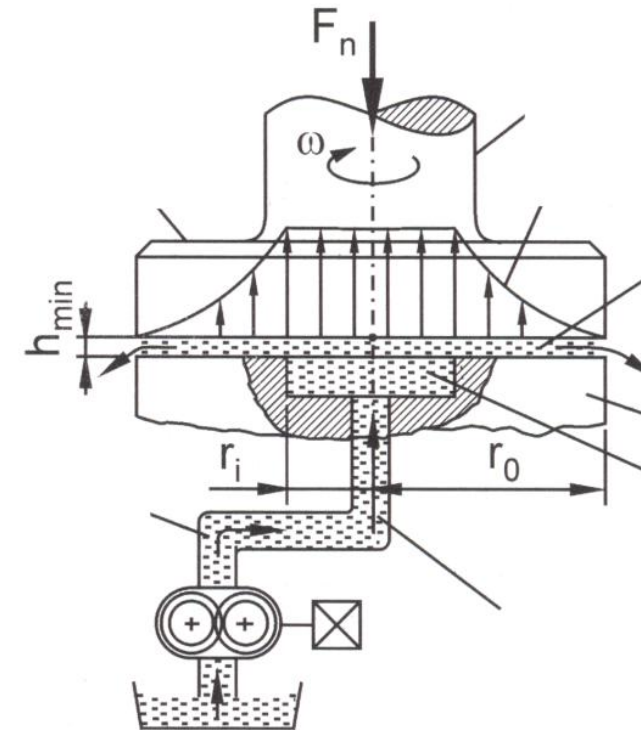
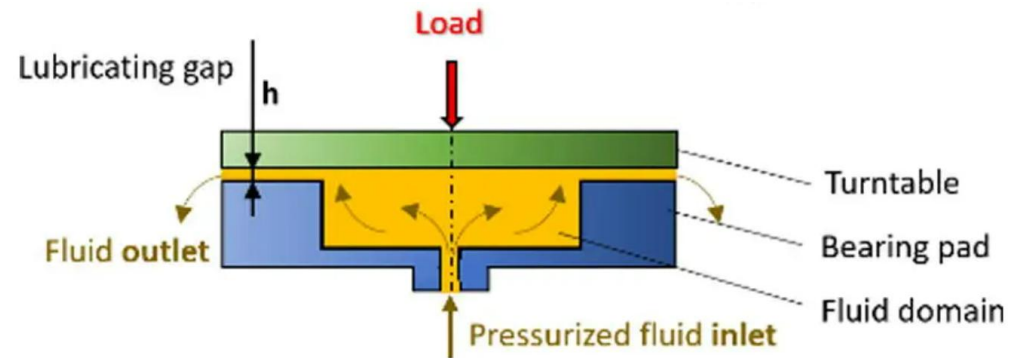


Recirculating ball screw and nut (better accuracy of workpiece positioning)

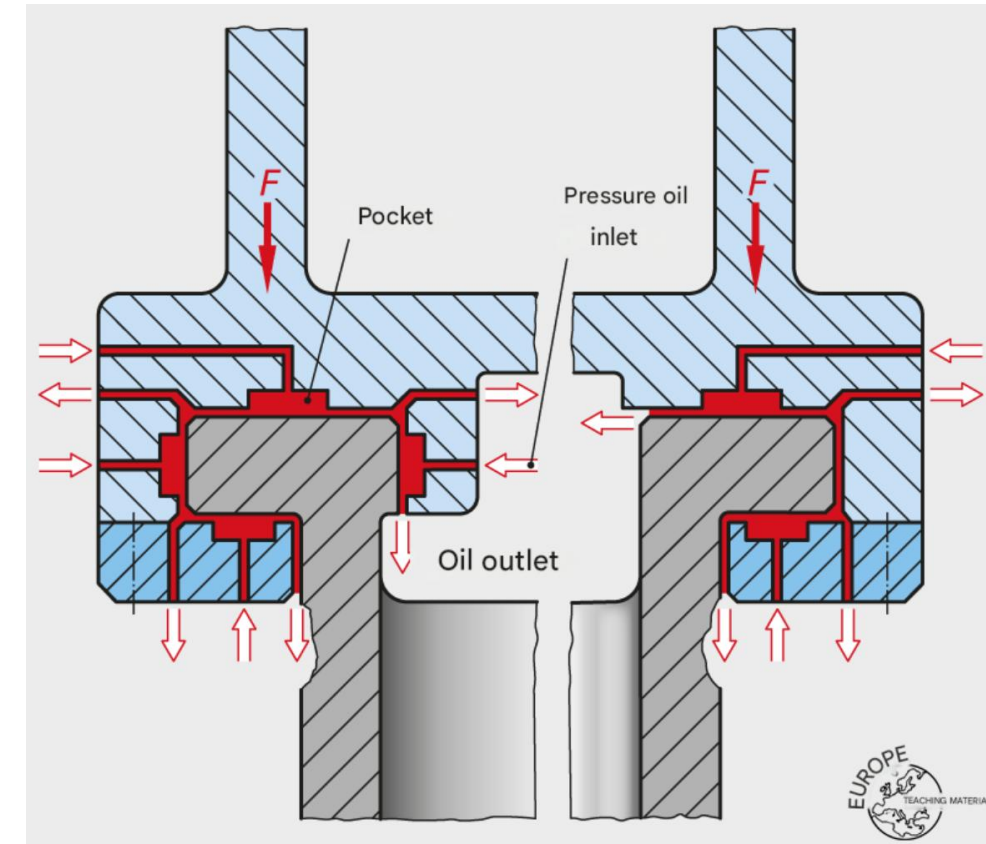
thread



- hydrostatic guides



- **hydrostatic guides** (for precise guidance of heavy loads at low speeds),
 - very low friction, no friction at positioning
 - movement of $0.1\ \mu\text{m}$ possible
 - no slip-stick effect at slow motion
 - „zero“ wear because there is no contact when operating
 - better damping,
 - no vibration, which is caused when reversing rolling systems
 - not sensitive to chips and other debris
 - extremely straight movement possible

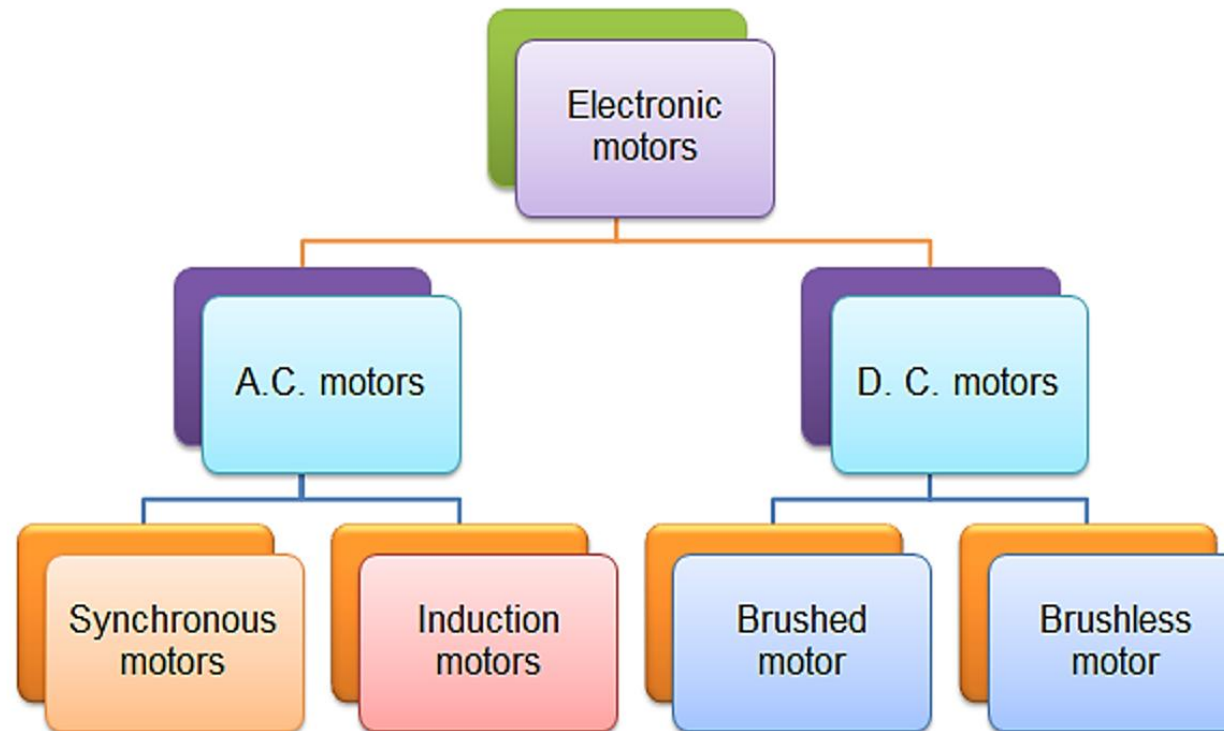


COMPONENTS OF CNC MACHINES – MECHANICAL PART

- drives
 - **Electrical drives**
 - direct (DC) or alternating current (AC) servo motors
 - small in size and are easy to control
 - **Hydraulic drives**
 - large power to size ration.
 - provide stepless motion with good accuracy.
 - difficult to maintain & bulky
 - protect hydraulic elements from corrosion.
 - the hydraulic oil should not be fire friendly.
 - **Pneumatic drives**
 - use air as a working medium and it is fire proof.
 - simple in Construction and are cheaper.
 - generates low power, **less positioning accuracy** and are noisy.

Feature	Hydraulic Drive	Pneumatic Drive	Electric Drive
Power to weight ratio	Highest	Lowest	Moderate
Payload Capacity	Heavy	Low	Medium
Controlling Device	Hydraulic Power Pack	Pneumatic control systems	Control systems needed.
Size & stiffness	Very High	Very Low	Low Stiffness
Compliance	Low	Good	Better
Leakage ,Cleanliness	Worst	Better	Nil
Reliability of Compo.	Low	Higher	High
Accuracy & Response	Good	Bad	High
Maintenance	Needed More	Low	Less
Pressure Torque at actuator	High	Medium	Medium to High
Operational Speeds	Wide	Very Little	Low-High
Spark generation	No	No	Possible

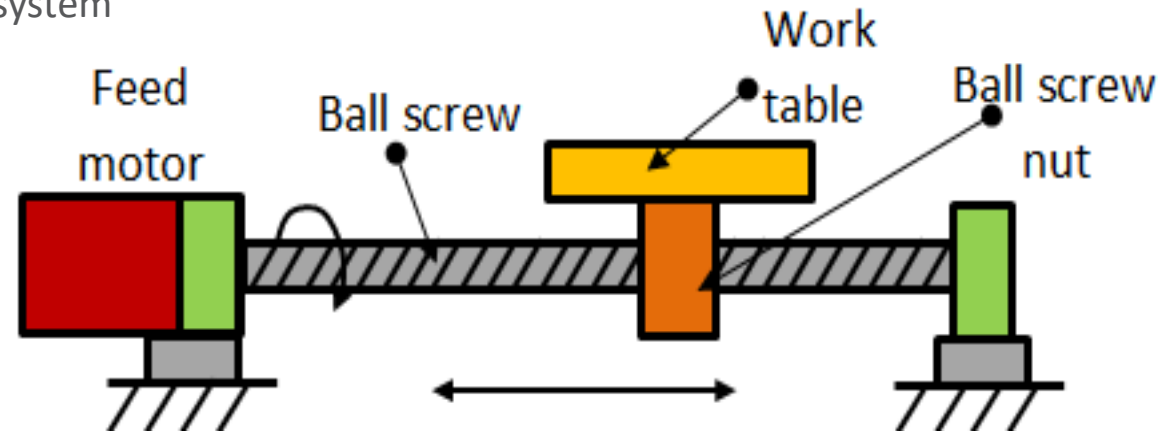
- The various drives used in CNC machines can be classified as:
 - **feed drives** to drive the axis,
 - **spindle drives** to provide the main spindle power for cutting action;



- **Feed drive**

- a feed servomotor
- mechanical transmission system

Schematic of a feed drive



- **requirements of feed drive**

- the feed motor needs to operate with **constant torque** characteristics to overcome friction and working forces
- It should be able to provide **variable speed with a speed range of 0,1 rpm to 2000 rpm** without waviness;
- It should be able to **position the tools with the smallest increment**
- high torque-to-weight ratio
- low rotor inertia
- quick response

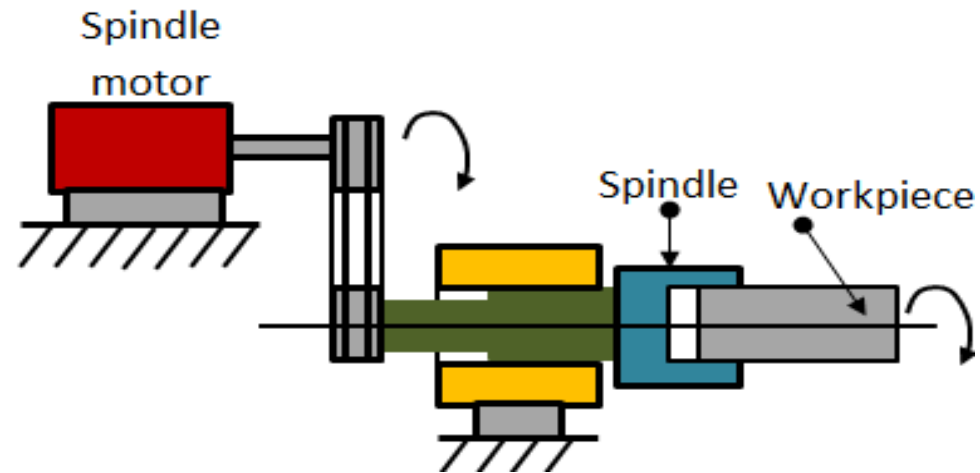
Feed drive used in CNC machines:

- DC servomotors
- AC servomotors
- Stepper motors
- Linear motors

- **Spindle drives**

- a spindle motor
- mechanical drives

Schematic of a spindle drive



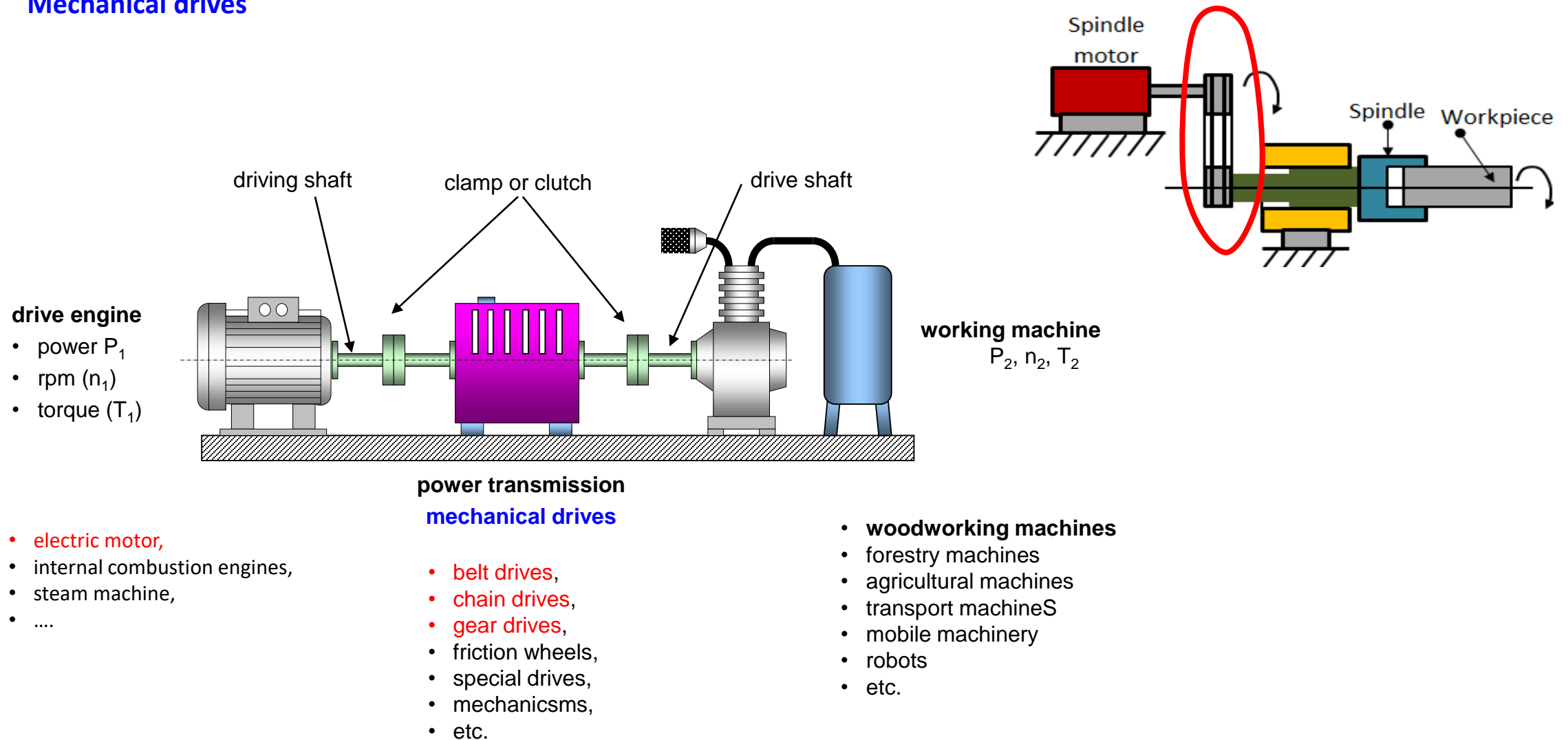
- **requirements of spindle drive:**

- wide constant power band
- high rotational accuracy
- fast dynamic response
- high speed up to 9000-20000 rpm
- high load capacity
- compactness

Spindle drive used in CNC machines:

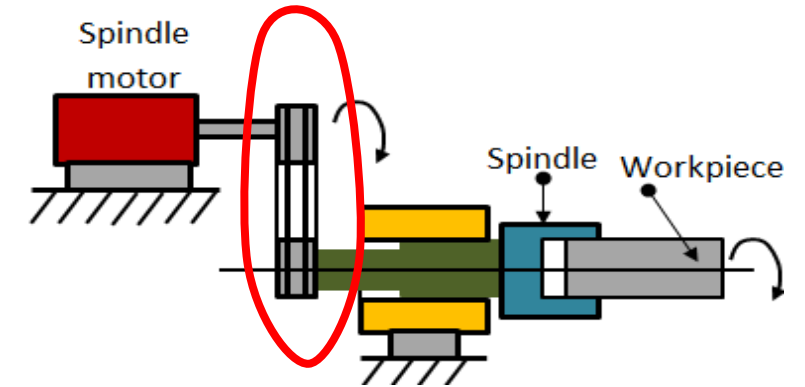
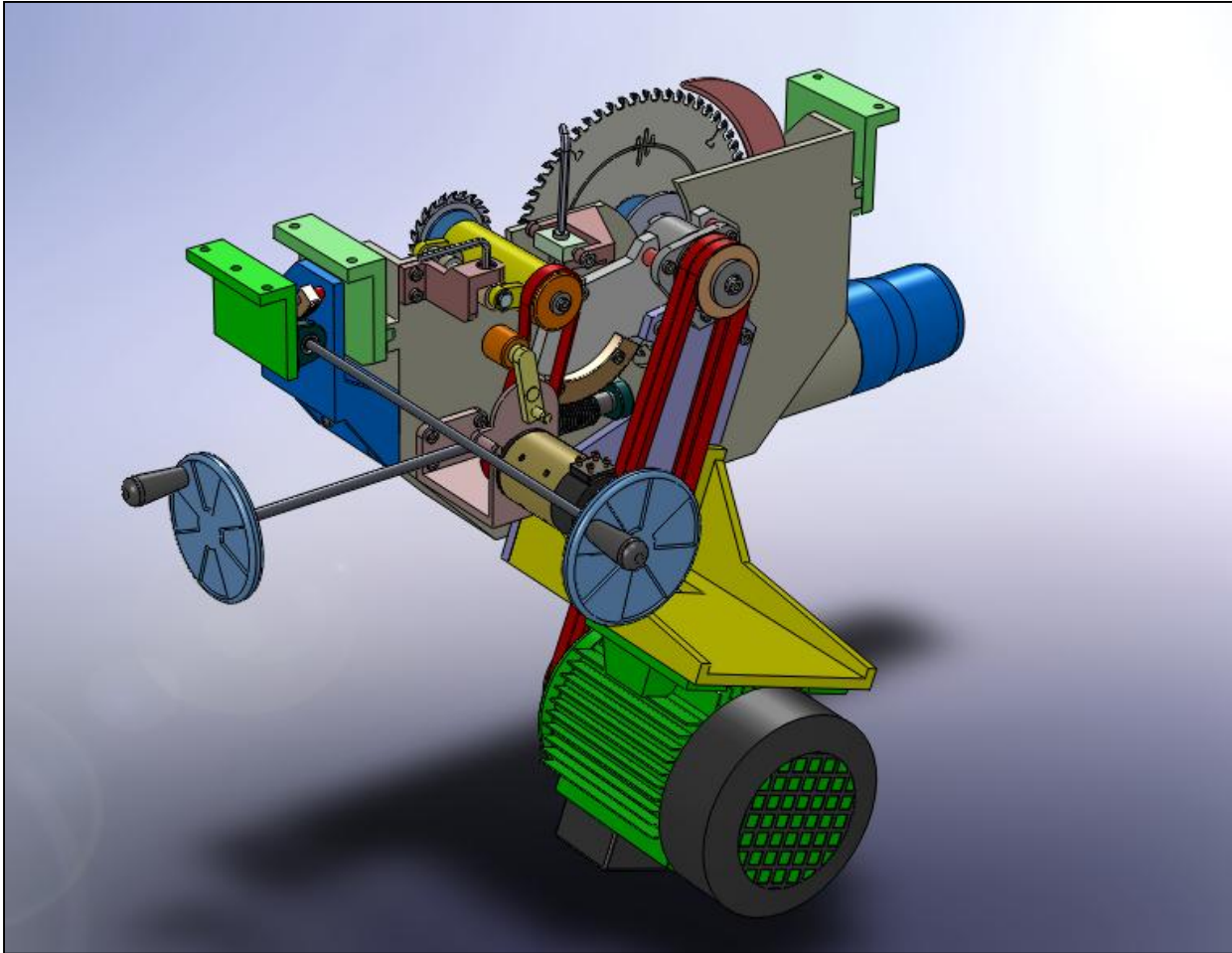
- normally the **DC drives** are used in machine tools
- with the availability of microprocessor-based AC frequency inverter, the **AC drives** preferred to DC drives

- **Mechanical drives**



COMPONENTS OF CNC MACHINES – MECHANICAL PART

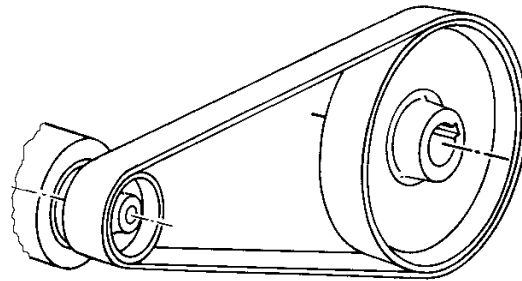
- Mechanical **BELT** drives



COMPONENTS OF CNC MACHINES – MECHANICAL PART

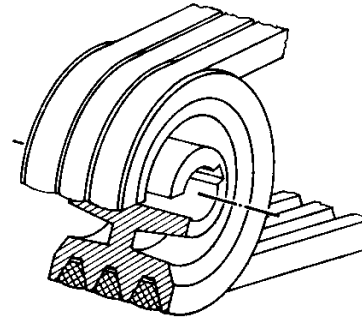
- Mechanical **BELT** drives

flat belt



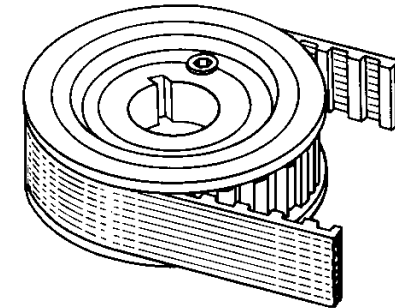
friction

V belt



friction

toothed belt



shape

- gear ratio i (gear)

$$i = \frac{\omega_1}{\omega_2} = \frac{n_1}{n_2}$$

ω_1, ω_2
 n_1, n_2

[s⁻¹]
[min⁻¹]

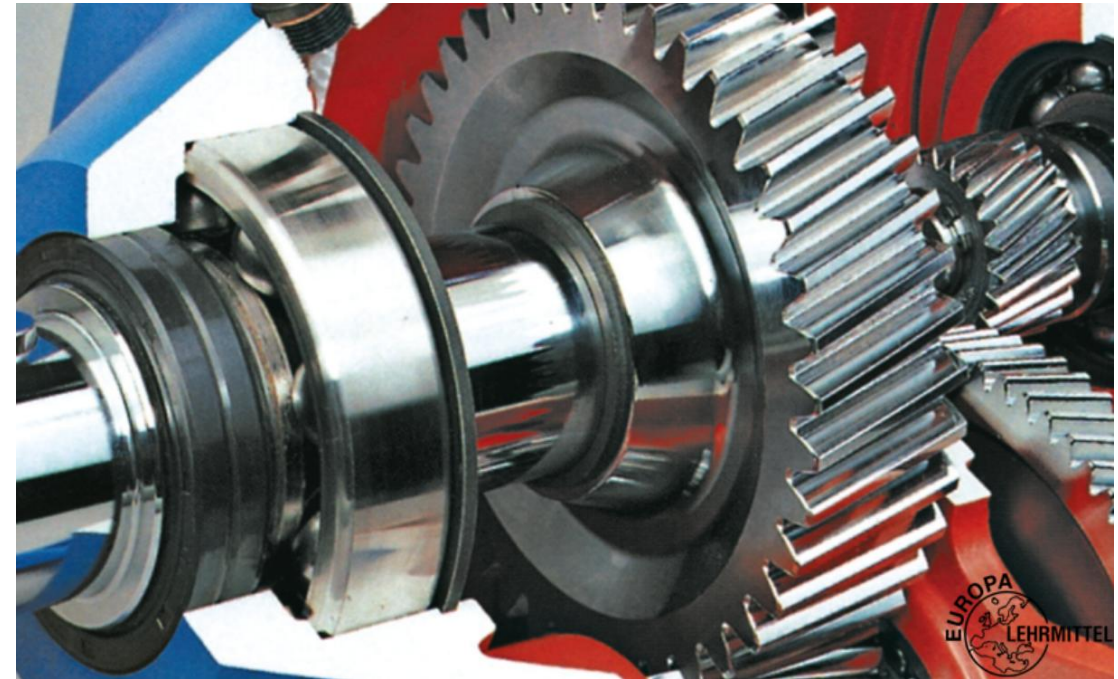
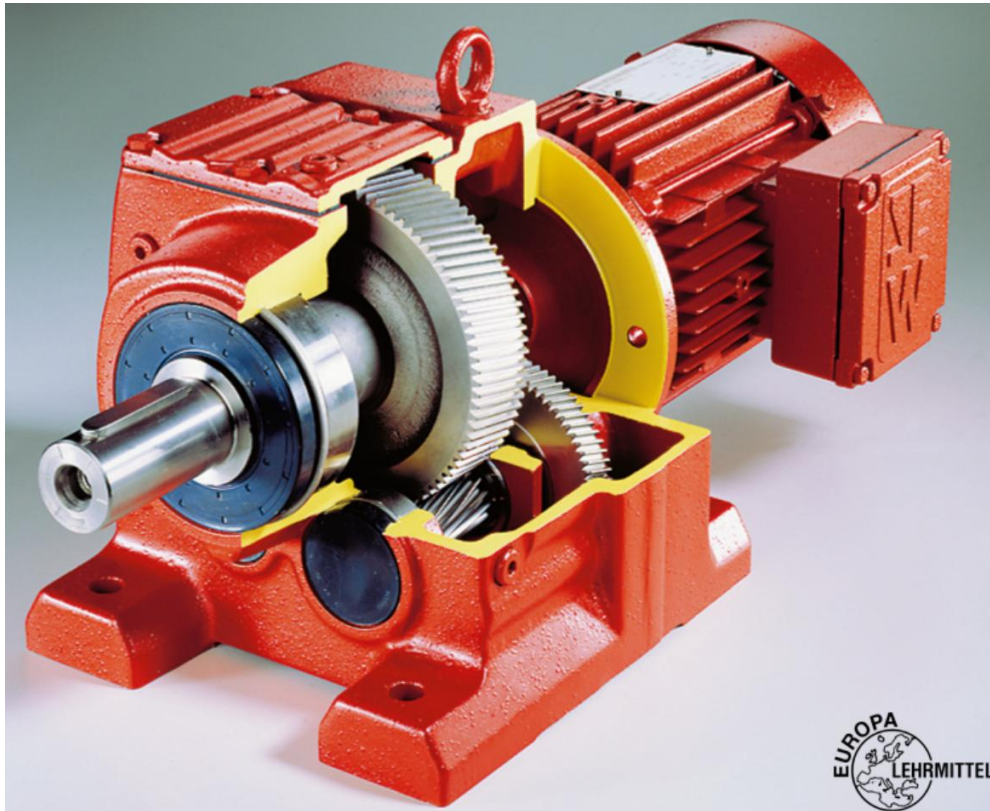
angular velocity of the drive (1), driven (2) part;
speed of the drive (1), driven (2) part



COMPONENTS OF CNC MACHINES – MECHANICAL PART

UL | BF

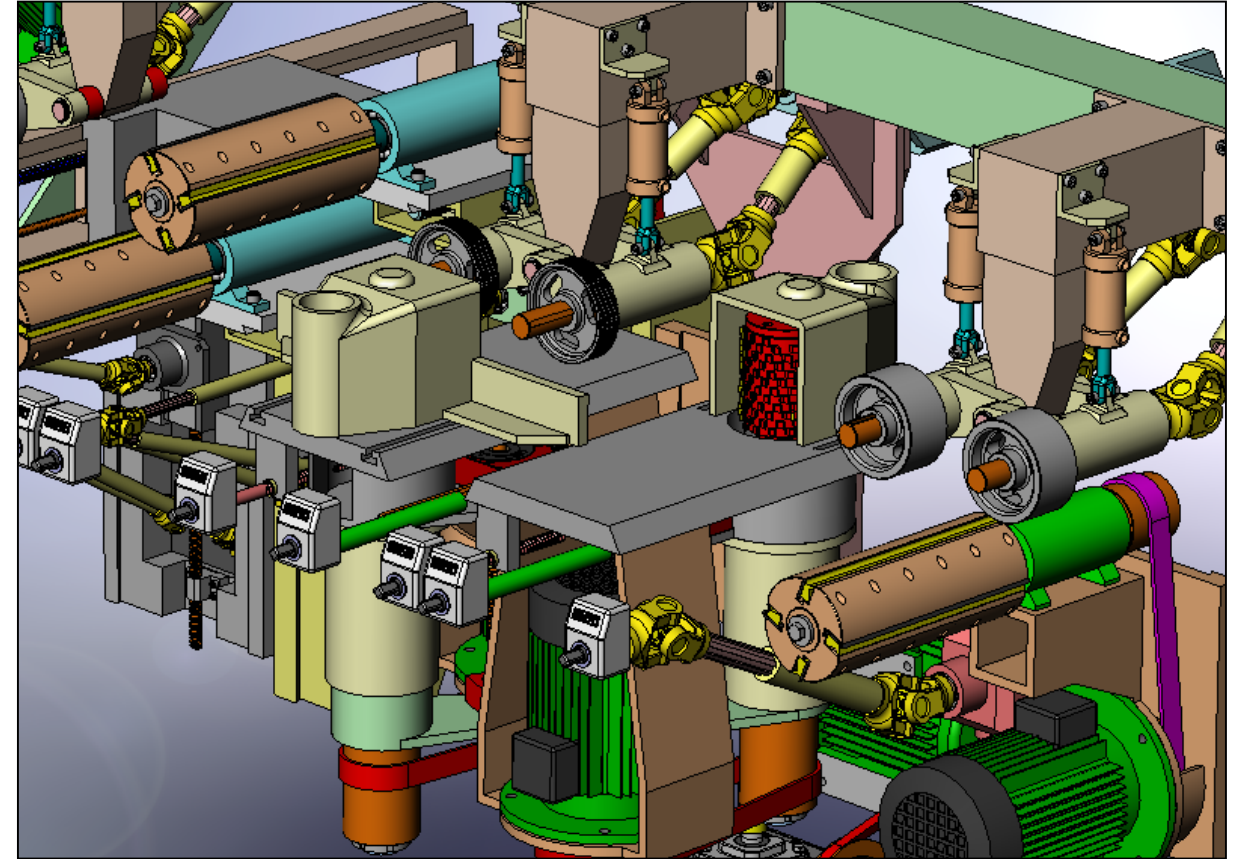
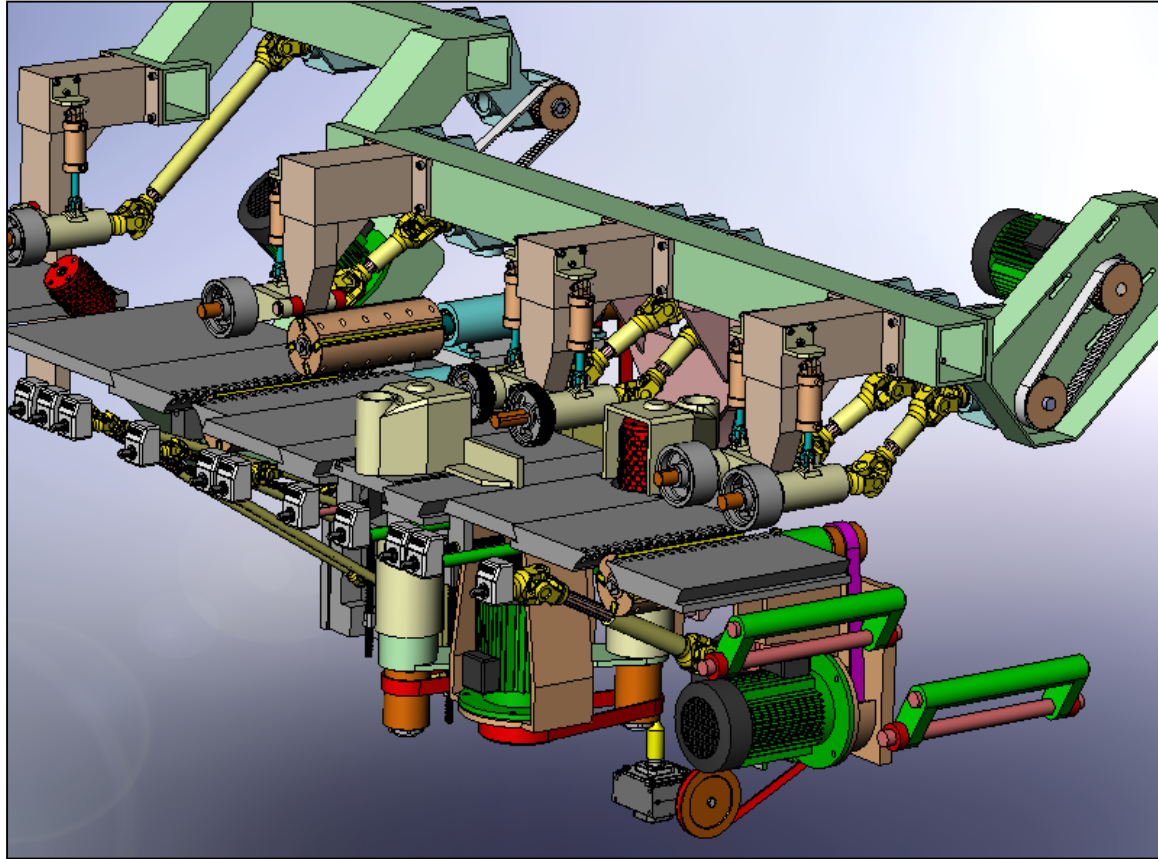
- Mechanical **GEAR** drives



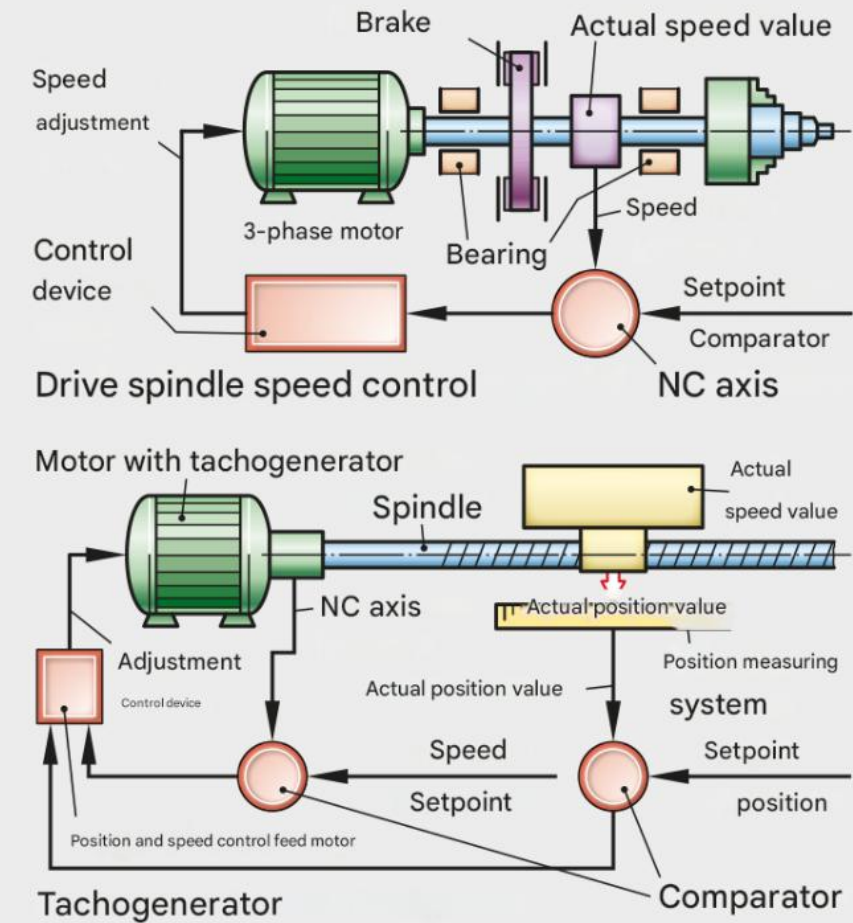
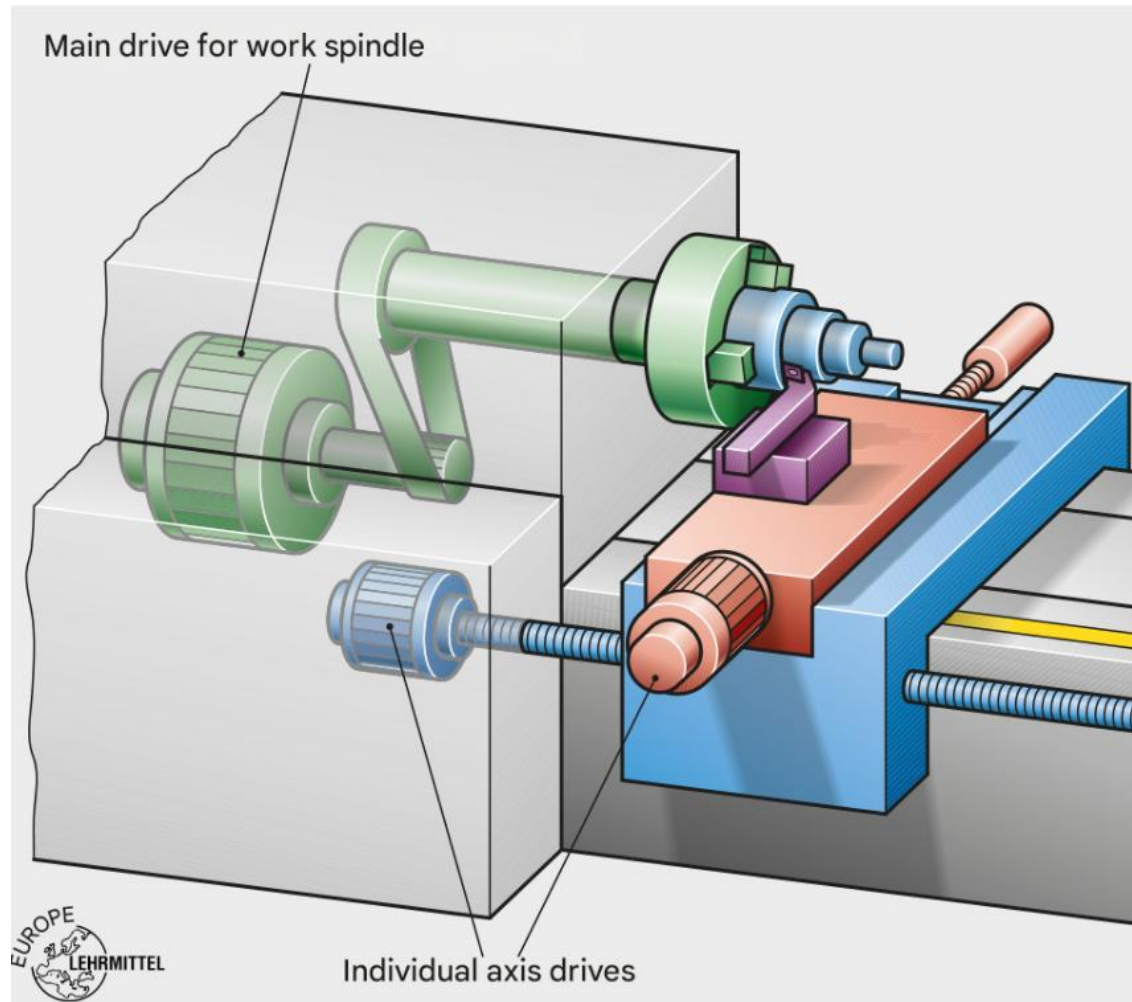
COMPONENTS OF CNC MACHINES – MECHANICAL PART

- Components of multi-spindle planing machines

SHAFTS AXLES SHAFT CONNECTIONS AND COUPLINGS **BEARINGS** SEALS SPRINGS CONNECTIONS



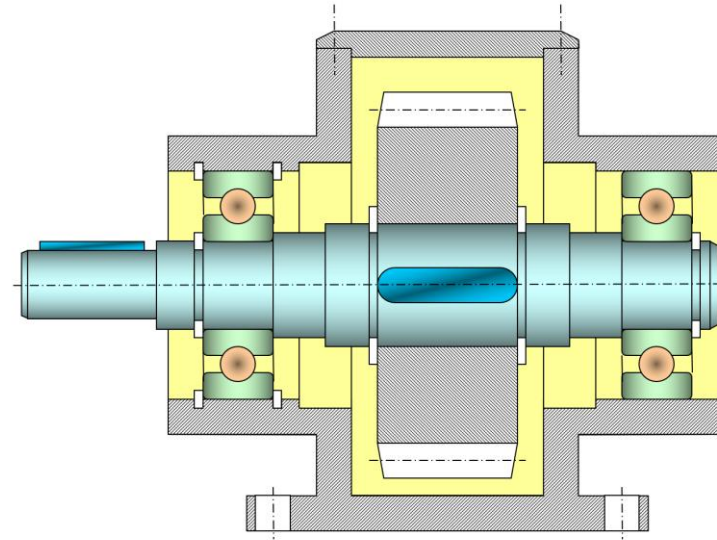
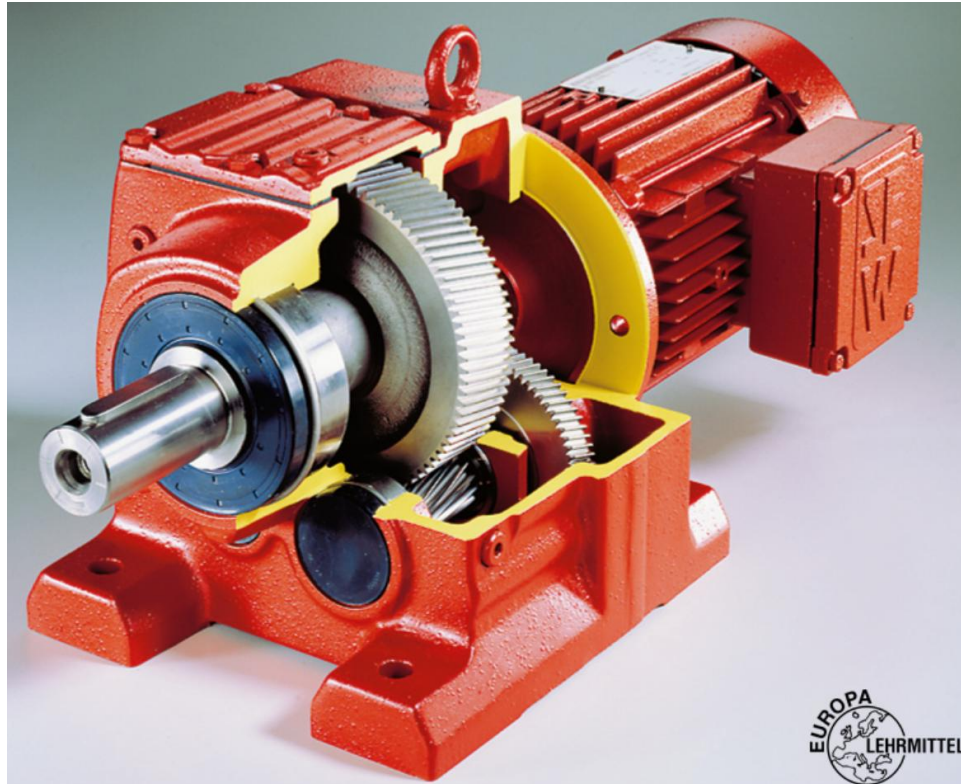
- Bearings



COMPONENTS OF CNC MACHINES – MECHANICAL PART

UL | BF

- Bearings



Radial ball bearings



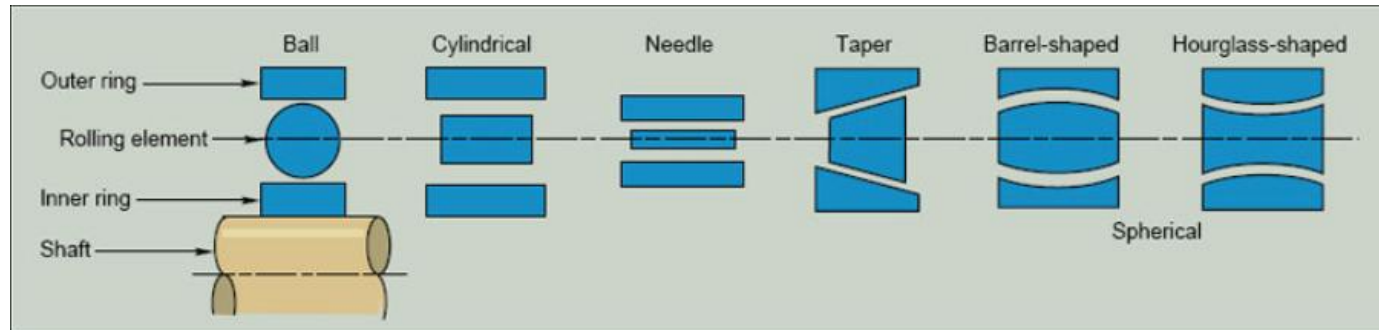
Axial ball bearing



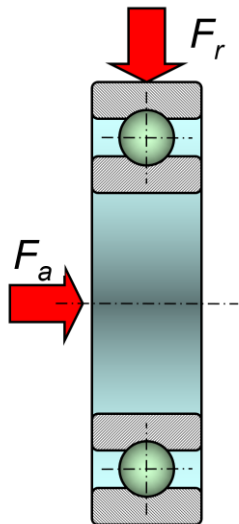
<http://www.riv.org/bearing.htm>

- **Bearings**

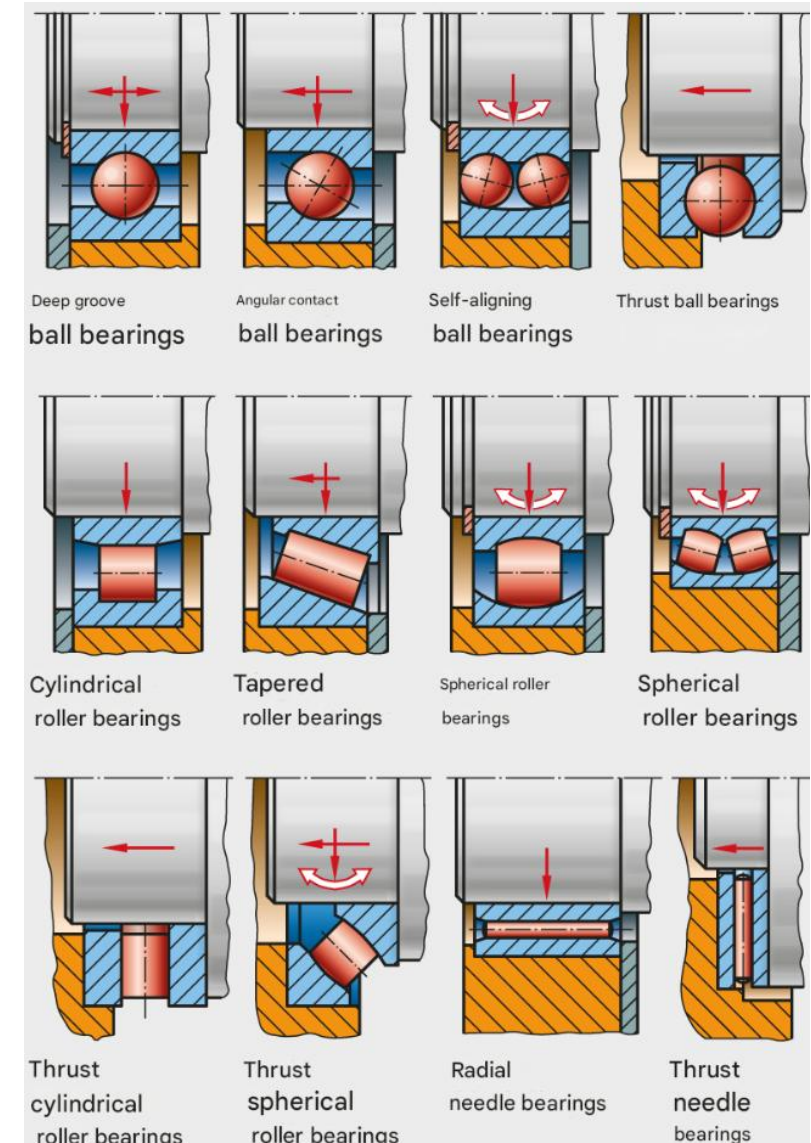
- standard design of radial bearings with different types of rolling bodies



<http://www.britbike.com/forums/ubbthreads.php?ubb=showflat&Number=536707>



<https://www.aubearing.com/si/the-ultimate-guide-to-cnc-machine-tool-spindle-bearings/>

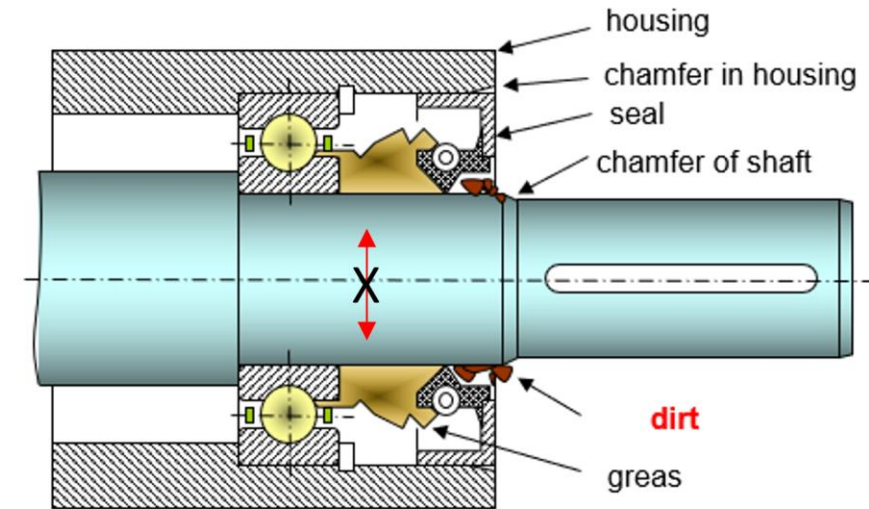
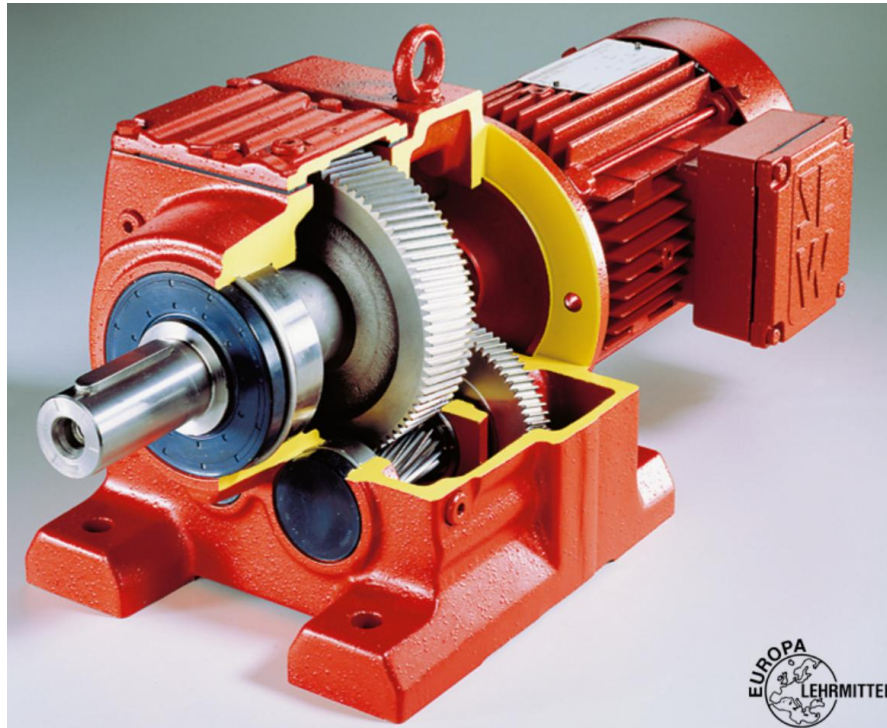


Deflection of elements -> Inaccuracy of workpiece positioning -> Machining quality is not good

<http://www.codex-shop.si/katalog.aspx/94/Prilagodljivi>

COMPONENTS OF CNC MACHINES – MECHANICAL PART

- Radial shaft seals



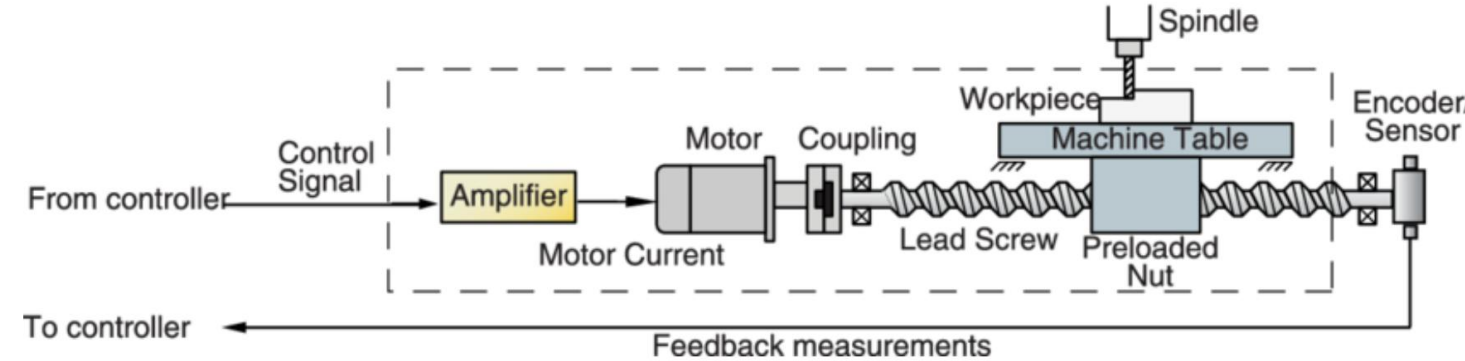
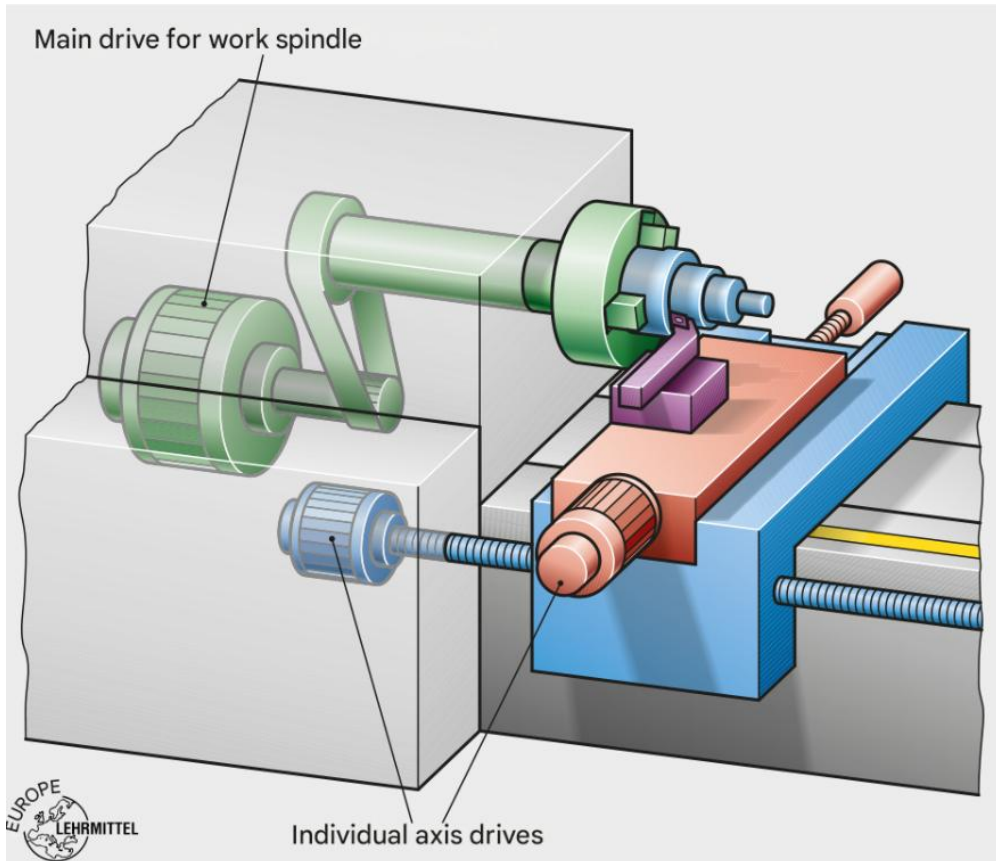
<http://www.espint.com/engineering/product-design-and-development/radial-shaft-seal-design.aspx>

http://www.tesnila-teng.si/program_izdelki.php?ID=31

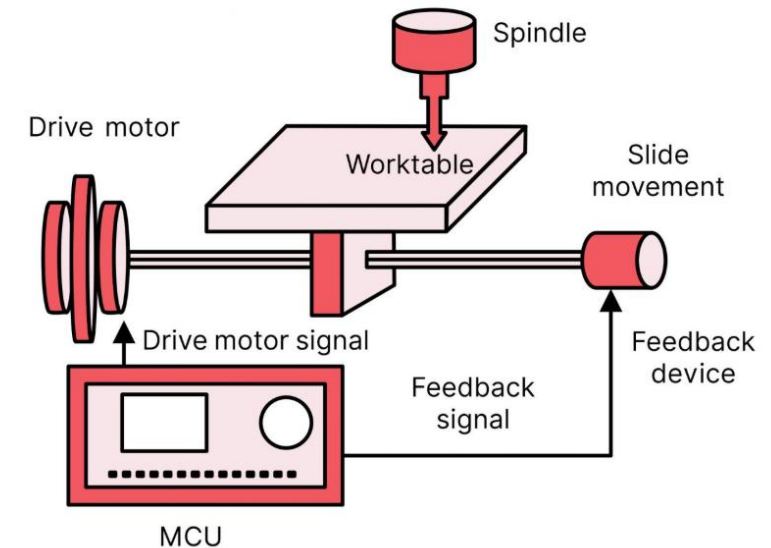
COMPONENTS OF CNC MACHINES – MECHANICAL PART

UL | BF

- position measurement

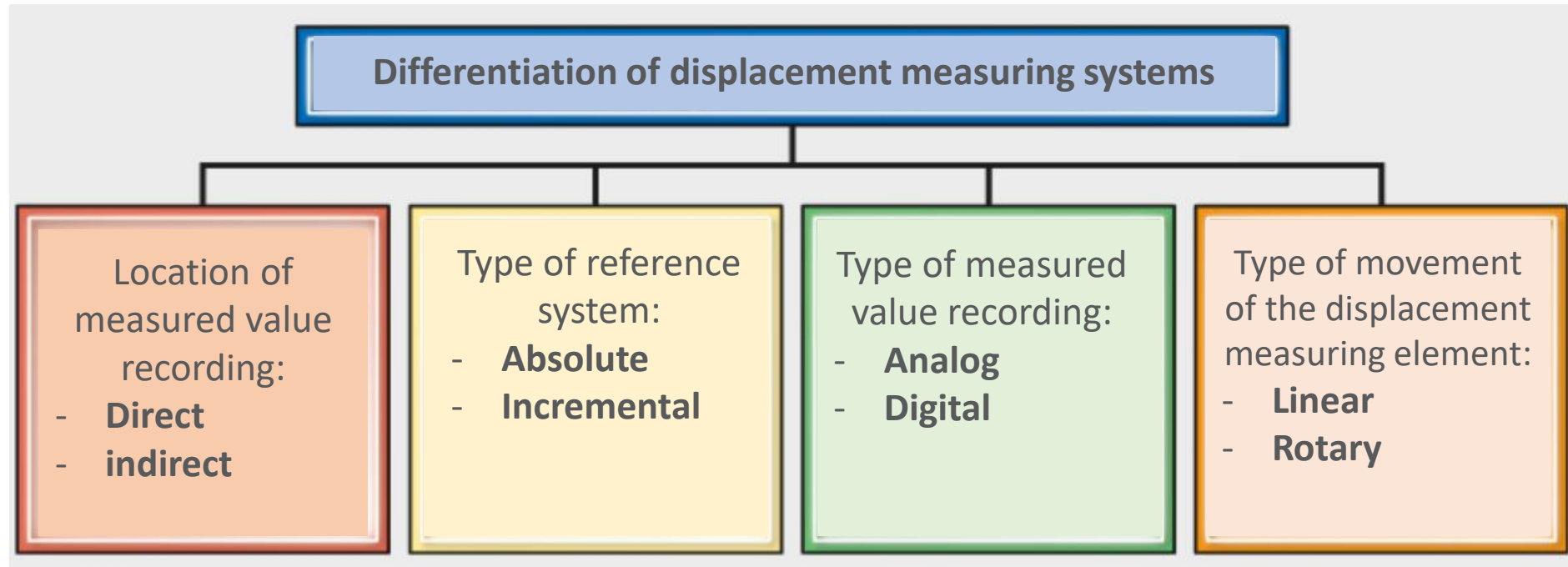


https://www.researchgate.net/figure/Feed-drive-mechanism-with-a-lead-screw-drive_fig2_222576909



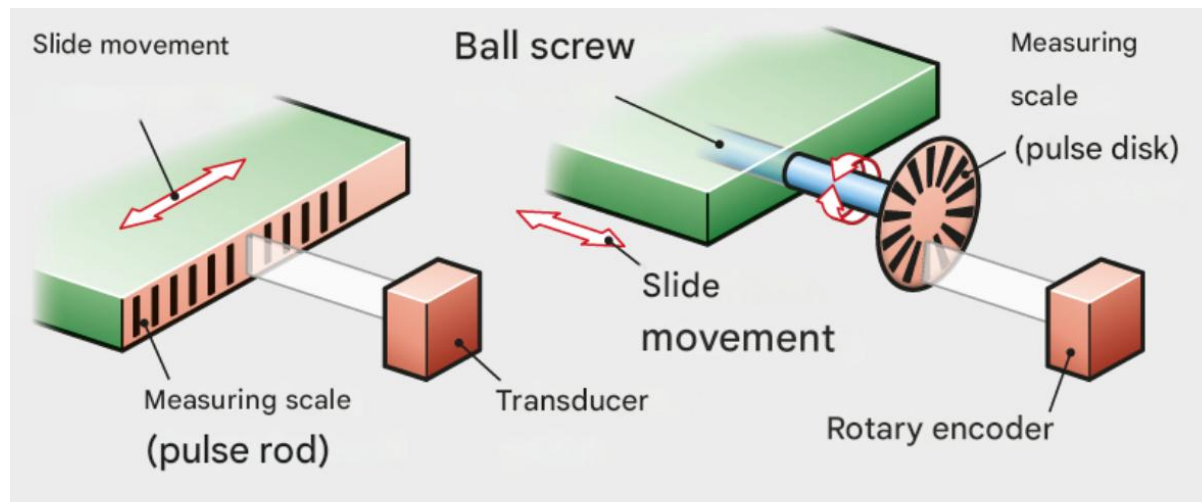
<https://www.madearia.com/blog/parts-of-a-cnc-milling-machine/>

- position measurement

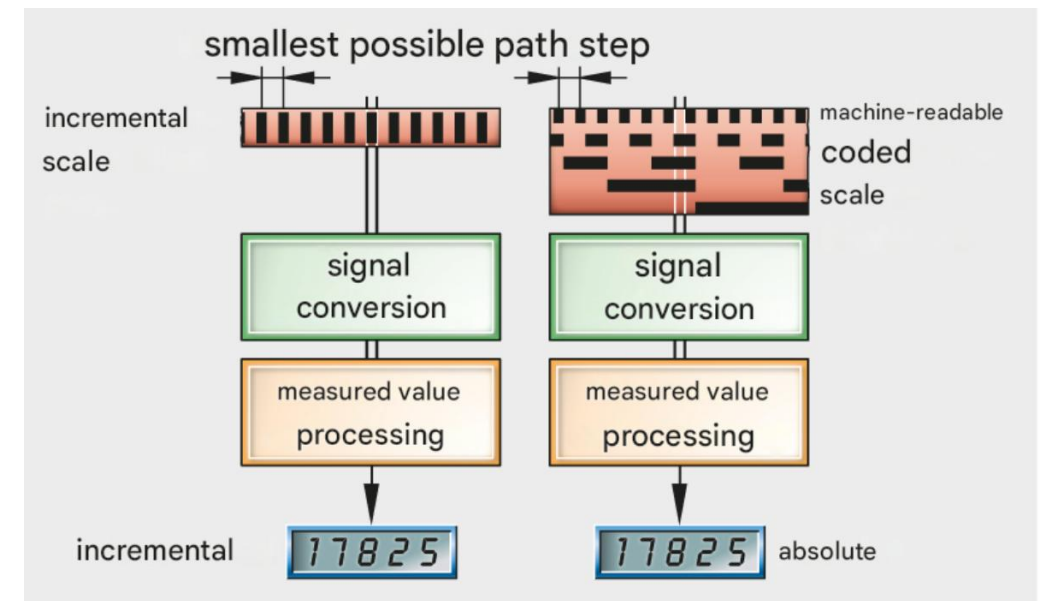


- position measurement

Direct/indirect



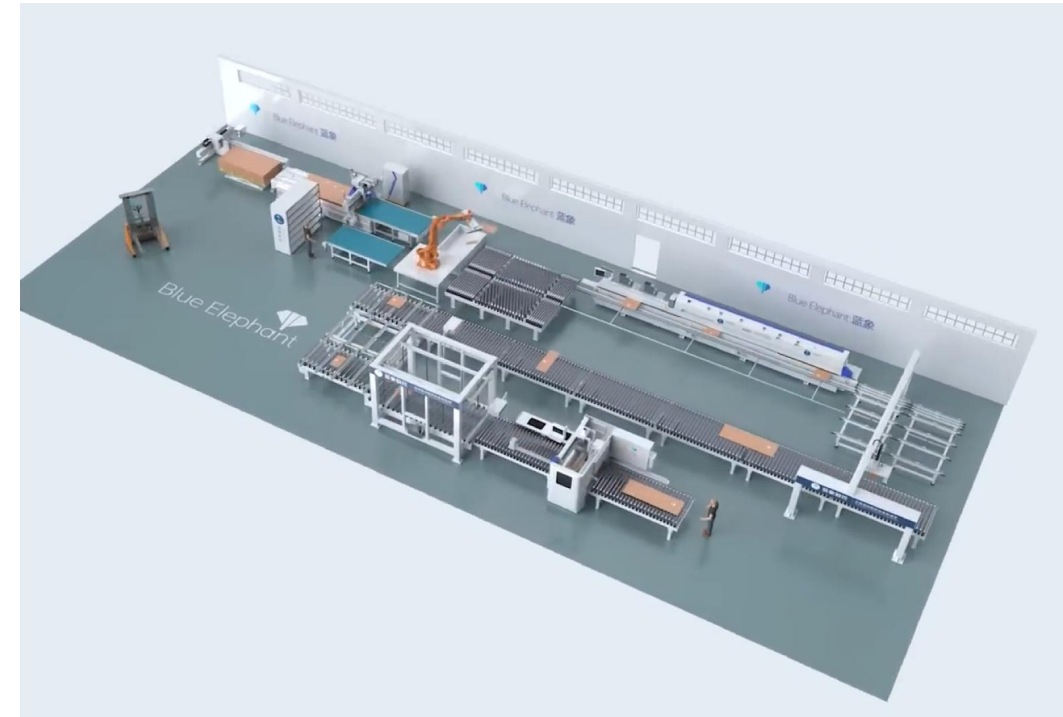
Absolute/Incremental



In the incremental measurement mode, the machine must first be set to the reference point after switching on.

AUTOMATION TODAY

- modern automation today is based on the installation of more complex assemblies:
 - modern robotic manipulators,
 - mobile systems and
 - assemblies with computer vision and/or speech.

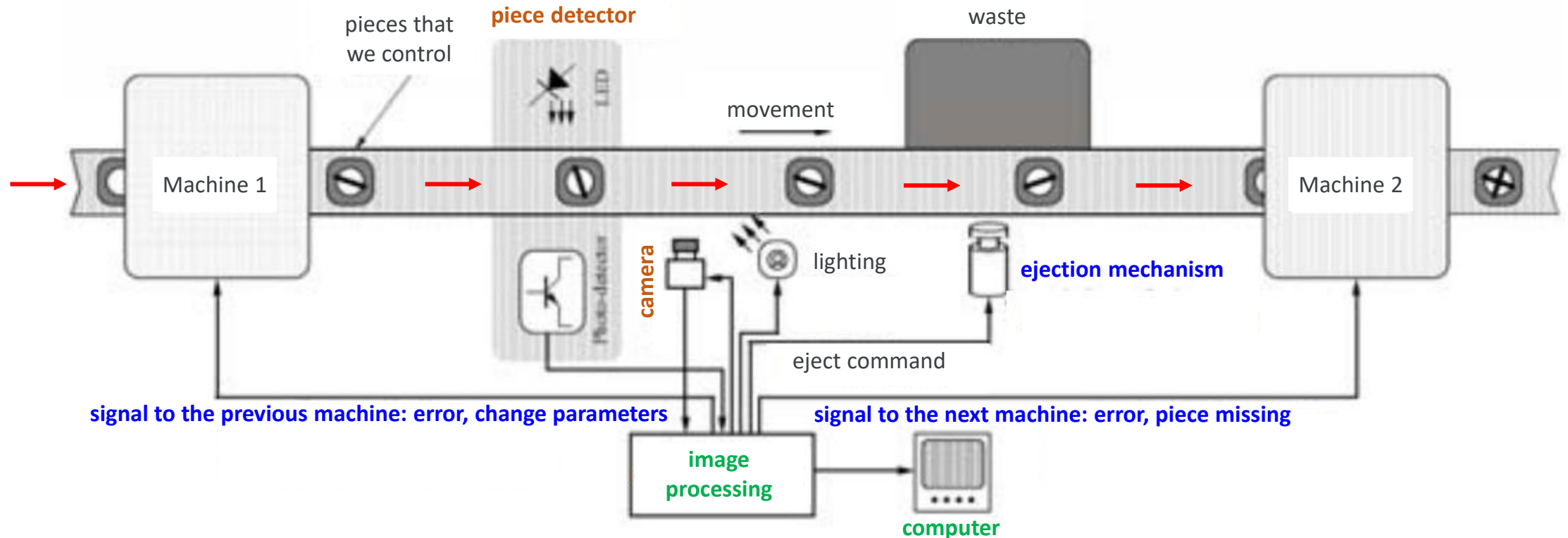


AUTOMATION TODAY

- modern automation today is based on the installation of more complex assemblies :
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 - mobile systems and
 - assemblies with computer vision and/or speech.



- modern automation today is based on the installation of more complex assemblies :
 - modern robotic manipulators,
 - mobile systems and
 - assemblies with computer vision and/or speech (automated assembly or **controlled** line)
 - quality control,
 - measurement,
 - sensing in robots, etc.



Main differences between robots and CNC machines:

- **Workspace**

The workspace of a CNC machine can usually be defined as a **small cube**.
Robots usually have a **large, spherical workspace**.

- **Accuracy**

CNC machines are usually **more accurate** than robots with accuracies going down to fractions of a micron.
Robot accuracies can be improved by calibration but are more likely to be 100s of microns.

- **Stiffness**

CNC machines usually have **high stiffness in all axes**.
The **stiffness** of robots is generally **lower** but it varies depending on the type of robot.

- **Z-axis machining**

CNC machine has limited machining height
Robot has no limitations (space,...)

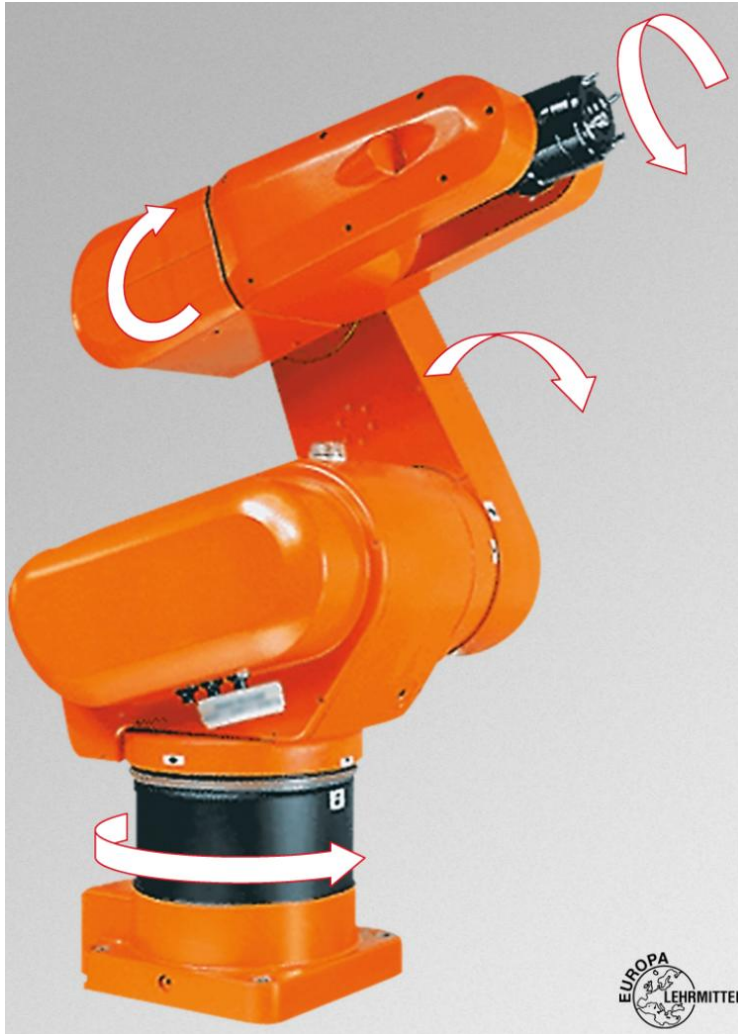
CNC machines are **limited to** just **machining tasks**.

Robots provide **flexibility** with their ability to adapt to different parts and applications.



ROBOT

Robot (6 axis)



Robot (7 axis)



Robot as a working machine

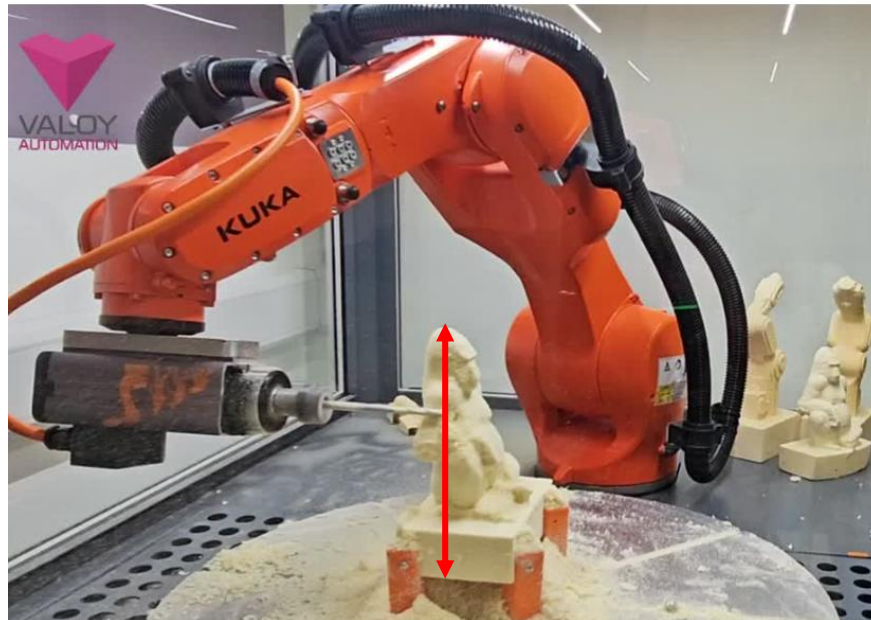


<https://industrialrobotics.it/robotic-solutions-for-production/>

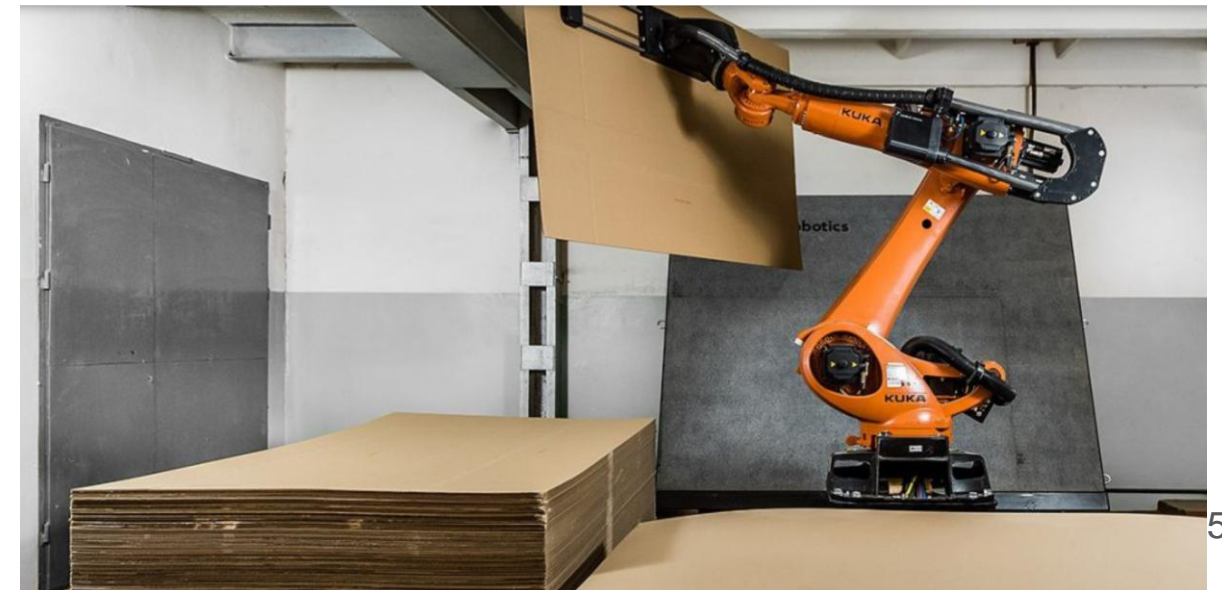
Robot as a feeding device for a CNC machine



Robot as a service device, assembly device,....

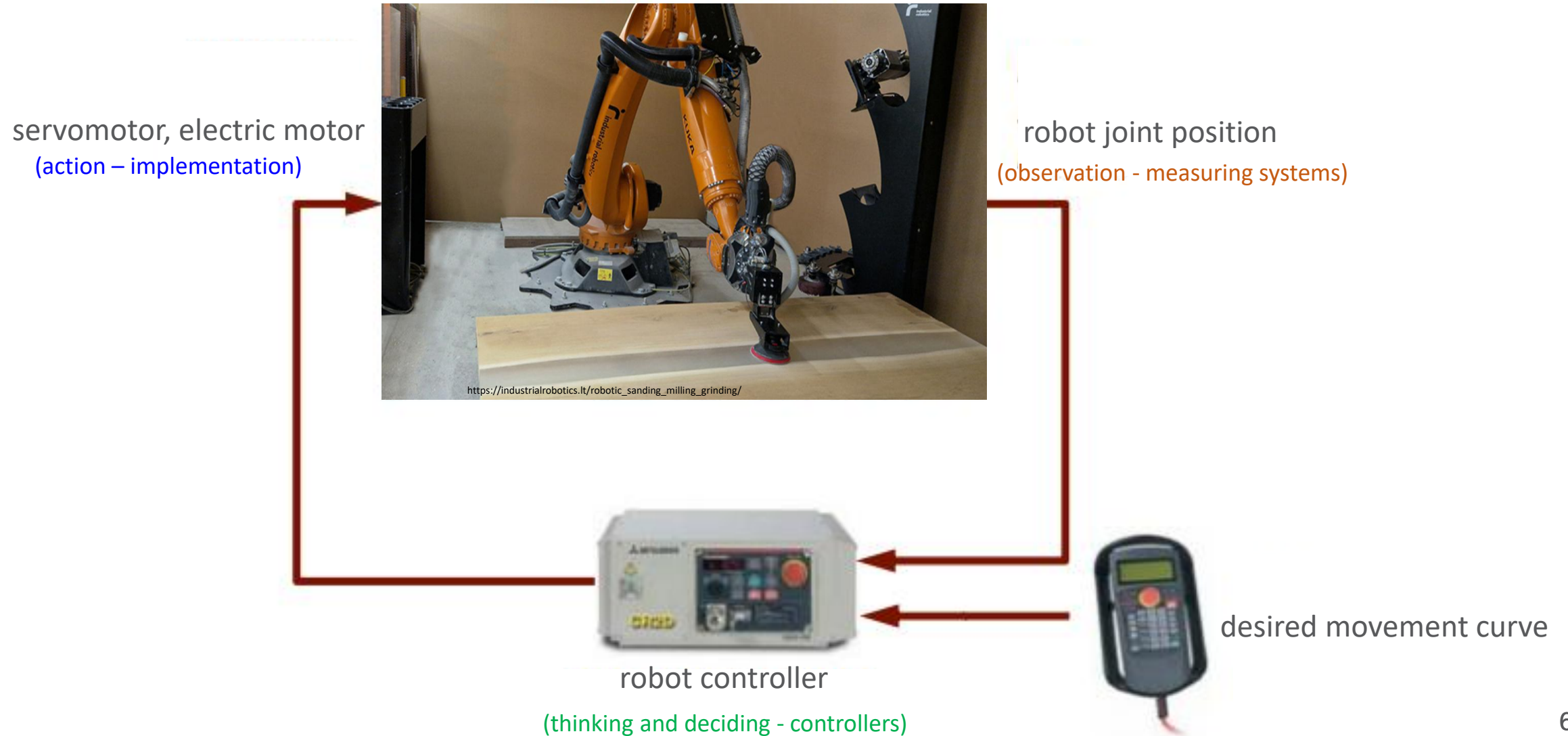


https://www.linkedin.com/posts/vanessaloiola_robotics-automation-kuka-activity-7192404331483070464-OvR6



https://industrialrobotics.it/2022/03/21/robots_furniture_production/

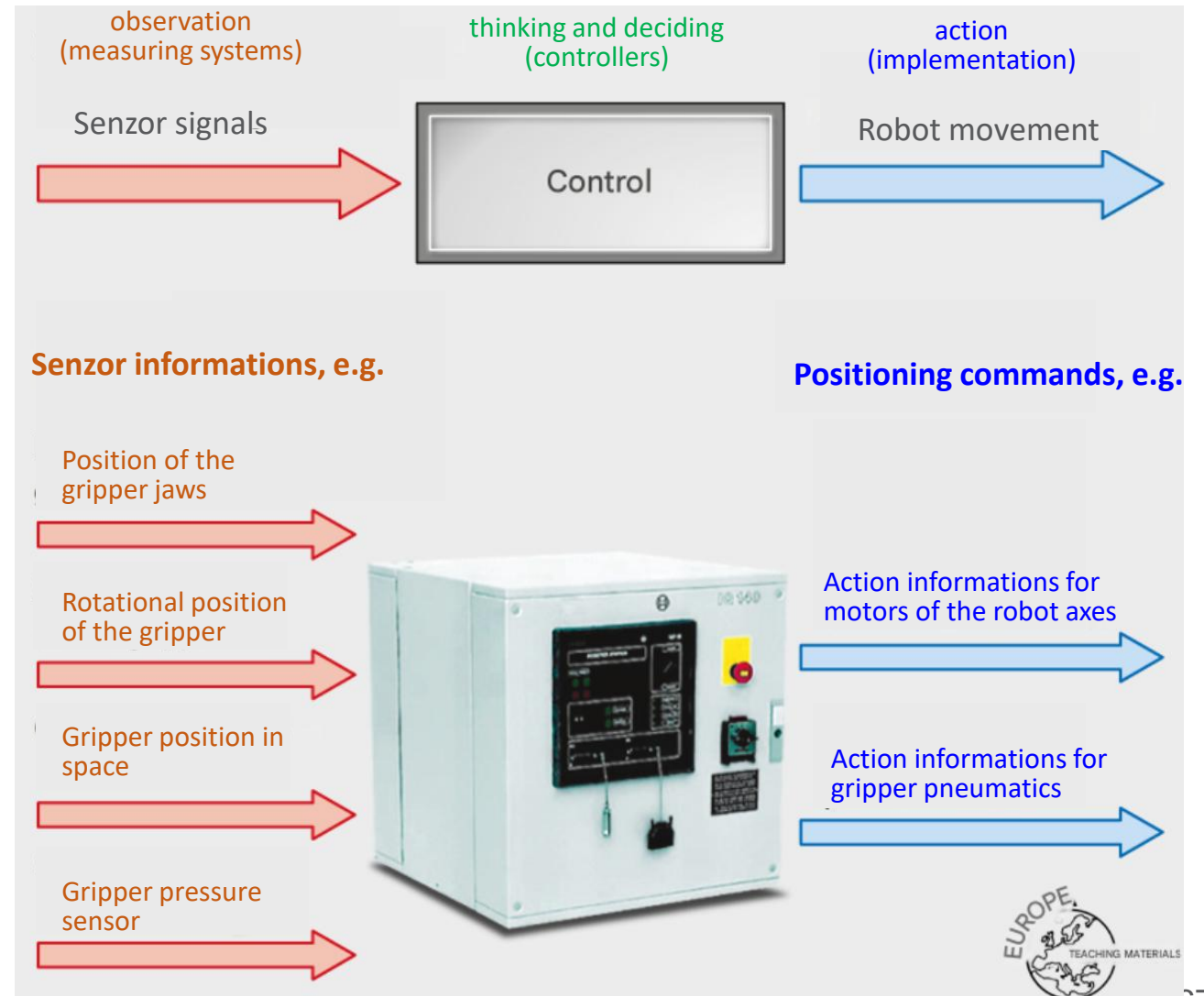
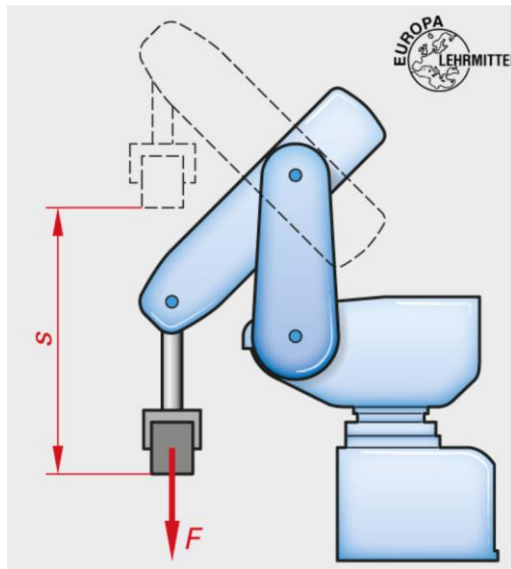
AUTOMATICALLY CONTROLLED SYSTEMS (ROBOTIC AS SANDING MACHINE)



ROBOT WITH GRIPPER

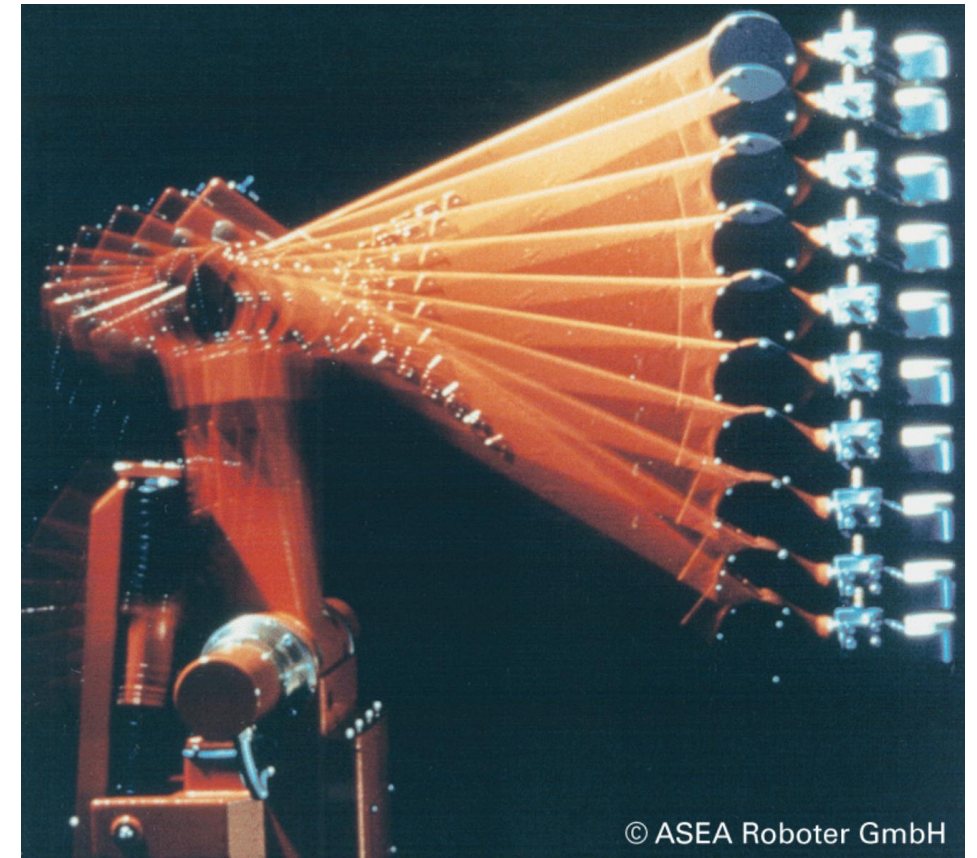
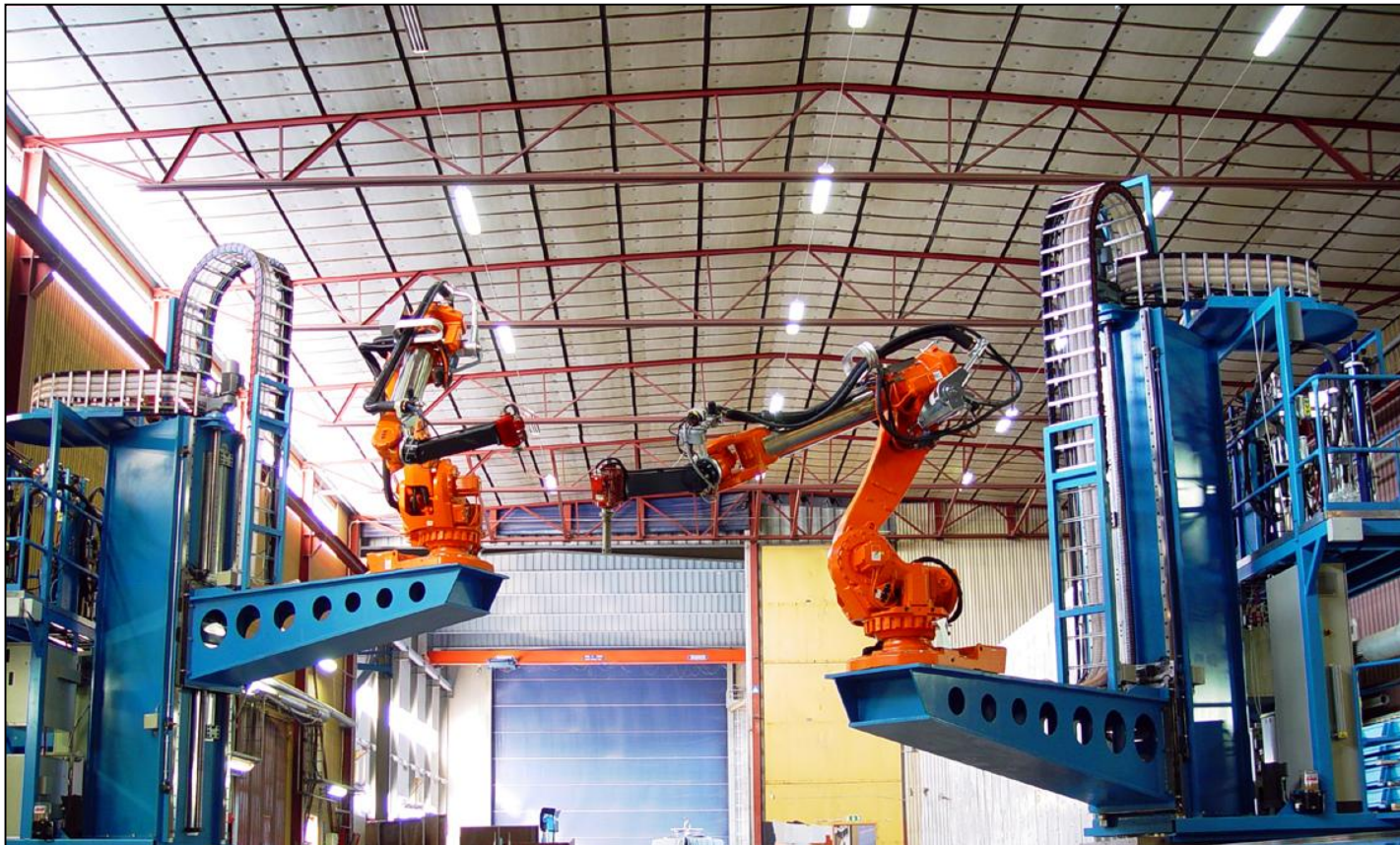


<https://www.pmdcorp.com/industries/motion-applications/robotic-gripper-control>



CNC - ROBOT

*A single CNC machine gives high performance for a **specific machining task**.
A single robot can achieve **many tasks** with a **different performance for each**.*



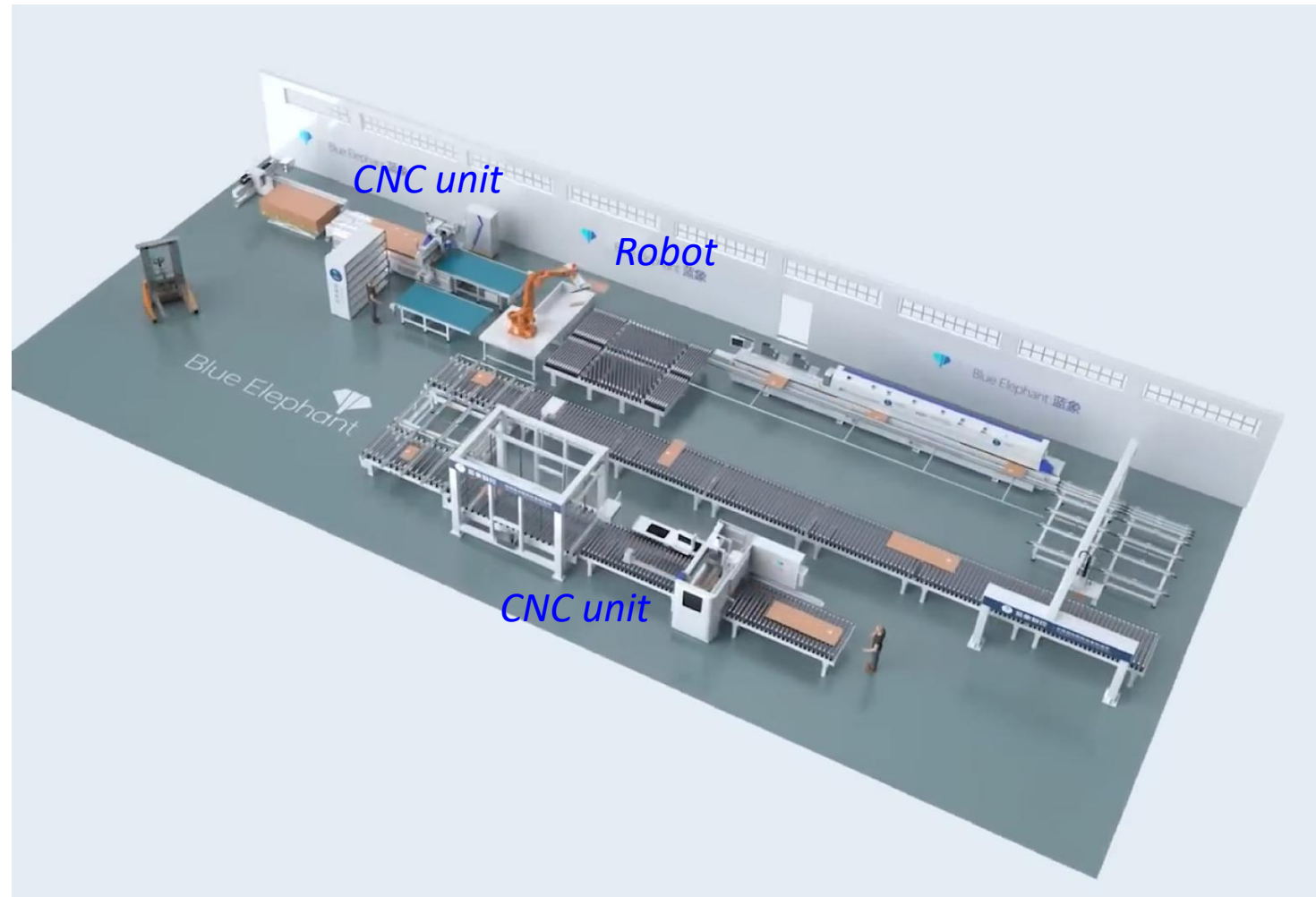
© ASEA Roboter GmbH

AUTOMATION OF MANUFACTURE PROCESS?

Whenever we want:

- Increase productivity
- Consistent quality and precision
- Cost reduction
- Greater safety
- Flexibility
- Competitiveness
- Tracking and Analysis
-

- which process, why?
- which unit (CNC, robot,...?)
- price (required quality,)
- suitable staff?
-



YES...TERDAY



UNIVERSITY
OF LJUBLJANA

BF

Biotechnical
Faculty

Thank you for your attention.

Designing of furniture from reused materials – how to repair furniture with new techniques (scanning, 3D printing)

Asst. Prof. Mirko Kariž, prof. Manja Kitek Kuzman

Overview

- Background:
 - Work on Department:
 - 3d modelling, Solidworks, Swood
 - SEMA
 - 3d print and wood
- Circular economy and furniture repair
- 3d scanning+3d print

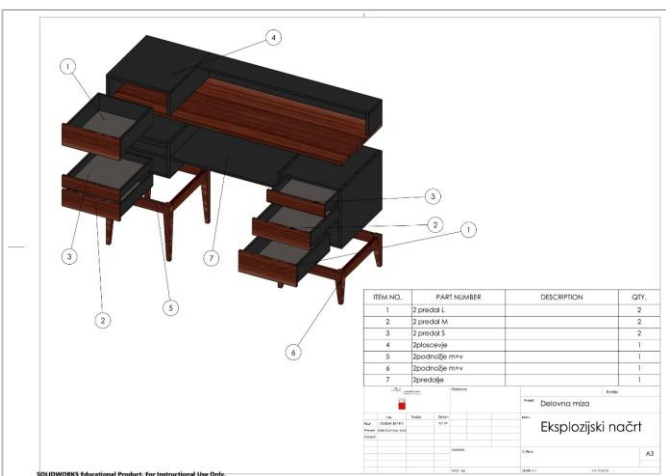
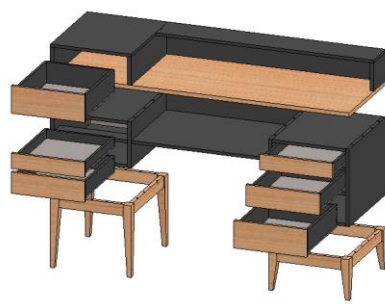
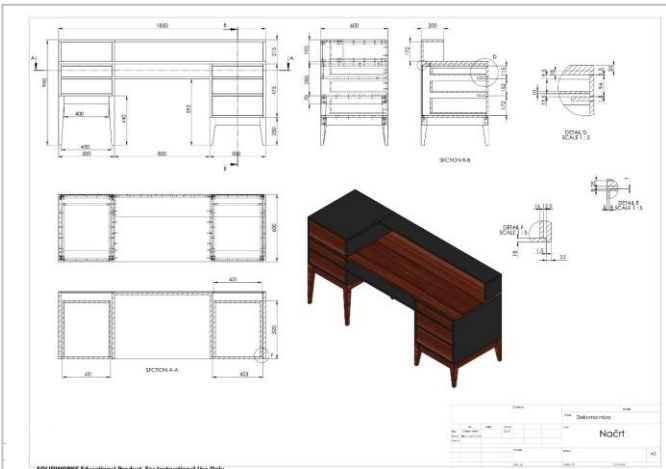
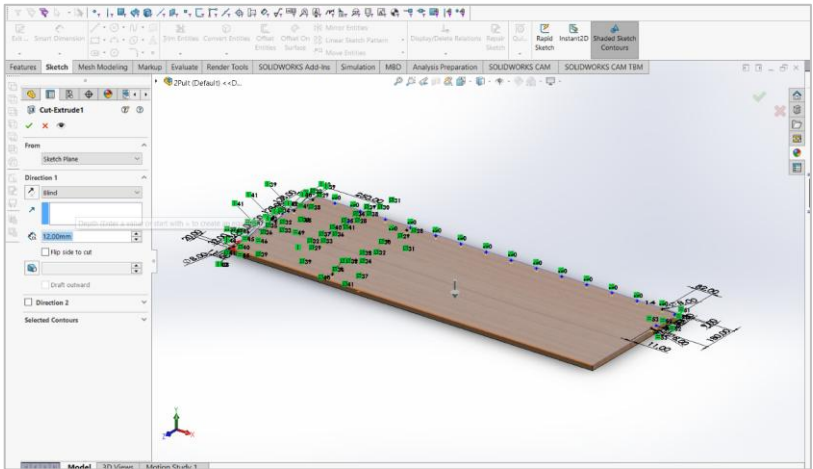
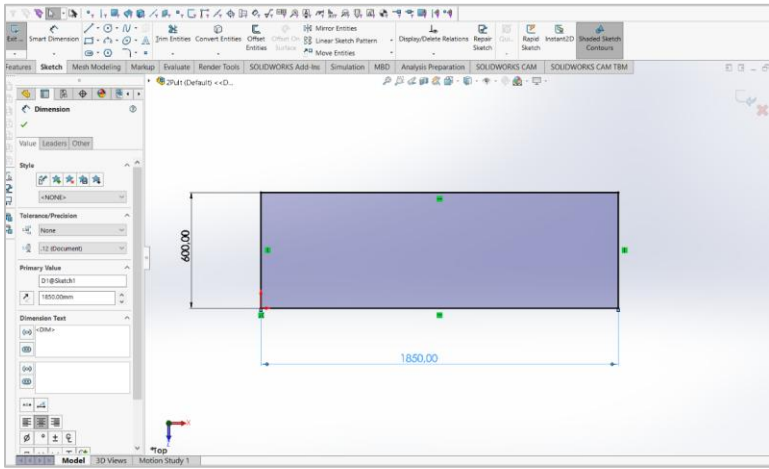
Background: Work on Department:

Pedagogical work

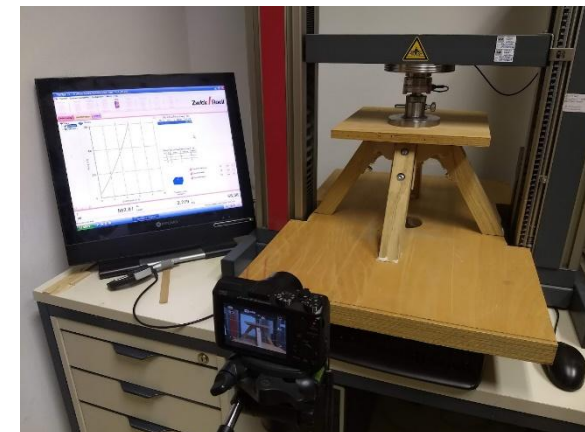
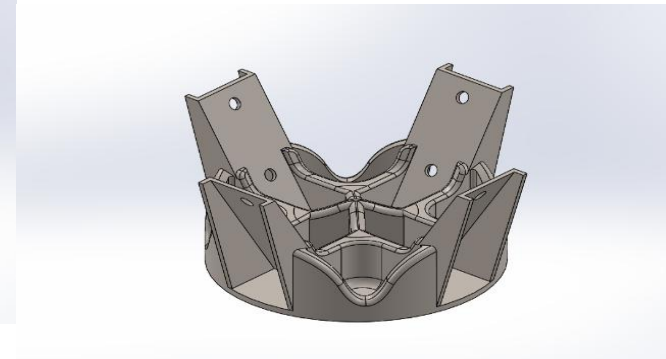
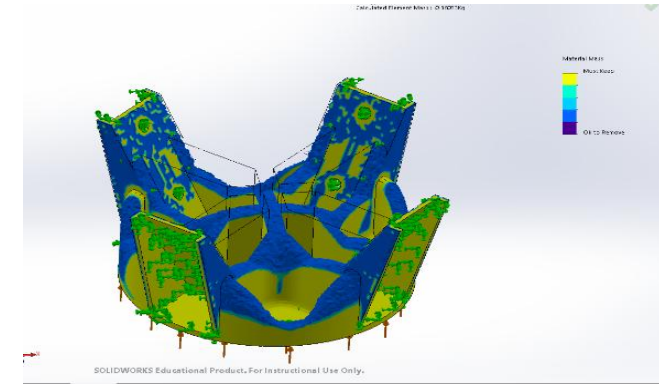
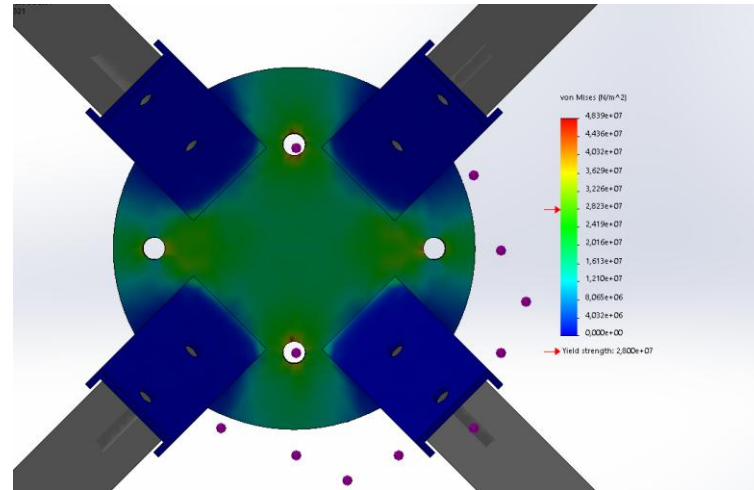
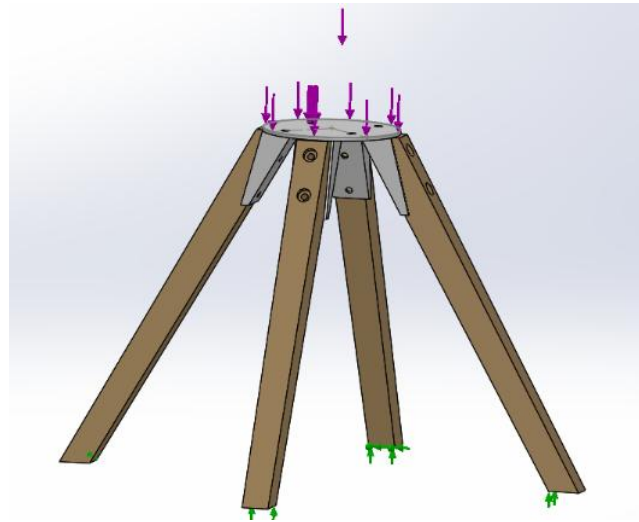
Research work



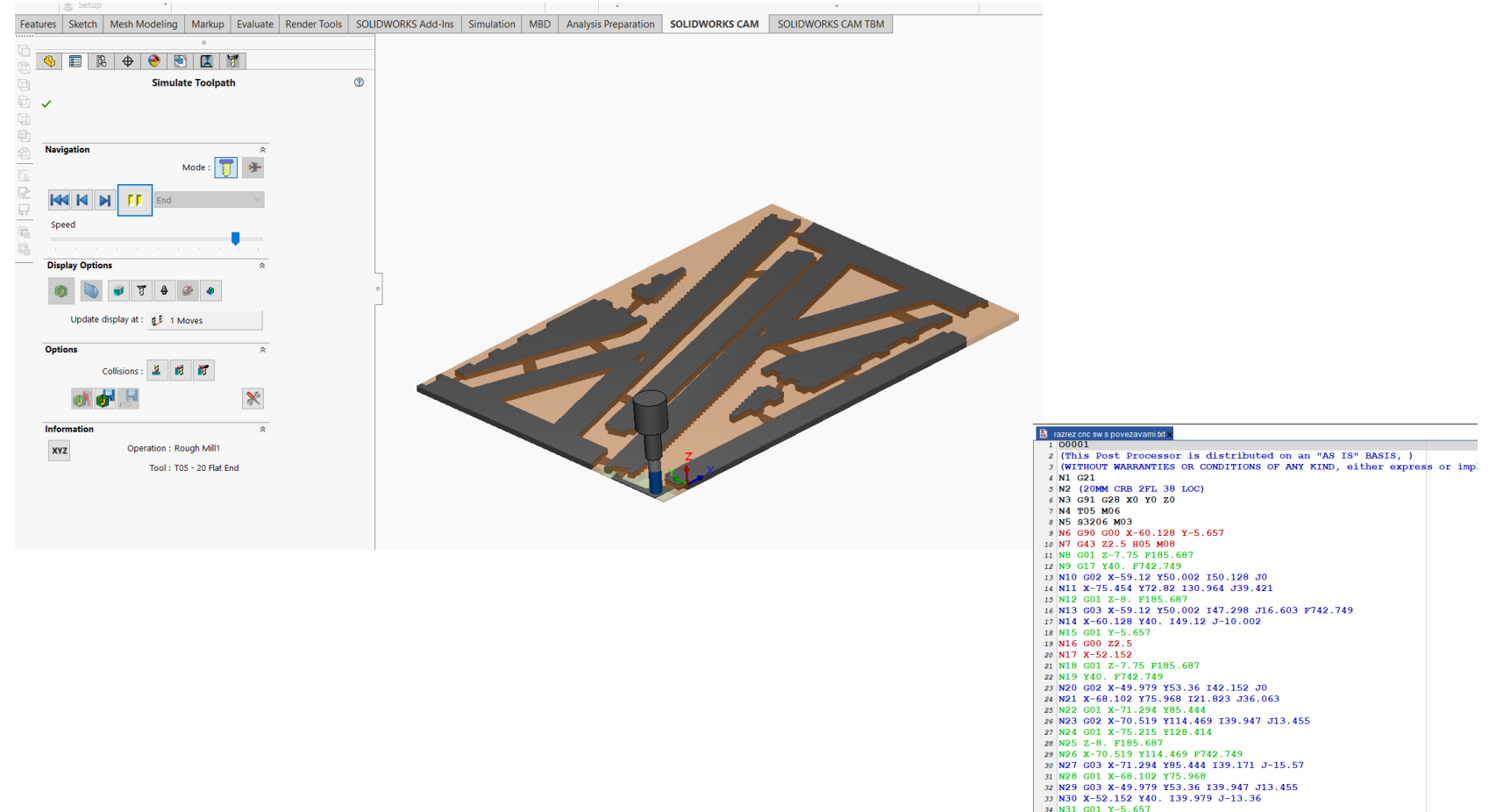
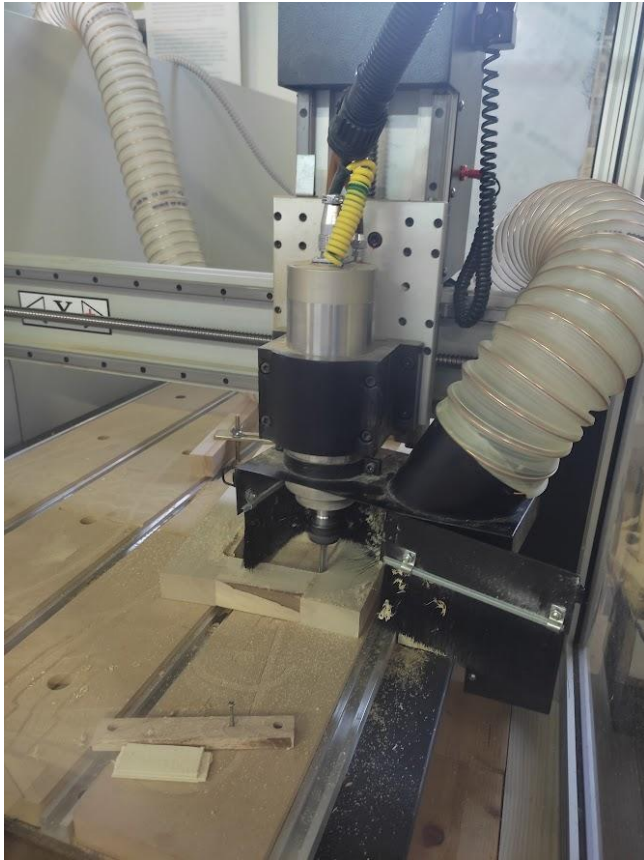
3D modelling, furniture construction- SolidWorks software



SW - Numerical simulations



SW -Cnc machining



Prototype/standard tests



Testing and Certification Center

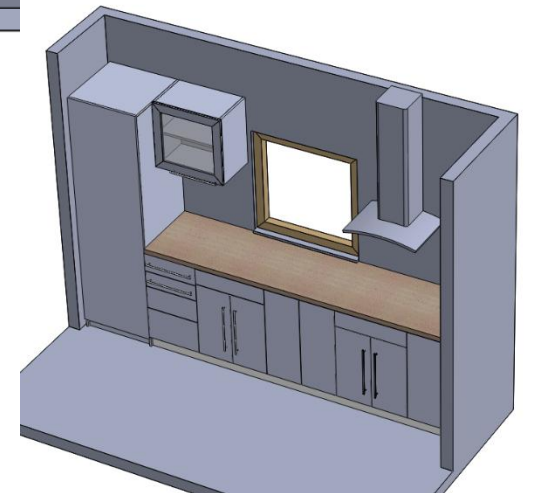
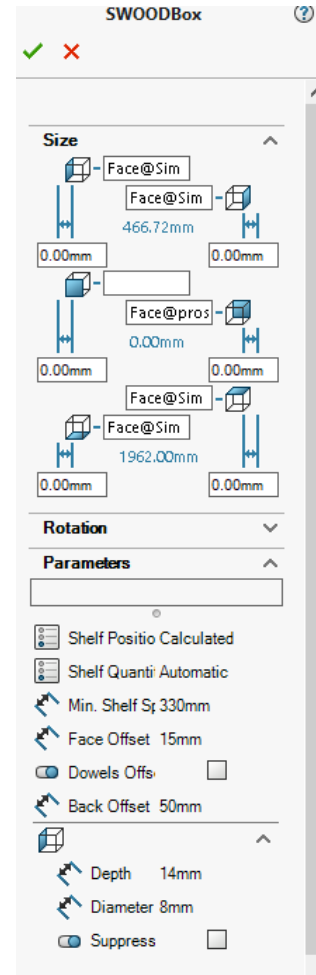
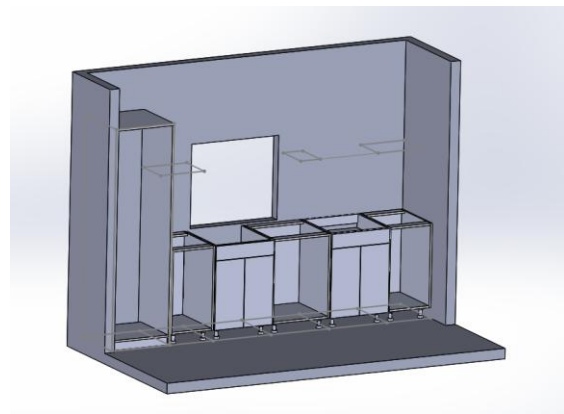
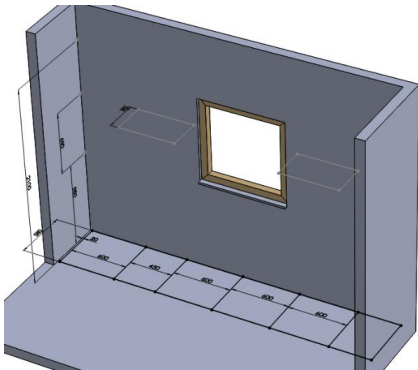
There is no content on this page at the moment.

Employees

- Tomaž Kušar
- Bogdan Šega

3D modelling, furniture construction- SolidWorks software-SWOOD

- Furniture elements/components library



Wood constructions-SEMA software



[Software](#)[SEMA.next](#)[College](#)[Support](#)[Download](#)[Company](#)[What's New](#)

SOFTWARE

Version 24.1

Highlights SEMA versions

Timber Construction

Stair Design

Facade & Metal Cladding

Features

Release History

Vocational Training

Customer Projects

SEMA SOFTWARE

From planning to production - the SEMA software covers the whole range of activities in timber and stairs construction, as well as in the sheet metal trade. Due to the software's modular structure and flexible master data, it adapts perfectly to the needs of your company.





3D CAD/CAM SOFTWARE

The range of applications comprises all fields: from 2D/3D CAD planning, design, photorealistic visualisation, calculation and tender preparation at the push of a button up to the output of the architecture, production plans and working drawings, and the lists of parts - all this you can find under one uniform, easy-to-use program surface.

With our Building and Stairs construction Assistants, you can enter multi-storey building envelopes and stairs in next to no time. Changes can be made anytime; the manifold options for processing in terms of planning and construction remain intact. Our Assistants have simplified the input of buildings and stairs significantly to set new standards when it comes to user-friendliness.

The image shows two side-by-side screenshots of the SEMA software interface. The left screenshot displays a 2D floor plan of a building with a grid of vertical and horizontal lines, representing structural elements. The right screenshot shows a 3D perspective view of the same building, highlighting the timber frame construction. Both views include a detailed sidebar with various toolbars and a 'My master data' panel on the right, which lists different construction elements like 'Timber framed construction', 'Fixed glazing', and 'Fixed glazing with turn element'.

The image shows two side-by-side screenshots of the SEMA software interface. The left screenshot displays a 3D perspective view of a building's timber frame, showing the roof structure and the main walls. The right screenshot shows a detailed table of construction data, including columns for 'Item', 'Description', 'Price', 'Width', 'Height', and 'Length'. The table lists various construction elements like 'Timber', 'Roof', 'Wall', and 'Floor' with their respective dimensions and prices. Below the table, there is a 'Material list and data' section, which provides a summary of the materials used in the construction.

- Using libraries for different elements of building
- Drawings
- Cnc machining
- Calculations
-

A 3D rendering of a modern wooden building with a red-tiled roof and large windows. The building is shown from a low angle, emphasizing its height and the texture of the wood and tiles.

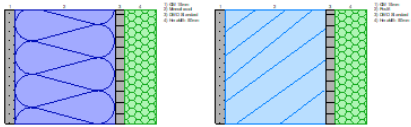
A 2D architectural drawing of a building facade, showing the structural details of the timber frame and the placement of windows. The drawing includes dimensions and a scale bar, indicating its use as a technical drawing for construction.

A 2D architectural drawing of a building facade, showing the structural details of the timber frame and the placement of windows. The drawing includes dimensions and a scale bar, indicating its use as a technical drawing for construction.

Energy performance report

Building project..... : poskus pocitniska hiska
Building project no..... :
Town..... :
Customer name..... :
Customer no..... :
Draughtsman..... :

Component : Exterior wall 160

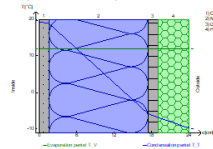


U value : 0,23 W/(m²*K)

Moisture calculation :

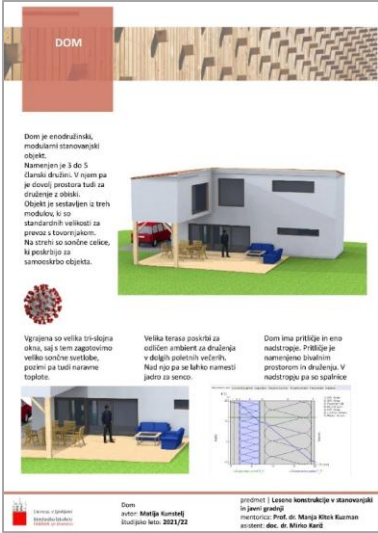
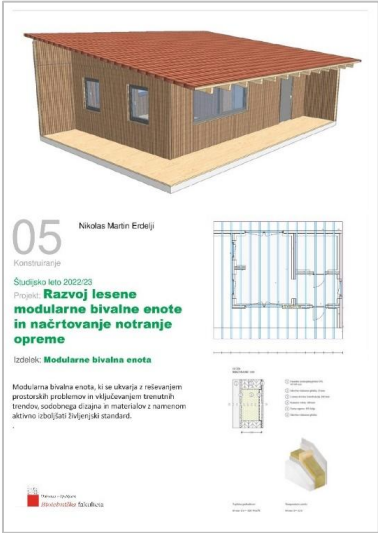
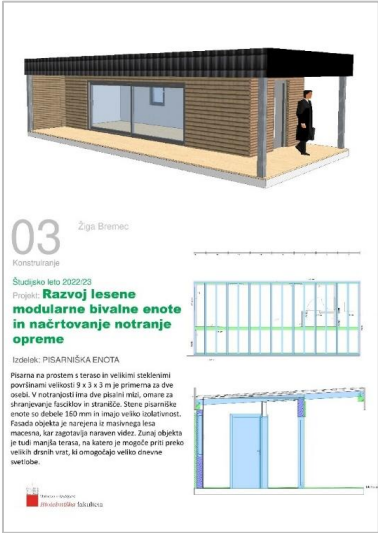
- Space : Moisture accumulation - please check
- Frames : OK

Temperature curve Space



Compilation of operands :

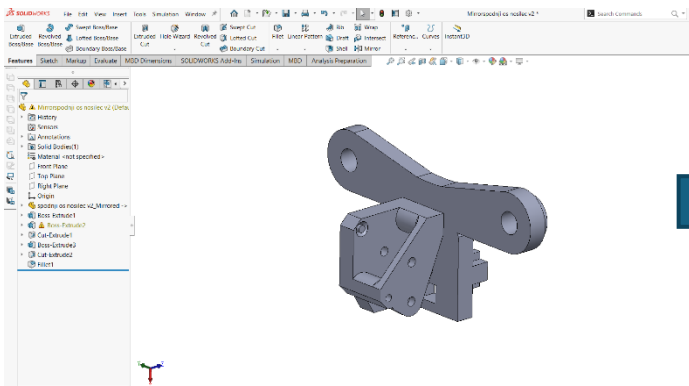
	d [m]	λ [W/(m·K)]	R [m²·K/W]	T T [°C]	T V [°C]
Heat transmission, inside			0,130	20,0 / 19,3	12,0 / 12,0
1) GW 15mm	0,0150	0,202	0,074	19,3 / 18,9	12,0 / 12,0
2) Mineral wool	0,1600	0,035	4,571	18,9 / -5,8	12,0 / 12,0
3) DWD Standard	0,0160	0,090	0,178	-5,8 / -6,8	12,0 / 12,0
4) Heraklith 50mm	0,0500	0,090	0,556	-6,8 / -9,8	12,0 / 12,0
Heat transmission, outside			0,040	-9,8 / -10,0	12,0 / 12,0
Total	0,2410		5,549		



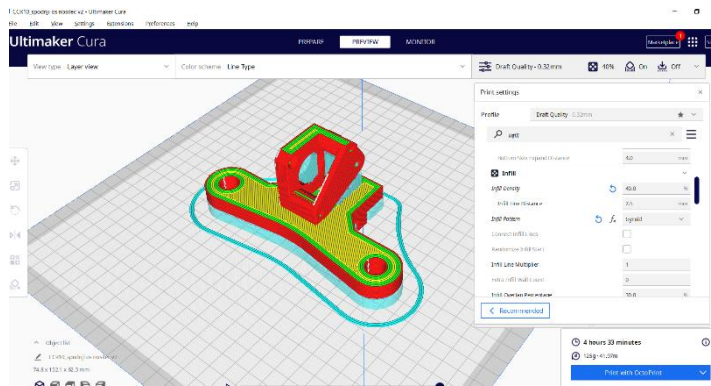
Additive manufacturing

3D printing

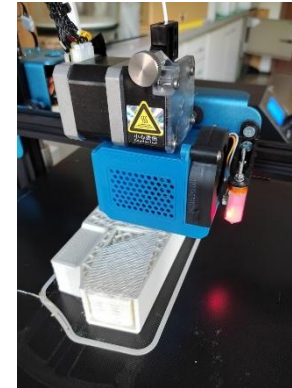
Digital 3D model
product



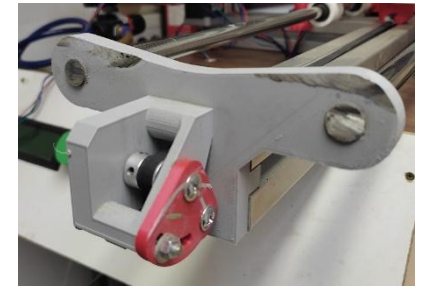
Slicer



3D printing



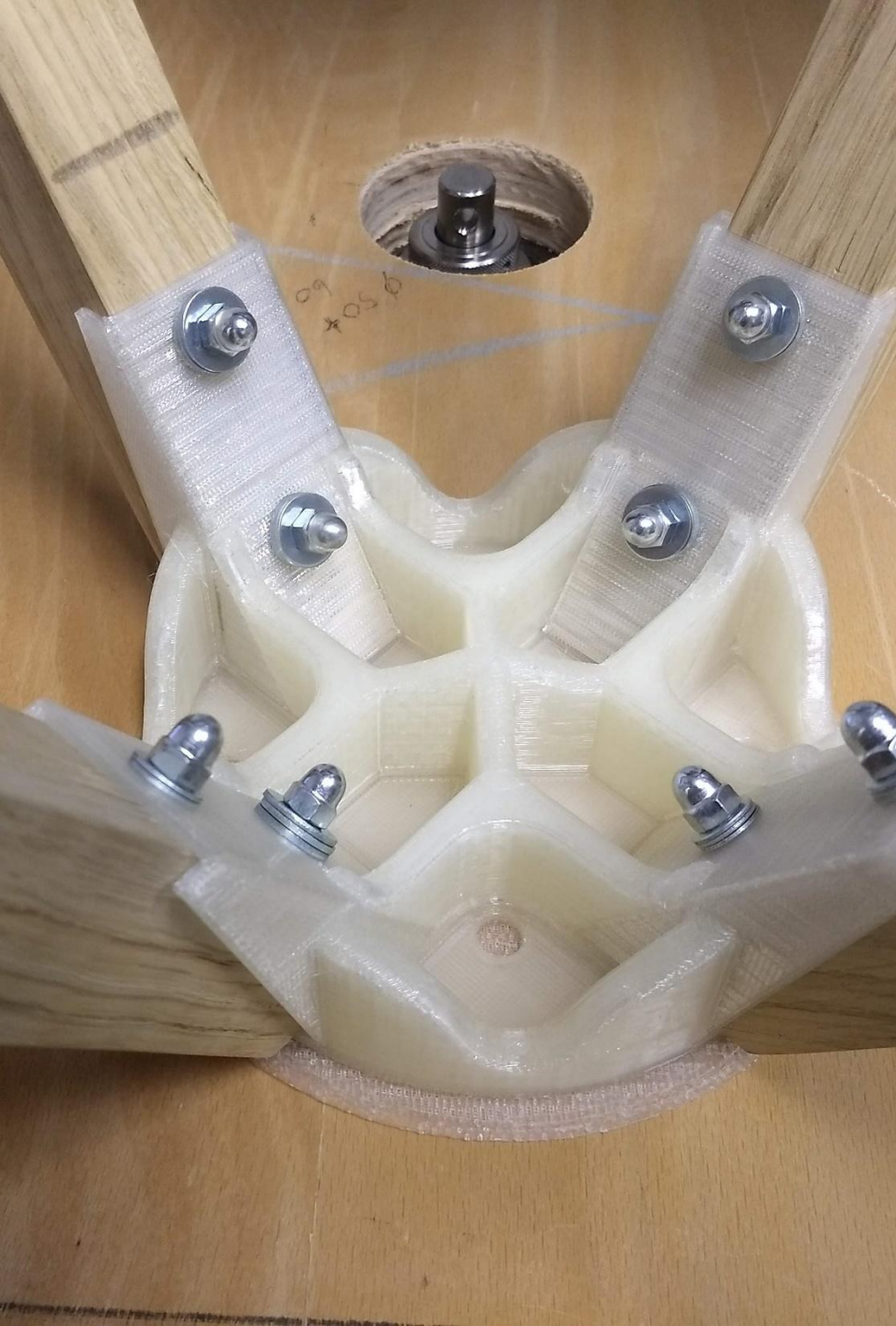
Final



- Local production, lower transport cost, less residues, better material efficiency, less shape limitations, new designs..

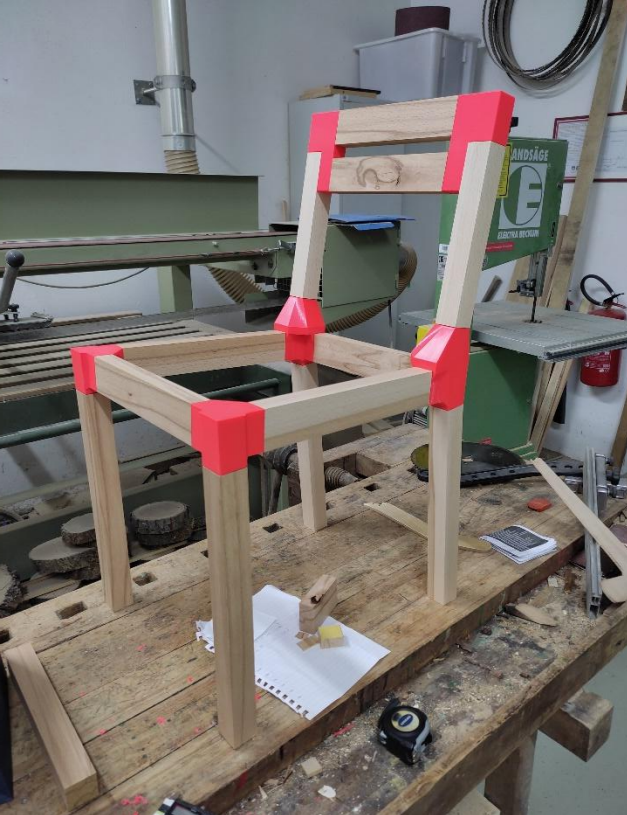
3D printing and wood

- FDM (Fused Deposition Modeling, FFF Fused filament fabrication...)
 - Thermoplastic polymers+wood, WPC composites
- LDM/paste extrusion
 - Liquid/paste extrusion
- Powder materials-inkjet powder printing/droplet application/spraying of binders,
- Laminated Object Manufacturing (LOM),
- Stereolithography (SLA), Selective Laser Sintering (SLS), Digital Light Process (DLP), Multi Jet Fusion (MJF), PolyJet, Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM)



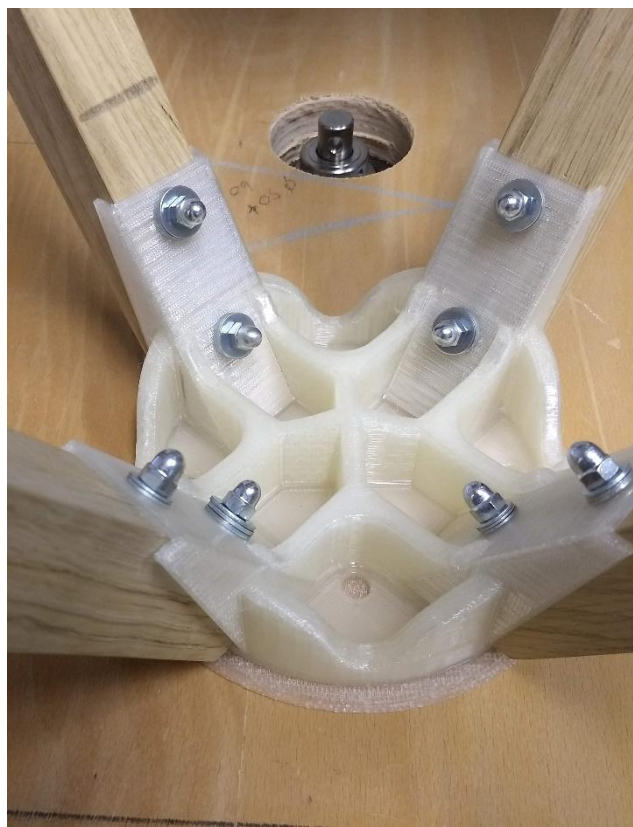
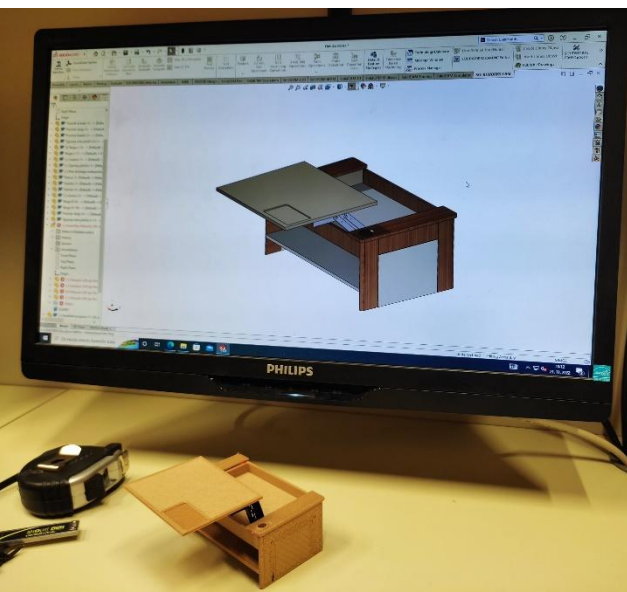
Wood and 3D print in our research

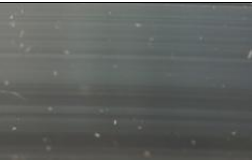
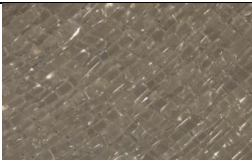
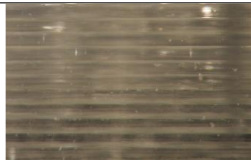


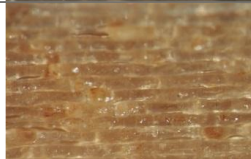












- FDM- wood-plastic filaments-as new materials and properties
- Wooden furniture with 3D printed connectors
- Prototypes
- Wood-adhesive paste extrusion 3D printing
- Direct printing to wood...
- „Mycelium“ printing
- Nanocellulose...



Wood and 3D print in our work with students

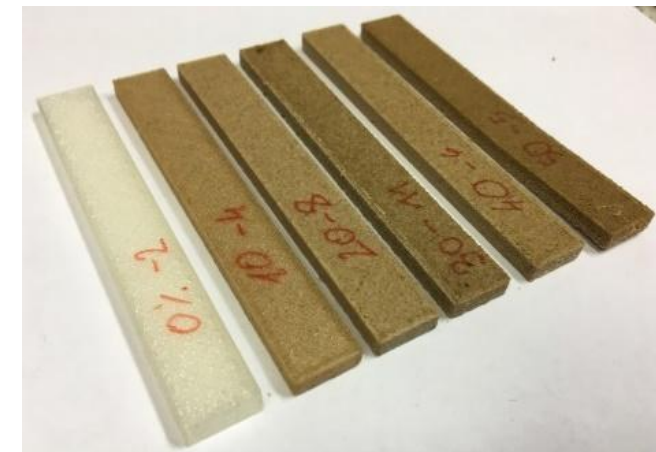
- Wooden furniture with 3D printed connectors
- Prototypes



Filament (wood content)	3D printed part		
	Filament (70x)	Surface (20x)	Edge (40x)
0 %			
10 %			
20 %			
30 %			
40 %			
50 %			

FDM Filaments with different wood ratio

- Beech wood powder
- PLA
- Ratios 10-50%



Faculty of
Polymer Technology

Kariz, M., Sernek, M., Obućina, M., & Kuzman, M. K. (2018). Effect of wood content in FDM filament on properties of 3D printed parts. *Materials Today Communications*, 14, 135-140.

Ayrlmis, N., Kariž, M., & Kitek Kuzman, M. (2019). Effect of wood flour content on surface properties of 3D printed materials produced from wood flour/PLA filament. *International Journal of Polymer Analysis and Characterization*, 24(7), 659-666.



Adhesive bonding of 3D-printed ABS parts and wood

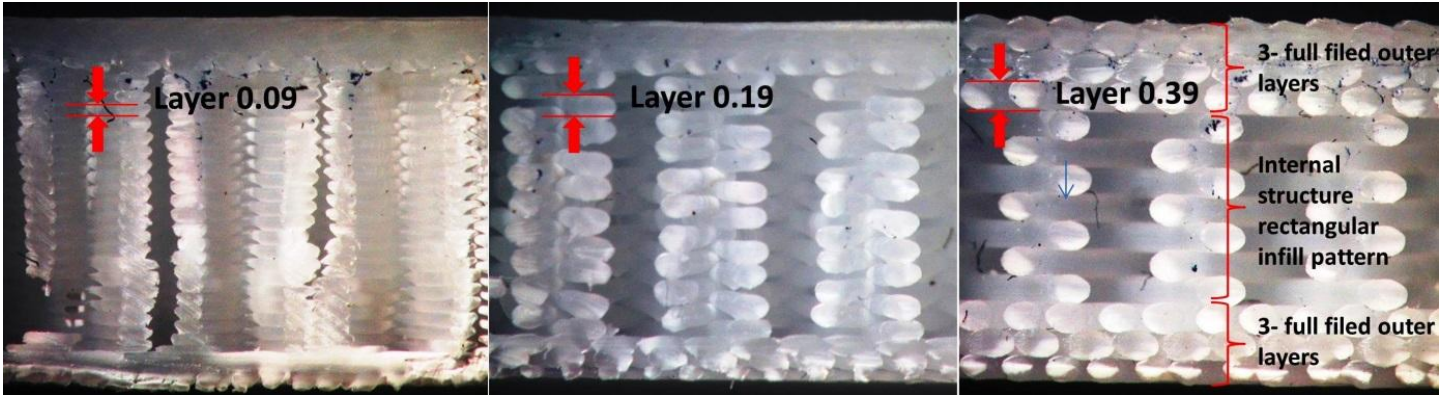
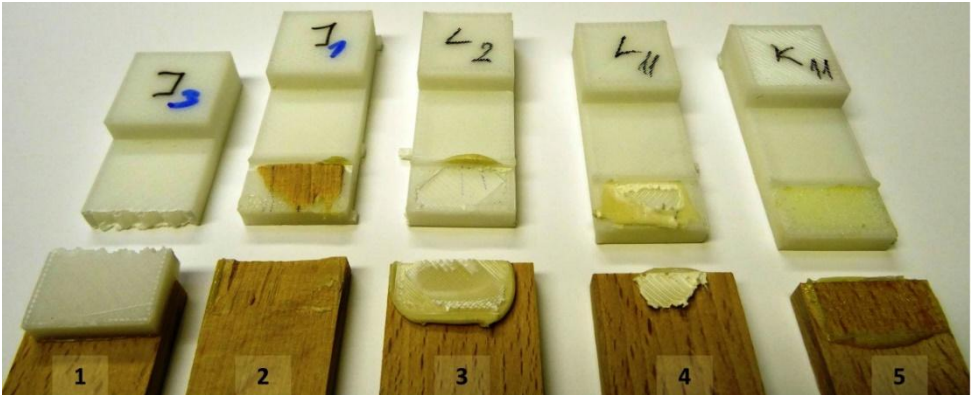
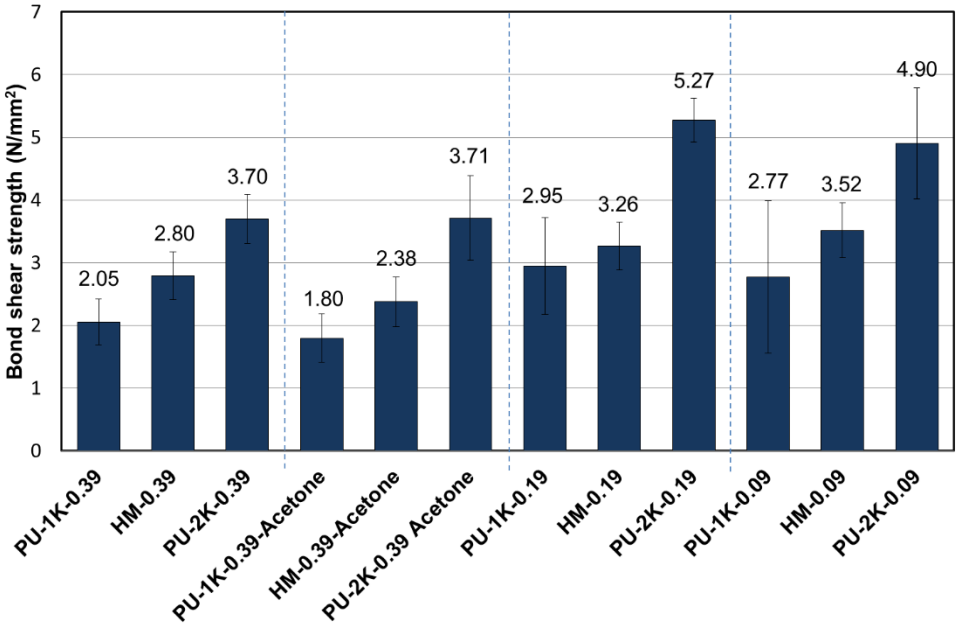


Fig. 1. Cut-through 3D-printed parts with different layer thickness (left, 0.09 mm; middle, 0.19 mm; and right, 0.39 mm)

Optimal layer thickness

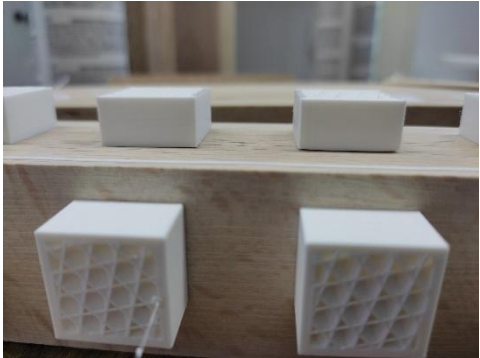
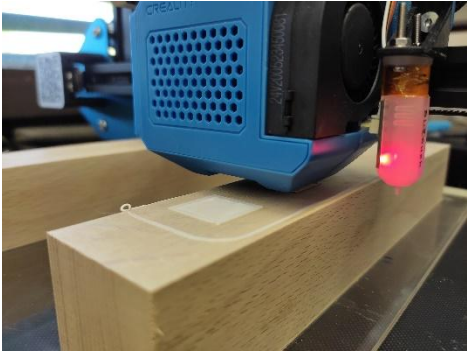
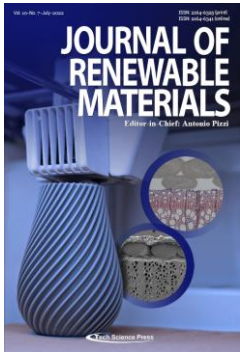
Adhesive

For furniture components...

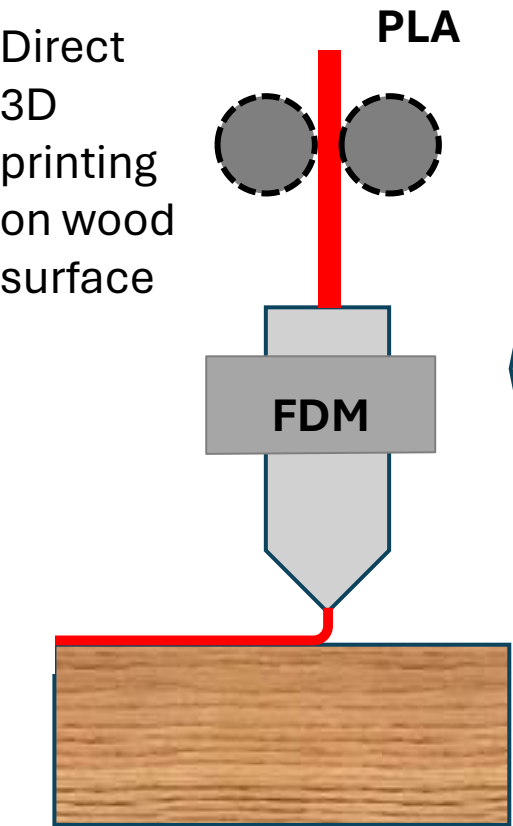


Average tensile
bond shear strength
for different printing
parameters and
adhesives

Direct 3D print on wood surface



Bond shear strength



Nozzle temperature:

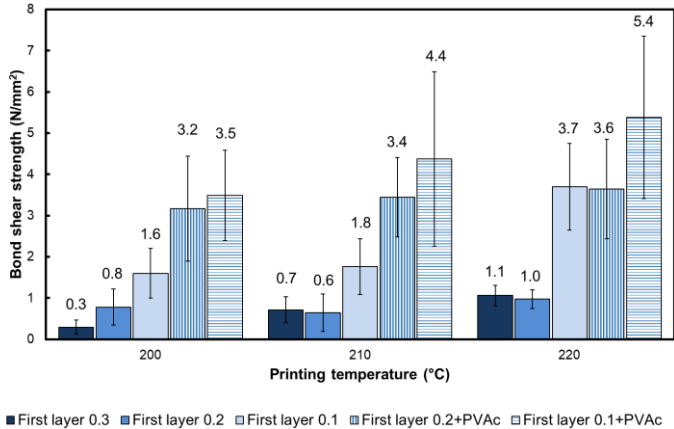
- 200°C
- 210°C
- 220°C

First layer thickness:

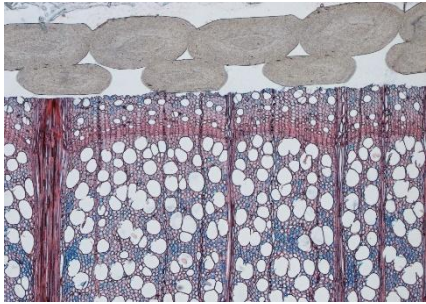
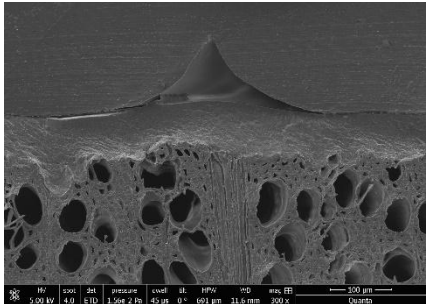
- 0.1 mm
- 0.2 mm
- 0.3 mm

Wood surface preparation:

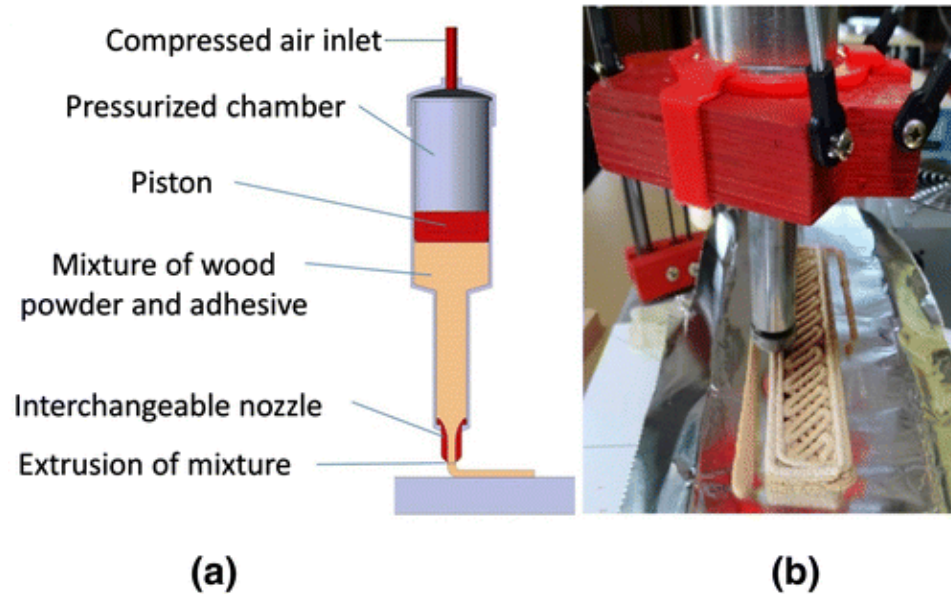
- Planned
- Planned + PVAc adhesive as primer



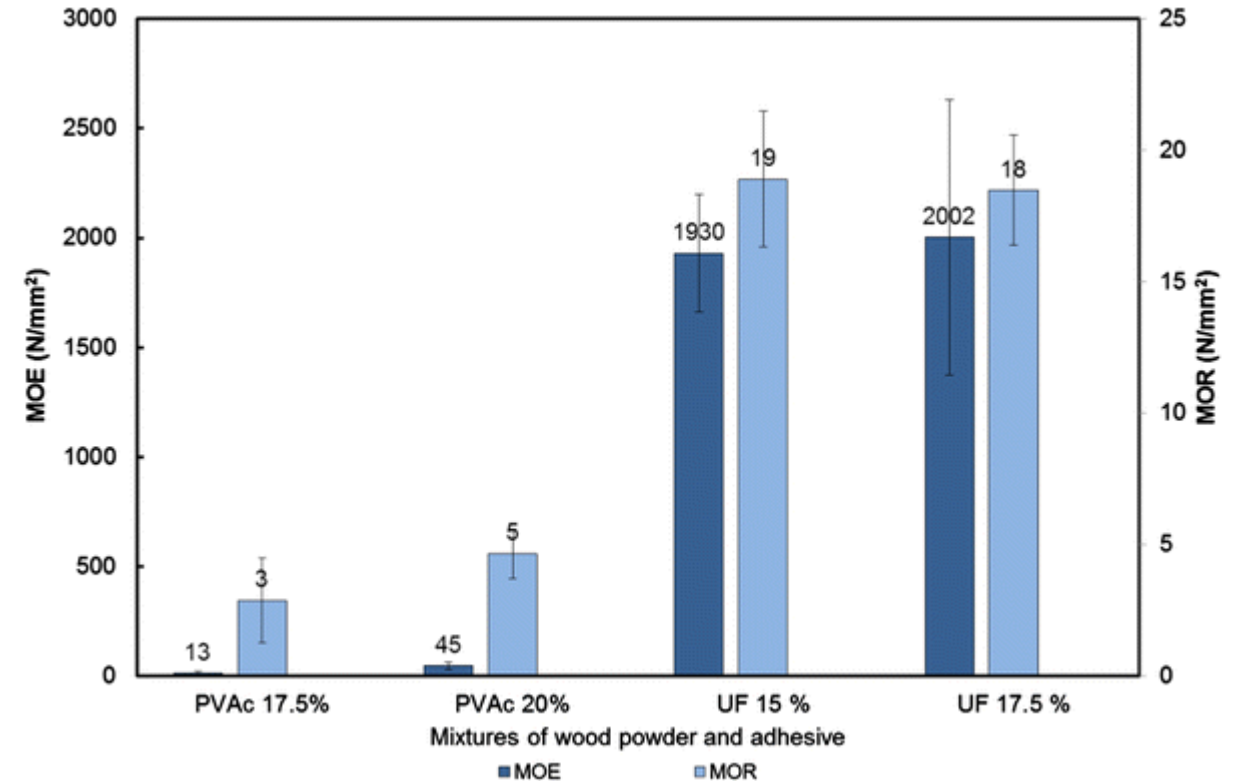
Microscopy



Wood adhesive paste extrusion 3D printing

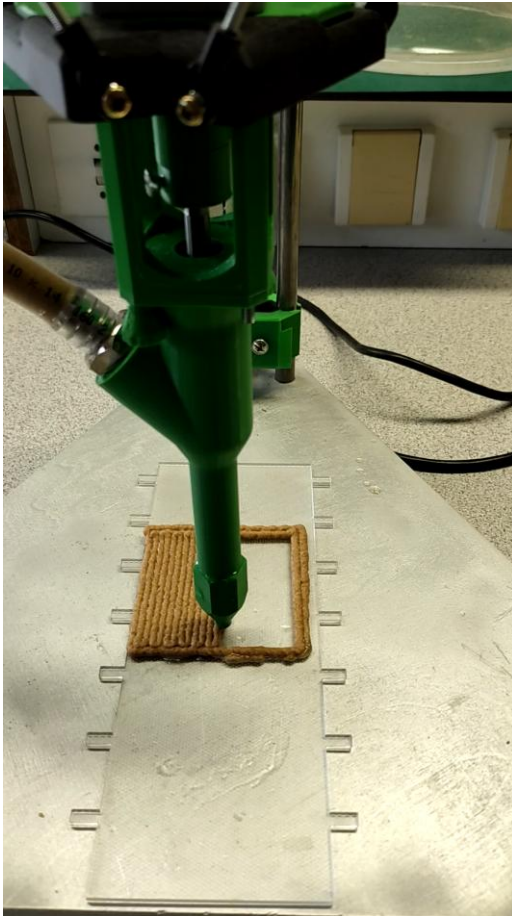


- Wood powder
- PVAC adhesive
- UF adhesive



Kariz, M., Sernek, M. & Kuzman, M.K. Use of wood powder and adhesive as a mixture for 3D printing. *Eur. J. Wood Prod.* **74**, 123–126 (2016). <https://doi.org/10.1007/s00107-015-0987-9>

Wood adhesive paste extrusion 3D printing



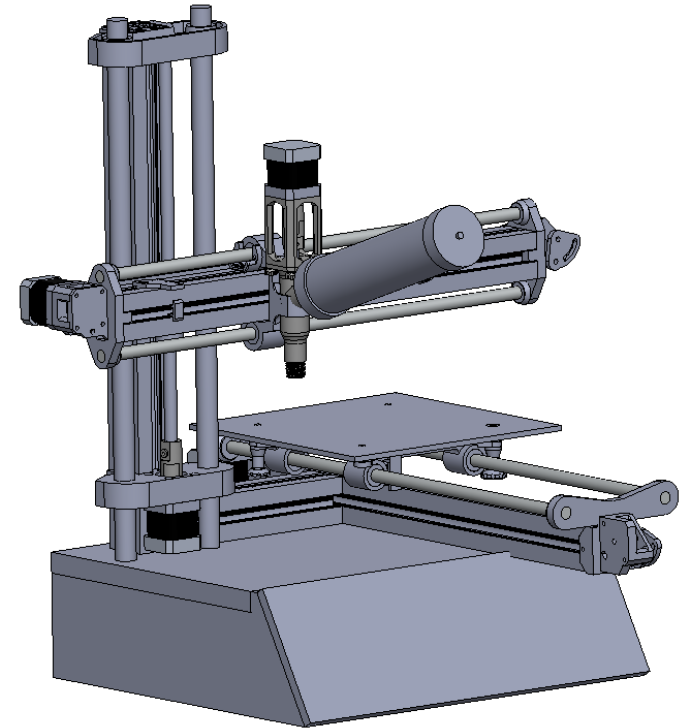
Rheology of the mixture

Flow vs buildability

Thixotropic properties...

Curing times

Screw vs air pressure driven



Lignocellulosic biomass and mycelium in 3D printing

- Davor Kržišnik, Blaž Žuran, Mirko Kariž, Miha Humar
- Various lignocellulosic biomass + fungal cultures
- Gelling agent- starch/ agar-agar
- Paste 3d printing, incubation, drying at 60°C



Mirko Kariž, 3D printing and wood

Circular economy and furniture repair/ design from reused material

Designing of furniture from reused materials

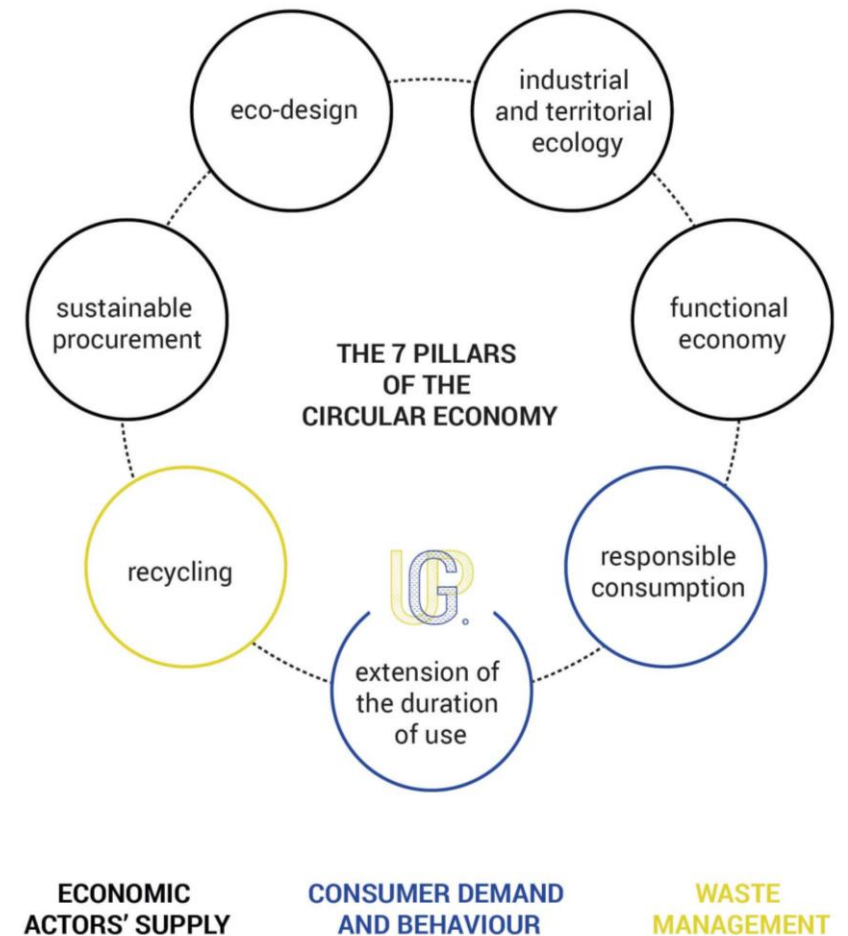
- Why reused materials?
- furniture waste in the EU accounts for **more than 4% of the total municipal solid waste stream (MSW)**.
- Waste arising from commercial sources is assumed to contribute 18% of total furniture waste generation across the sector.
- Total annual EU28 furniture waste come to **10,8 million tons**.
- 80% to 90% of the EU furniture waste in MSW is incinerated or sent to landfill. That means only about 10% is recycled.
- Low recycling rates might be due to the fact that furniture is considered as bulky waste and not separated from other municipal waste correctly and a proper recycling service is missing.

Source : FURN 360 – Circular economy in the furniture :overview of current challenges and competences needs - 2017

Introduction/circular economy

Kirchherr, Reike & Hekkert found that most scholars describe circular economy by referring to the **3Rs**:

- **Reducing** materials need and waste
- **Reusing** products and product parts
- **Recycling** materials.



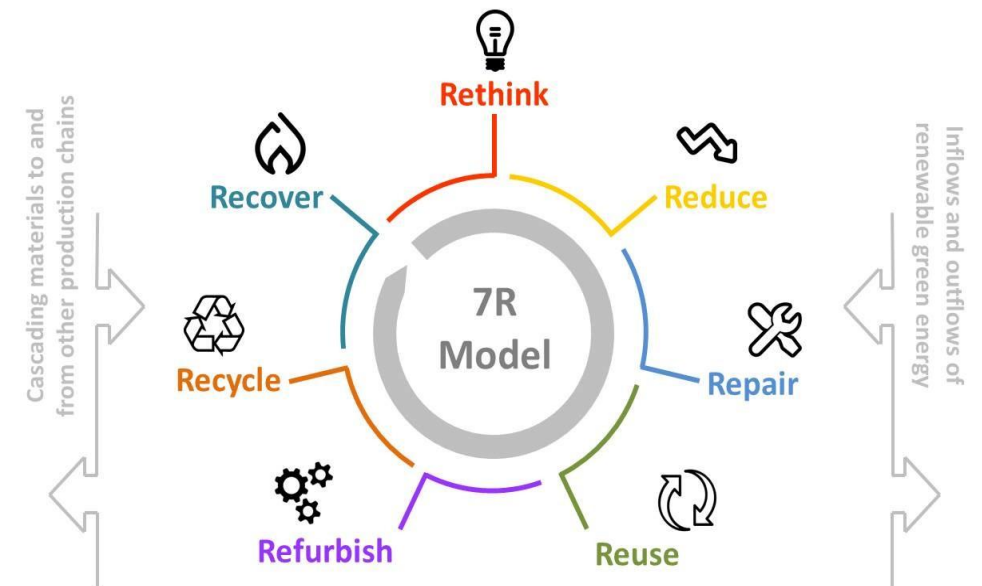
Source: descriptif-schema-economie-circulaire.pdf (ademe.fr)

The 7R model for a circular economy

The 7r model is complementary to 7 pillars of circular model. It focus on redesign to extend the life of products and give them a second life.

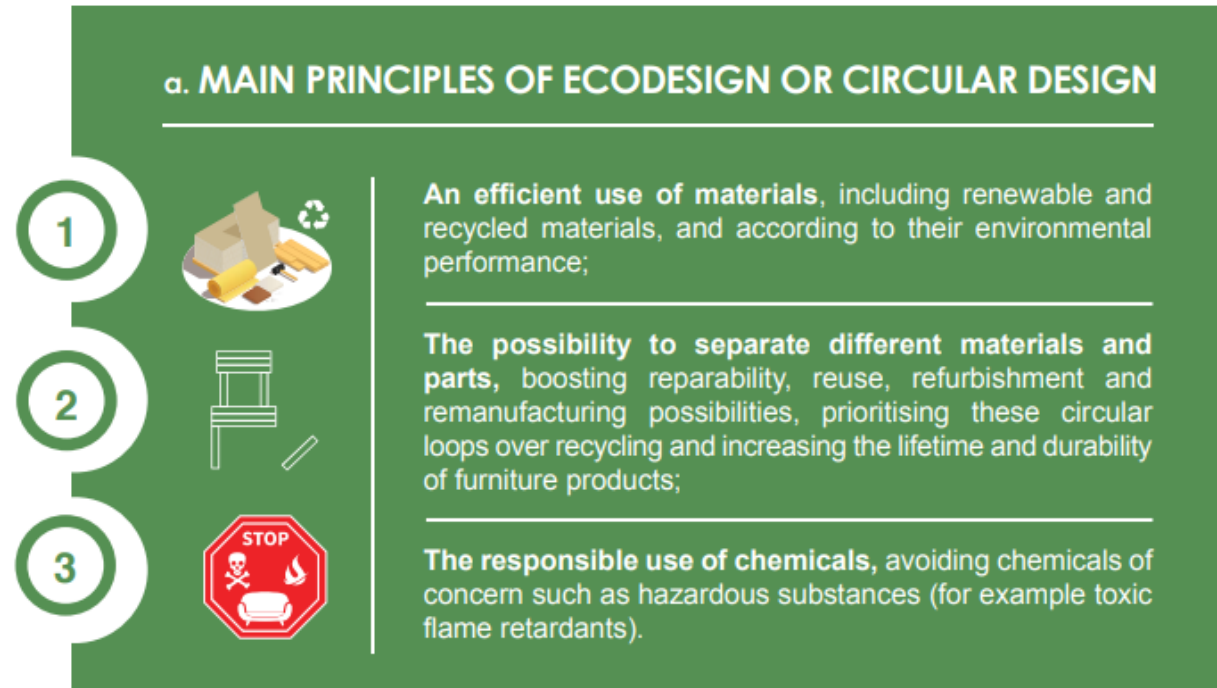
It is for this reason that the concept of the 7Rs was created :

- **Rethink** : the idea of environmental conception takes into account environmental impacts as another factor to consider when designing
- **Reduce** : reducing your consumption and optimizing resources
- **Reuse** : giving a second use to product
- **Repair** : lengthening the useful life of a product
- **Refurbish** : Reusing products for other things which may also be
- **Recover** : the circular economy favours sharing things
- **Recycling** : giving a second life to our waste



Circularity during furniture production

- 80% of the environmental impact of a product is determined by its design, the impact of products can be significantly reduced at the production stage if principles of circular design are applied.



Source : EFIC – The furniture sector and circular economy 2.0

Why reuse/remodelling / repair is not used so much?



Main barriers towards more circularity

- **Lower quality materials and poor design** : the move away from solid wood and metal furniture to cheaper plastic, chipboard and medium-density fibreboard (MDF), particularly in flat-pack furniture, restricts the potential for a successful second life since products are often insufficiently robust to be moved easily. In addition, products are often not designed for disassembly and reassembly, or reconfiguration
- **REACH Regulation (on Registration, Evaluation, Authorization and Restriction of Chemicals)** : Legacy hazardous substances bring challenges and additional costs for recyclers. Moreover, there is a lack of information on chemicals contained in products and on ways how to deal with them appropriately.
- **Weak demand for second hand furniture** : There are two things in this point. First, sometimes the price differential between new furniture against the cost of second-life furniture, is not significant enough to drive more sustainable purchasing behaviour. Secondly, it's about mentality. People want to have their own furniture. They want furniture as new.
- **Poor consumer information** : Consumers are rarely given guidance on how to maintain and repair furniture, in order to prolong and extend lifespan.
- **Availability of spares** : A lack of spare parts encourages to purchase new furniture over circular consumer patterns

Main barriers towards more circularity

- **High cost of repair and refurbishment :** In many parts of the EU, transport and labour costs are high, making any significant repair and refurbishment costly, particularly where re-upholstery is required. In general, economies of scale and economic incentives are needed to make repair and refurbishment viable
- **Limited collection and reverse logistics infrastructure :** There are weak drivers and underinvestment in the collection and logistics for furniture take-back. Producer responsibility mechanisms are not widely used in the furniture sector.
- **Weak over-arching policy drivers :** Underinvestment in reuse, repair and 11 remanufacturing infrastructure limits the potential for furniture being managed in accordance with the principles of the waste hierarchy or the circular economy.

Exemples of furniture based on Circular Economy model

<p><i>Kata chair</i></p>  <p>Arper Kata, © Salva Lopez</p>	<p><i>Why is it a success?</i></p> <p>The Kata chair is designed with circular sustainability at its core, lightweight in form and environmental footprint. The chair is manufactured using innovative 3D knit technology that reduces overall material waste.</p>	<p><i>Lessons learnt</i></p> <p>Arper realised it is possible to successfully unite traditional craftsmanship and modern processes leading to a reduced environmental footprint.</p>
<p><i>Producer</i></p>  <p>Arper is a leading Italian company that manufactures chairs, tables, and furnishings for community, work and home.</p>	<p><i>Challenges</i></p> <p>Arper saw an opportunity to reconsider 3D knit technology from a completely different aesthetic angle, interpreting it not in its traditional usage – high tech, synthetic, bold, and sporty – but in a way that combines high tech materials with an artisan feel.</p>	<p><i>More information/Contact</i></p> <p>EFIC collection of best practices</p> <p>Arper: www.arper.com EFIC: info@efic.eu</p>




Collection of Circular Economy Best Practices in the Furniture Sector by European Furniture Industries Confederation
Copyright Arper & EFIC

Exemples of furniture based on Circular Economy model


<p>Resol Toledo Aire Armchair Green Edition</p> 	<p>Why is it a success?</p> <p>The Toledo chair - like the entire Resol Green Edition range - is made of 100% recycled materials, resulting in a 100% recyclable product with an optimised weight. The company is a pioneer in the use of advanced gas injection systems in its products. This allows furniture to be created with a considerable reduction in weight and therefore with a reduction in the CO₂ footprint.</p>	<p>Lessons learnt</p> <p>In 2018 Resol began a project for the development of post-consumer recycled materials, which in 2020 led to the GRITEK® formula. This consists of a high-quality post-consumer recycled polypropylene, that allows Resol to offer customers a new range of sustainable products.</p>
<p>Producer</p>  <p>Resol is a furniture company founded in 1961 with more than 50 million chairs sold to date.</p>	<p>Challenges</p> <p>Resol is a furniture manufacturer that uses plastic as a raw material. The company's challenge with the Green Edition has been to make sustainable, beautiful, and affordable plastic furniture. The Green Edition products are recycled, recyclable, have a longer lifespan and are less intensive in raw materials.</p>	<p>More information/Contact</p> <p>Resol: www.resol.es/green-thinking Contact: info@resol.es</p> <p>EFIC collection of best practices EFIC: info@efic.eu</p>

Collection of Circular Economy Best Practices in the Furniture Sector by European Furniture Industries Confederation
Copyright Resol & EFIC

Exemples of furniture based on Circular Economy model

<p>Product: Lilla Snåland</p> 	<p>Why is it a success?</p> <p>'From Waste to Chair' - Lilla Snåland is an upcycling stool, entirely created and designed on the concept of using waste that otherwise would be incinerated for energy production. Lilla Snåland is made using 14 pieces of waste left over from cutting the ends off the Lilla Åland (picture below) seat before it is turned.</p>	<p>Main results</p> <p>High class products have been developed and put on the market based on the circular concepts of upcycling and upgrading.</p>
<p>Producer </p> <p>Stolab, a Swedish furniture producer, created a new concept, New Life™, to promote ideas, projects and products that create opportunities for 'new life' by merging sustainability with growth.</p>	 <p>Lilla Åland chair</p>	<p>More information/Contact</p> <p>Stolab New Life EFIC collection of best practices</p> <p>Stolab: https://www.stolab.se/en/ EFIC: info@efic.eu</p>

Collection of Circular Economy Best Practices in the Furniture Sector by European Furniture Industries Confederation
Copyright Stolab & EFIC



Revor Circular mattress



Producer



Revor Bedding is a Belgian company producing mattresses and boxsprings. The company holds high circularity ambitions.

Why is it a success?

Revor Circular is a mattress made of two main materials: Polyester and Metal. Both materials can be separated at end-of-life and recycled into new raw materials, out of which new mattresses can be made. Revor Circular offers the same comfort level as traditional foam mattresses.

Challenges

Revor Circular finds good ways to mix different materials. The ability to separate them at the end of life proved to be challenging.

Lessons learnt

Not all players are ready for the circular concept. Encouraging the market and suppliers to give the concept more space is key.

More information/Contact

[EFIC collection of best practices](#)

REVOR: www.revor.be

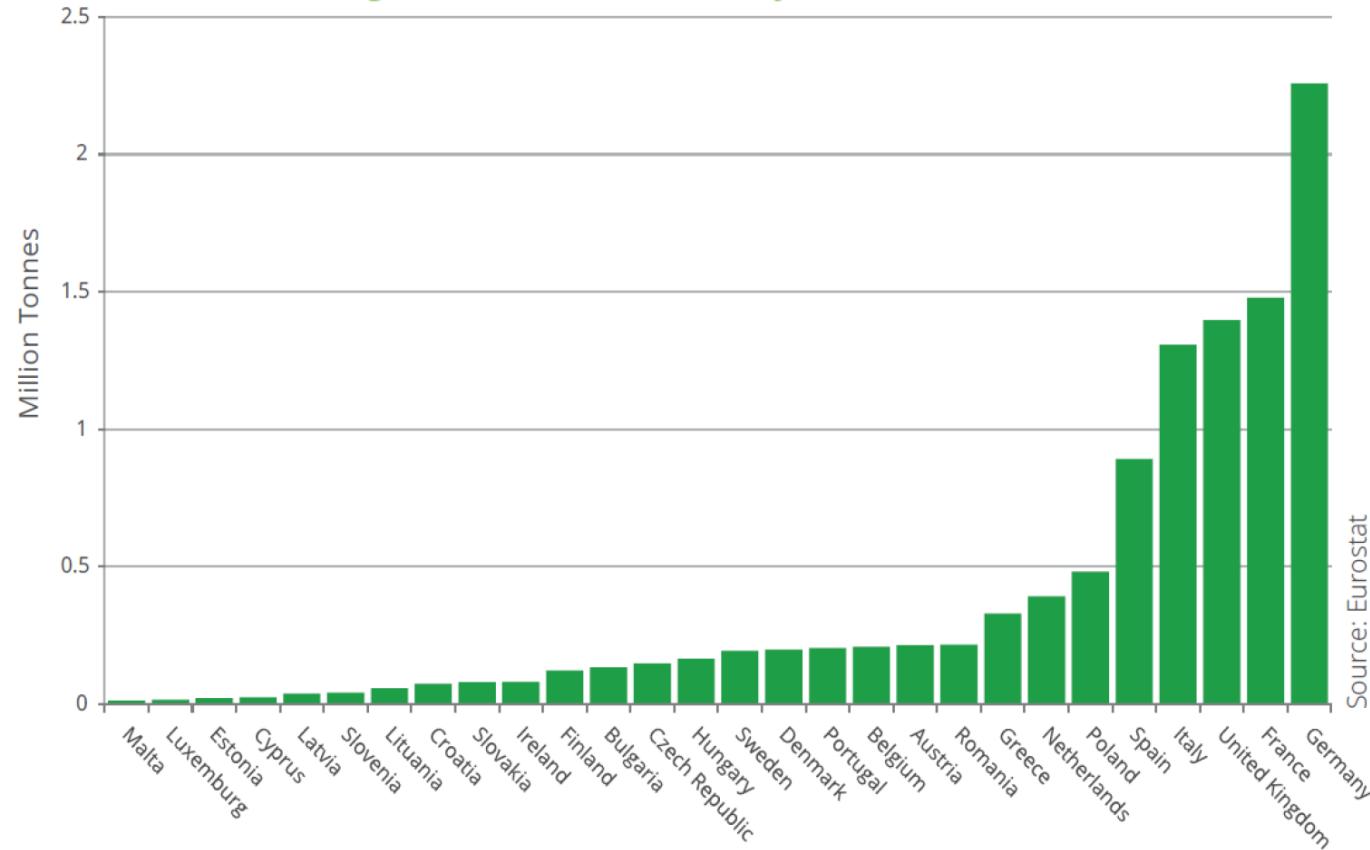
EFIC: info@efic.eu

- Circular economy in mind during the design phase, but what to do with used furniture after their end of use???



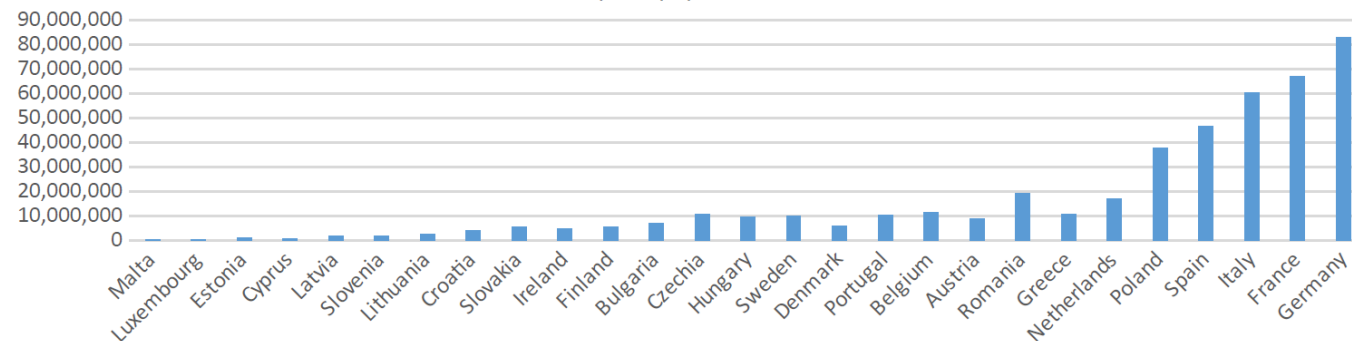
Source : [EEB 2017 – Circular economy opportunities in the furniture sector](#)

Figure 3: Furniture Waste by EU Member State



Source: Eurostat

European population 2019



Source : Eurostat

Unit 2 – Waste : new opportunities to create

Furniture waste in Europe

It is estimated that around **10.5 million tonnes** of furniture waste is produced annually (EU28).

Case Study – Companies initiatives

Voucher Scheme for Unwanted Furniture, IKEA France



IKEA introduced a “Second Life for Furniture” programme for its customers. Initially introduced in France and Belgium, the scheme allows customers to return unwanted IKEA furniture into a store in exchange for a voucher, which can be redeemed against a purchase of new furniture products in-store.

In Sweden, IKEA are piloting this business model further, by offering allowing customers to also return non-IKEA plastic furniture in exchange for a voucher.

How the service works

It's easy. Fill in the form and upload photos of the IKEA furniture. We'll evaluate the furniture and offer you a price for it. If you agree, you can bring the furniture to your favourite IKEA store, where you'll get the promised value in the form of a charged digital refund or refund card. We will then offer the purchased IKEA furniture for the same price and with a 1-year guarantee in our Bargain corner.

We provide this service for free, and it is not subject to any fees, with the exception of delivery, should you wish to order this.


I want to buy second hand furniture

I want to offer the furniture

X IKEA Brno

150 items


-42%




VÄRMD RU 904.307.03
mikrovlnná trouba, , IKEA 300 černá Doprodej z důvodu uzavření OD v Rusku

3 490,-

1 990,-

 Dostupné v IKEA Brno


-40%




SLÄKT
rám postele, 90x200 cm, bílá Odřená hrana na zadní straně čela (NEPOHLEDOVÁ STRANA)

1 990,-

1 190,-

 Dostupné v IKEA Brno


-45%



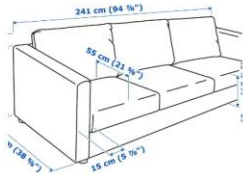
LÖNSET
lamelový rošt, 70x200 cm Drobně odřená hrana jedné z lamel

1 200,-

649,-

 Dostupné v IKEA Brno


-60%



VIMLE
rám 3místný díl, POTAH SE PRODÁVÁ ZVLÁŠTĚ Poškozený obal

10 000,-

3 990,-

 Dostupné v IKEA Brno

<https://www.ikea.com/cz/en/customer-service/services/second-life-of-furniture-pub4bb667a0/>

Joint Research Centre, Eu commision, JRC

Study: Repairability

- The Joint Research Centre of the European Commission (JRC) published a report in March 2019 on the analysis and development of a rating system for the repair and upgrade of products. Although all case studies address EEE (electrical and electronic equipment), the proposed guidelines provide an interesting framework for thinking about school furniture.
- For simplicity, we will call this the repairability index.
- The Joint Research Centre considers that the repairability index is based on three pillars:
 - The so-called priority components
 - Key parameters for repair
 - The index framework



Possibility of repair

- Example of a national display of the repairability index (in France): mandatory information on 5 product categories and the development of a label for repairer competence

INDICE DE

RÉPARABILITÉ



REPAIRABILITY SCORE



Studio 5.5



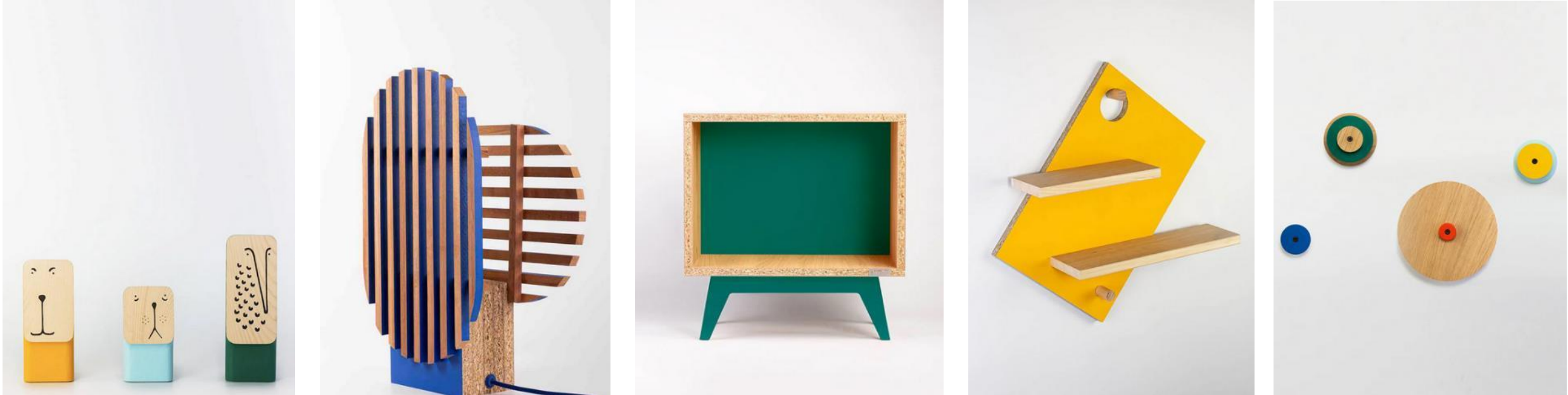
- **Réanimate** it is a Studio 5.5 project, whose aim is to repair furniture and restore its original function.

Maximum

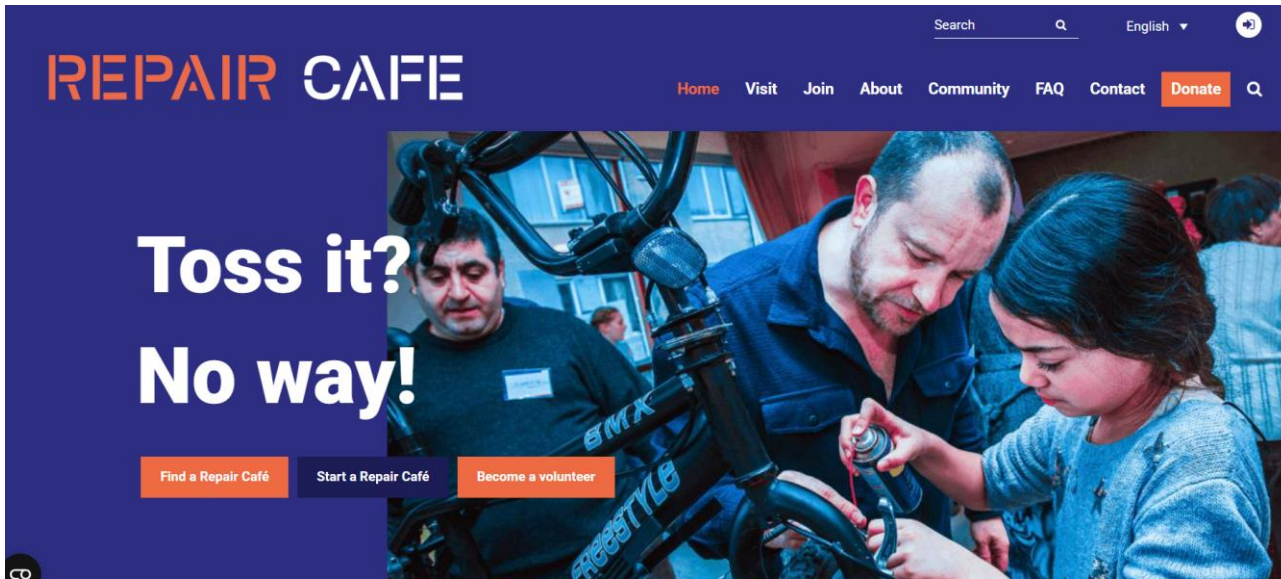


- The company Maximum produces furniture from industrial production surplus. Their goal is to offer high-quality furniture, made in France and entirely 'recycled', all at an affordable price.

Atelier Emmaüs



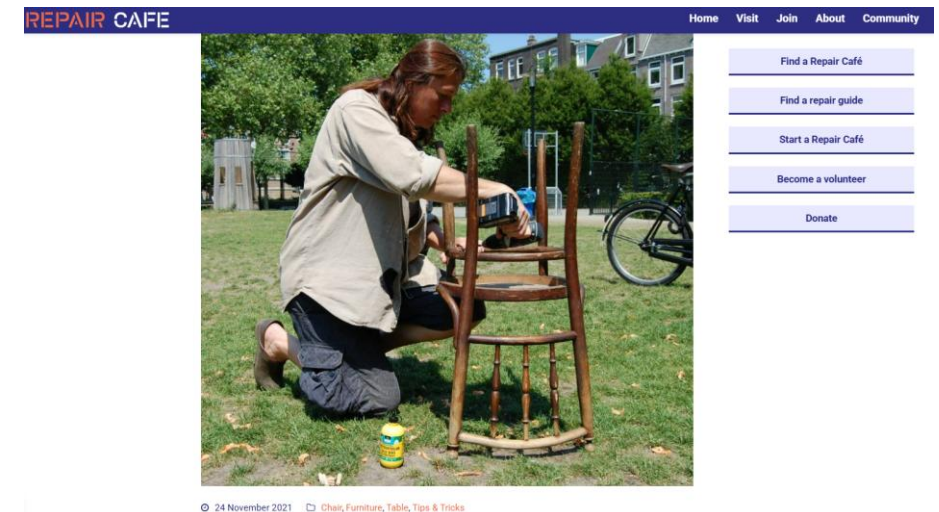
- Atelier Emmaüs is a carpentry school/workshop that combines social inclusion with environmental responsibility. Its vision is of a resilient and sustainable society in which beauty is placed at the service of people."ija: prožna in trajnostna družba, v kateri je lepota v službi ljudi."

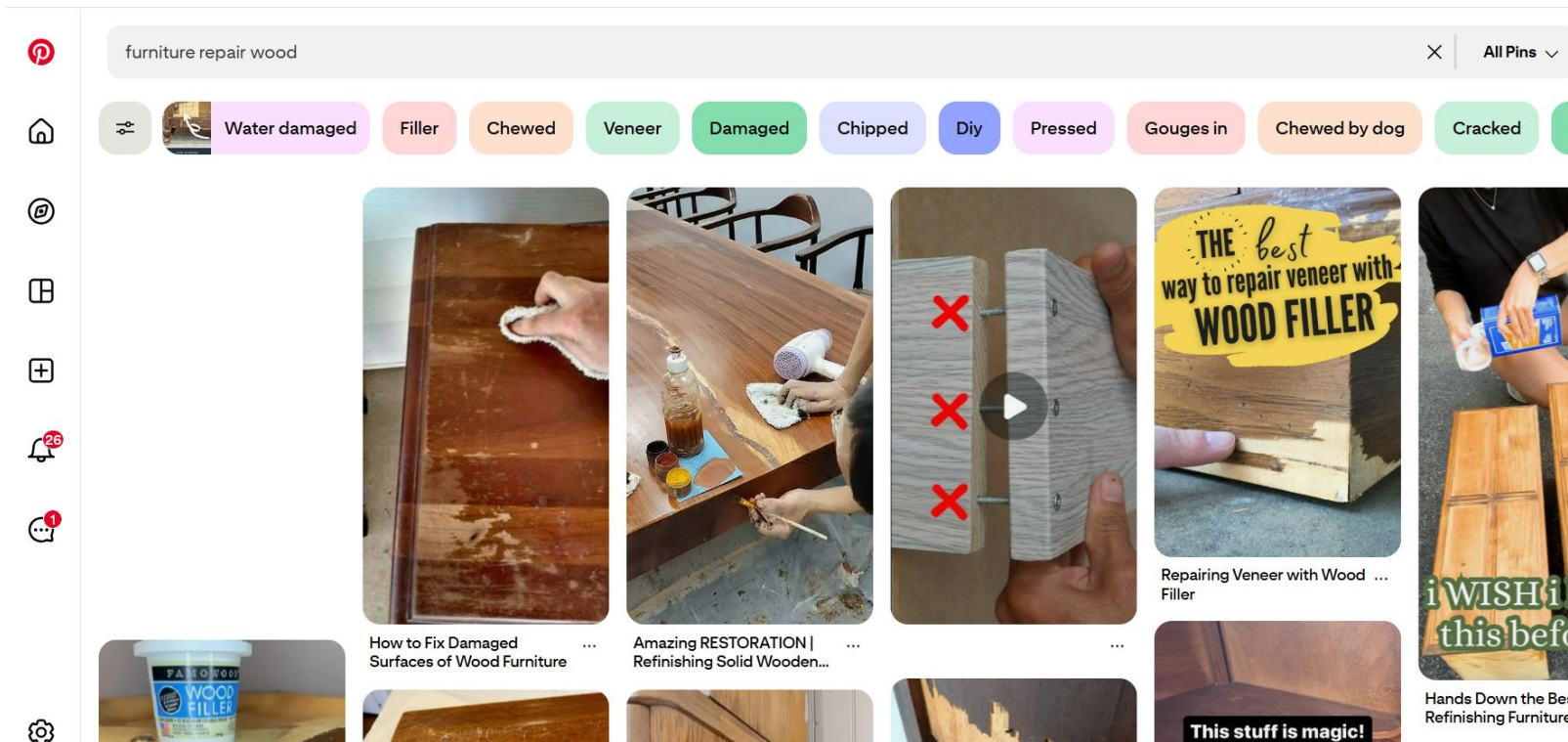


Repair Cafés are free meeting places and they're all about repairing things (together). In the place where a Repair Café is located, you'll find tools and materials to help you make any repairs you need. On clothes, furniture, electrical appliances, bicycles, crockery, appliances, toys, et cetera. You'll also find expert volunteers, with repair skills in all kinds of fields.

https://youtu.be/vMOnCmeHhzwk?si=Udoc2yDK_xN0gr0C

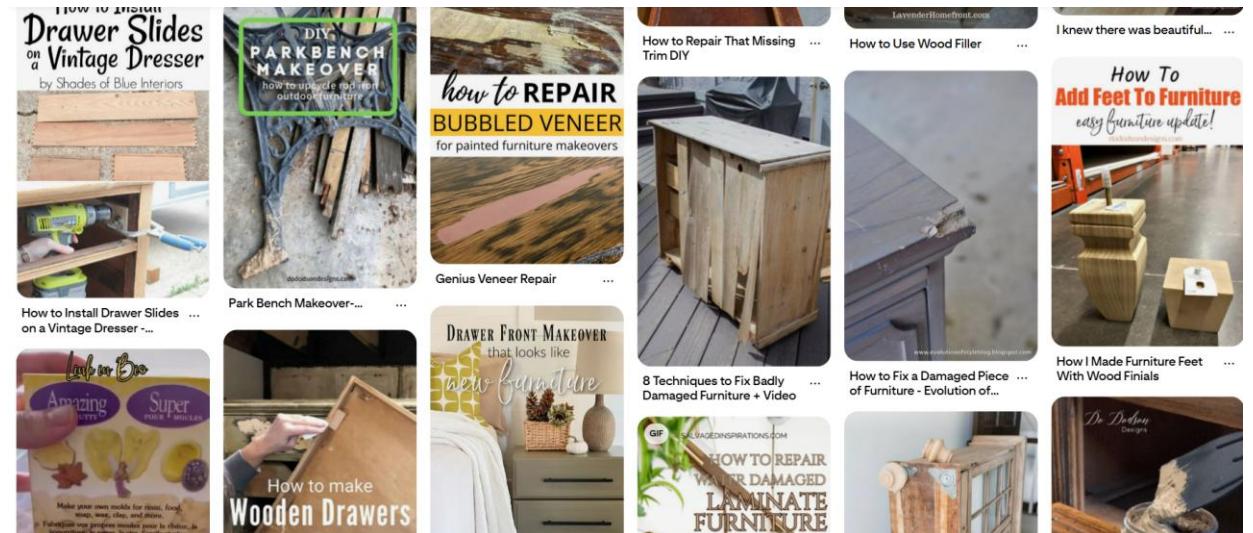
<https://www.repaircafe.org/en/repairing-furniture/>

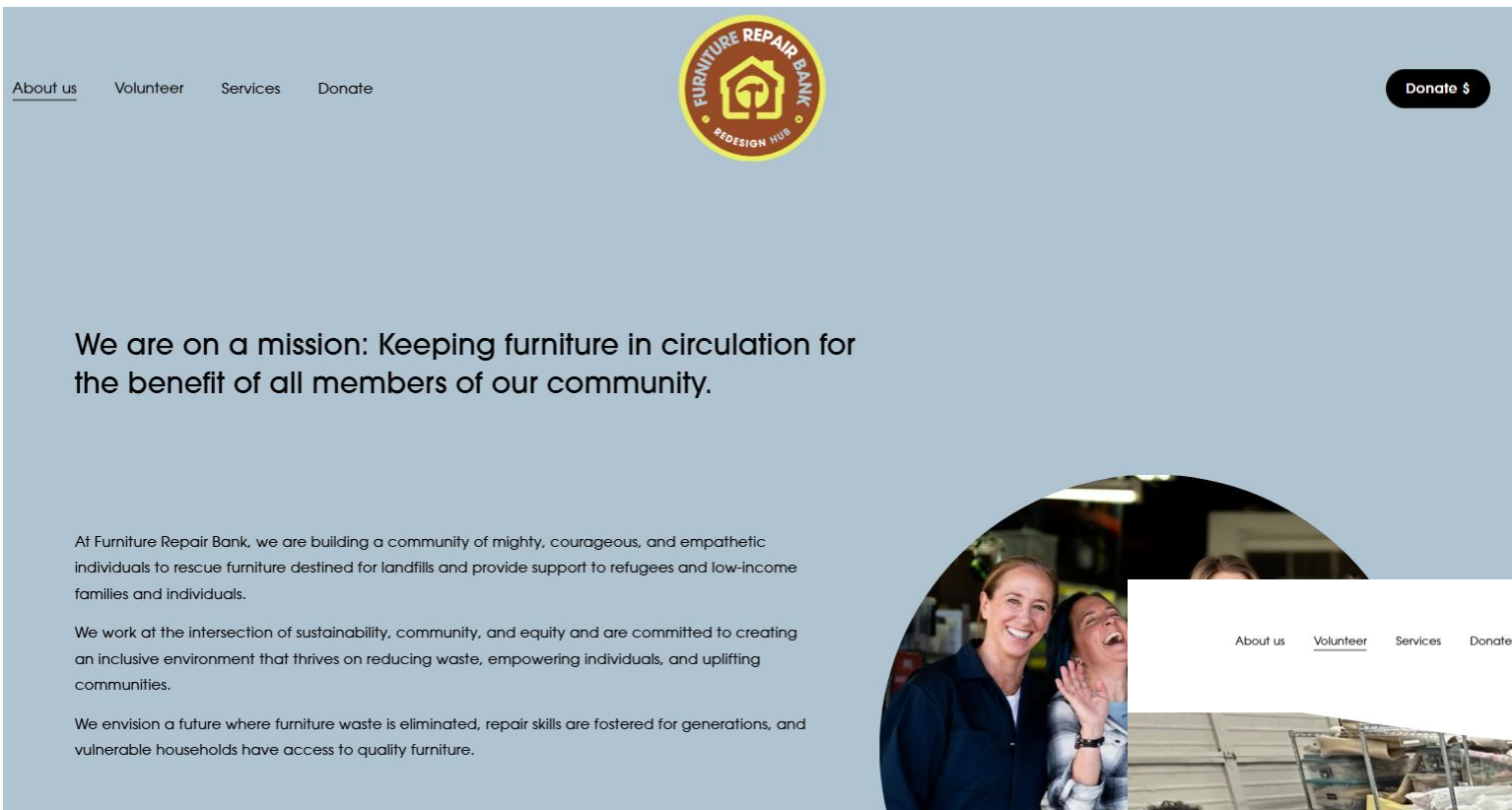




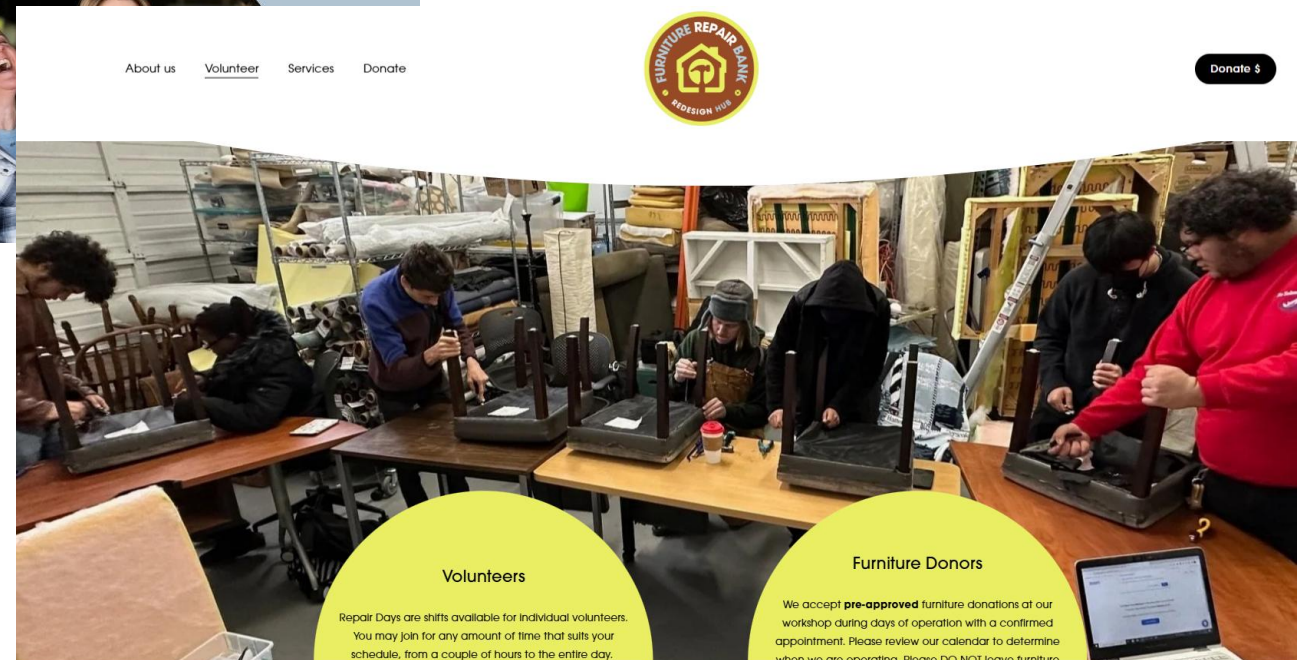
People want to repair their furniture

-lack of knowledge/materials/equipment





<https://www.repairbank.org/about-us>



Pei, X., Italia, M., & Melazzini, M. (2024). Enhancing Circular Economy Practices in the Furniture Industry through Circular Design Strategies. *Sustainability*, 16(15), 6544.
<https://doi.org/10.3390/su16156544>

Abstract: The furniture industry represents a substantial segment of Europe's economy, with the European Union producing approximately 25% of the world's furniture. This sector is currently transitioning towards a circular economy. This study aims to thoroughly examine the **circular initiatives undertaken by European furniture companies**, emphasising the role of design in fostering innovative solutions. By employing a multiple case study methodology, the research demonstrates that existing circular solutions predominantly **focus on materials and products, with significant adoption of circular design strategies**. The majority of furniture companies are implementing these strategies to enhance **resource efficiency and prolong product lifespans**. Additionally, some companies are developing complementary service systems to improve product performance and **longevity** further. However, only a few have successfully implemented circular business models alongside circular product design strategies. This study also highlights that **increasing user engagement** and adopting a systemic perspective that includes various stakeholders in creating mutually beneficial solutions are areas that are **still underdeveloped**. Finally, we propose a framework to effectively guide furniture companies in implementing design strategies from a systemic perspective, aiming to generate comprehensive circular solutions within the European furniture sector.

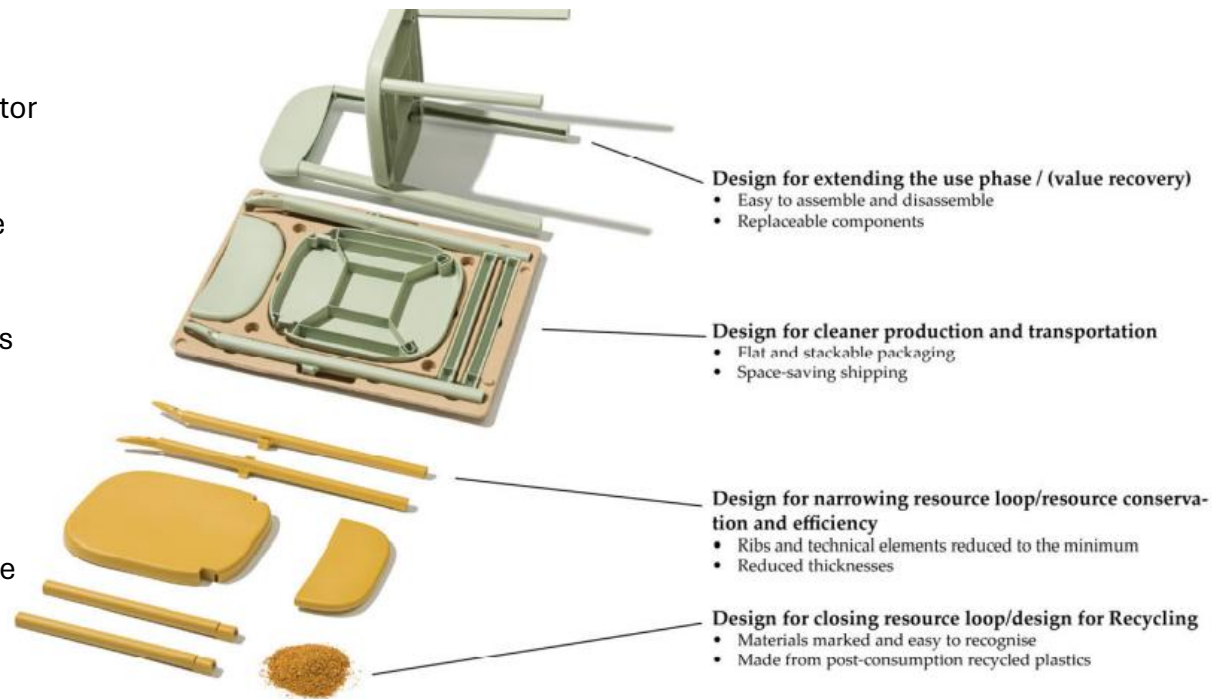


Figure 3. OTO chair main circular design strategies, elaborated by the authors based on the original images of ONE TO ONE.

Design from reused material

- Different waste plastics (and wood particles)
- From wooden elements/panels...
- How to save and manage used materials stock?



<https://creativecolour.org/2020/05/01/sustainable-furniture-from-recycled-rubbish>

Key Elements for Managing Used Material Stocks & Using in New Design

- **Inventory / Audit:** Photographing, cataloguing, assessing condition, assigning unique IDs (QR codes etc.). Essential to know what stock you have.
- **Digital Tools / Platform:** To store the inventory, to allow designers / procurement people to search what is available, perhaps even virtually try fit for reuse.
- **Logistics & Storage:** Need physical space to store items/materials, protect from damage, control moisture etc. Timing is important (e.g. collecting before demolition), planning where to store.
- **Classification & Sorting:** Separating by material type, quality, usability. Some items may need refurbishment; some can be used directly.
- **Procurement / Policy Frameworks:** Public tenders or internal policies that allow and favour reuse/refurbishing; inclusion of refurbished or used elements in new builds; ensuring warranties, safety.
- **Collaboration / Networks:** Between designers, manufacturers, demolition / deconstruction teams, waste management, social enterprises. Also between municipalities or regions, so material stock doesn't go unused elsewhere.
- **Design Adaptation:** Designers must be flexible to adapt designs based on what used materials are available – sizes, shapes, qualities. Tools or methods to design “around” the stock.
- **Sustainability & Traceability:** Document environmental savings (waste, emissions), cost savings to motivate stakeholders.

Help of AI, XR?

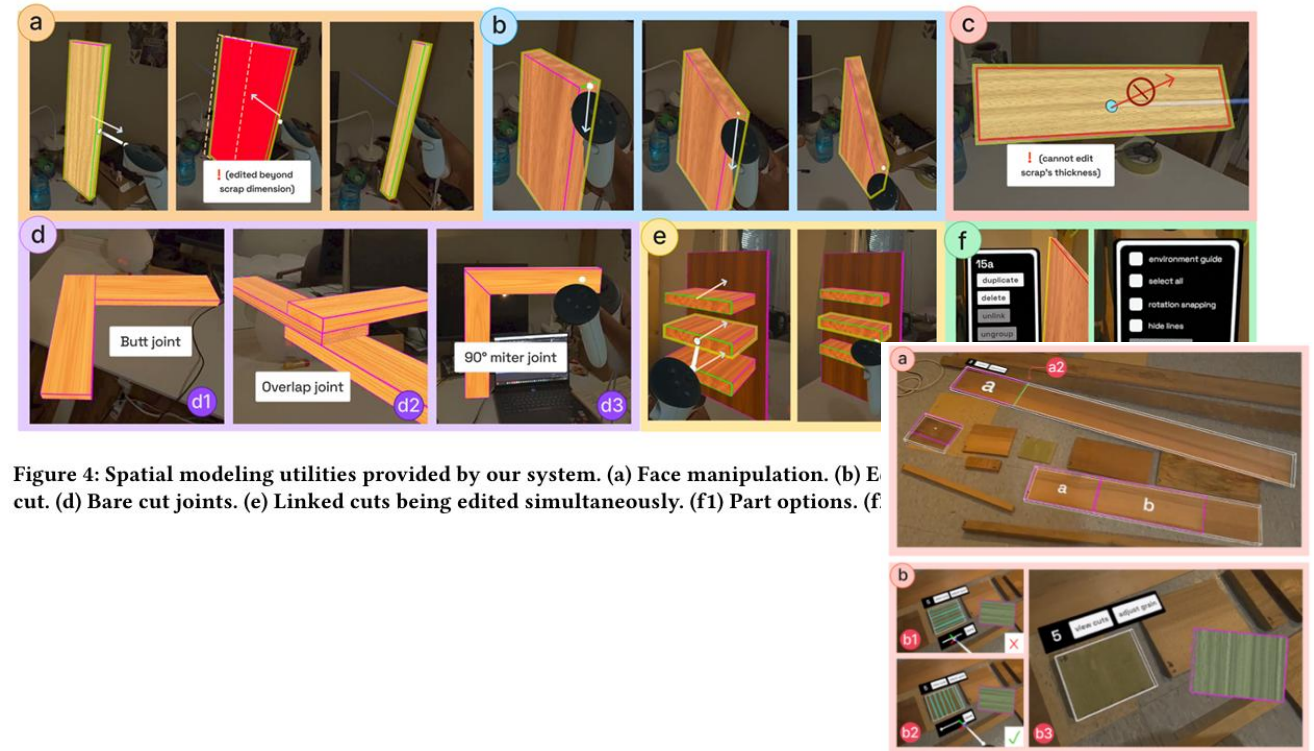
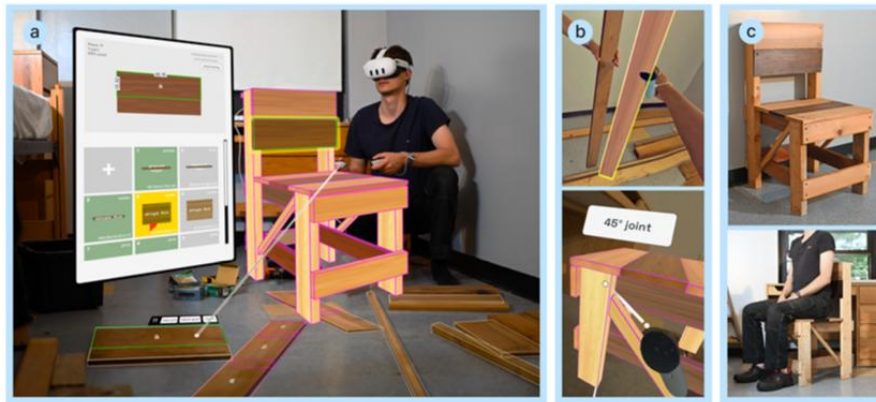
XR-penter: Material-Aware and In Situ Design of Scrap Wood Assemblies

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SENAB project

- Furnishing inventory
- Interior design concept & floor plan
- Refurbishing & customizing existing furnishings
- Buying, selling & donating
- Recycling & disposal
- Logistics & coordination

Mikado
Mide Clear Kuler

Baklag: metakern, midt hval og skuffe
Baklag: metakern, midt hval og skuffe

595
535

303
303

050261
050262

SDK

1 740
1 380

Mide Star
Mide Star Kuler

Baklag: metakern, midt hval og skuffe
Baklag: metakern, midt hval og skuffe

595
535

739
739

050400
050401

4 095

1 545

Sandalen
Sandalen Kuler

Baklag: metakern, langt smedning, hvidebørn
Baklag: metakern, langt smedning, hvidebørn
2 af hval klar brunn, 2 af hval med brunn 75 mm

655
655

405
405

050444
050445

6 535

7 445

Sandalen Star
Sandalen Star Kuler

Baklag: metakern, langt smedning, hvidebørn
Baklag: metakern, langt smedning, hvidebørn
2 af hval klar brunn, 2 af hval med brunn 75 mm

655
655

475
475

050445
050446

7 755

8 675

Rugbrædder
Rugbrædder udvaskelige

Baklag: indlagt HPS
2 af hval klar brunn, 2 af hval med brunn 75 mm

648
735

525
525

050677
050678

5 865

6 585

Mide HPS
Mide HPS

Mide HPS: 4 udvaskelige, hvidebørn
Mide HPS: 4 af udvaskelige, midt brunn 50 mm øst

885
885

435
435

050834
050835

7 785

7 785

TRAG



<https://www.senab.com/en/reuse?>

From waste to workspace: Supplying reused and refurbished furniture to Niort City Hall

- Renovations/using used furniture/used materials
- Anti-waste and Circular Economy Law –France
- Municipality of Niort



Niort City Hall



Niort City Hall

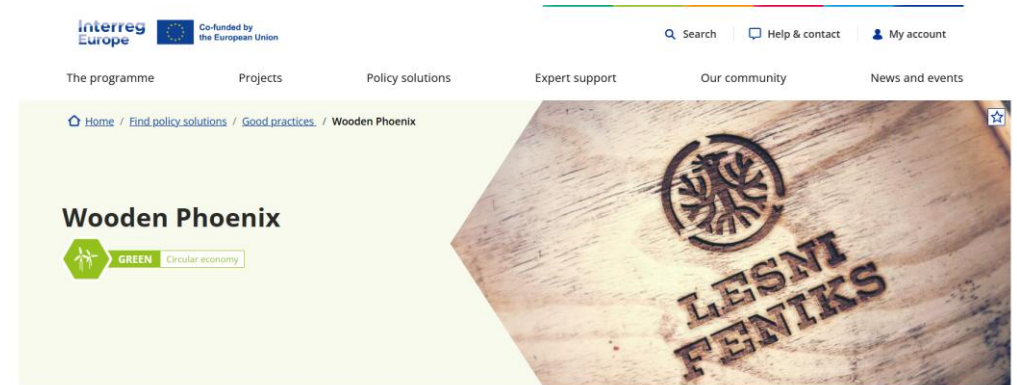


<https://www.lesnifeniks.si/>

- The project complements local infrastructure, such as the nature swimming pool in Žiri, with urban wooden elements like benches, deckchairs, and wardrobes made entirely from reused wood.
- This initiative highlights how local and regional authorities, in collaboration with private and educational actors, can boost sustainable development, resource efficiency, and community participation.

<https://www.lesnifeniks.si/>

<https://www.interregeurope.eu/good-practices/wooden-phoenix>



Material Reuse & Circular Economy

- Extends product lifespan and reduces waste streams.
- Promotes sustainable resource management through upcycling.

In construction and architecture, modern trends are moving toward the reuse of old wood in both interior and exterior spaces. Wood can be reused for many purposes. In interiors, it can serve as furniture, wall cladding, or ceiling covering. The advantages of old wood include better dimensional stability, aesthetic appearance, and historical value.

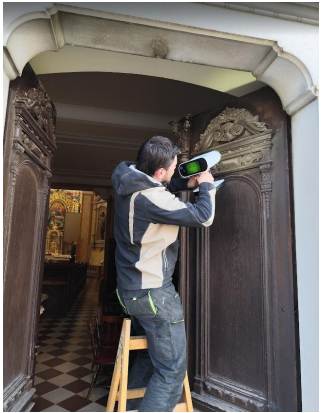


Examples of old wood cladding, Žužek Interieri d.o.o

3d scanning as a tool for repair?

- Handcraft/manual repair or modern technologies for repair?
- **Hybrid Repair Methods**
 - Combination of traditional woodworking and advanced digital fabrication.
 - Ensures functional, aesthetic, and structural integrity.
- **Customization & Adaptability**
 - Replacement parts tailored to unique or antique designs.
 - Enhances design flexibility and user-centered innovation.

- 3d scanning as a tool for repair?



3d
scanning



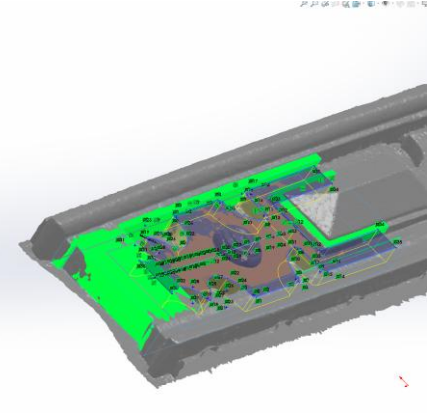
Point
cloud



Surface model, export to
different formats, cad
formats

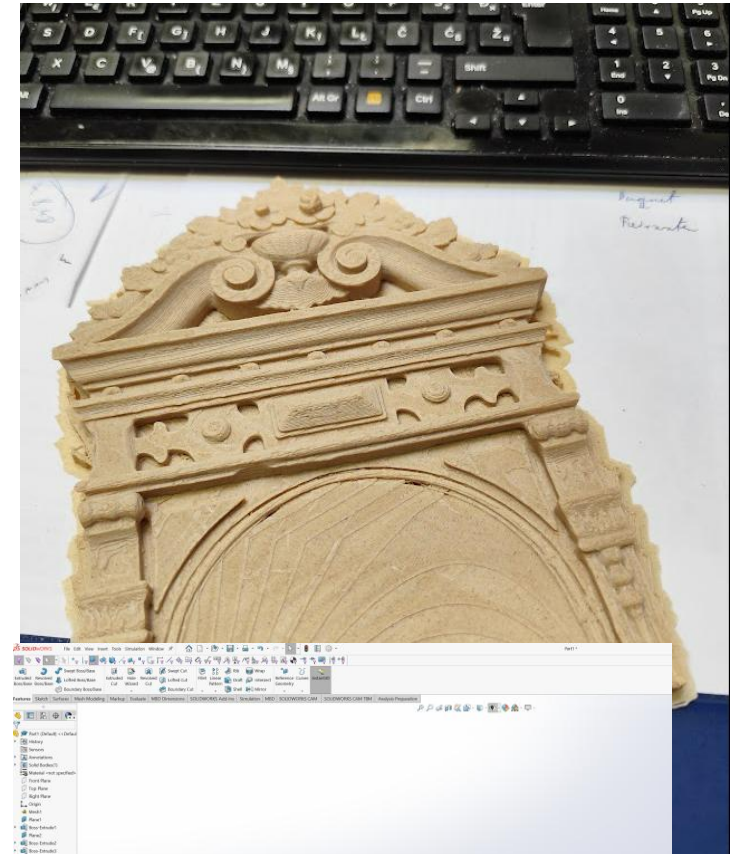
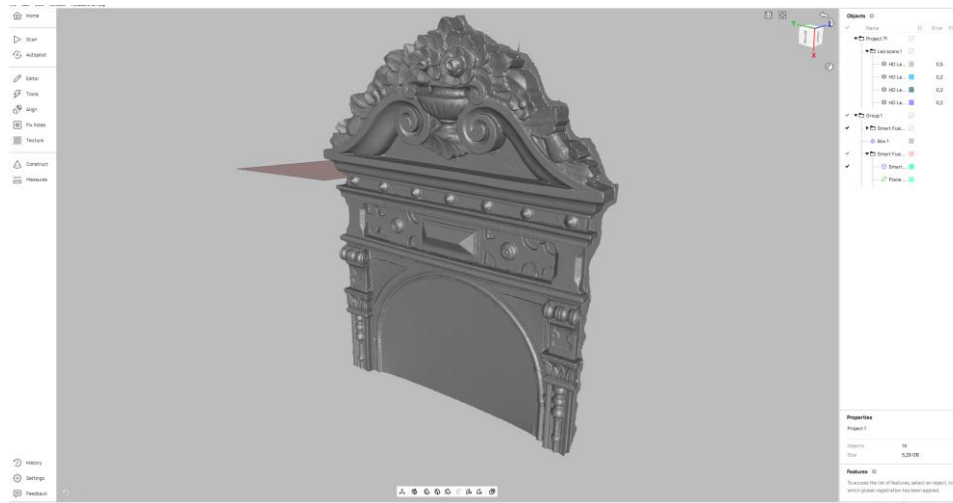


CAD modeling,
solid model



CNC machining, 3D
print

3d scanning-for copies or repairs

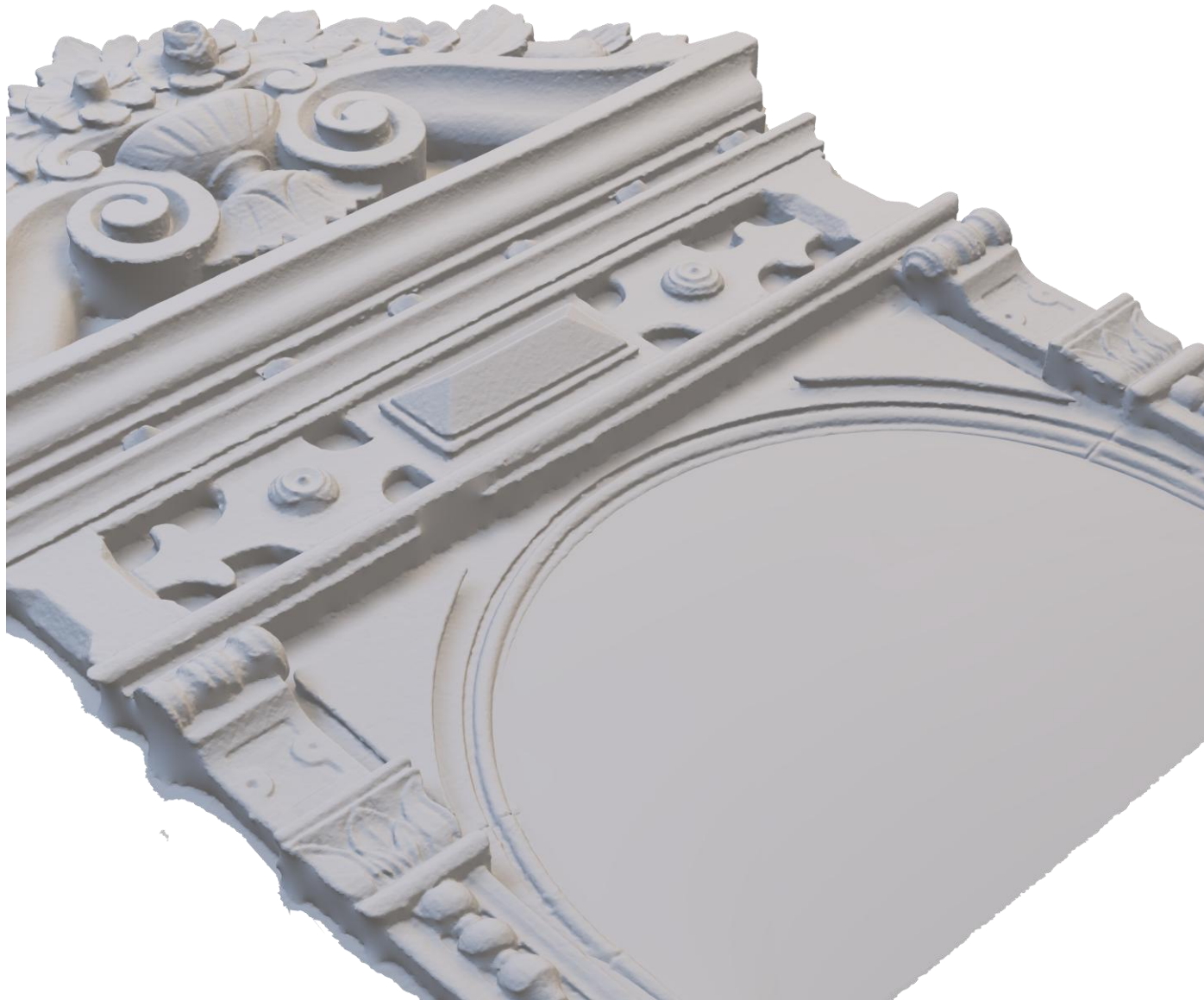






Replica- no need
to edit details,
repair details...
Replicate all the
details, with
damages,
handmade details
etc

3d print



Examples of Repair with New Techniques (Scanning, 3D Printing)

•Chair Joint Replacement

- A broken wooden chair leg joint is scanned with a handheld 3D scanner.
- A **precisely fitting replacement joint** is 3D printed in recycled bioplastic or wood-PLA composite.

•Antique Furniture Ornaments

- Missing decorative elements (carvings, handles, knobs) are digitally scanned from the intact side.
- 3D printed replicas restore **symmetry and historical accuracy**.

•Tabletop Repair

- Damaged corners of a table are reconstructed using **3D scanning of intact edges**.
- Replacement corner pieces are 3D printed and seamlessly integrated.

•Drawer Handles & Knobs

- Original handles are scanned, and exact **replicas are 3D printed** in durable materials.
- Customization possible for ergonomic upgrades.

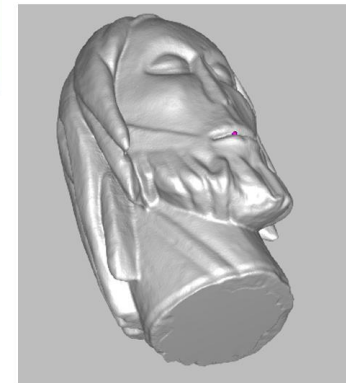
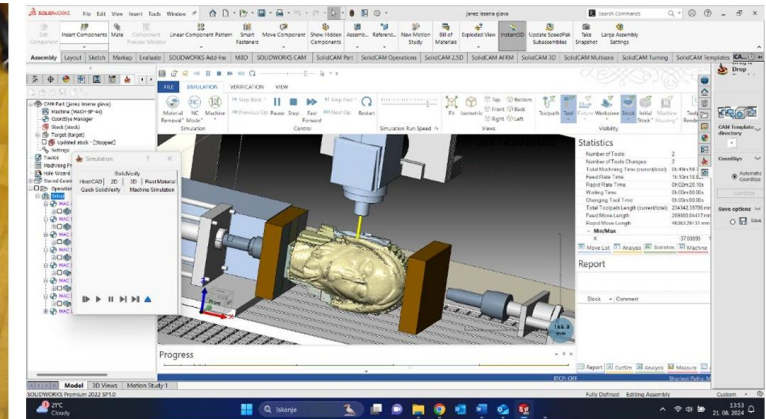
•Upholstered Furniture Frames

- Hidden support parts (e.g., connectors, brackets) scanned before breaking fully.
- 3D printed parts restore **structural integrity** without replacing the entire frame.

•Hybrid Wooden-Plastic Repairs

- Broken wooden chair rungs or crossbars replaced with **biomimetic 3D-printed lattice inserts**, reducing material while improving strength.

3d scanning-for copies/replicas/digital models

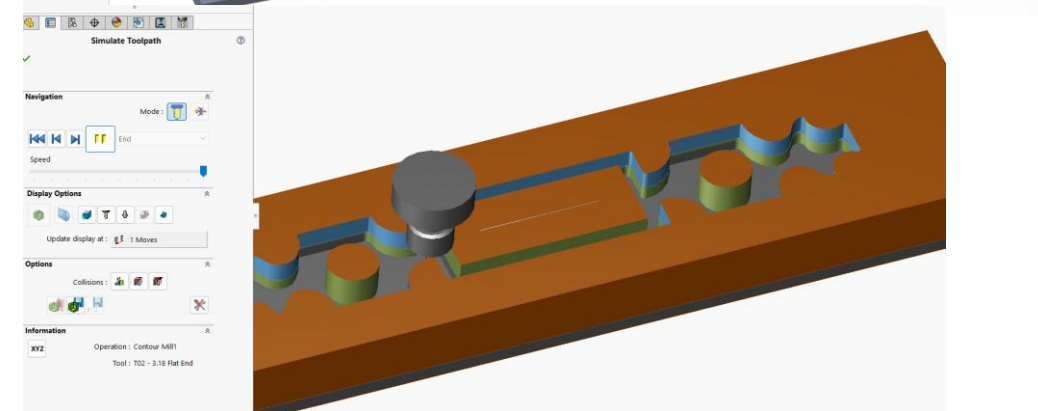
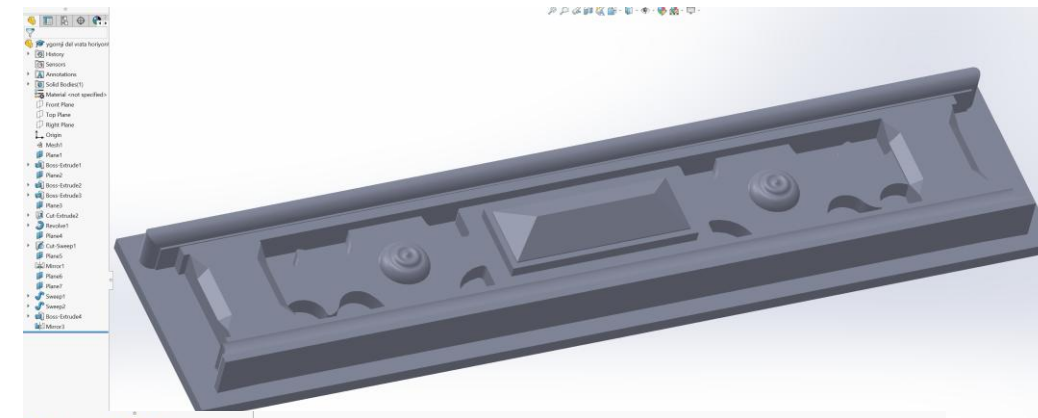
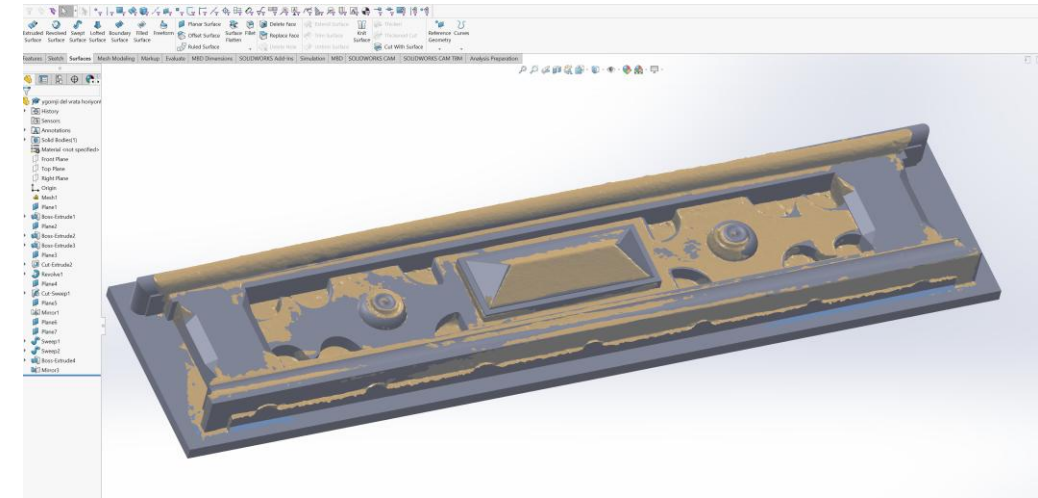
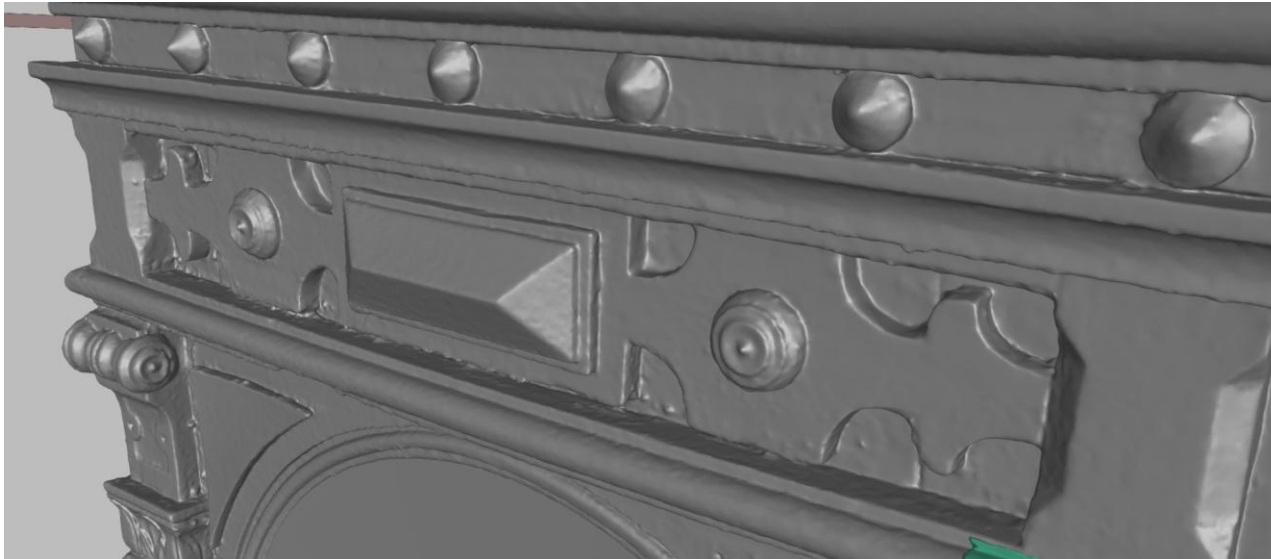


Izdelava prostorskega modela in lesene kopije kipa glave Janeza Krstnika iz Bohinja
[Cerar, Anže](#) (Avtor), [Merela, Maks](#) (Mentor), [Merhar, Miran](#) (Komentor)
<https://repozitorij.uni-lj.si/Dokument.php?id=191245&lang=slv>

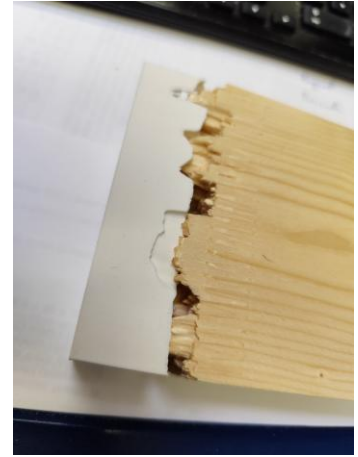
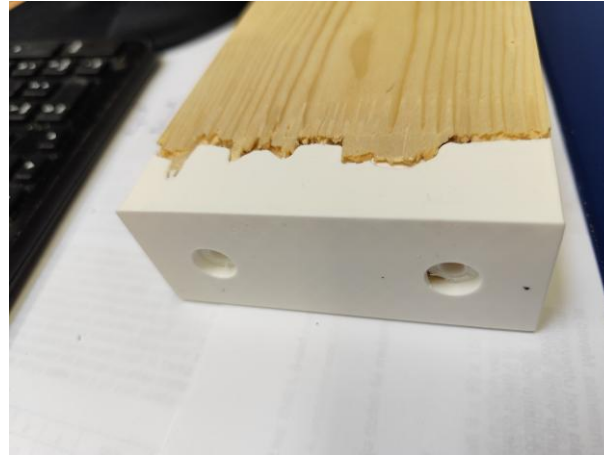
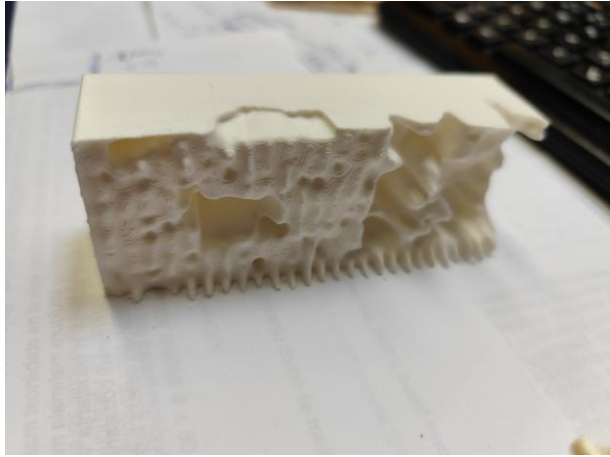


Challenges

- Exact copy/replica or repaired/3d model
- Machining?

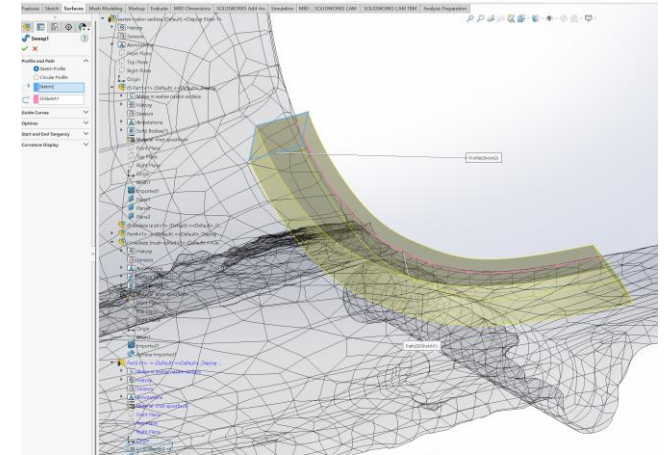
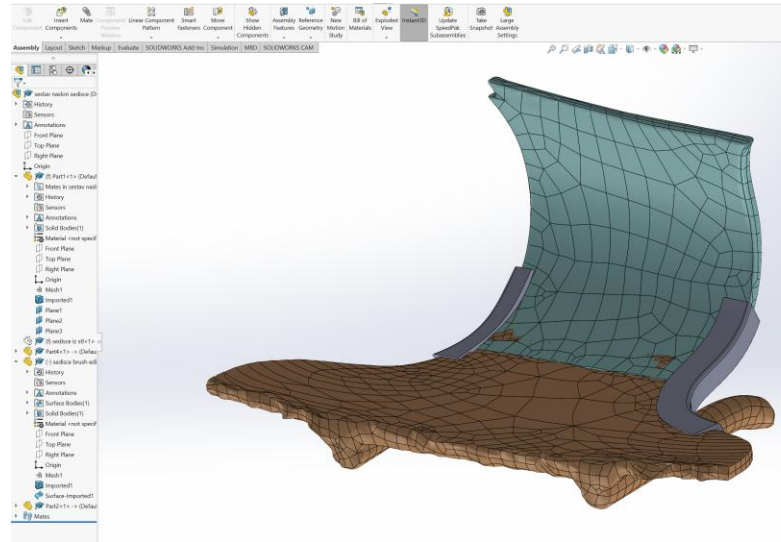


3d scanning for repair

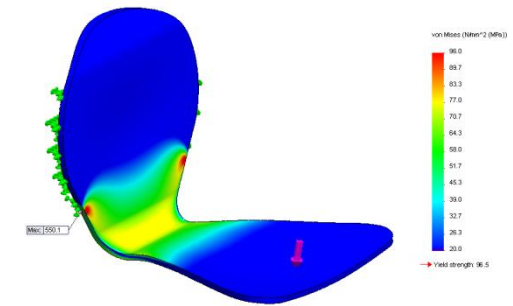
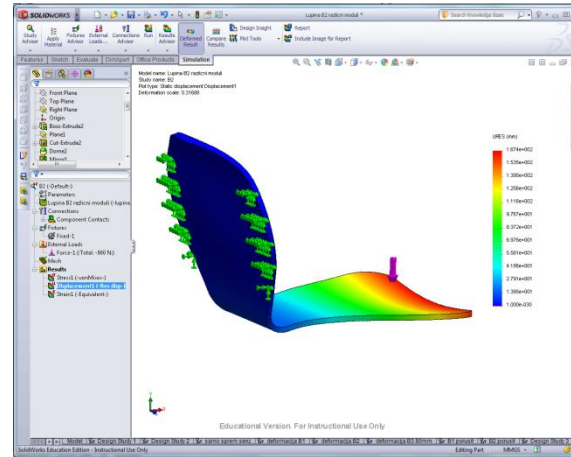


Challenges 3d scanning- modelling-repair

- Not just negative shape
- Negative angles
- Assembly? Direction of assembly
- Adding connectors, reinforcement



- Strength of such parts?
- Material selection (PLA, PETG, ABS, PA, carbon fibres filaments...)
- Still recyclable? How to connect new materials to broken parts? Reversible connections?
- Visual repair, functional repair...



- Simulations
- Topology optimization

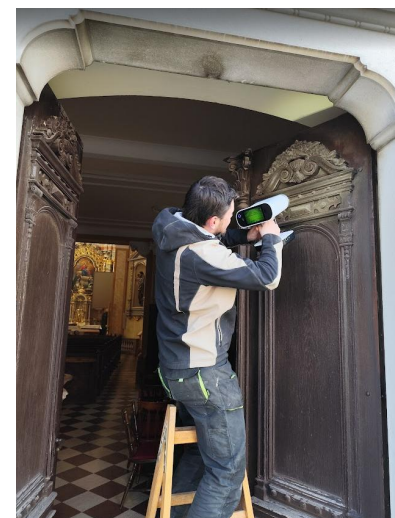
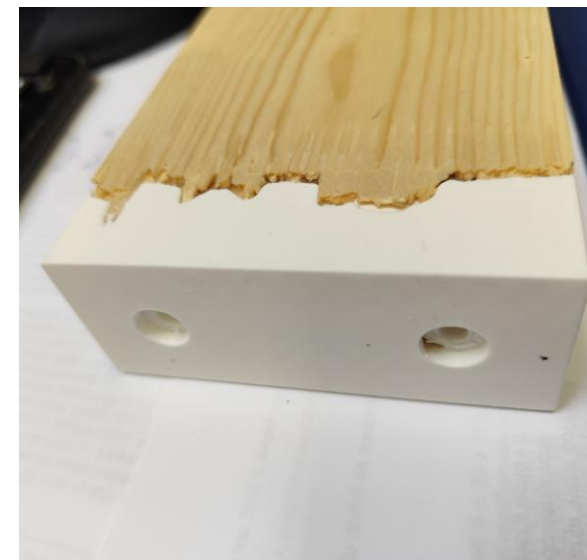
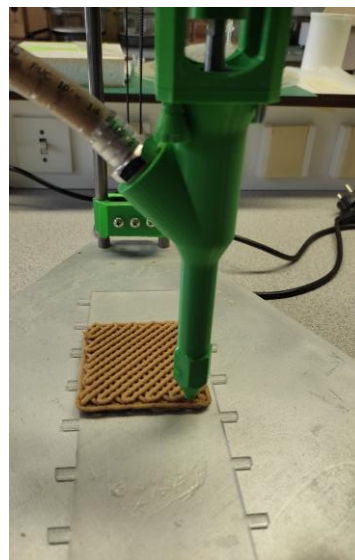
- Repairing furniture?
- Is it worth? Price/costs? Environmental awareness
- Is it strong enough? Still fulfill standard requirements?

Department of wood science and
technology

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manja.kitekkuzman@bf.uni-lj.si



MATERIALS IN FURNITURE PRODUCTION – SUSTAINABLE MATERIALS UTILIZATION: WOOD AND OTHER BIOBASED MATERIALS, RECYCLED MATERIALS AND SUSTAINABLY SOURCED WOOD

prof. dr. Sergej Medved

*University of Ljubljana, Biotechnical Faculty,
Department of Wood Science and Technology*

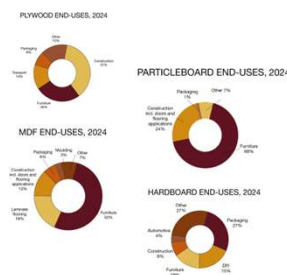
1

Introduction

UL | BF

→ Usual materials for furniture production

- Solid wood
- Plywood
- Particleboard
- MDF
- Hardboard
- Wood-plastic composites (WPC)
- Sandwich composites



Source: EPF, 2025

23.09.2025

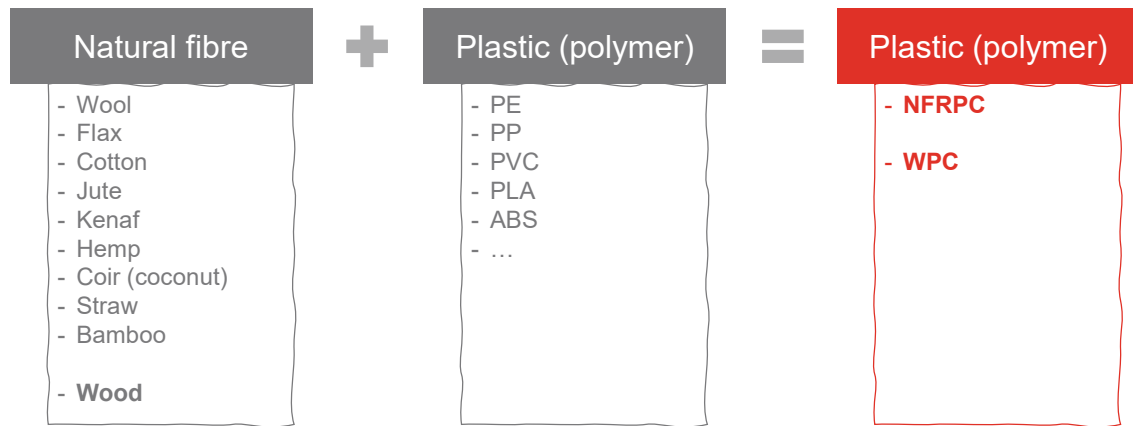
SUSFUR 2025

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2

Wood-Plastic Composites

UL | BF



23.09.2025

SUSFUR 2025

3

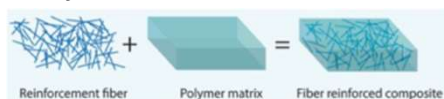
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Wood-Plastic Composites

UL | BF

→ Composites

- Matrix: continuous phase
 - Plastic/polymere: PVC, PP, LDPE, HDPE, PLA
- Fibrous element discontinuous phase
 - Fibre/particle shape
- Ideally: matrix should surround each fibre or particle



Source(s): Maiti et al., 2022

23.09.2025

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4

4

Wood-Plastic Composites

UL | BF

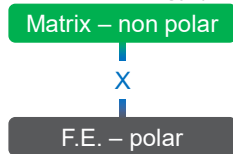
→ Limitations & Conditions

→ Wood and natural fibres: organic origin, hygroscopic, presence of OH groups; **polar**

→ Plastic: **non-polar**

→ Bonding

→ Surface energy (tension) of substrate > surface tension of matrix



...component X is

- Maleic Anhydride
- Silane
- Ethylene-Acrylate
- Isocyanates

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5

5

Wood-Plastic Composites

UL | BF

→ Process

→ Compounding

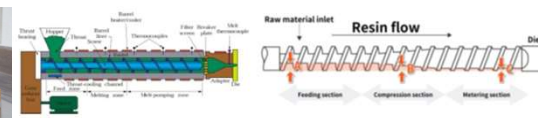
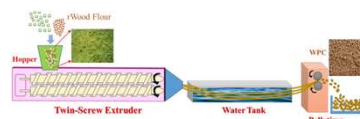
→ Mixing of matrix + primer + wood

→ Heating

→ Pressing

→ Hardening (cooling)

→ Extruder



Source(s): Bausano, 2025; Chiou, 2022; Kingshine, 2025; Farag et al., 2018; Far East Network, 2025

23.09.2025

SUSFUR 2025

6

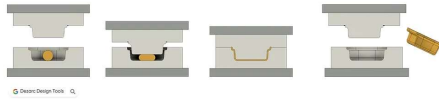
6

Wood-Plastic Composites

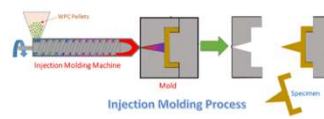
UL | BF

→ Process

→ Compression moulding



→ Injection moulding



Source(s): Chiou, 2022; Xometry pro. 2025

23.09.2025

SUSFUR 2025

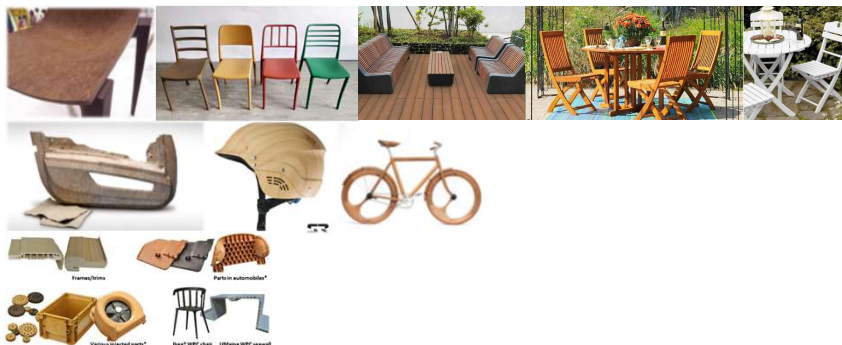
7

7

Wood-Plastic Composites

UL | BF

→ Products



Source(s): Dornob, 2023; BASF, 2018; MAK, 2025; Seven Trust, 2025; Gardner et al., 2015

23.09.2025

SUSFUR 2025

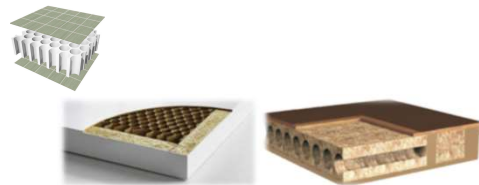
8

8

Sandwich composites

UL | BF

- Multistructural, layered symmetrical composites
- Individual layer with specific function
 - Skin layer: PW, PB, MDF, HDF, HB
 - Core layer for furniture purposes
 - Honeycombe core
 - Stripes: veneer, MDF, HDF/HB



(De Havilland DH98 Mosquito T.MkIII RR299/G-ASKH: www.baesystems.com in morfusuk.com)
 Skin layer: 3 – layer birch based PW
 Core: balsa wood

23.09.2025

SUSFUR 2025

9

9

Sandwich composites

UL | BF

- Structure
 - Furniture and general purpose usage
 - Skin layer: $t \leq 8$ mm (mostly 4 – 6 mm)
 - Core: 10 mm – 50 mm
 - Structural insulation panel (SIP)
 - Skin layer: $t \geq 11$ mm (mostly 15 – 18 mm)
 - Core: $t \leq 180$ mm
 - Light weight sandwich panel
 - Skin layer: $t \leq 4$ mm
 - Core: $t \leq 35$ mm



Source: Egger, 2022; Korwall ind., 2018; Ukcampsite, 2022

23.09.2025

SUSFUR 2025

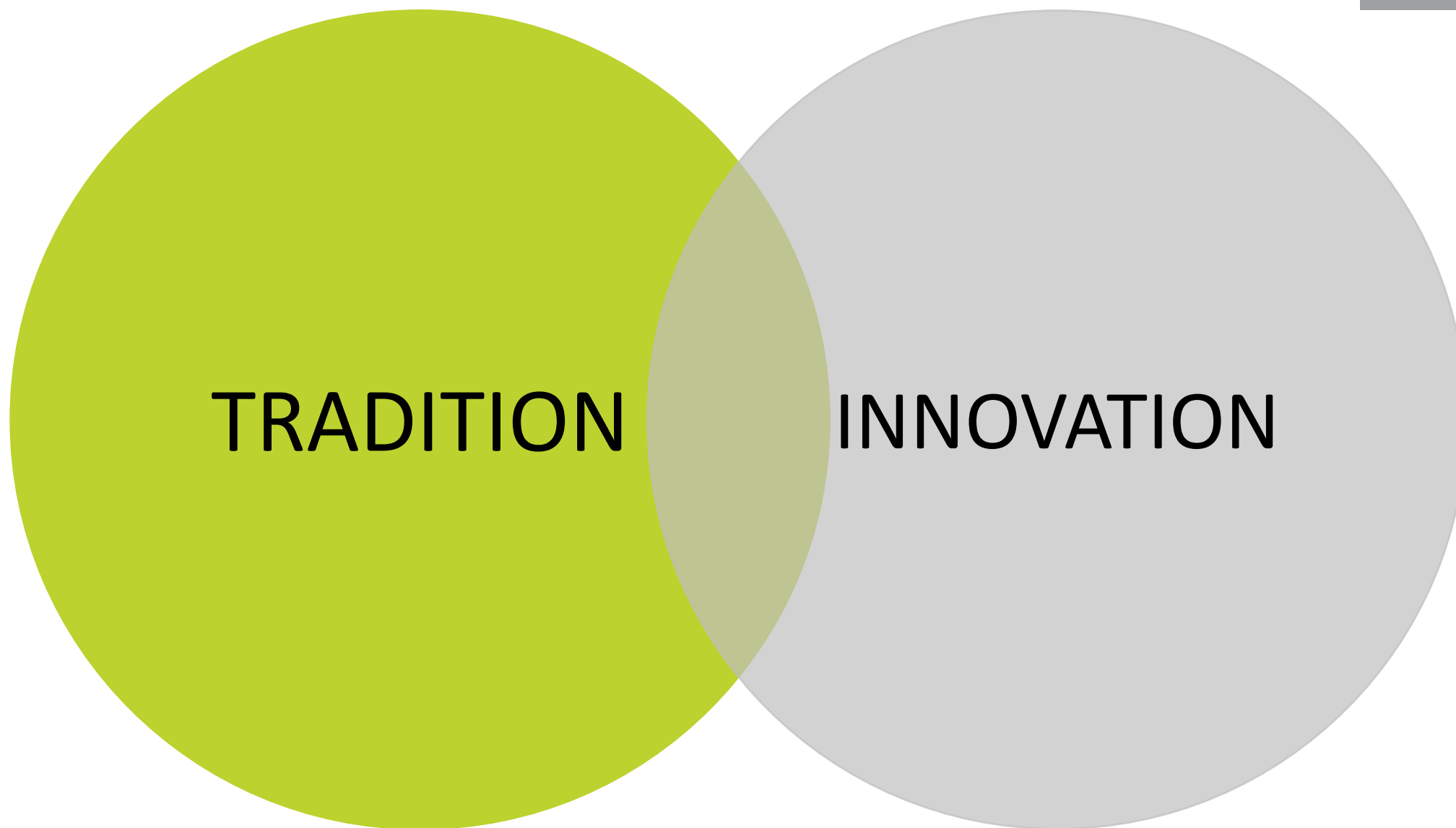
10

10

Susfur project –M SORA

24.9.2025

(Barbara Šubic, Marko Bertoncelj, Benjamin Kavčič)







OUR VALUES

M SORA
držnost

M SORA
spoštovanje

M SORA
zdrava kmečka
pamet

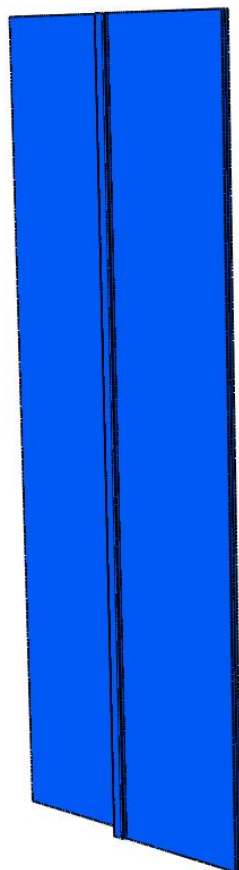
M SORA
pripadnost

1. Boldness

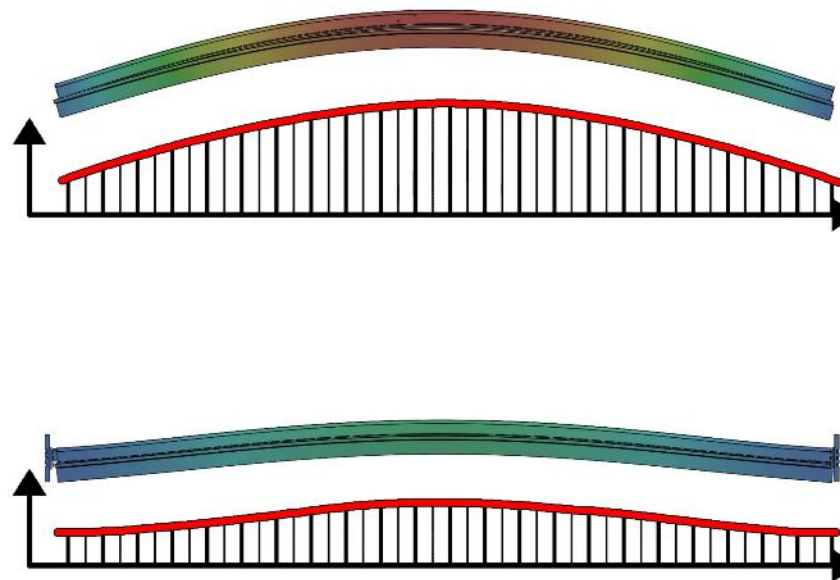
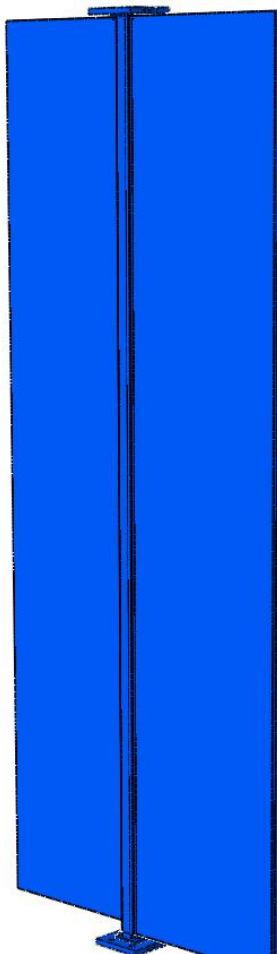


2. Common sense

Sliding wall without
reinforcements



Sliding wall with
reinforcements



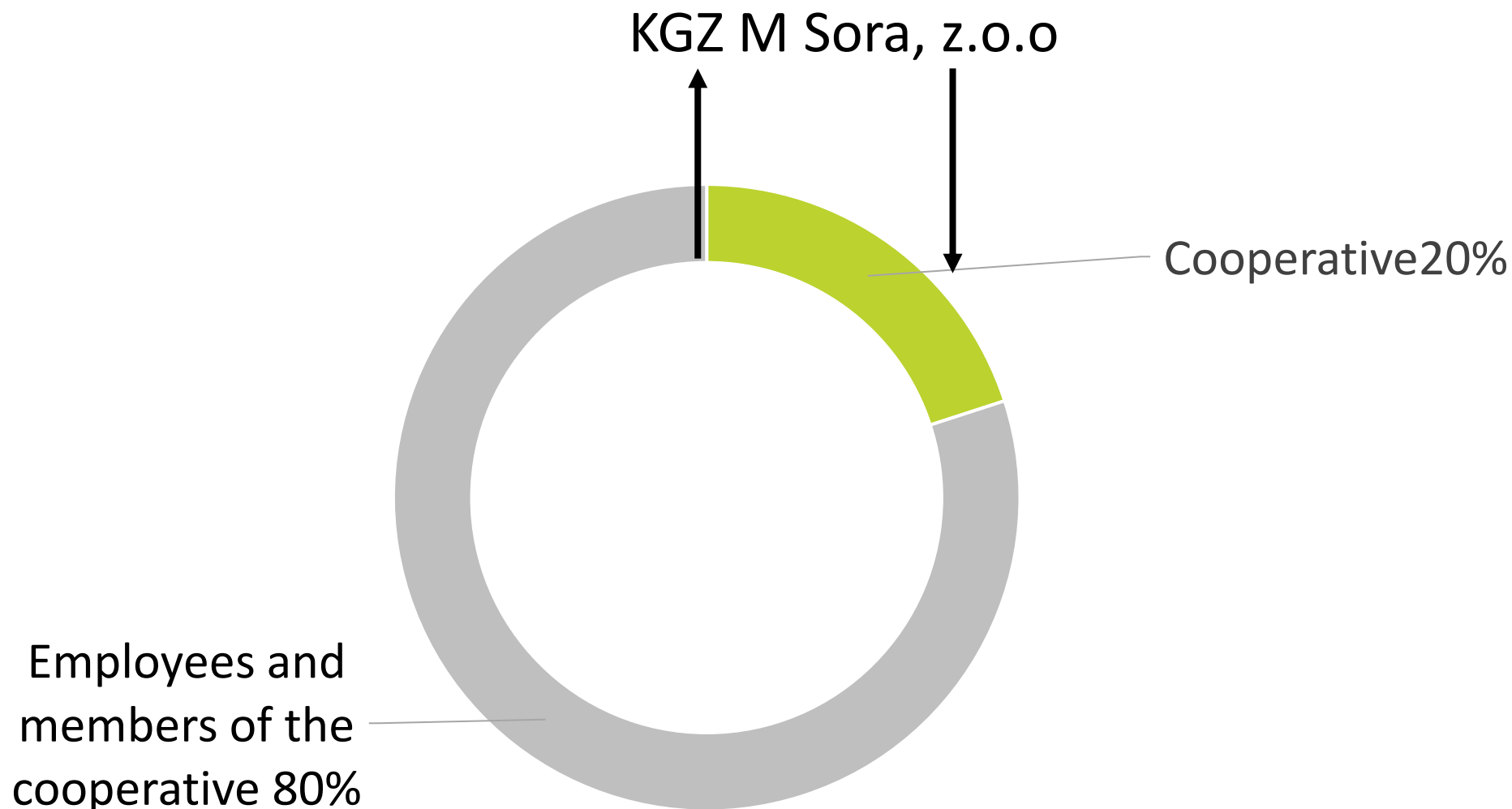
3. Belonging

- HISTORY OF M SORA:
- 1948 - Establishment of the cooperative in Žiri
- 1985 - Entry into the Žiri carpentry workshop
- 2006 - Establishment of a new company M SORA d.d.
- 2007 - Opening of the new carpentry workshop
- 2023 - 75 years of M SORA

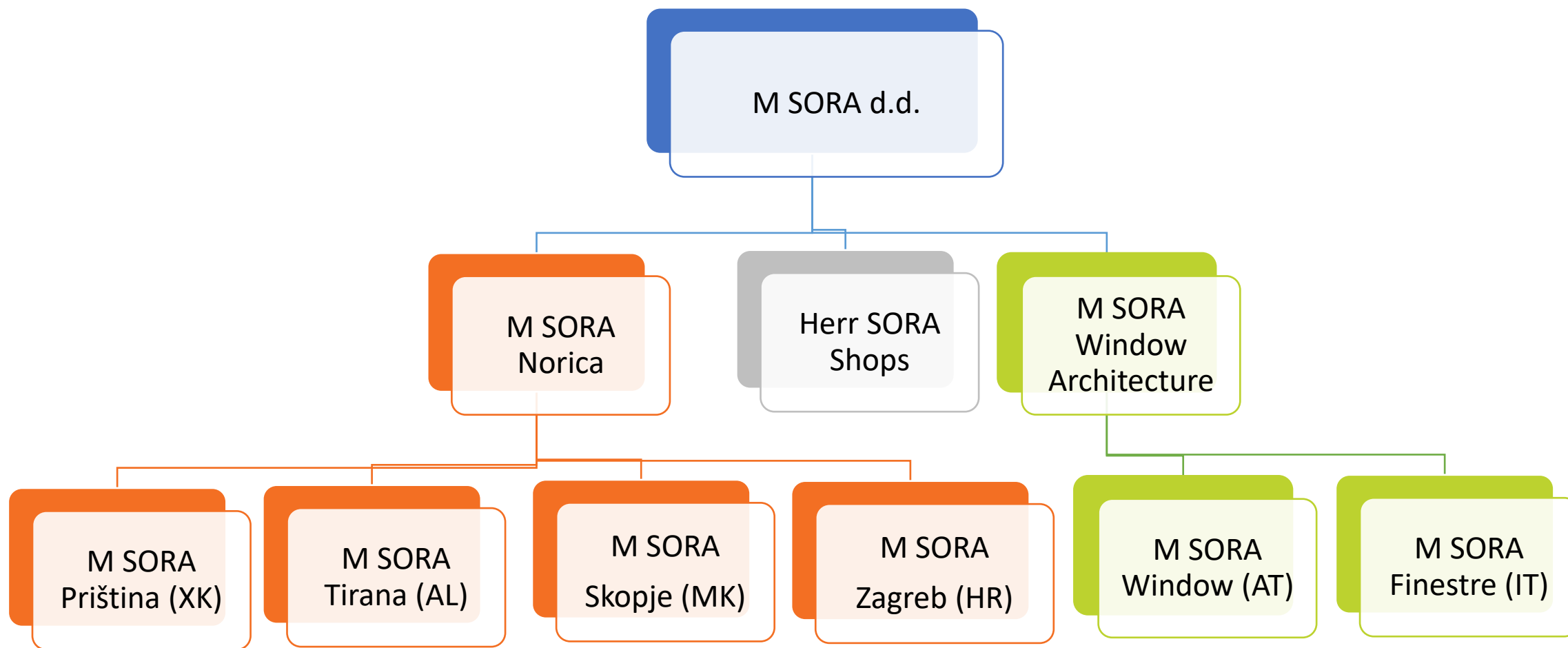


Imejte svoj pogled

OWNERSHIP OF M SORA D.D.



M SORA Group:



4. Respect



Nature



Customers



Employees



Local community

Modern architecture



Modern architecture



Modern architecture



High elements



High elements



Lots of glass surfaces



Lots of glass surfaces



Lots of glass surfaces



Lots of glass surfaces



Glass corners



Imejte svoj pogled

Glass corners



Imejte svoj pogled

Hidden frames



Hidden frames



Hidden frames



Imejte svoj pogled

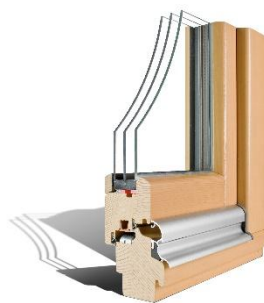
How do we address
sustainability?

1. We implement it into our products and services

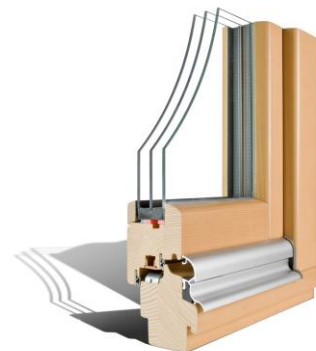
Wooden windows, Natura line



Natura



Natura 3



Natura Baroque



Natura Optimo XLS



Natura Optimo



Natura Optimo XL

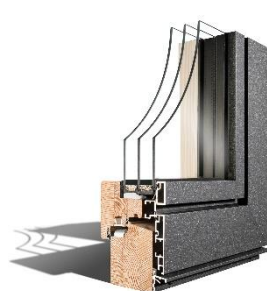


Natura Optimo XLT

Wood-aluminium windows, Line Comfort



Comfort 3Q



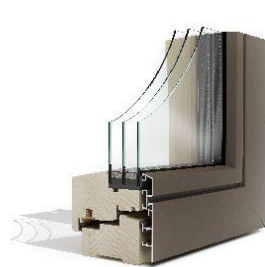
Comfort 3QL



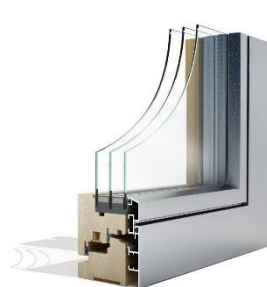
Comfort Passive



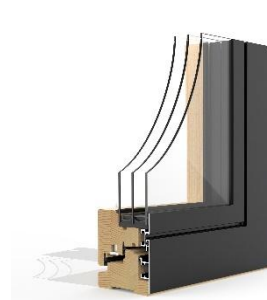
Comfort E112



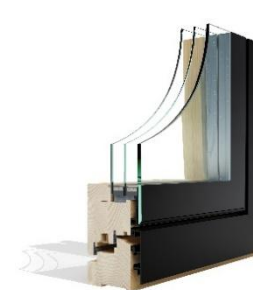
Comfort Optimo L



Comfort Optimo XLS



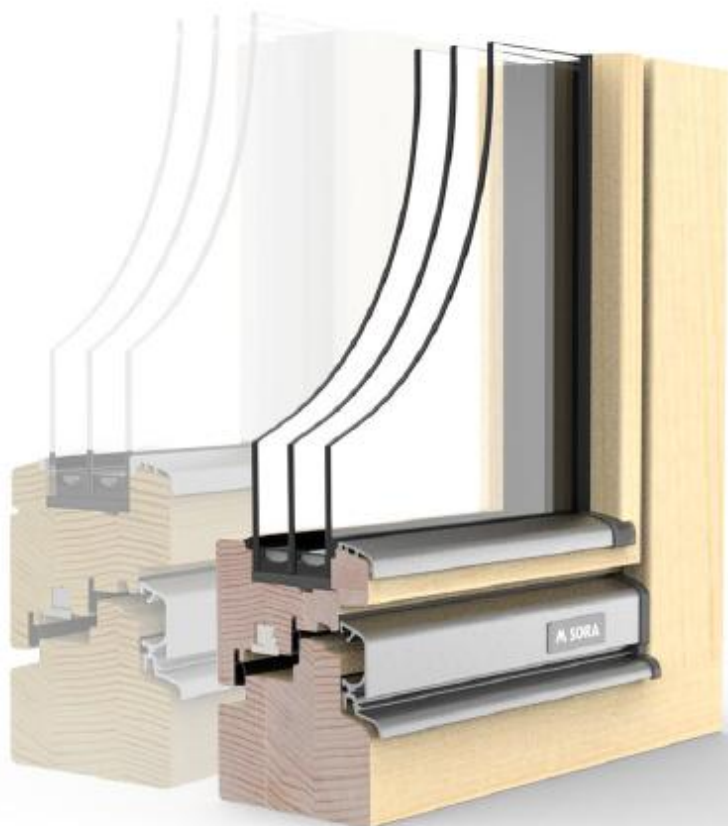
Ultimate Comfort



Vision XL

NATURA LUMNIA 66

thinner window sash
more light
unlimited view



M SORA

More
light, less
frames

Modern
look

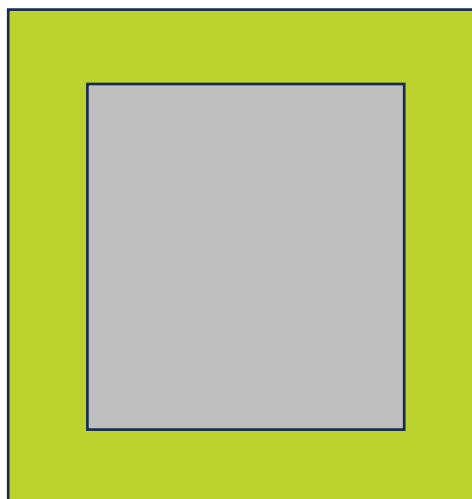
No glazing
bits

Finish in
wood and
wood-
aluminium

Imejte svoj pogled

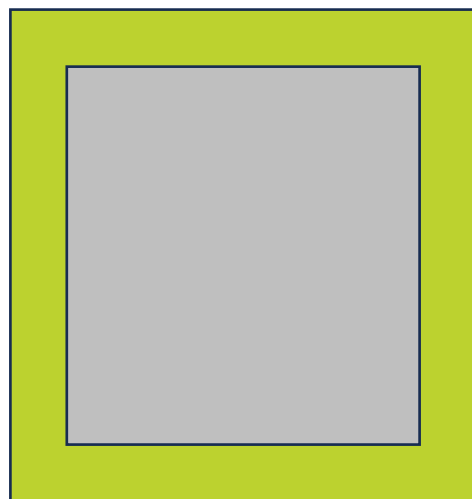
Lumnia line – more light

Natur Optimo



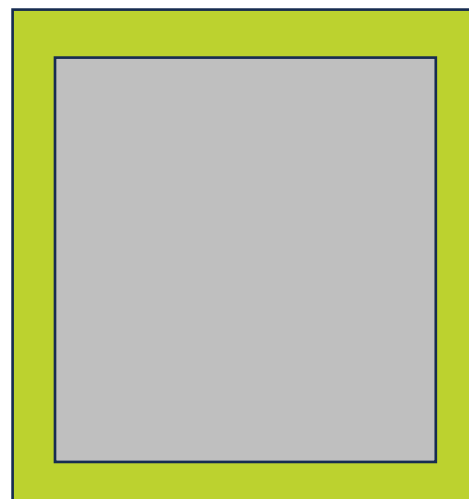
78 %

Lumnia 66



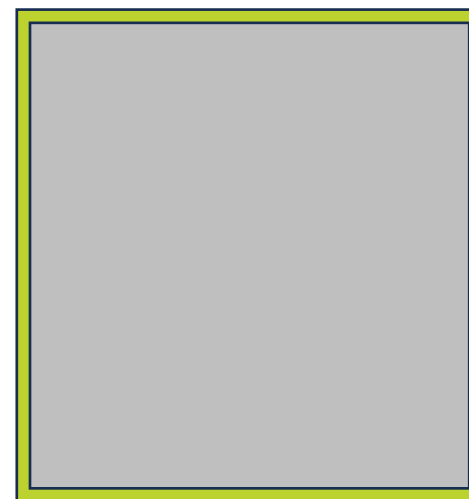
81 %

Lumnia 62






82 %

Lumnia 50



86 %

Thermal transmittance of windows depending on the type of wood

TM spruce	Spruce	Larch	Oak	Red grandis
				
$\lambda = 0,09 \text{ W/mK}$ $\underline{U_w} = 0,87 \text{ W/m}^2\text{K}$	$\lambda = 0,11 \text{ W/mK}$ $\underline{U_w} = 0,91 \text{ W/m}^2\text{K}$	$\lambda = 0,13 \text{ W/mK}$ $\underline{U_w} = 0,95 \text{ W/m}^2\text{K}$	$\lambda = 0,18 \text{ W/mK}$ $\underline{U_w} = 1,0 \text{ W/m}^2\text{K}$	$\lambda = 0,18 \text{ W/mK}$ $\underline{U_w} = 1,0 \text{ W/m}^2\text{K}$

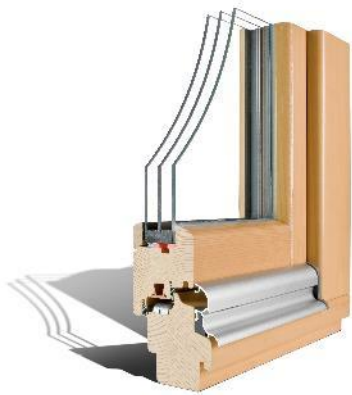
Wooden window
92mm



The reference window size on the certificates is: 123 cm x 148 cm and always with glass $U_g = 0.7 \text{ W/m}^2\text{K}$.

Thermal transmittance of windows depending on the thickness of the profiles

Nature 3 (68 mm) Comfort Optimo XLS (75 mm) Comfort Optimo (92 mm) Comfort Optimo XL (110 mm)



TM spruce	$U_w=0,87 \text{ W/m}^2\text{K}$	$U_w=0.71 \text{ W/m}^2\text{K}$	$U_w=0.75 \text{ W/m}^2\text{K}$	$U_w=0.71 \text{ W/m}^2\text{K}$
Spruce	$U_w=0,91 \text{ W/m}^2\text{K}$	$U_w=0.75 \text{ W/m}^2\text{K}$	$U_w=0,78 \text{ W/m}^2\text{K}$	$U_w=0.74 \text{ W/m}^2\text{K}$
Larch	$U_w=0.95 \text{ W/m}^2\text{K}$	$U_w=0.79 \text{ W/m}^2\text{K}$	$U_w=0.81 \text{ W/m}^2\text{K}$	$U_w=0.77 \text{ W/m}^2\text{K}$
Oak	$U_w=1.0 \text{ W/m}^2\text{K}$	$U_w=0.88 \text{ W/m}^2\text{K}$	$U_w=0.86 \text{ W/m}^2\text{K}$	$U_w=0.83 \text{ W/m}^2\text{K}$
Red grandis	$U_w=1.0 \text{ W/m}^2\text{K}$	$U_w=0.88 \text{ W/m}^2\text{K}$	$U_w=0.86 \text{ W/m}^2\text{K}$	$U_w=0.83 \text{ W/m}^2\text{K}$

Passive certified window designs

Nature E112



$U_w=0.65 \text{ W/m}^2\text{K}$



Comfort E112



$U_w=0.65 \text{ W/m}^2\text{K}$



Nature Optimo XLT



$U_w=0.66 \text{ W/m}^2\text{K}$



Carbon footprint of different wood species

Wood type (density)	Origin of wood (length and type of transport)	Calculated CO2 emissions
Siberian larch (620 kg/m ³)	Russia, Nizhny Tagil (4,150 km by truck)	152 kg/m ³
Meranti (650 kg/m ³)	Malaysia, Kelang (15,000 km by boat and 1,250 km by truck)	145 kg/m ³
Red grandis (570 kg/m ³)	Uruguay, Montevideo (11,600 km by boat and 1,200 km by truck)	107 kg/m ³
Oak (700 kg/m ³)	Slovenia (100 km by truck)	4 kg/m ³
Spruce (400 kg/m ³)	Slovenia (30 km by truck)	2 kg/m ³

PHPP – $U_g=0,5 \text{ W/m}^2\text{K}$, $g=0,5$



Passive House Verification



Building:	Stanovanjska hiša ŠUBIC	
Location and Climate:	Širi	Ljubljana
Street:		
Postcode/City:		
Country:	Slovenija	
Building Type:	P+M	
Home Owner(s) / Client(s):	Barbara in Miha ŠUBIC	
Street:	Triglavska 21	
Postcode/City:	4226 Širi	
Architect:	ARI d.o.o., Nika Fiderer, udia	
Street:	Podlubnik 139a	
Postcode/City:	Škofja Loka	
Mechanical System:	BIRO MIKROKLIMA, Medard Hafner, s.p.	
Street:	Klobocova ul. 1	
Postcode/City:	4220 Škofja Loka	
Year of Construction:	2012	
Number of Dwelling Units:	1	Interior Temperature: 20,0 °C
Enclosed Volume V_{e} :	470,0 m ³	Internal Heat Gains: 3,7 W/m ²
Number of Occupants:	6,0	

Specific Demands with Reference to the Treated Floor Area			
Treated Floor Area:		145,0	m ²
Specific Space Heat Demand:	12,7	kWh/(m ² a)	
Pressurization Test Result:	0,0	n	
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	129	kWh/(m ² a)	
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	51	kWh/(m ² a)	
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		kWh/(m ² a)	
Heating Load:	14	W/m ²	
Frequency of Overheating:	0	%	
Specific Useful Cooling Energy Demand:		kWh/(m ² a)	
Cooling Load:	5	W/m ²	
PH Certificate:			Fulfilled?
15 kWh/(m ² a)			Yes
0,6 h ⁻¹			Yes
120 kWh/(m ² a)			No
over 25 °C			
15 kWh/(m ² a)			

We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on:

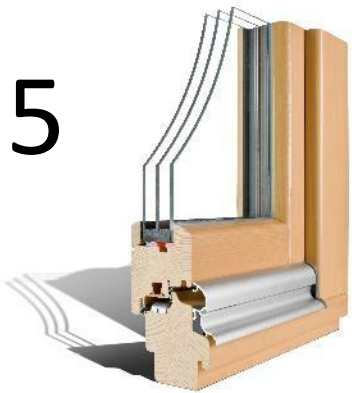
Jun.12

signed:

Simon BRLEK



PHPP – $U_g=0,6 \text{ W/m}^2\text{K}$, $g=0,5$



Passive House Verification



Building:	Stanovanjska hiša SUBIC		
Location and Climate:	Šiši	Ljubljana	
Street:			
Postcode/City:			
Country:	Slovenija		
Building Type:	PaM		
Home Owner(s) / Client(s):	Barbara in Miha SUBIC		
Street:	Triglavska 21		
Postcode/City:	4226 Šiši		
Architect:	ARI d.o.o., Nika Fiderer, udia		
Street:	Podlubnik 139a		
Postcode/City:	Škofja Loka		
Mechanical System:	BIRO MIKROKLIMA, Medard Hafner, s.p.		
Street:	Klobocova ul. 1		
Postcode/City:	4220 Škofja Loka		
Year of Construction:	2012		
Number of Dwelling Units:	1	Interior Temperature:	20,0 °C
Enclosed Volume V _i :	470,0 m ³	Internal Heat Gains:	3,7 W/m ²
Number of Occupants:	6,0		

Specific Demands with Reference to the Treated Floor Area			
Treated Floor Area:		145,0 m ²	
Specific Space Heat Demand:	15,3 kWh/(m ² a)	PH Certificate:	Fulfilled?
Prevention of Frost Risk:	0,0 m	15 kWh/(m ² a)	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	131 kWh/(m ² a)	0,6 h ⁻¹	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	52 kWh/(m ² a)	120 kWh/(m ² a)	No
Specific Primary Energy Demand (Energy Conservation by Solar Electricity):	kWh/(m ² a)		
Heating Load:	15 W/m ²		
Frequency of Overheating:	0 %	over 25 °C	
Specific Useful Cooling Energy Demand:	kWh/(m ² a)	15 kWh/(m ² a)	
Cooling Load:	5 W/m ²		

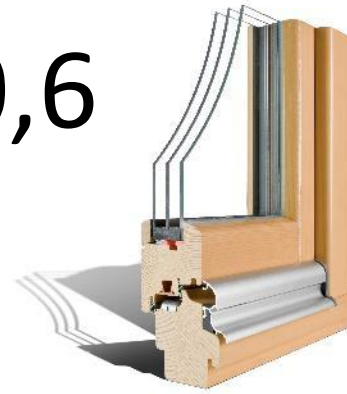
We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on: Jun 12
signed: Simon BRLER



PHPP – $U_g=0,7 \text{ W/m}^2\text{K}$, $g=0,6$

M SORA



Passive House Verification



Building:	Stanovanjska hiša ŠUBIC		
Location and Climate:	Širi	Ljubljana	
Street:			
Postcode/City:			
Country:	Slovenija		
Building Type:	P+M		
Home Owner(s) / Client(s):	Barbara in Miha ŠUBIC		
Street:	Triglavska 21		
Postcode/City:	4226 Širi		
Architect:	ARI d.o.o., Nika Fiderer, udia		
Street:	Podlubnik 139a		
Postcode/City:	Škofja Loka		
Mechanical System:	BIRO MIKROKLIMA, Medard Hafner, s.p.		
Street:	Klobovcova ul. 1		
Postcode/City:	4220 Škofja Loka		
Year of Construction:	2012		
Number of Dwelling Units:	1	Interior Temperature:	20,0 °C
Enclosed Volume $V_{e,i}$:	470,0 m ³	Internal Heat Gains:	3,7 W/m ²
Number of Occupants:	6,0		

Specific Demands with Reference to the Treated Floor Area				
Treated Floor Area:	145,0	m ²		
Applied:	Monthly Method	PH Certificate:		Fulfilled?
Specific Space Heat Demand:	14,5	kWh/(m ² a)	15 kWh/(m ² a)	Yes
Pressurization Test Result:	0,6	h ⁻¹	0,6 h ⁻¹	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	130	kWh/(m ² a)	120 kWh/(m ² a)	No
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	52	kWh/(m ² a)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		kWh/(m ² a)		
Heating Load:	16	W/m ²		
Frequency of Overheating:	1	%	over 25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m ² a)	15 kWh/(m ² a)	
Cooling Load:	5	W/m ²		

We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on:

Jun. 12

signed:

Simon BRLEK



Imejte svoj pogled

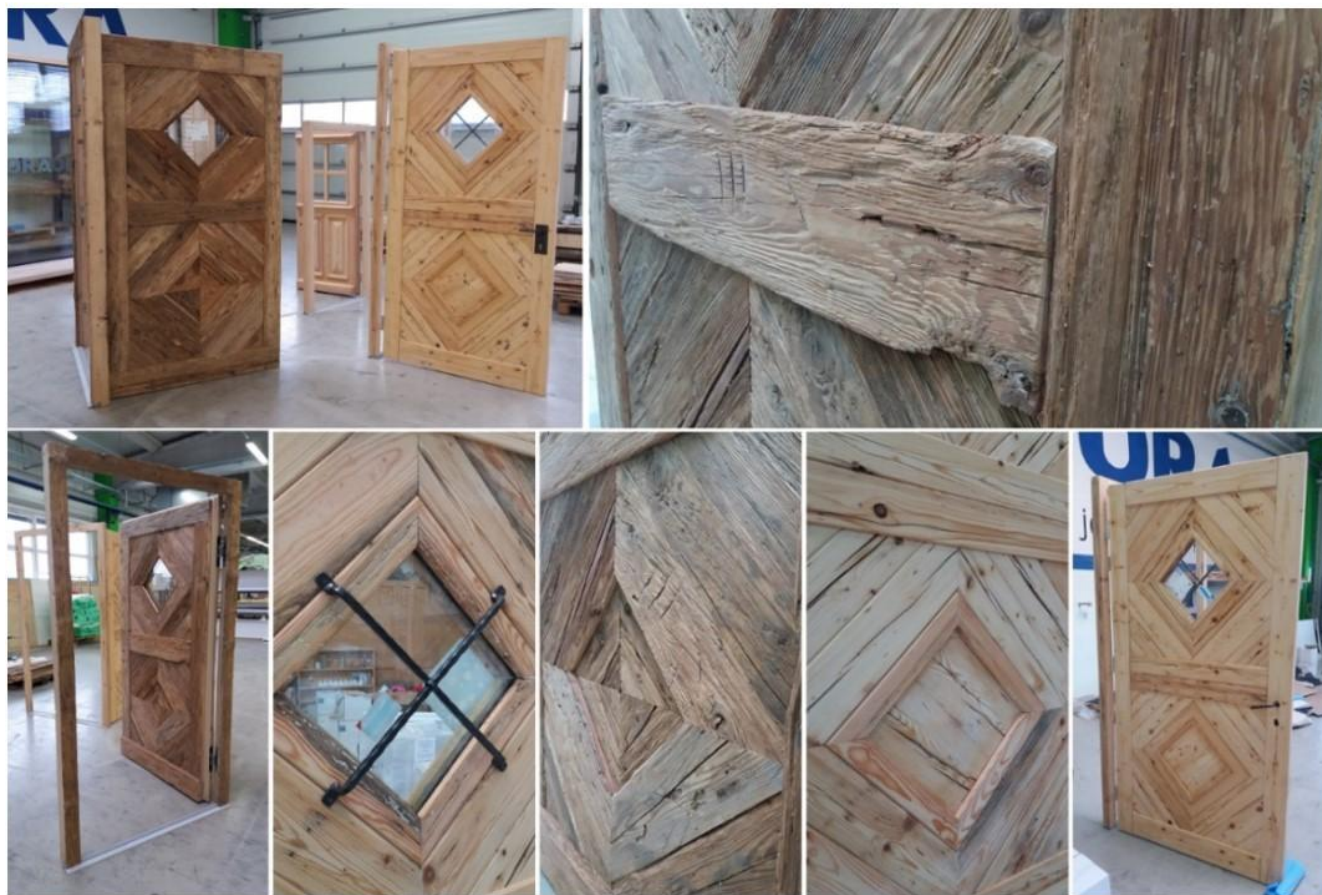
Using hemp or wool instead of classical PU foam for installation



Using discarded wood and giving it new life



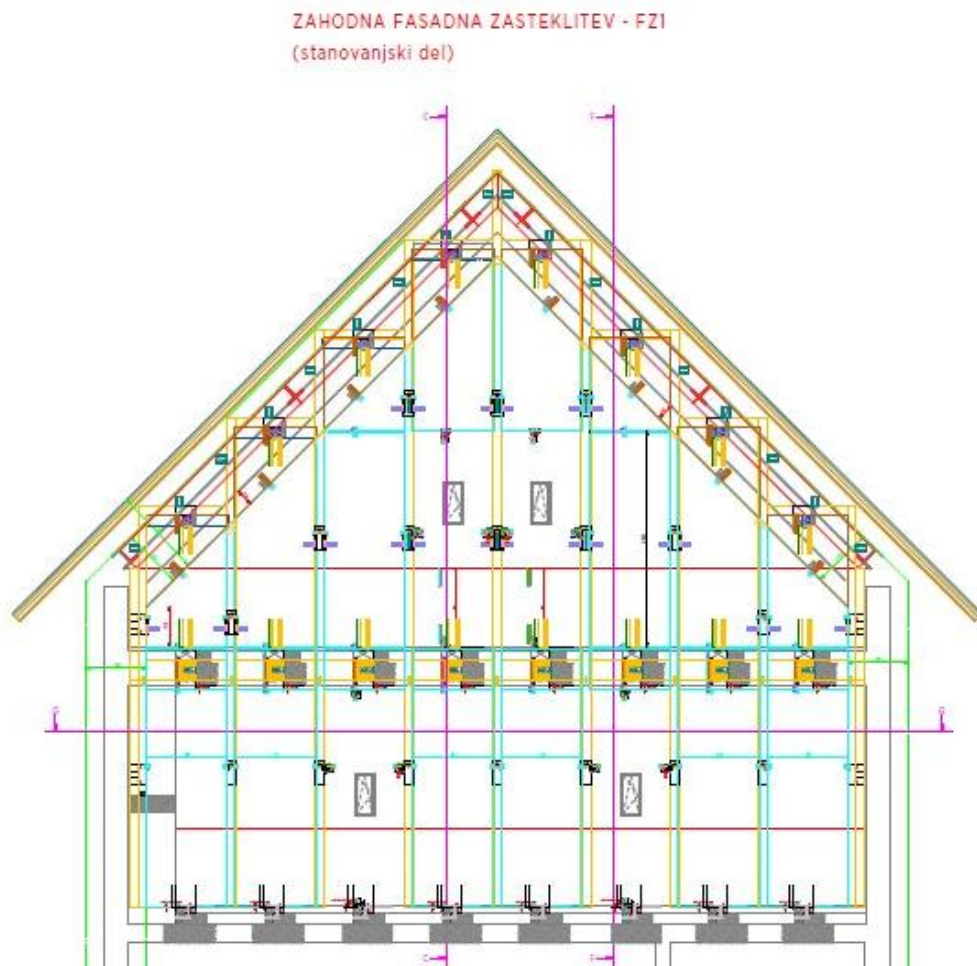
Using discarded wood and giving it new life



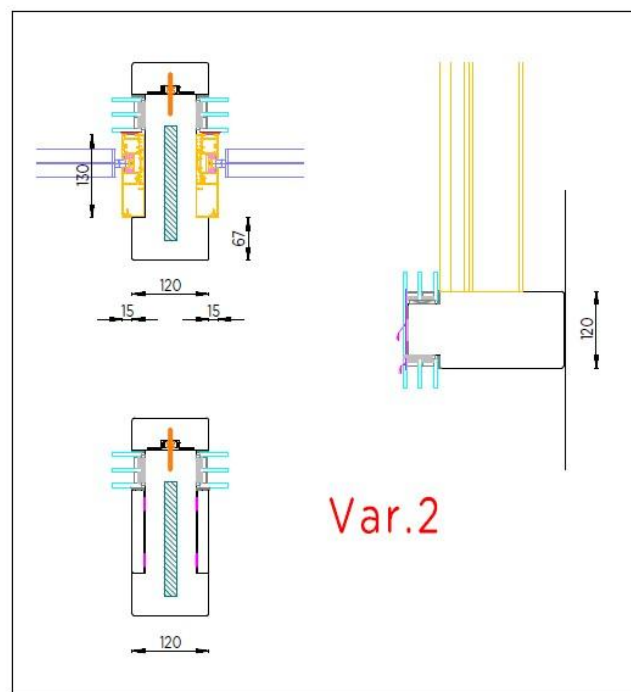
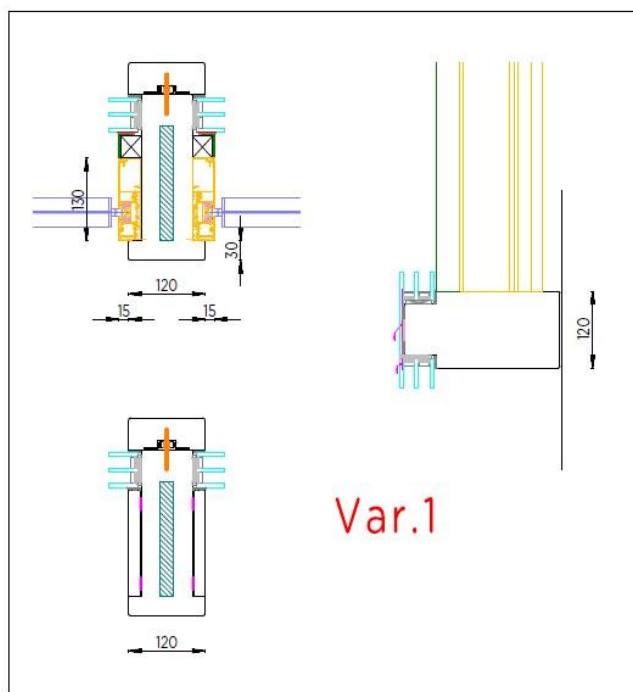
Using discarded wood and giving it new life



We can bring wood into project previously doable only with aluminium frames



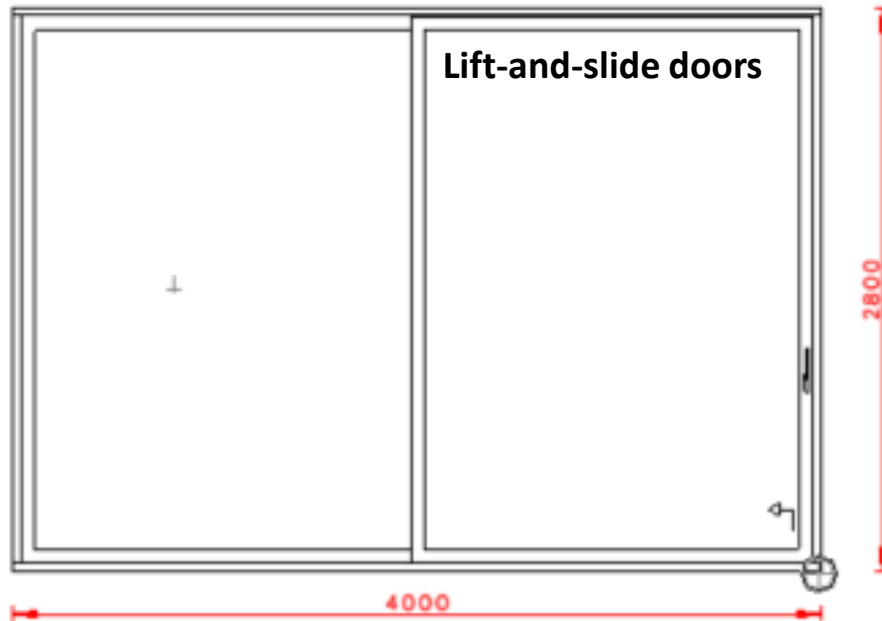
We can bring wood into project previously doable only with aluminium frames





Sustainable advises

- It is sustainable to suggest the best and not always the most expensive solution

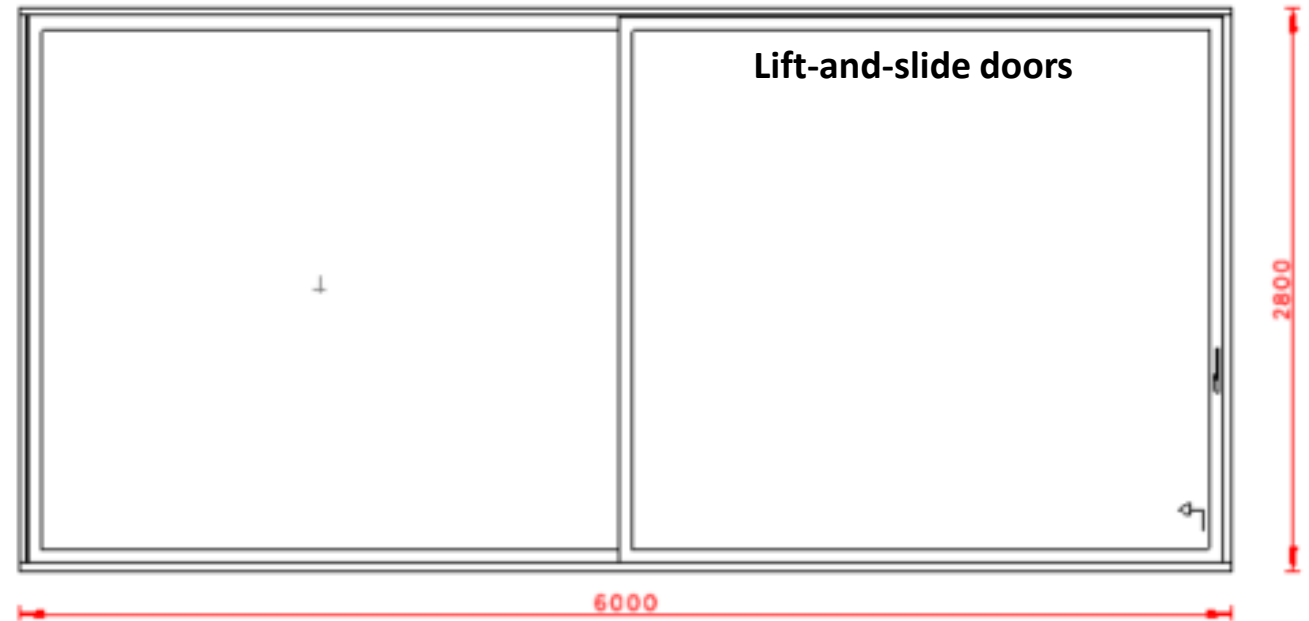


Sash size: 2000 x 2800 mm

Wing weight: **250 kg**

Glass composition: 6/18/6/18/6

Practicality: normal everyday use



Sash size: 3000 x 2800 mm

Wing weight : **500 kg**

Glass composition : 8/18/8/18/8

Practicality: not exactly for frequent daily use

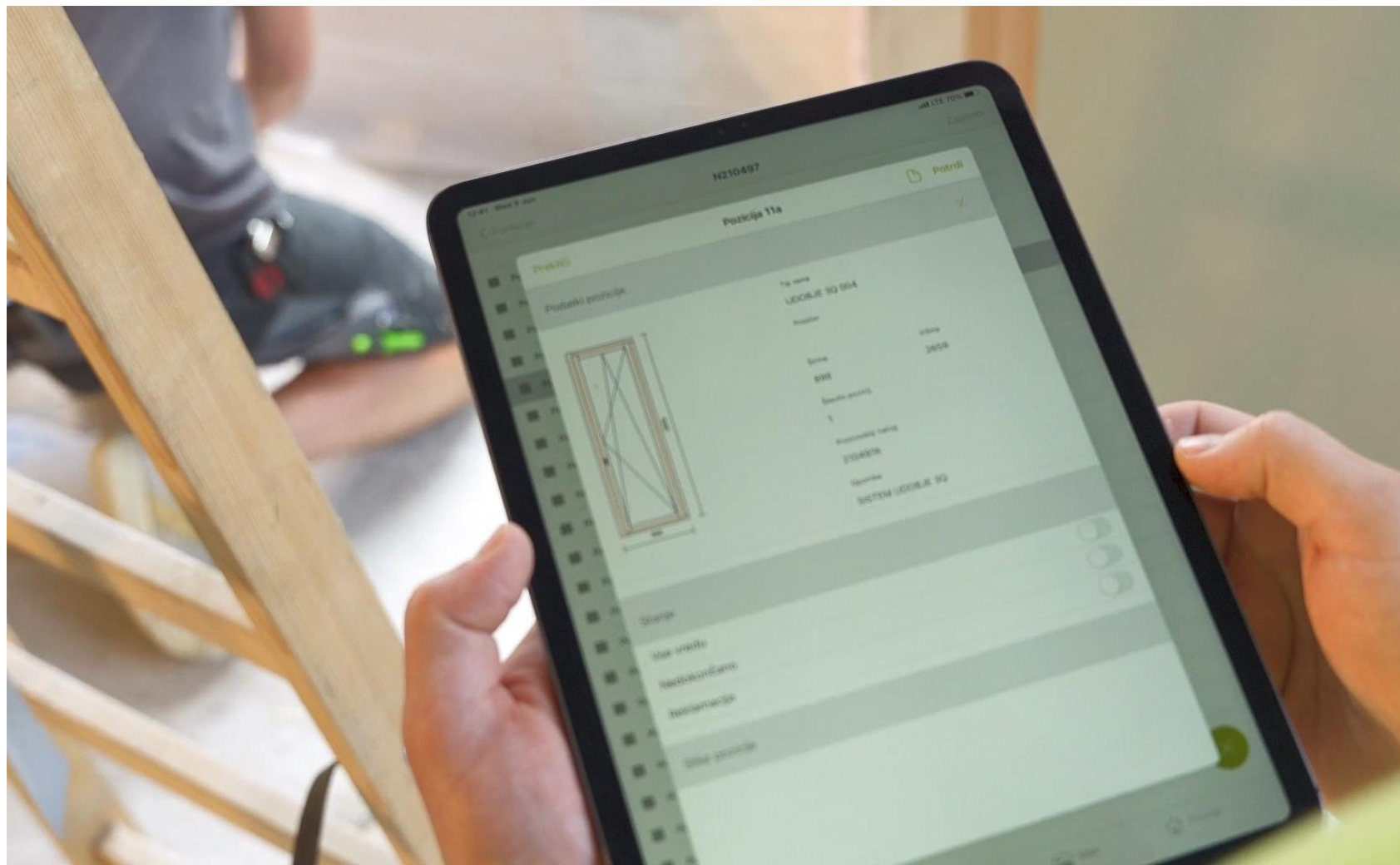
Sustainable transport



Kranjska koča na Ledinah (1689 m)



Using digital platforms on site instead of paper

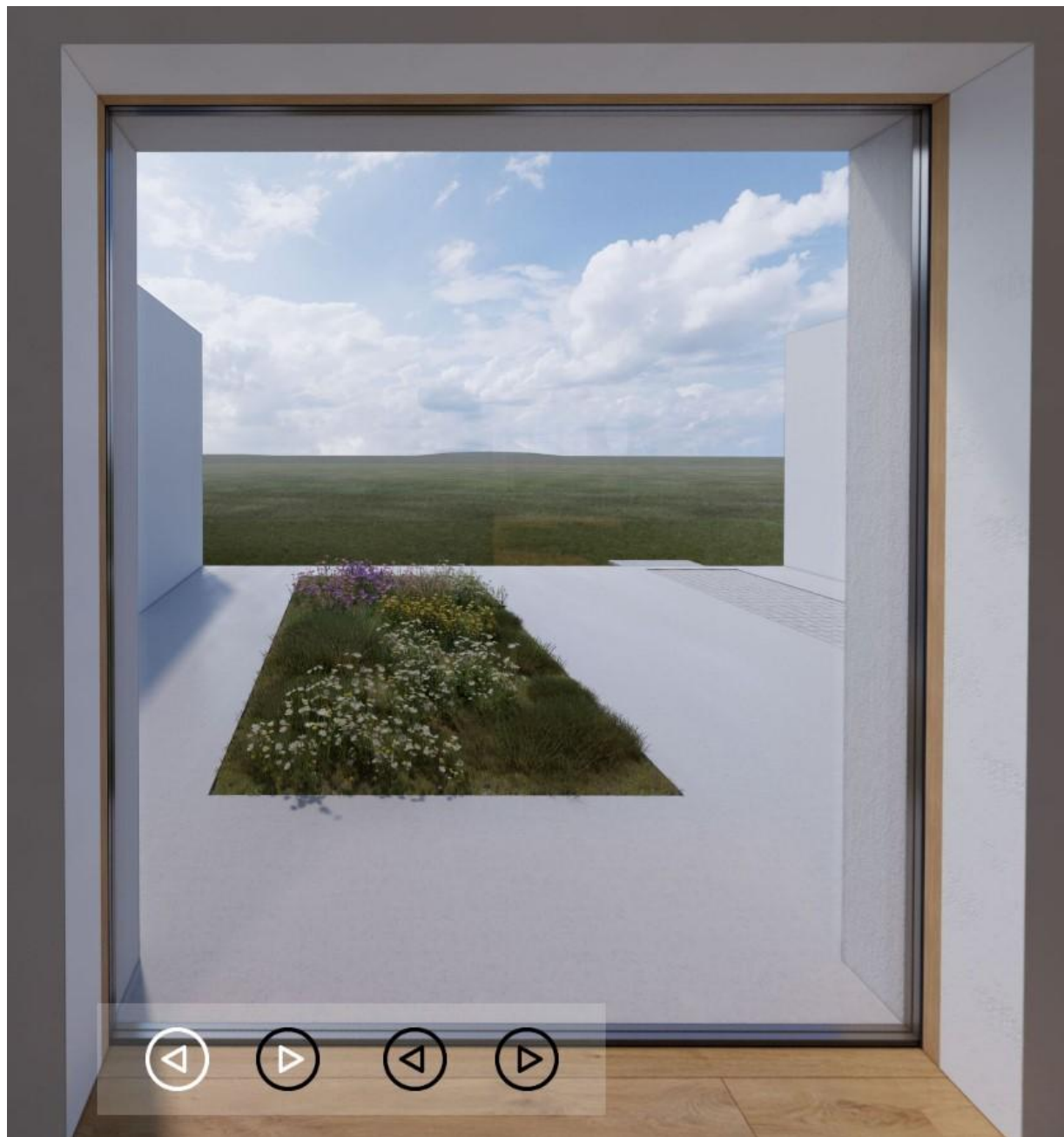


Imajte svoj pogled

Virtual showroom



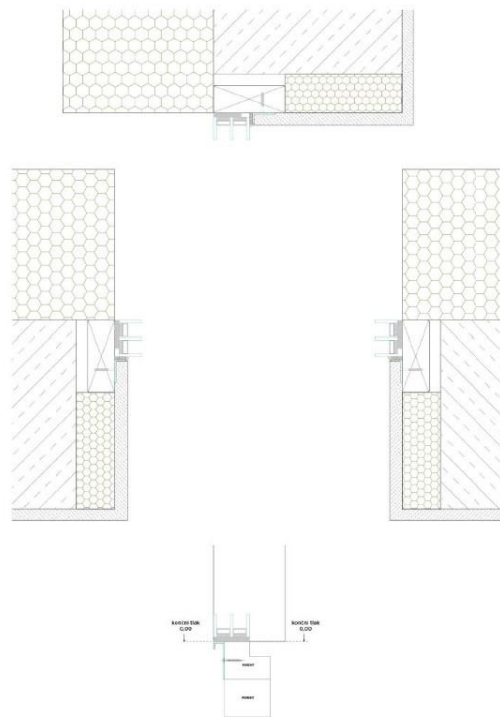
Imejte svoj pogled



Virtual showroom

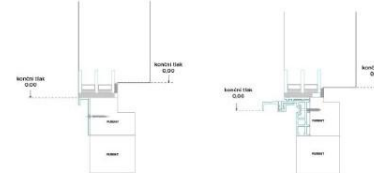


VAR.3: s pokrivanjem okvirja povsem do stekla



Detalj s steklom potopljenim v tlak

DODATNO: detajl za lovljenje linije z GU steno

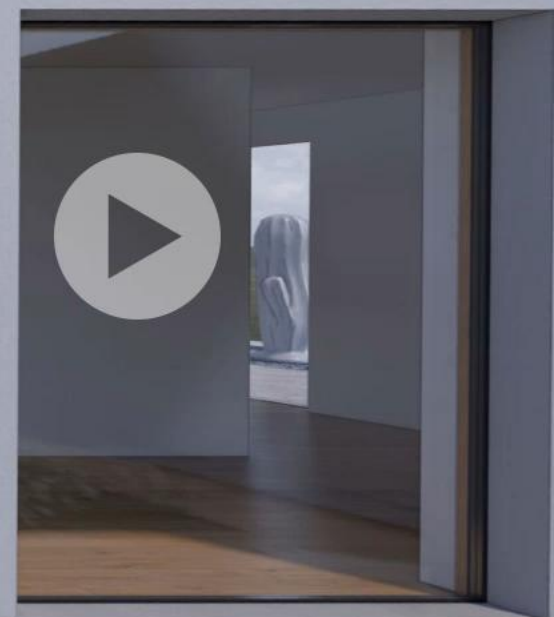


[SLO](#)[EN](#)[DE](#)[IT](#)[FR](#)

Paviljon M Sora

Virtualni razstavni prostor

Virtualni sprehod po razstavnem salonu stavbnega pohištva podjetja M Sora. Za namen realne predstave so v 3D obliki prikazane osnovne opcije in podvarjante oken in notranjih vrat. V pomoč kupcem, oblikovalcem in arhitektom.



Services – warranty, warranty extension and preventive service inspections:



SI ŽELITE NEOMEJENO GARANCIJO ZA VAŠA OKNA?

REDUCE

EDINI V SLOVENIJI PONUJAMO

PODALJŠANJE GARANCIJE S PREVENTIVNIM SERVISNIM PREGLEDOM

BREZPLAČNI REDNI SERVISNI PREGLED

REUSE

RECYCLE

2. We install it into our
everyday business and processes

Sustainability strategy

- SA1 - Environment, Society, and Governance (ESG)
- SA2 - Processes, Competencies, and Responsibilities
- SA3 - System Optimization
- SA4 - Products, Services, and Future Market Paths
- SA5 - Technological Process Optimization
- SA6 - Material Operations and Production Process Optimization
- SA7 - Productivity and Quality in Production
- SA8 - Professional Installation, Service, and Claims
- SA9 - Sustainable Marketing
- SA10 - Research, Development, and Innovation



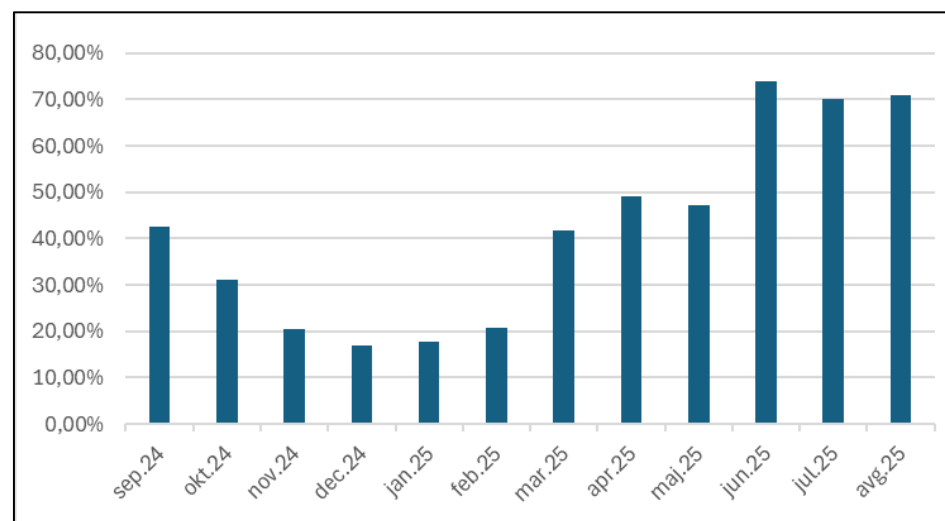
Wood residues in production — use for heating production facilities



Solar power plant:



Self-sufficiency rate



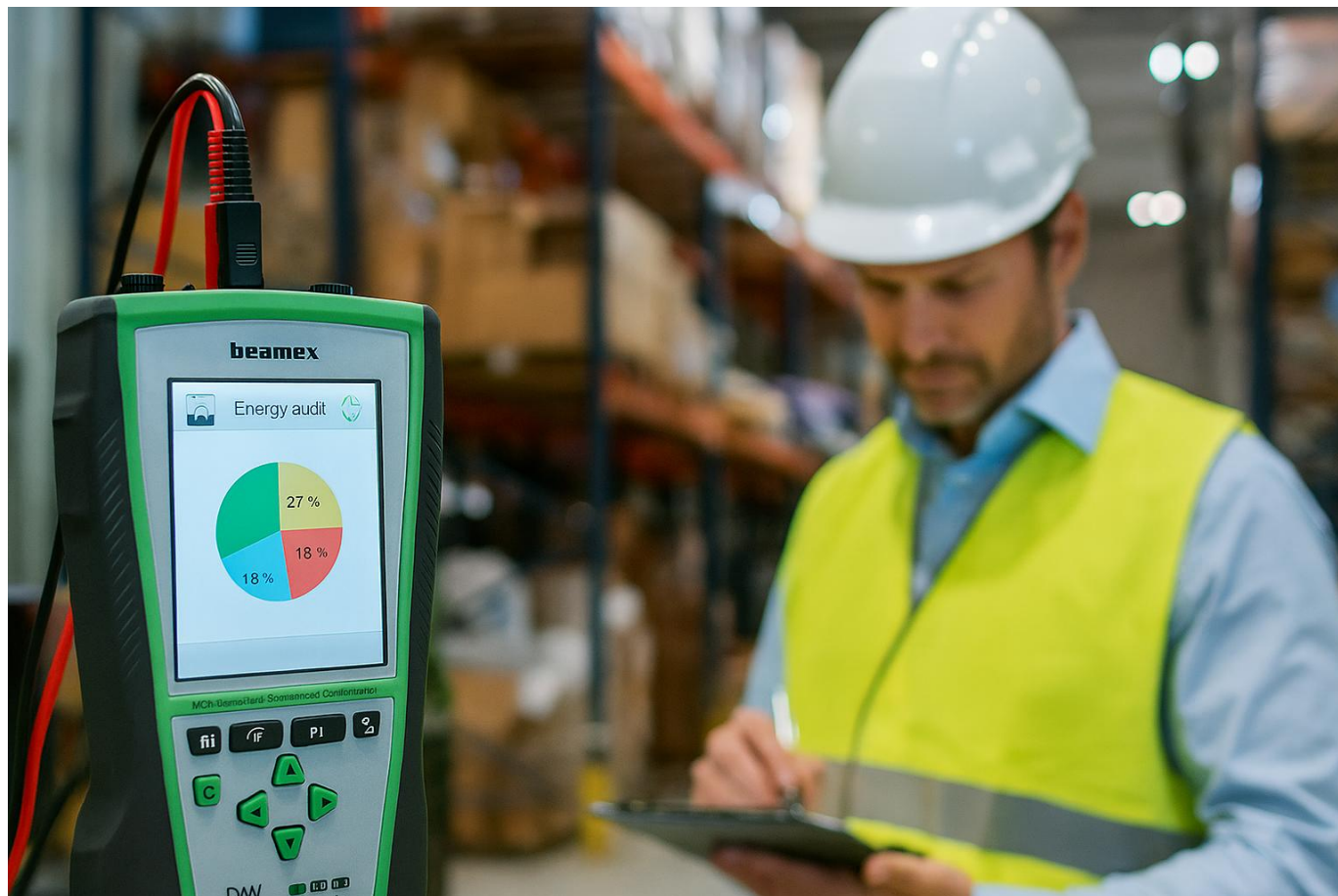
42%

Power of the solar power plant: 758 kW
Three energy storage units: each 100 kW/215 kWh

Green star certificate, sustainability report



Energy audit of the company



3. It is part of our research
and development work

Testing wood and colour changes in different climates



Žiri (Slovenia)



Ljubljana (Slovenia)



Hannover (Germany)



Skellefteå (Sweden)



Madrid (Spain)

Comparison of color changes over the years

Žiri, 20.10.2015



Žiri, 9.8.2016



Žiri, 10.11.2020

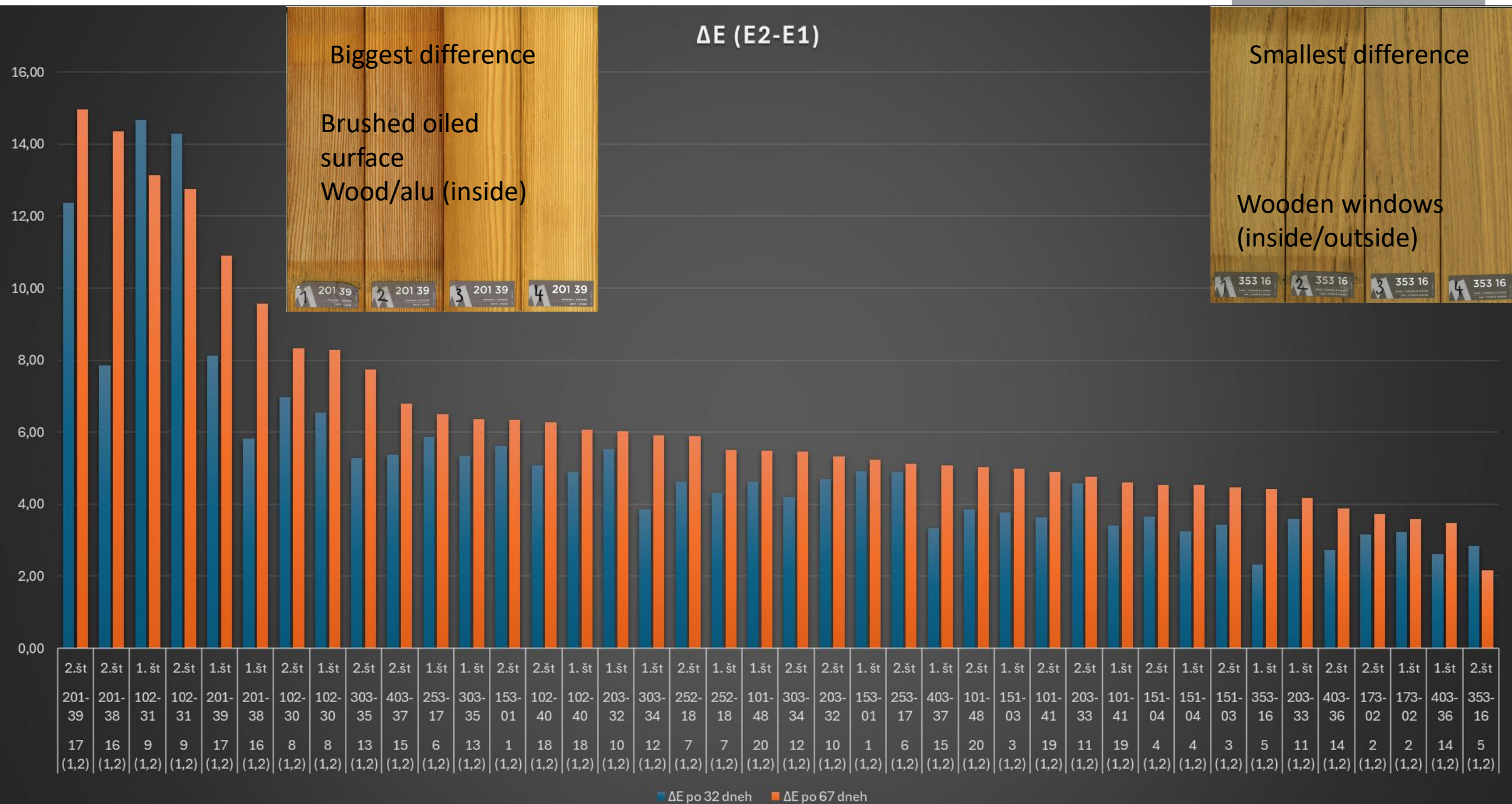


Žiri, 6.2.2021



Žiri, 14.10.2022





ΔL (L2-L1)



ΔA (A2-A1)

6,00

Woode/alu (inside)

Wood/alu (inside)

4,00

2,00

0,00

-2,00

-4,00

-6,00

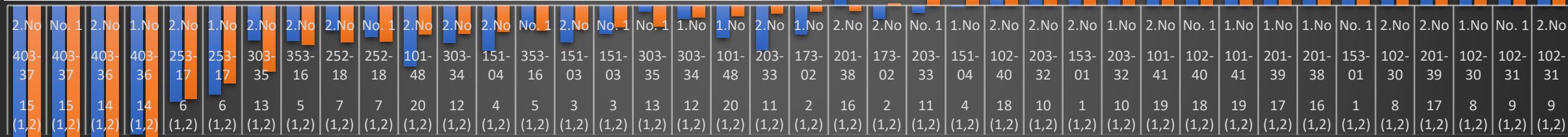
Gaining green pigment

Gaining red pigment

Wood/alu (inside)

wood/alu (inside)

■ ΔA 32 days ■ ΔA 67 days



Exploring the possibilities of reusing wood

CareWood,
Mijav project



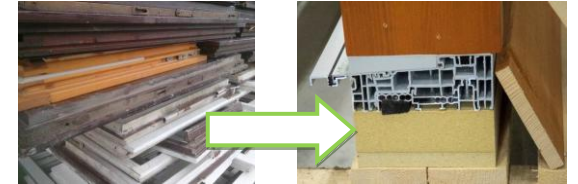
Forest Phoenix



ReWin



Start Circles: COMET



RecAPpture



Project WOOLF



Exploring the possibilities of reusing wood



Exploring the possibilities of reusing wood

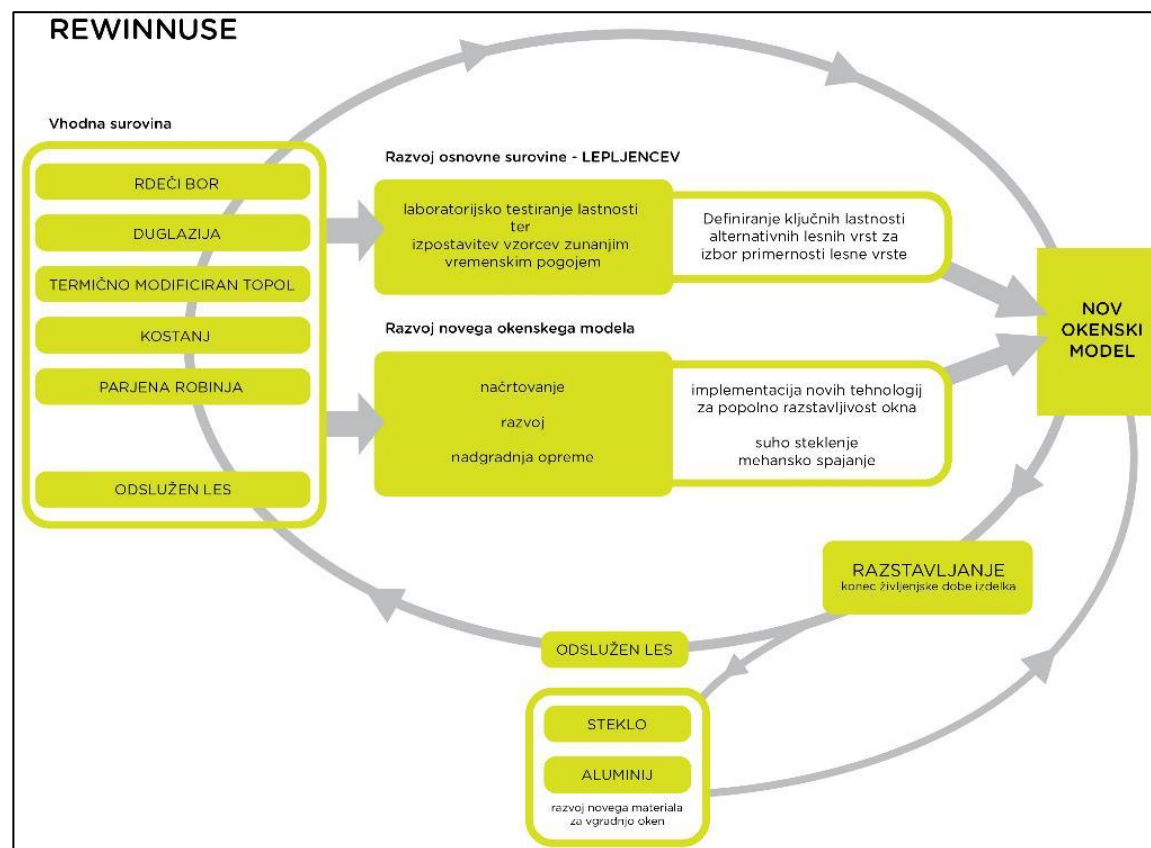


Imejte svoj pogled

Exploring the possibilities of reusing wood



Exploring new wood species for the manufacture of windows



Digitalization:





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