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Marie Skłodowska-Curie Actions (MSCA)

DOVETAILED MASSIVE WOOD BOARD ELEMENTS FOR MULTI-STORY BUILDINGS (DoMWoB project)

12.12.2022

Dr. Hüseyin Emre Ilgın & Prof. Markku Karjalainen

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Dr. Hüseyin Emre Ilgın (born 1981)

- **2003, 2006, 2018** - BArch, MSc, PhD on tall building design, METU, Ankara
- **2005** - Project architect @ Architectural office, Ankara
- **2006** - Research assistant @ Cankaya University, Ankara
- **2005 - 2007** - Researcher @ Several research projects, Ankara
- **2007 - 2017** - Part-time instructor @ METU & Baskent University, Ankara
- **2007 - 2010** - Chief of architectural project office @ Ministry of Interior, Ankara
- **2010 - 2018** - Project coordinator & Architectural site supervisor @ Ministry of Health Ankara *(inspecting many city hospital projects over 1 million m²)*
- **2018** - Post-doc. visiting scholar @ Aalto University
- **2019** - ... Post-doc. visiting scholar & Marie Curie Fellow @ Tampere University

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WHAT IF
adhesive- and metal-fastener-free massive wood boards
were available in global construction market?

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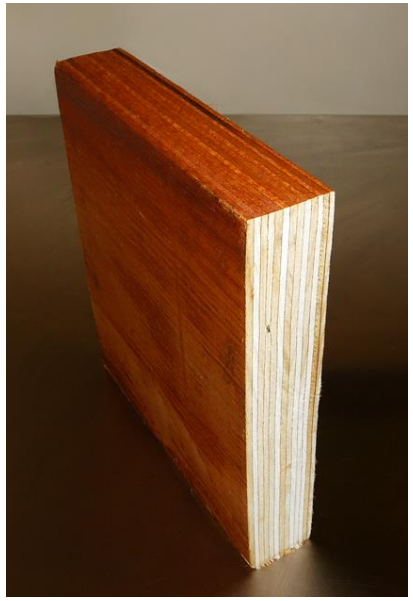
Engineered wood products are increasingly used in the construction industry due to their many advantages *e.g., their stiffness, and environmental features.*

CLT (Cross laminated timber)



LVL (Laminated veneer lumber)

GLT (Glue-laminated timber)

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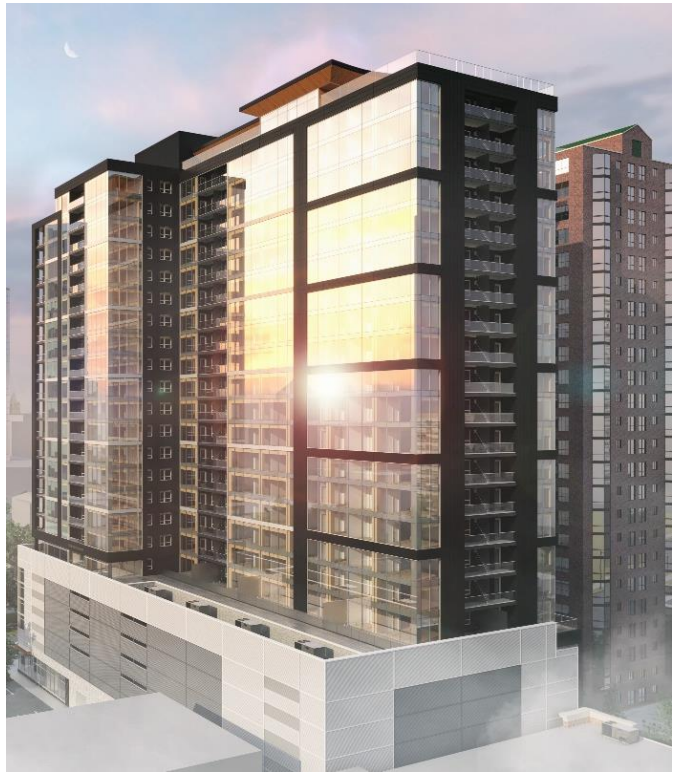
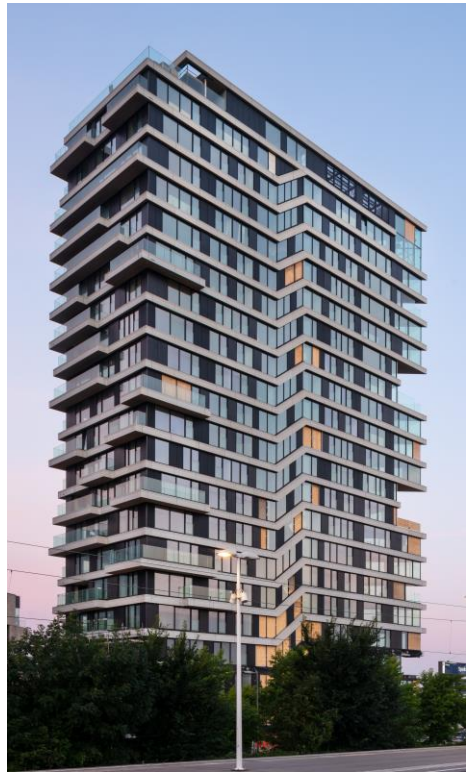
Wood has come back to break into **tall building** construction.



Ascent, USA, 2022 – *25-story,* ***87m***

Mjøstårnet, Norway, 2019 – *18-story,* ***85m***

HoHo, Austria, 2020 – *24-story,* ***84m***



HAUT, Netherlands, 2022 – *22-story,* ***73m***

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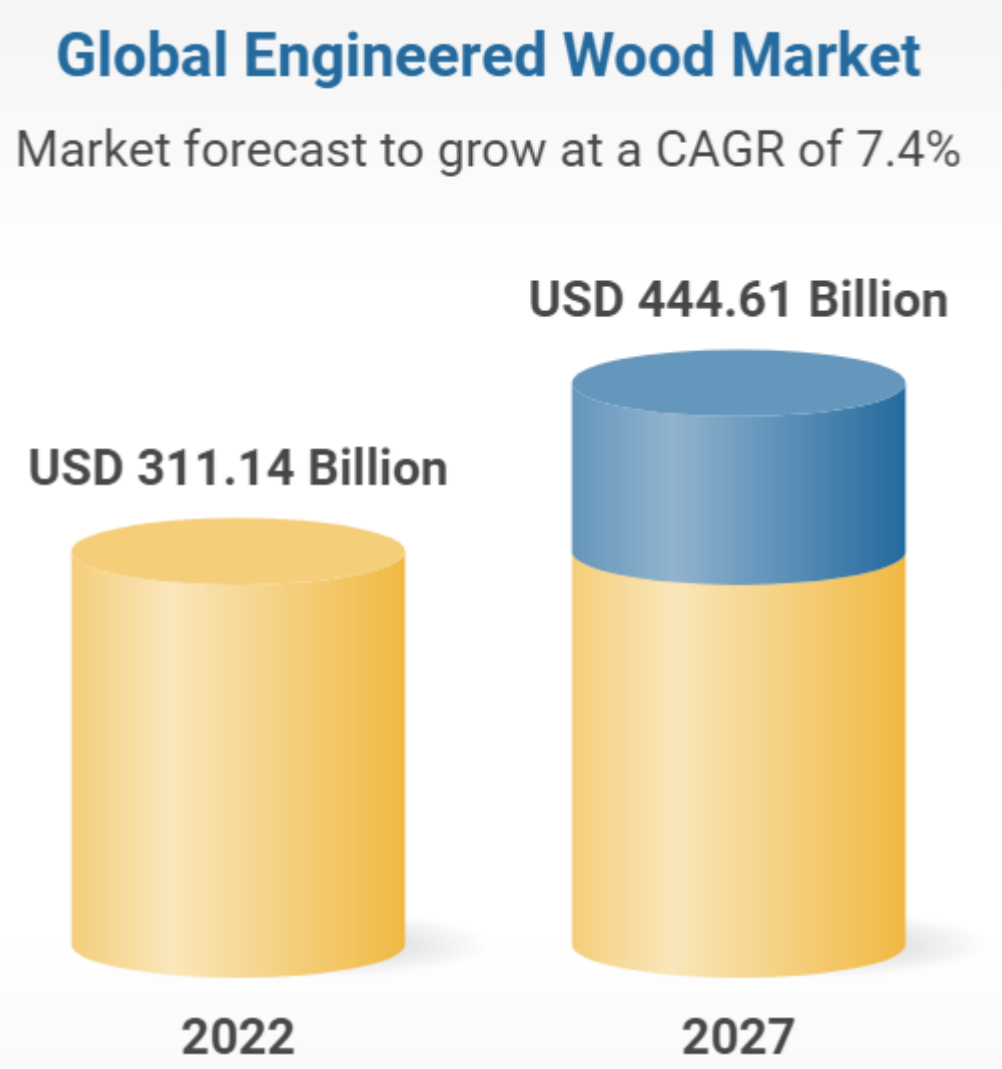
Engineered wood market

$311 billion in **2022**

$445 billion by **2027**

with **7.4%** annual growth rate



https://www.researchandmarkets.com

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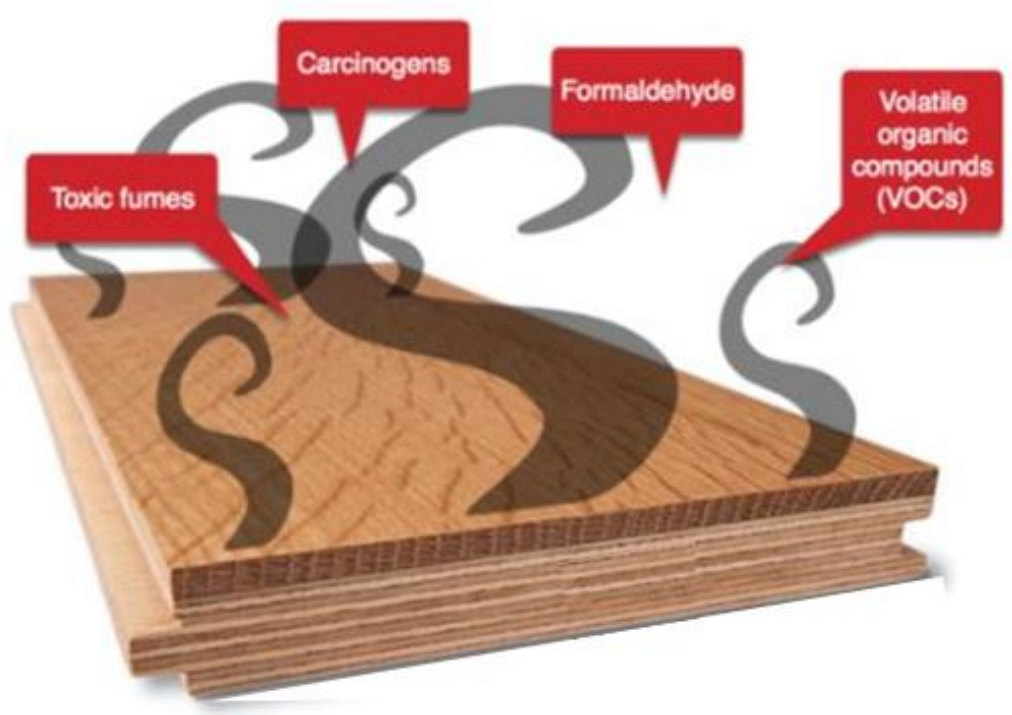
BUT

Engineered wood products contain large amounts of

<u>petroleum-based-adhesives</u> *(with Volatile organic compounds -VOC and formaldehyde)* that adversely affect **environment & human health**



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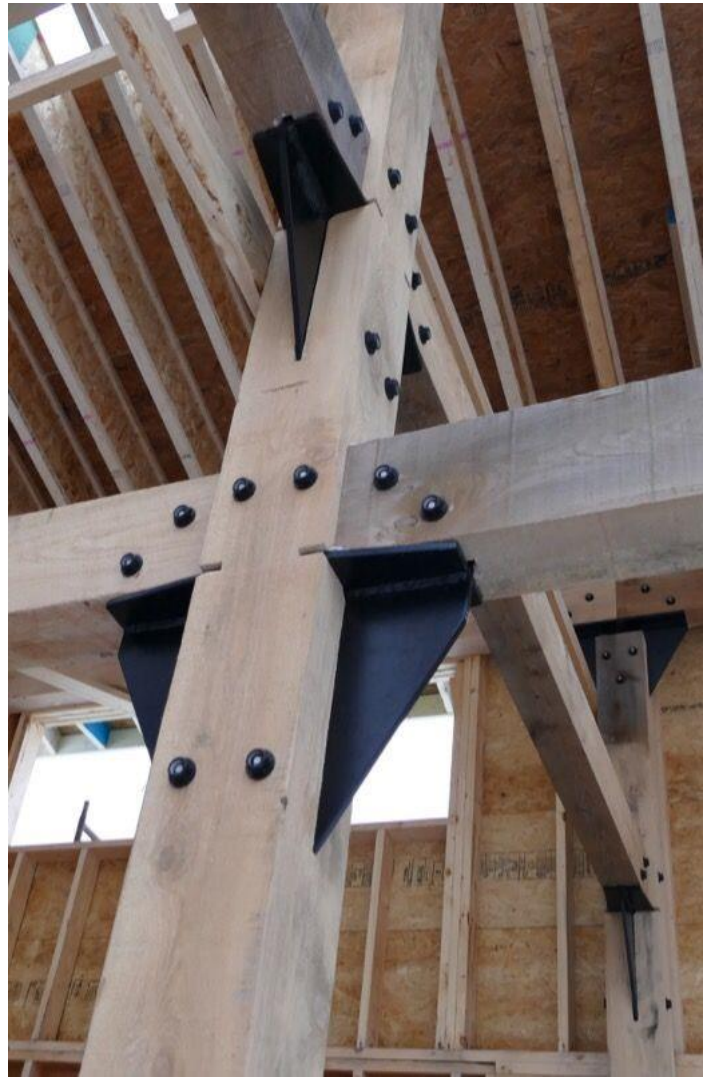
They contain also

metal fasteners that negatively affect

their **end-of-life disposal, recyclability,**

& reusability



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In addition, **Global Wood Recycling Market 2019-2023**

with **ONLY 4%** annual growth rate

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Moreover, increase in the cost of engineered wood products

* Stock: 60 - 70 € / m^3

* Sawn timber: 200 - 250 € / m^3

* CLT, LVL,GLT: 750 - 1000 € / m^3

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SOLUTION

Completely pure wood,

dovetailed massive wood board element

adhesive- and metal connector-free

based on one of the oldest joining methods

Our solution

Traditional dovetail joint

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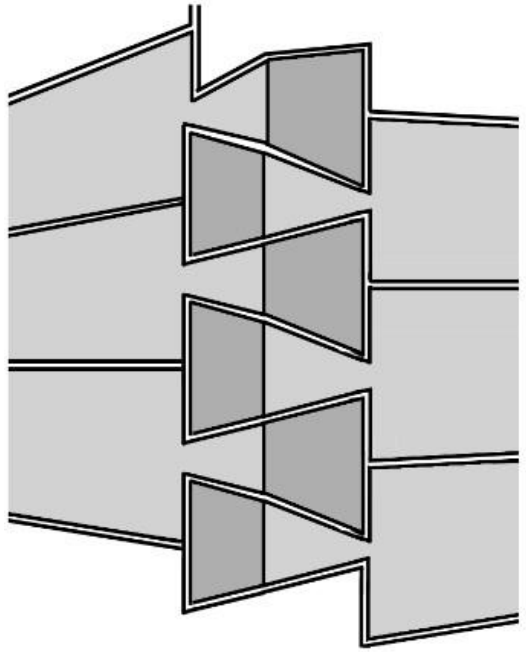
History of Dovetail Joint Technique

The history of this technique goes back to before Christ. Some of the earliest well-known examples were in ancient Egyptian furniture, stone pillars at temples, old churches, and Japanese traditional buildings.

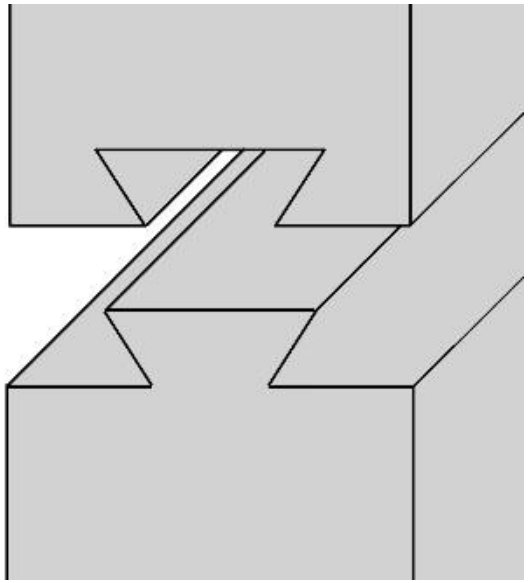
A stone pillar

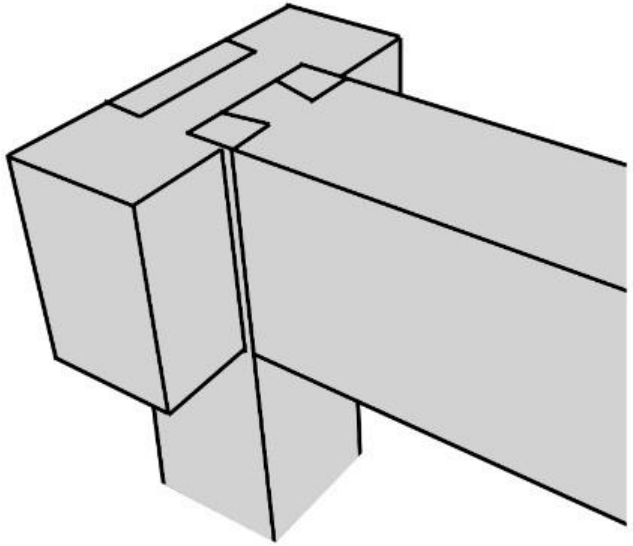


The Church in Cewków, Poland with dovetail corner detail

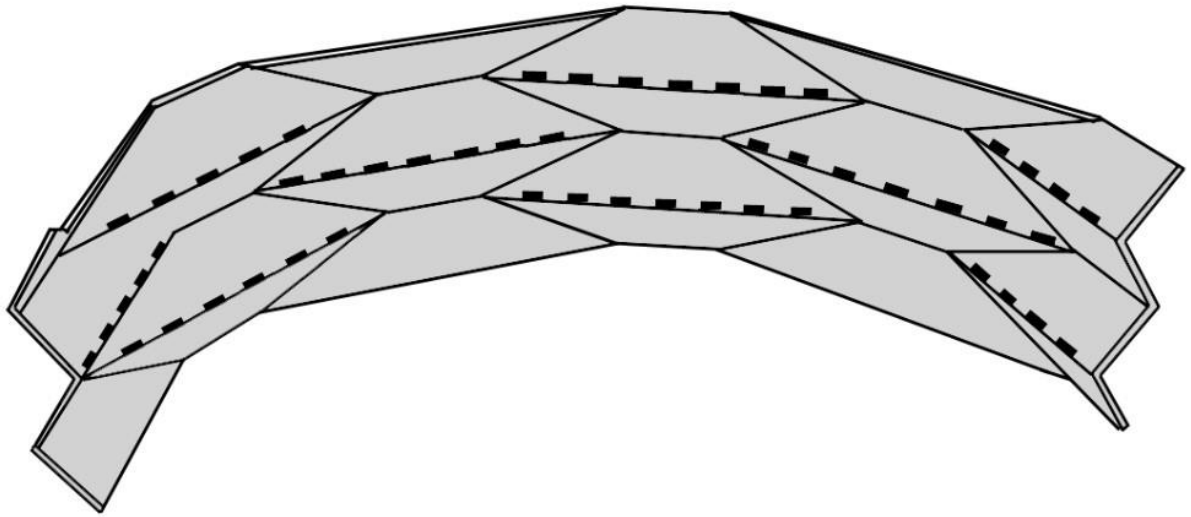
Current State-of-the-art of Dovetail joints

There is a limited number of studies on dovetail massive wood elements. To date, literature is based on a few research mostly about structural analysis and model testing of several types of joint details rather than assessing overall technical performance of structural components such as floor slab.





The dovetail joist for the test specimen



Folded-plate arch prototype

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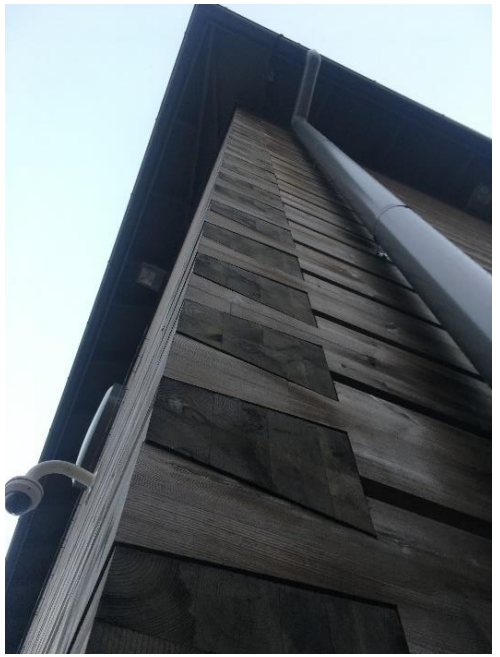
Current State-of-the-art of Dovetail joints

10,000 m² - School campus
Pudasjärvi, Finland



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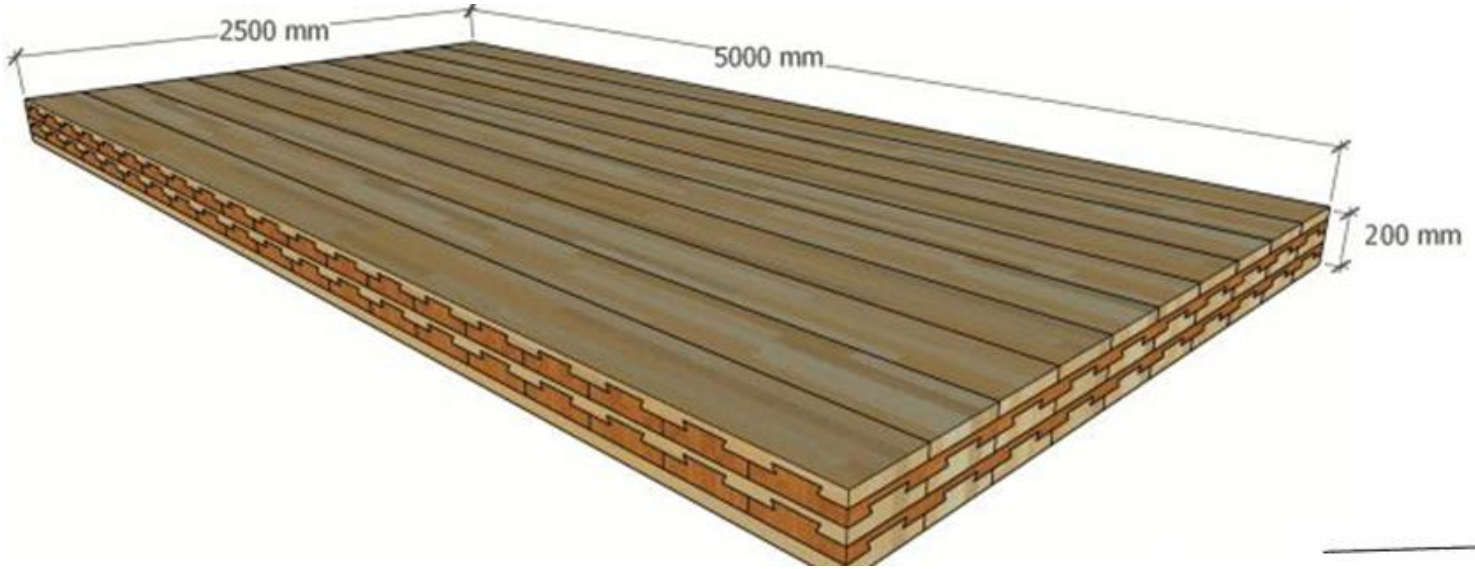
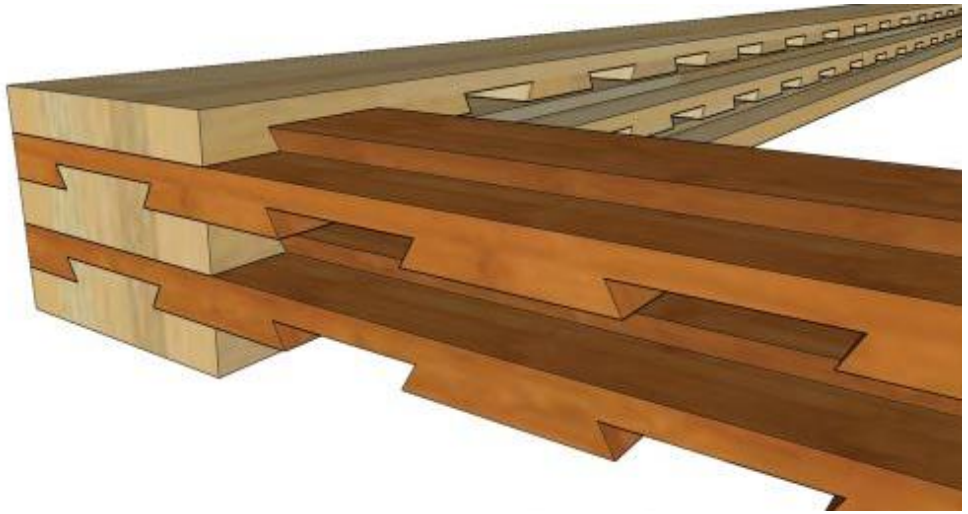
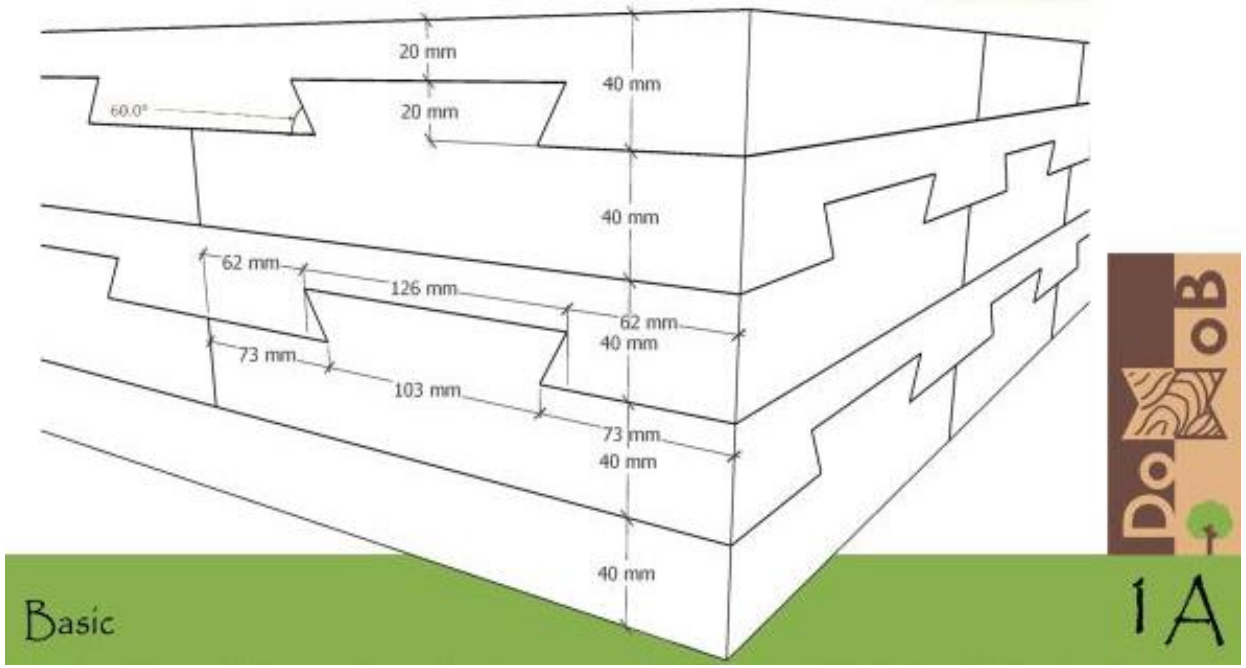
Dovetailed Massive Wood Board Elements for Multi-Story Buildings



Our aim:

- Design
- Producing
- Testing of **dovetail wooden slab element**
  (structural, fire, sound insulation, air-tightness)
- Comparison with equivalent sized CLT





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TEAM

- **Olli-Paavo Koponen** *(Chief advisor)*

  Professor (Arch. History), TAU / School of Architecture

- **Markku Karjalainen** *(Supervisor)*

  Professor (Arch. Construction), TAU / School of Architecture

- **Hüseyin Emre Ilgın** *(Principal researcher)*

  Post-doc researcher, TAU / School of Architecture

- **Sami Pajunen** *(Structural consultant)*

  Professor (Lightweight structures), TAU / Civil Engineering

- **Mikko Malaska** *(Fire safety consultant)*

  Professor (Fire safety), TAU / Civil Engineering

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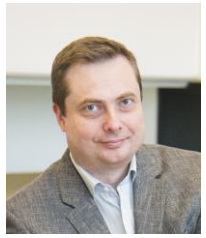
TEAM

- **Juha Vinha** *(Building physics consultant)*

  Professor (Building physics), TAU / Civil Engineering



- **Valtteri Hongisto** *(Acoustics consultant)*

  Research team leader, Turku University of Applied Sciences

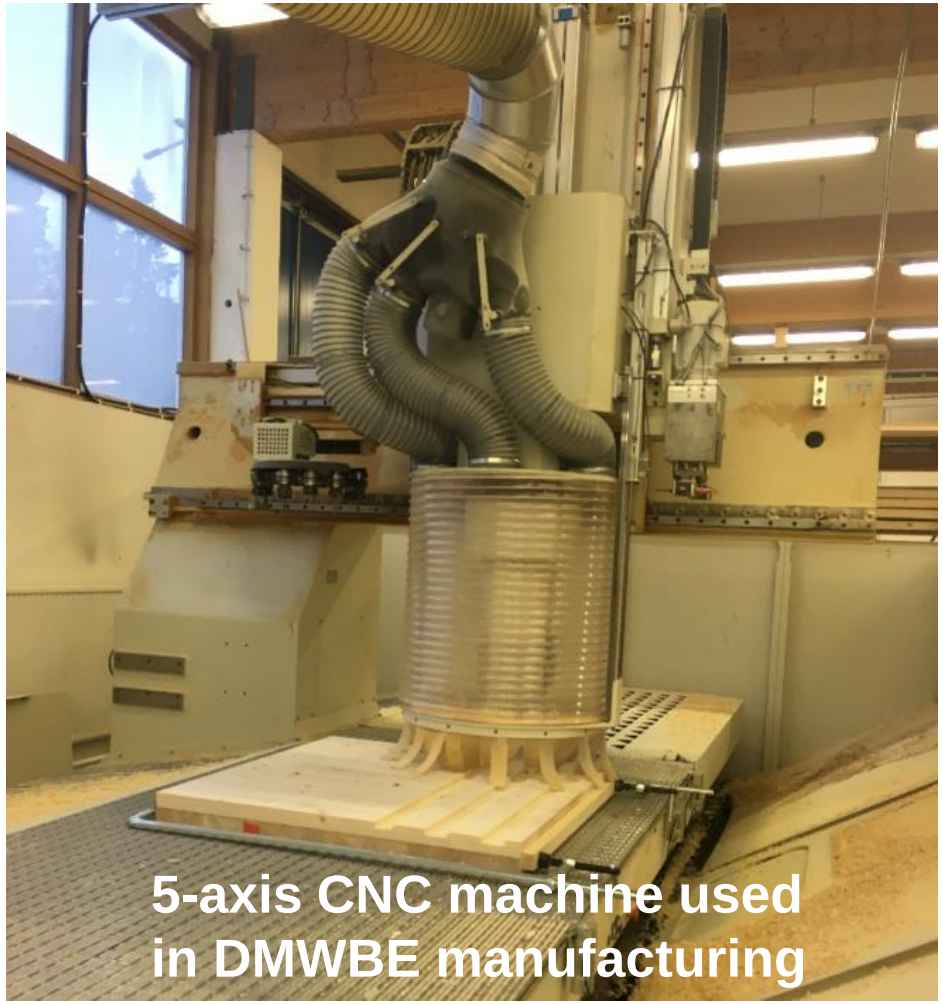
- **Teemu Laine** *(Marketing & patenting consultant)*

  Professor (Industrial Eng. and Manag., CMC), TAU / MAB

Manufacture of dovatail test specimens

DMWBE were manufactured at **Vocational College Lapland**, Kemi, Finland.

- 5-axis CNC machine with NUM operating system
- compatible SOLIDWORKS computer application
- CNC post-processor methodology
- toolpath optimization and G-code simulation
- moisture content of 10-12% during manufacture



5-axis CNC machine used in DMWBE manufacturing

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CLT test specimens

CLT boards were produced locally at **CLT Plant Oy (Kauhajoki, Finland)**

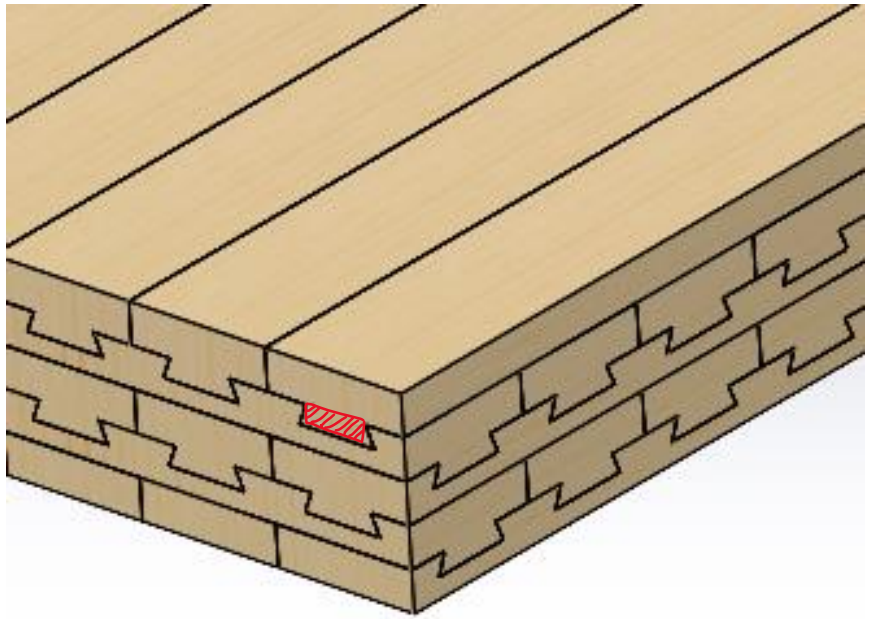
for a comparison with DMWBE in technical performance tests.

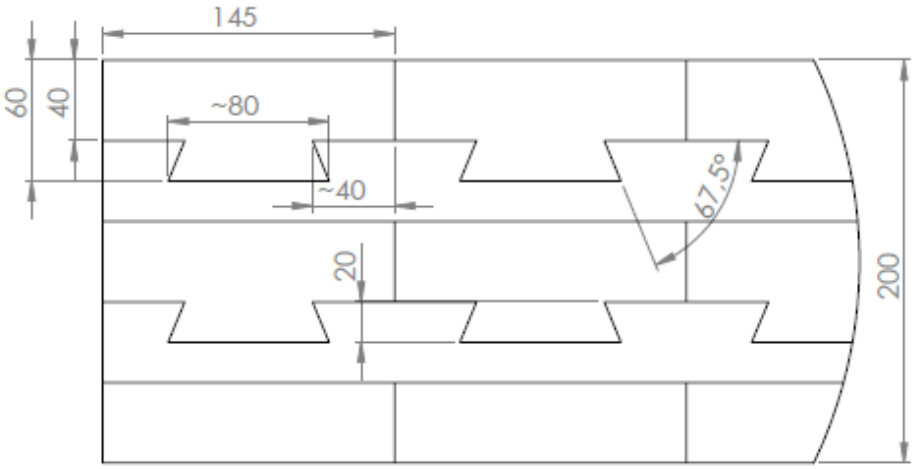
The adhesive used in CLT panels was **M1 class polyurethane,** used on four sides.

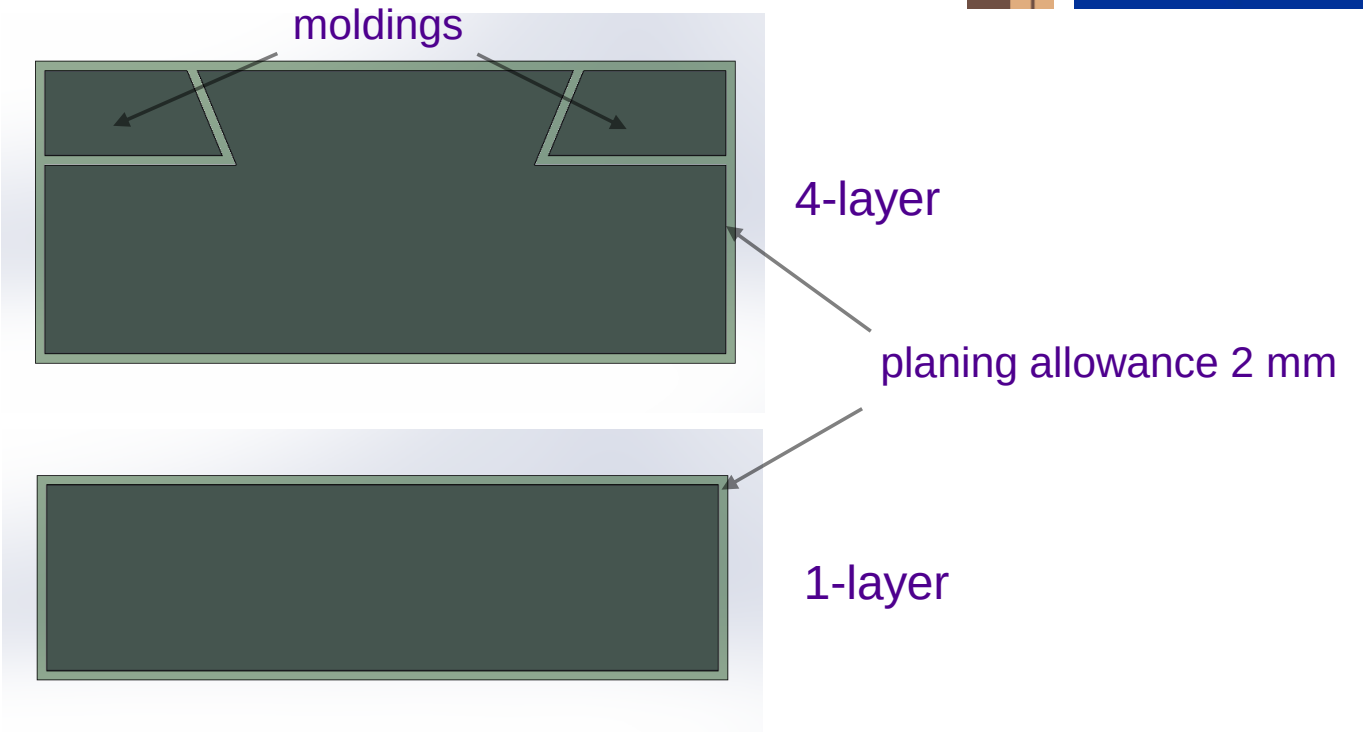
The panels were made of **Norway Spruce** with strength class **C24** PS.

Manufacture of dovatail test specimens

(raw material usage / waste amount ratio)







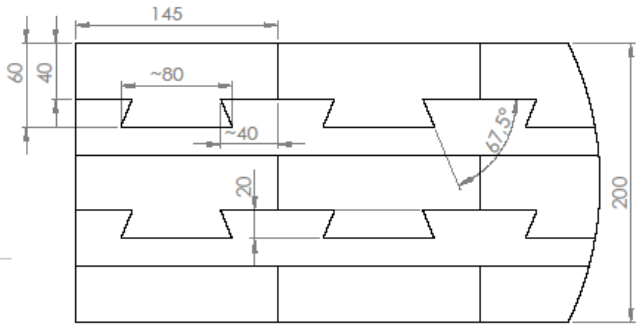
Dovetail board (5-layer) raw material usage ratio
before planing and CNC machining

- **1,54** (without moldings)
- **1,37** (with moldings)
- **~ 1,25** (+ rectangular cut to be used as sill or plinth)

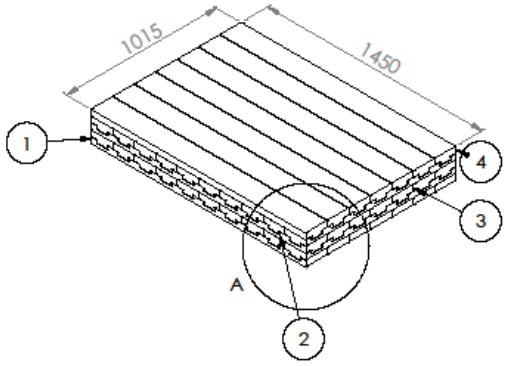
- *CLT raw material usage ratio ~**1,13***

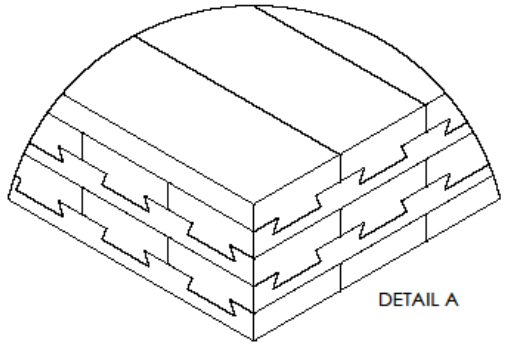
Fire resistance test specimens

PARAMETRIC DOVETAIL BOARD



Right View





DETAIL A

ITEM NO.	QTY.	CNC-table	LENGTH	SUM (mm)
1	7	1 layer	1450	10150
2	20	2 and 4 layer	1015	20300
3	7	3 layer	1450	10150
4	7	5 layer	1450	10150
			SUM all	50750

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR: | FINISH: | DEBURR AND BREAK SHARP EDGES

LAPPIA

	NAME	SIGNATURE	DATE
DRAWN	Matti	Yliniemi	
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Tampereen yliopisto Arkkitehtuurin yksikkö

MATERIAL: Spruce timber

DWG NO. DW Test 5 layer

A3

WEIGHT:

SHEET 1 OF 1

26.01.2022

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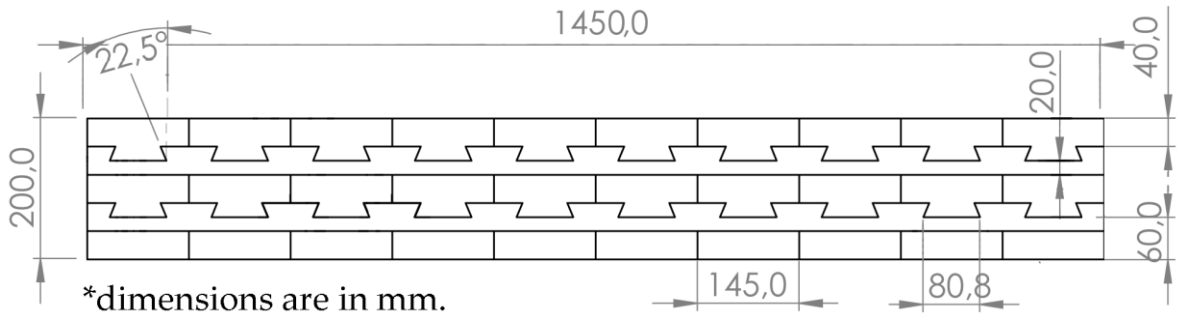
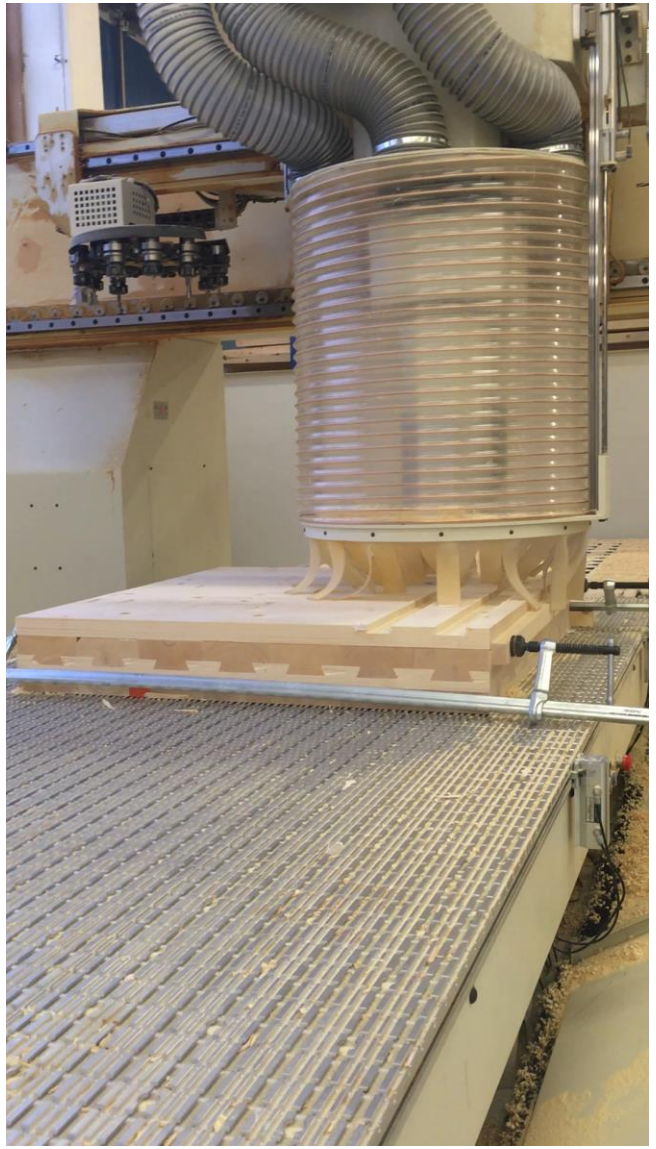
Fire resistance test specimens





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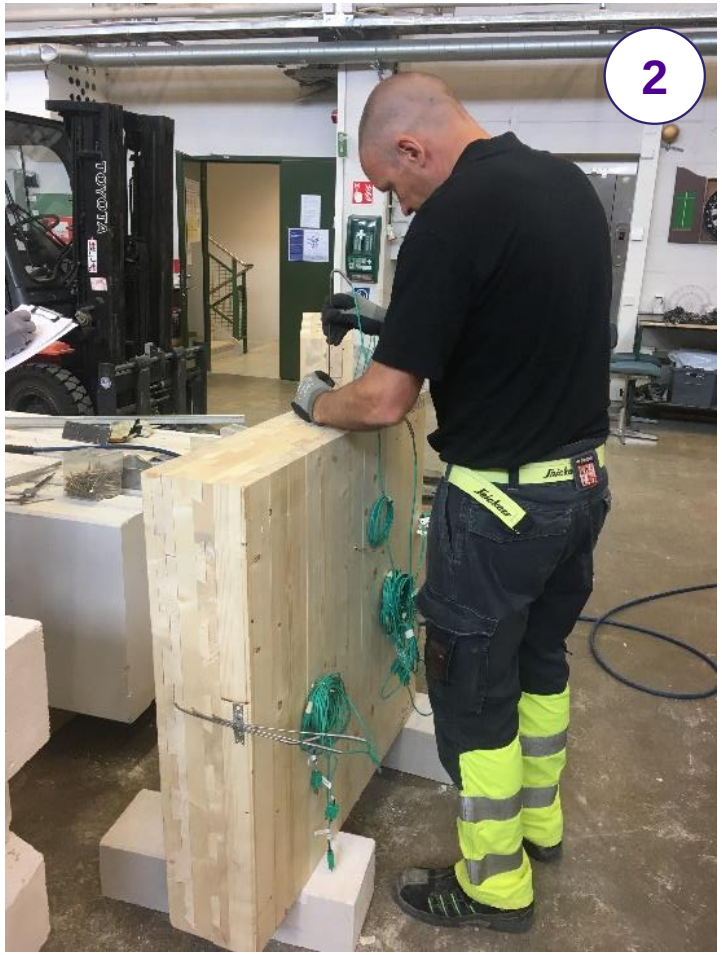
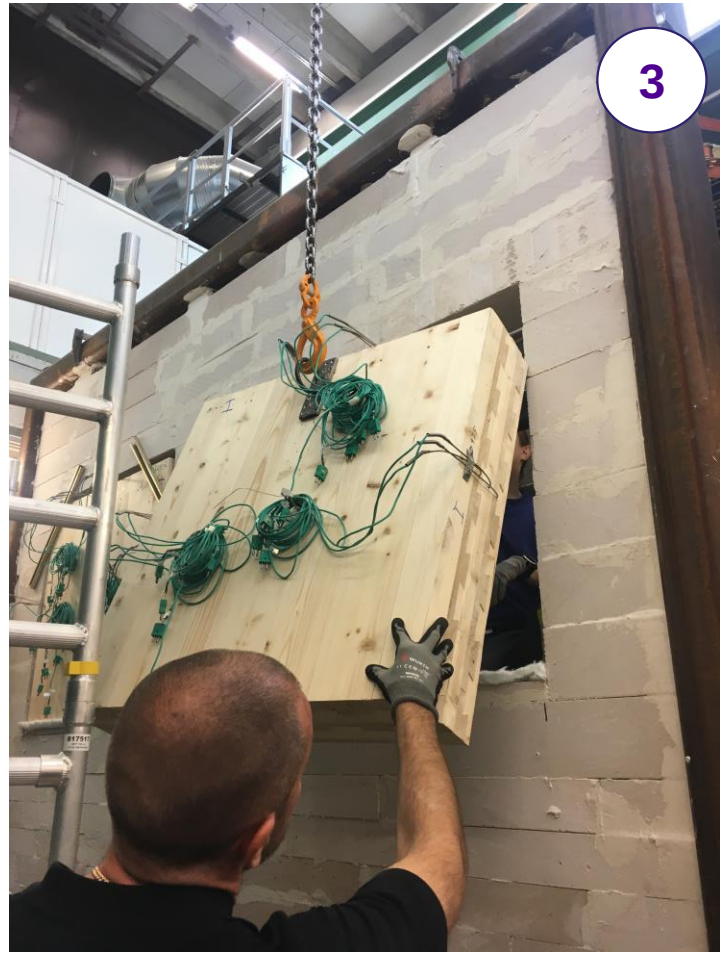
Fire resistance test / Dovetail boards

(14.04 - 28.04.2022) (SFS-EN 1363-1:2020)





Preparation of dovetail specimens for fire resistance test at Tampere University Fire Laboratory
(1) **drilling** (2) **thermocouple insertion** (3) **mounting on the supporting construction**

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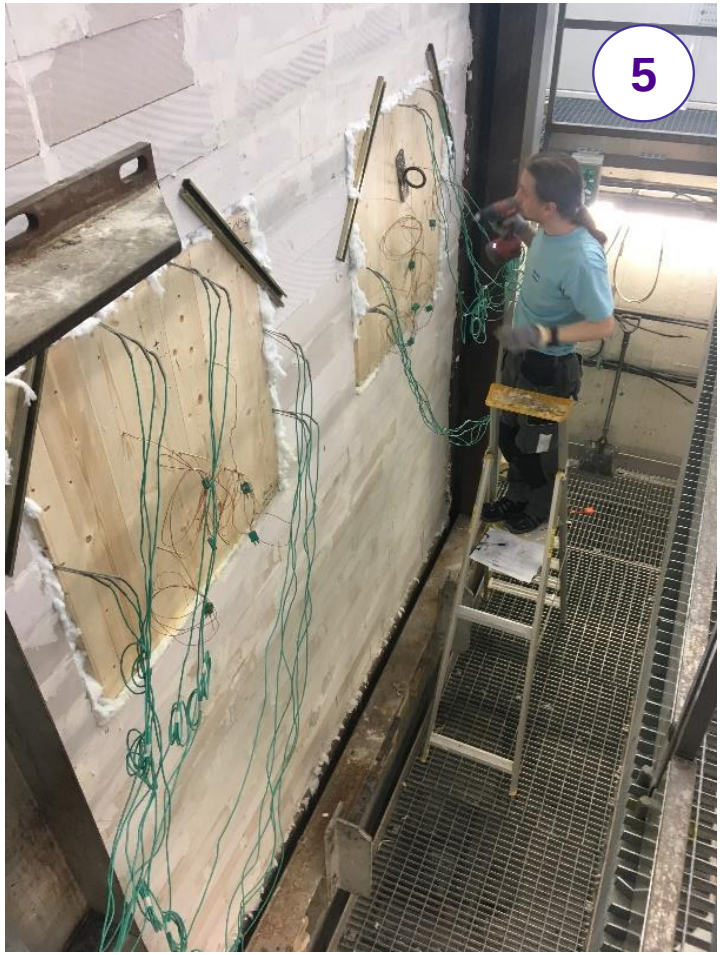
Fire resistance test / Dovetail boards

(14.04 - 28.04.2022)



Preparation of dovetail specimens for fire resistance test at Tampere University Fire Laboratory
(4) **moving the wall to the furnace** (5) **connecting sensors**

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Fire resistance test / Dovetail boards

(14.04 - 28.04.2022)

(6) **BURNING** (7) **disassembly of test pieces and removal of sensors** (8) **cutting specimens**

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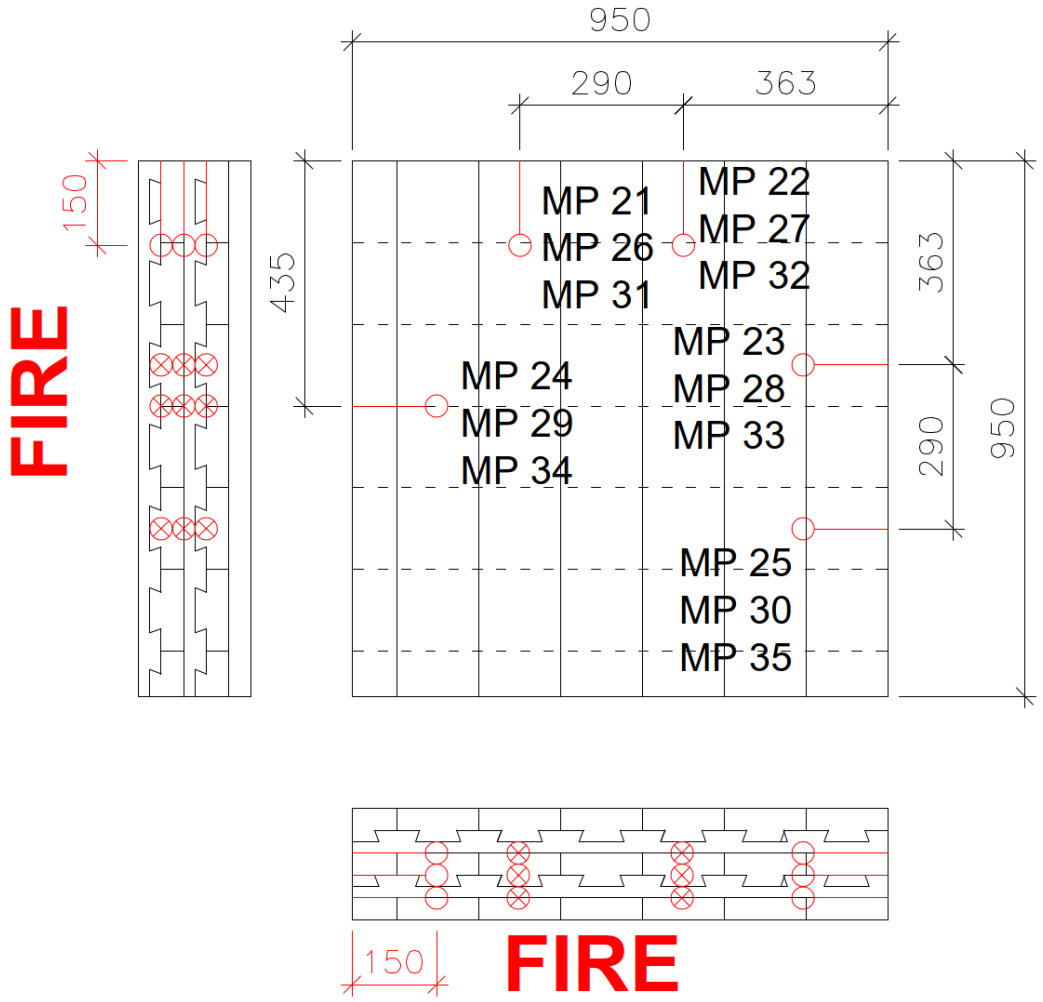
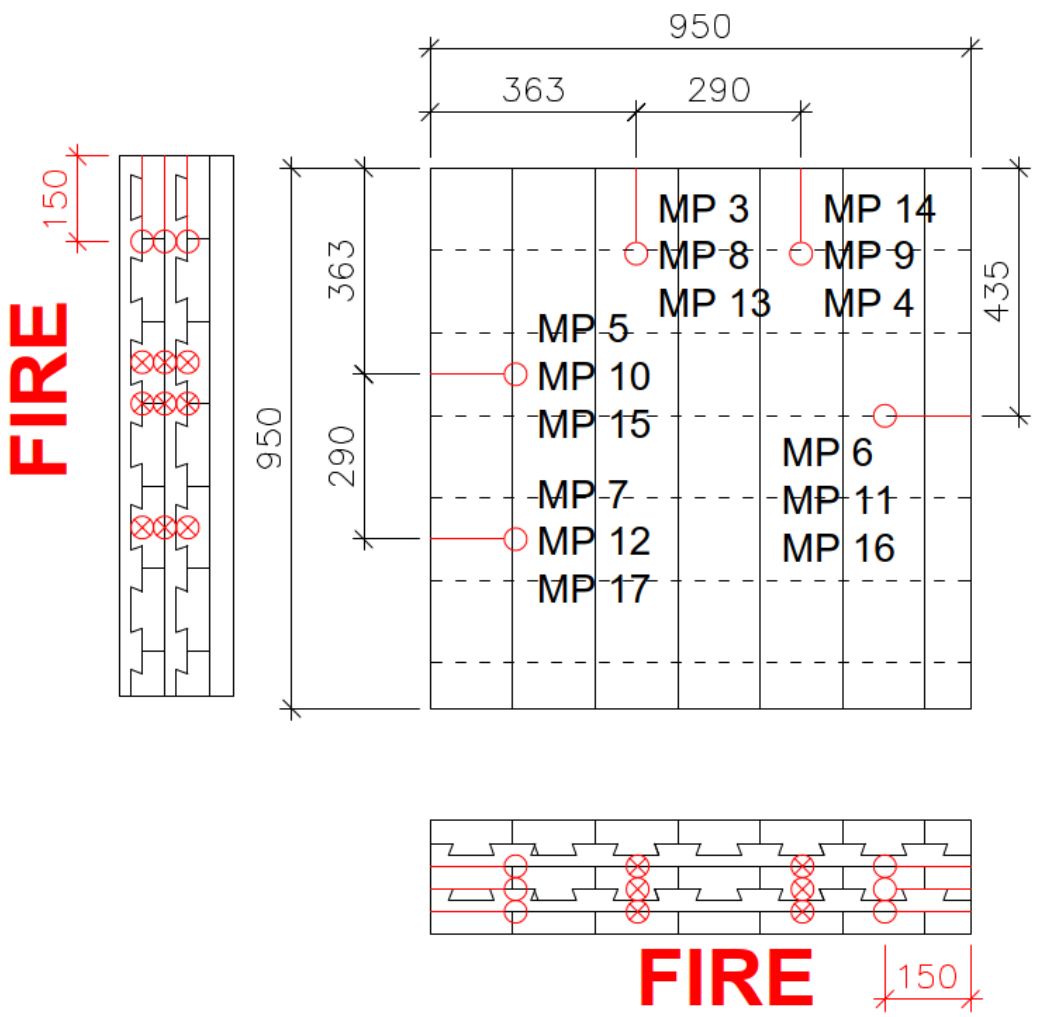
Fire resistance test (char depth)

(Dovetail boards)

Specimen I



Specimen II



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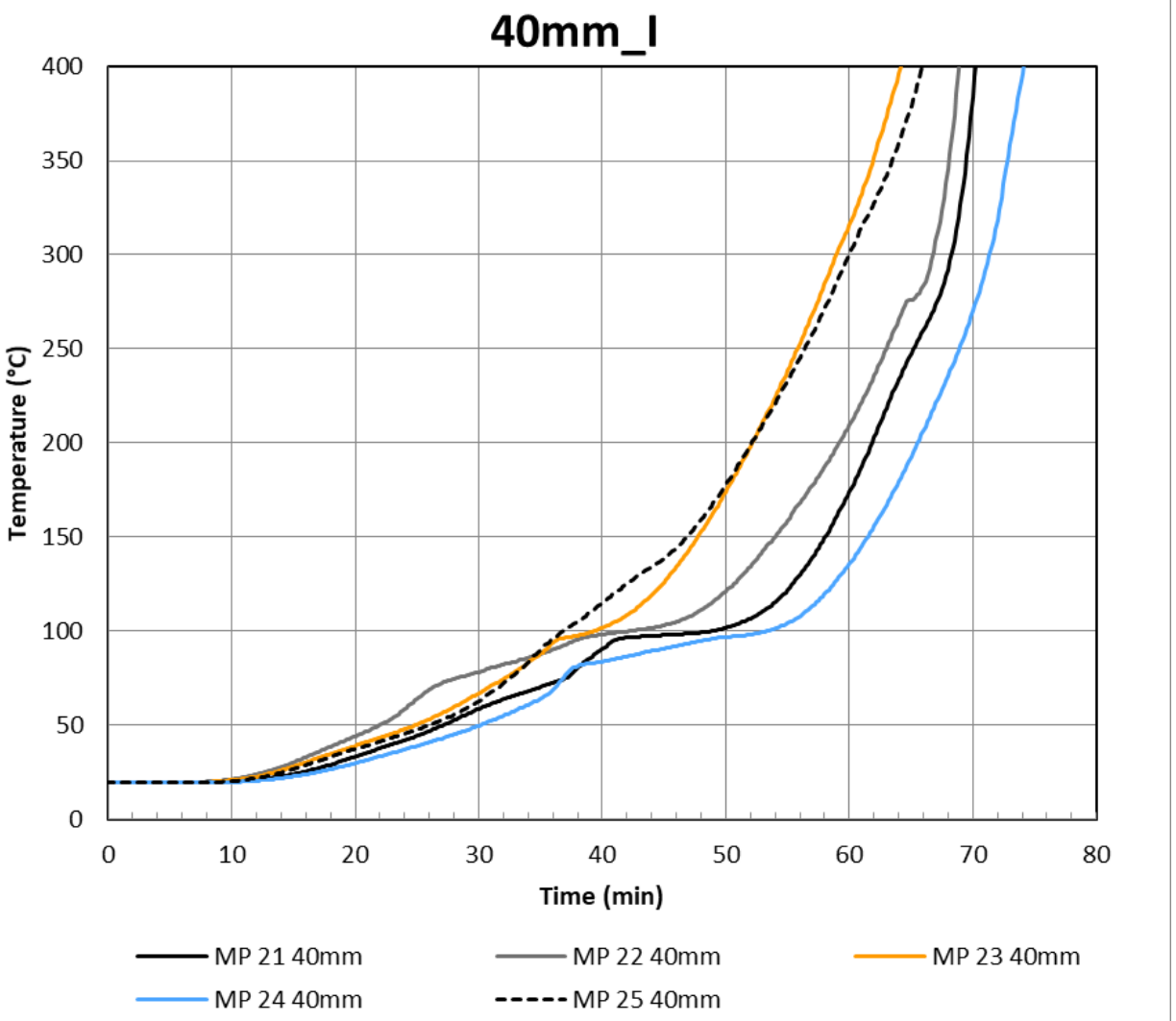
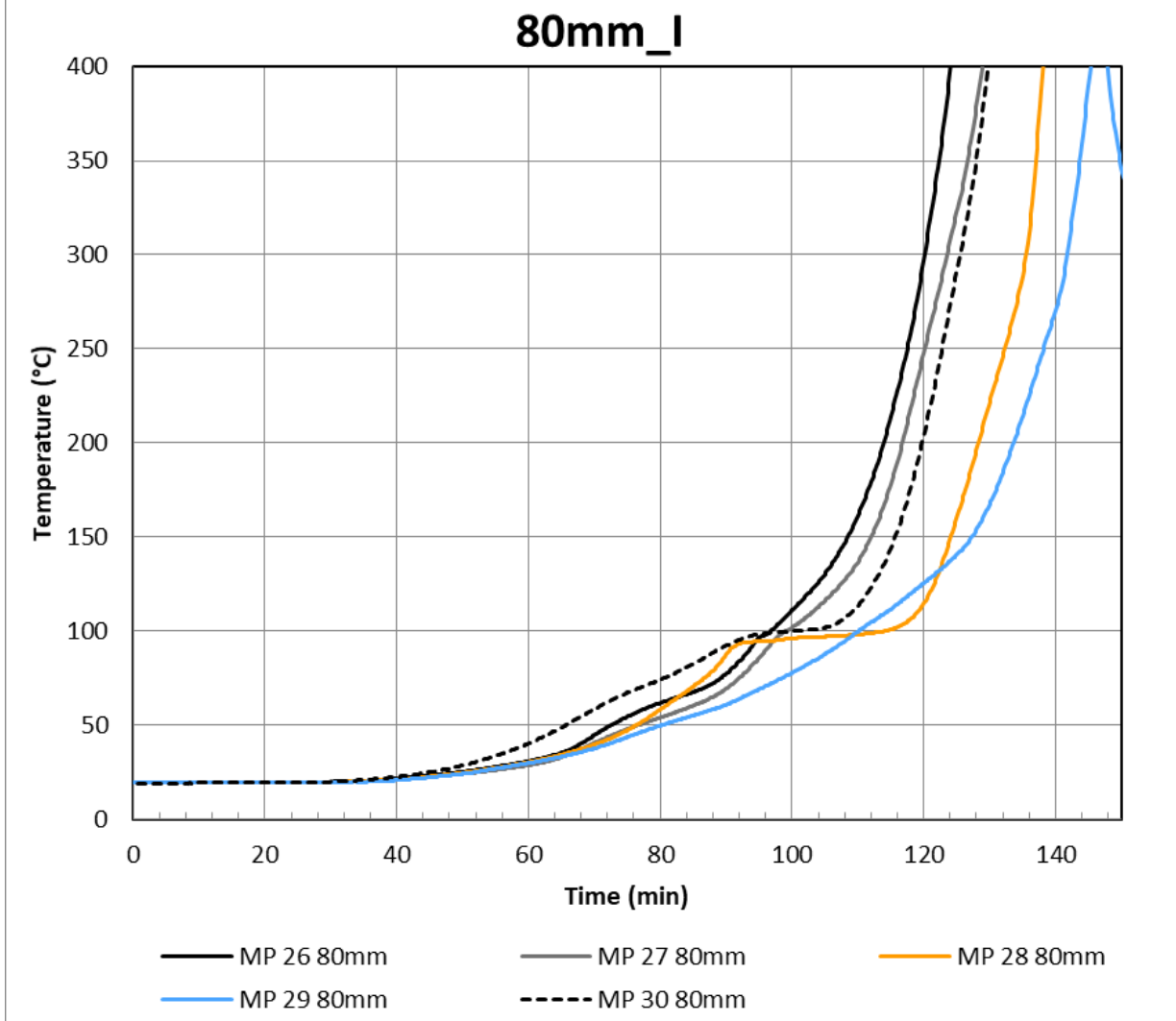
Fire resistance test

(Dovetail board_Specimen I)





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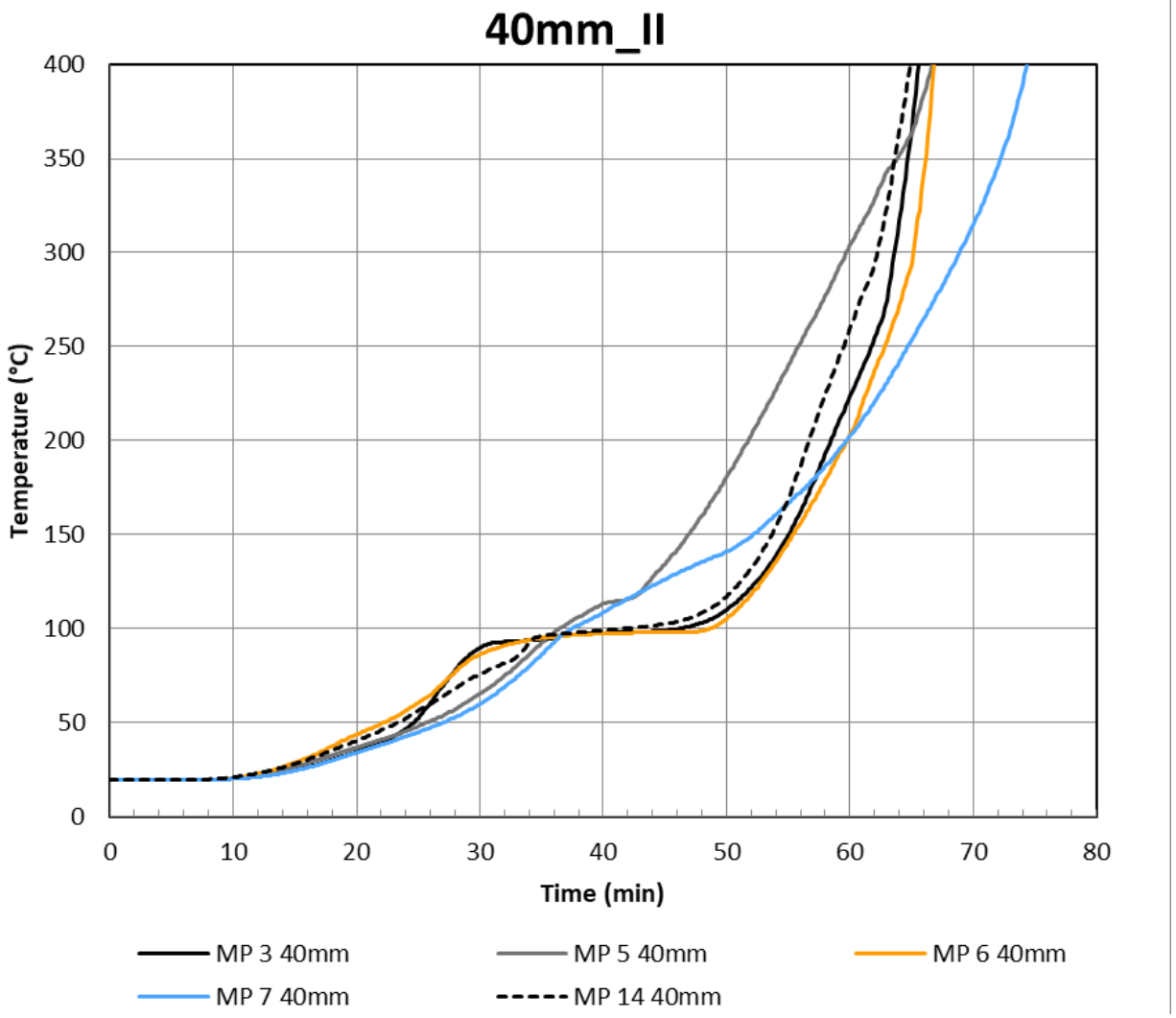
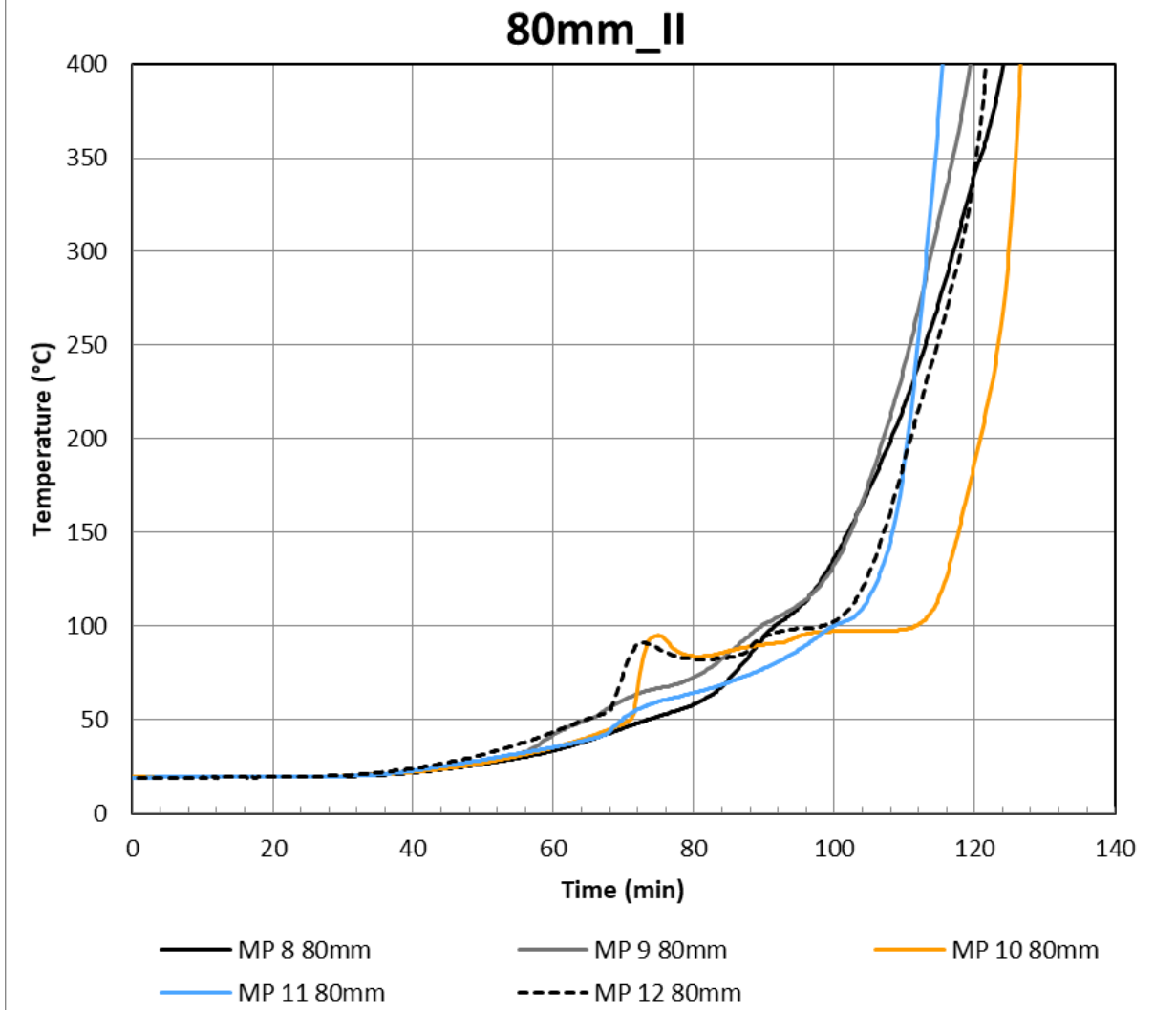
Fire resistance test

(Dovetail board_Specimen II)





Charring is reached measurement point when the temperature reaches **300°C** ***(1.57 min)***

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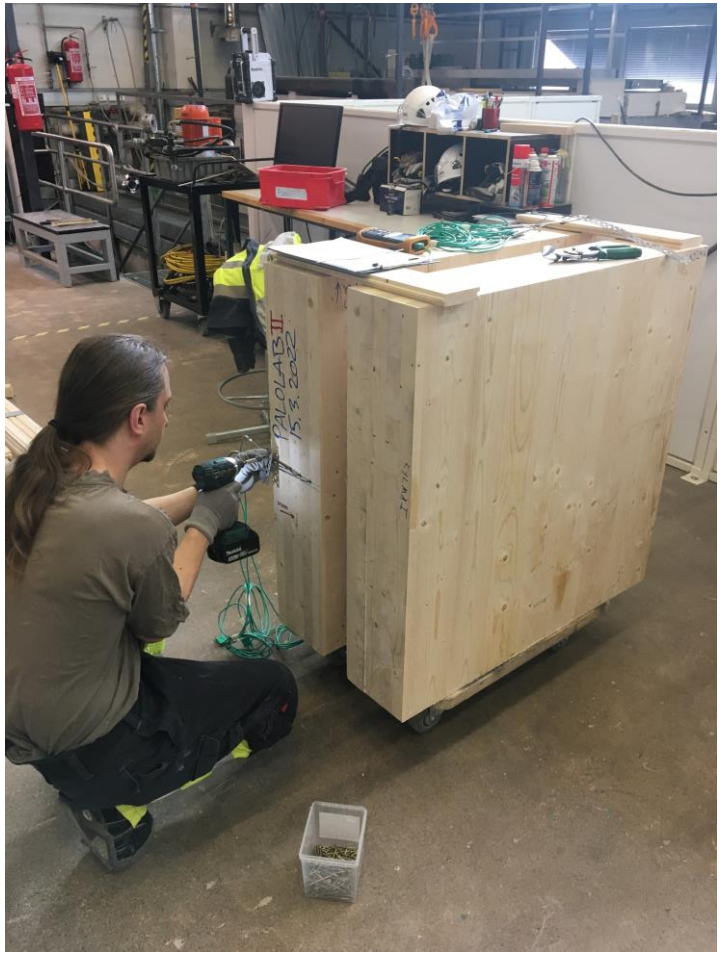
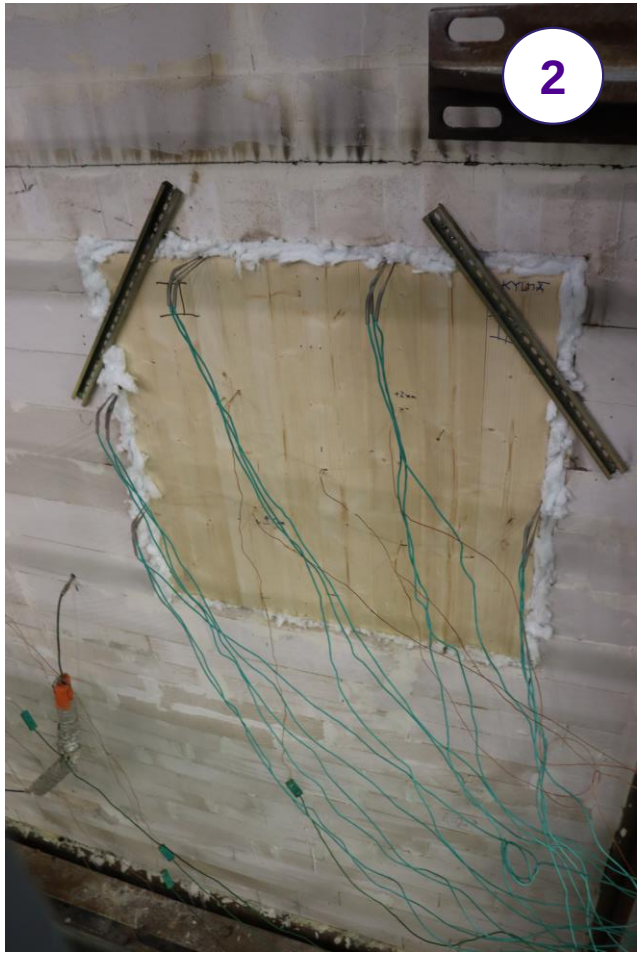
Fire resistance test / CLT boards

(02 - 09.05.2022)





Preparation of CLT specimens for fire resistance test at Tampere University Fire Laboratory
(1) **drilling & thermocouple insertion** (2) **mounting on the supporting construction**

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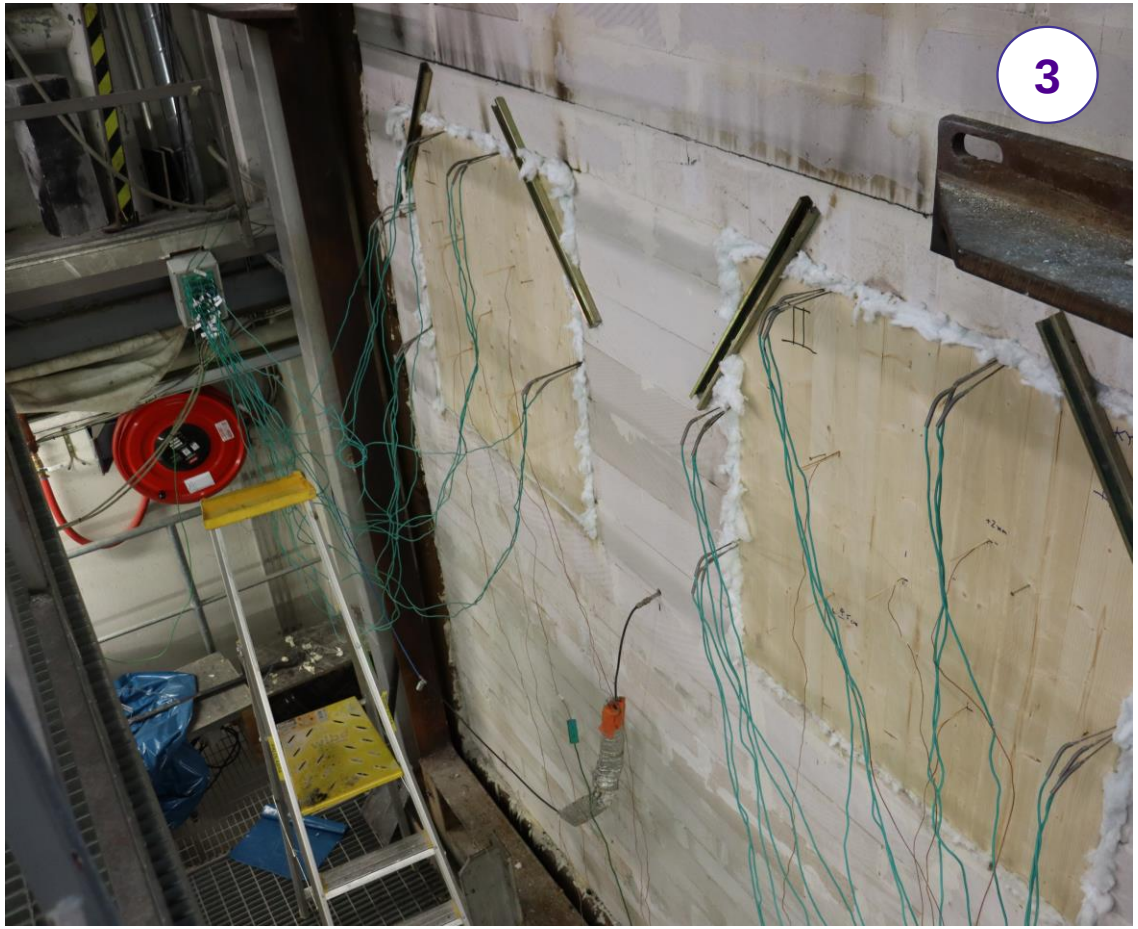
Fire resistance test / CLT boards

(02 - 09.05.2022)



(3) **moving the wall to the furnace & connecting sensors** (4) **BURNING**

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Fire resistance test / CLT boards

(02 - 09.05.2022) (SFS-EN 1363-1:2020)

(5) **disassembly of test pieces and removal of sensors** (6) **cutting specimens**

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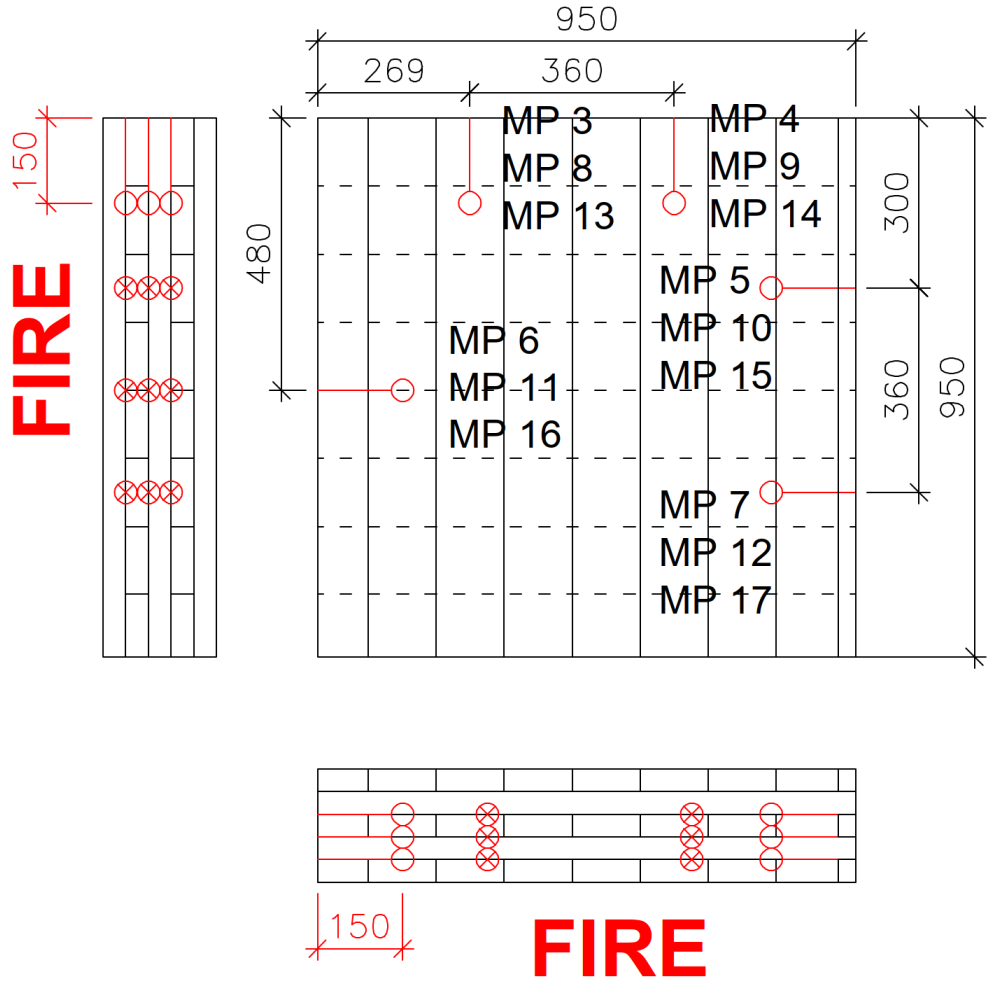
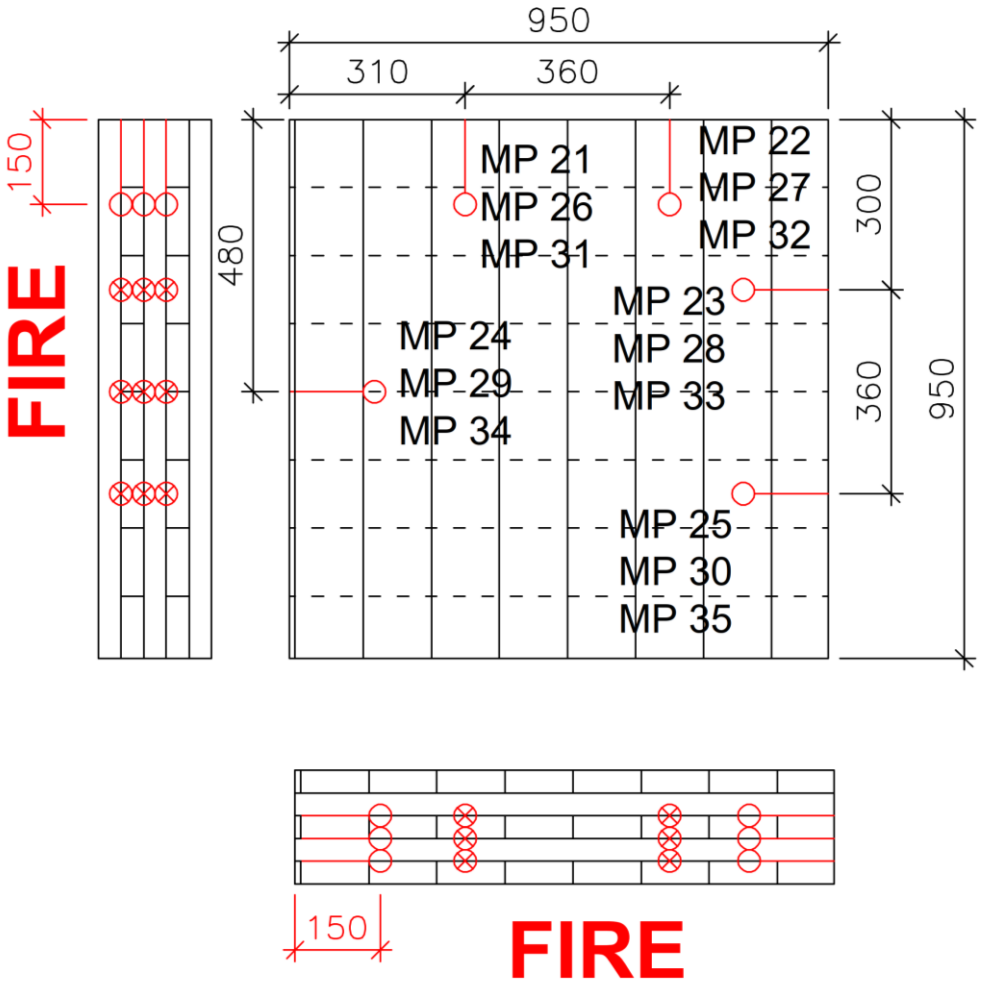
Fire resistance test (char depth)

(CLT boards)

Specimen I



Specimen II



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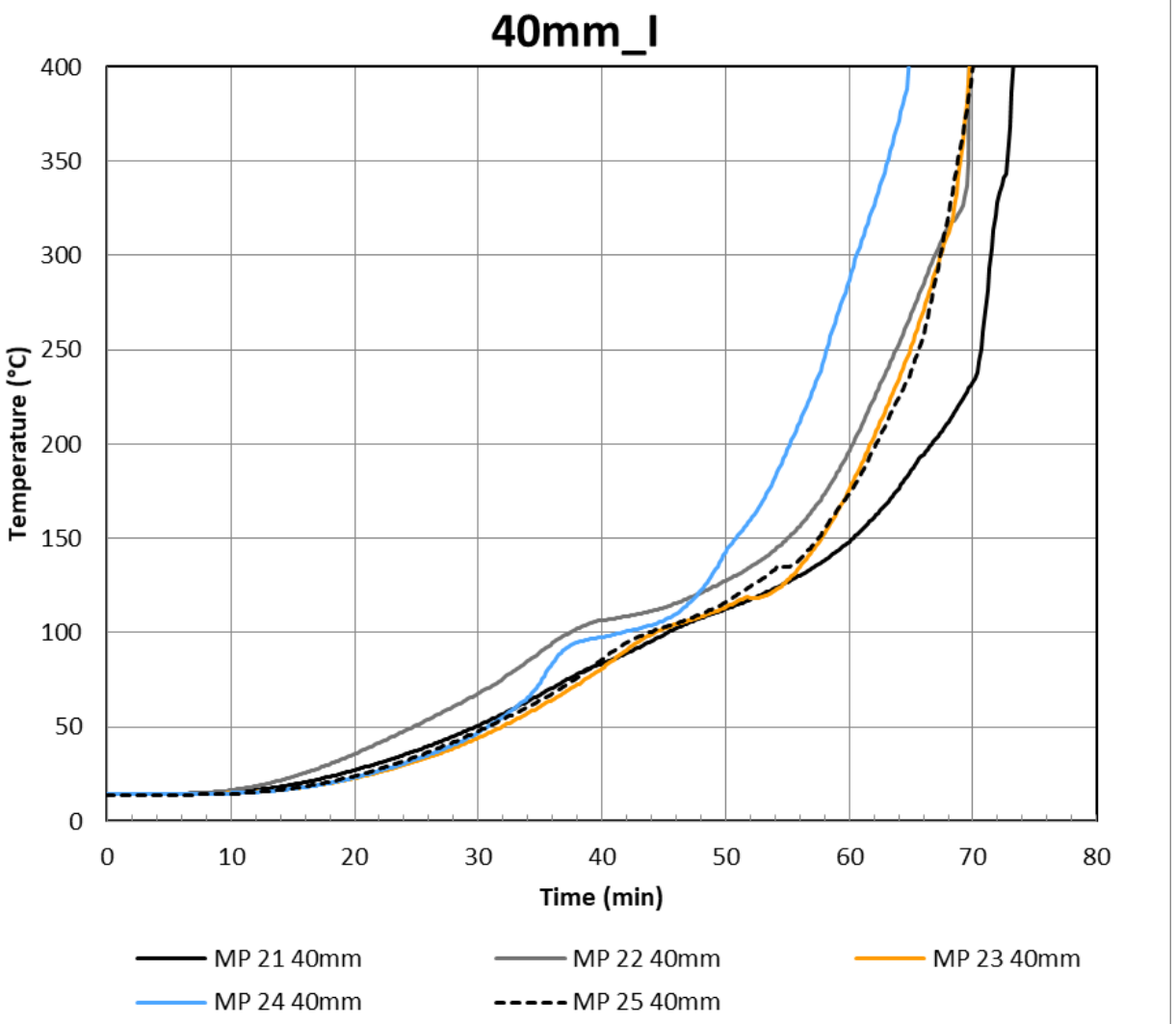
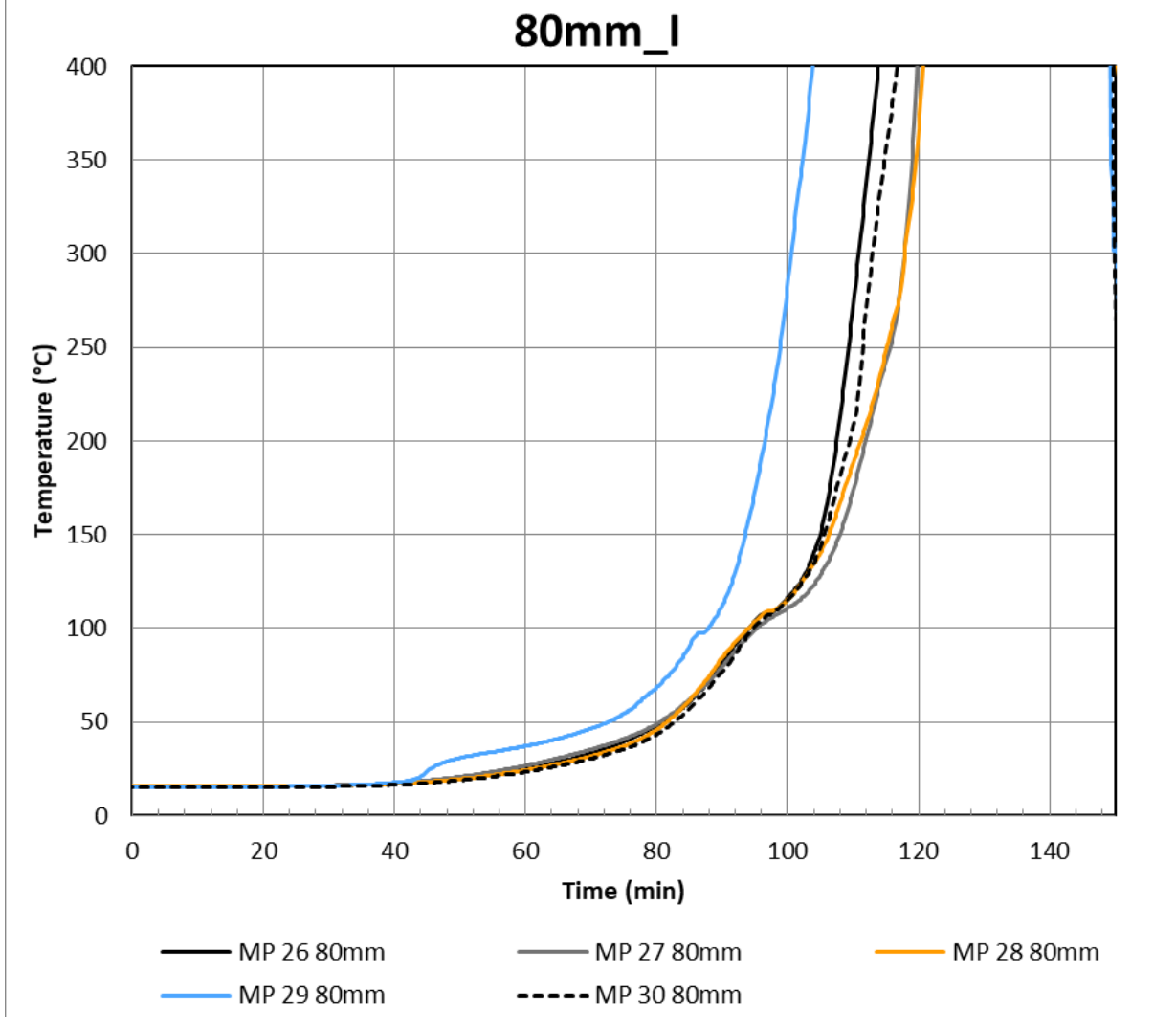
Fire resistance test

(CLT board_Specimen I)





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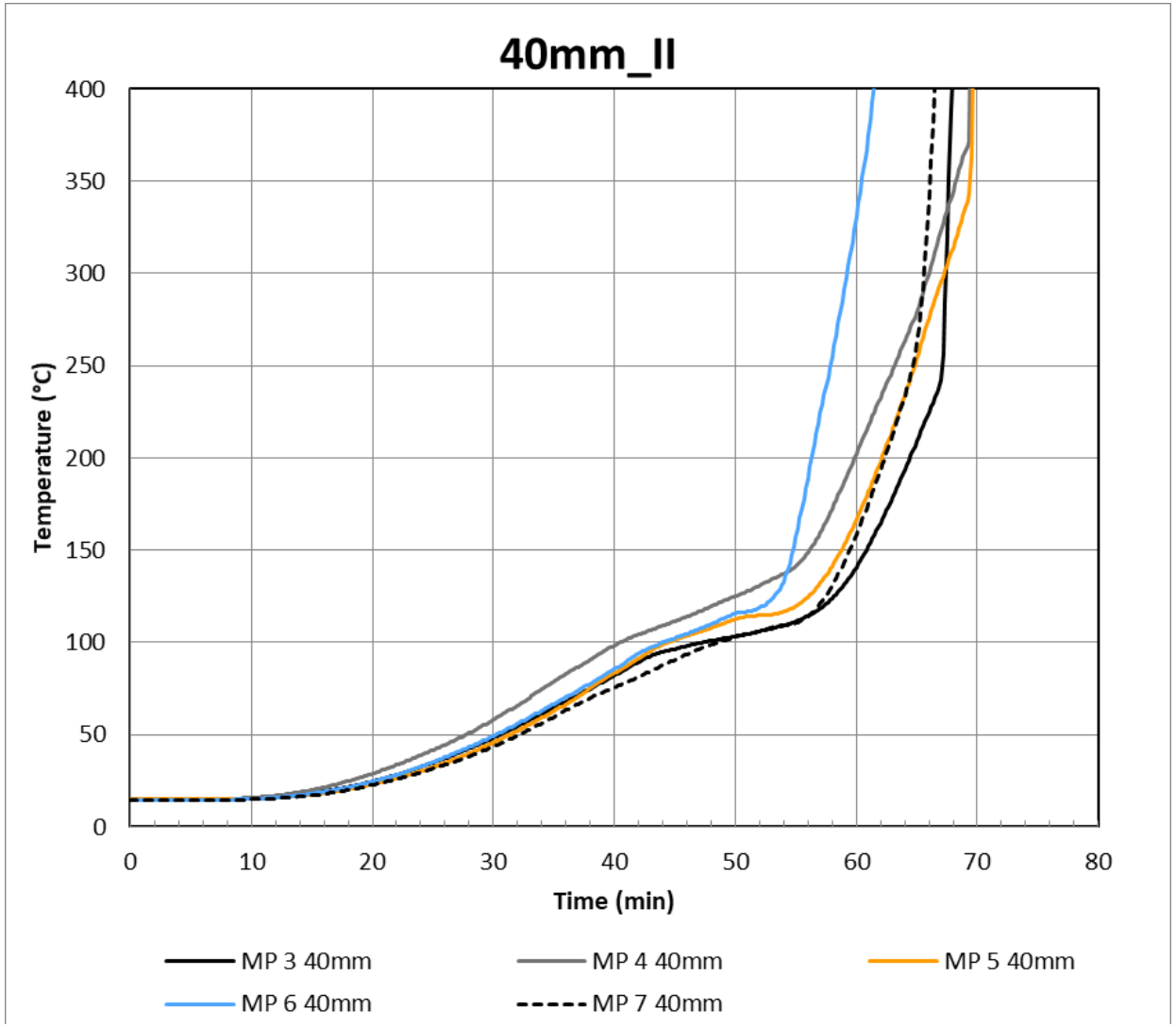
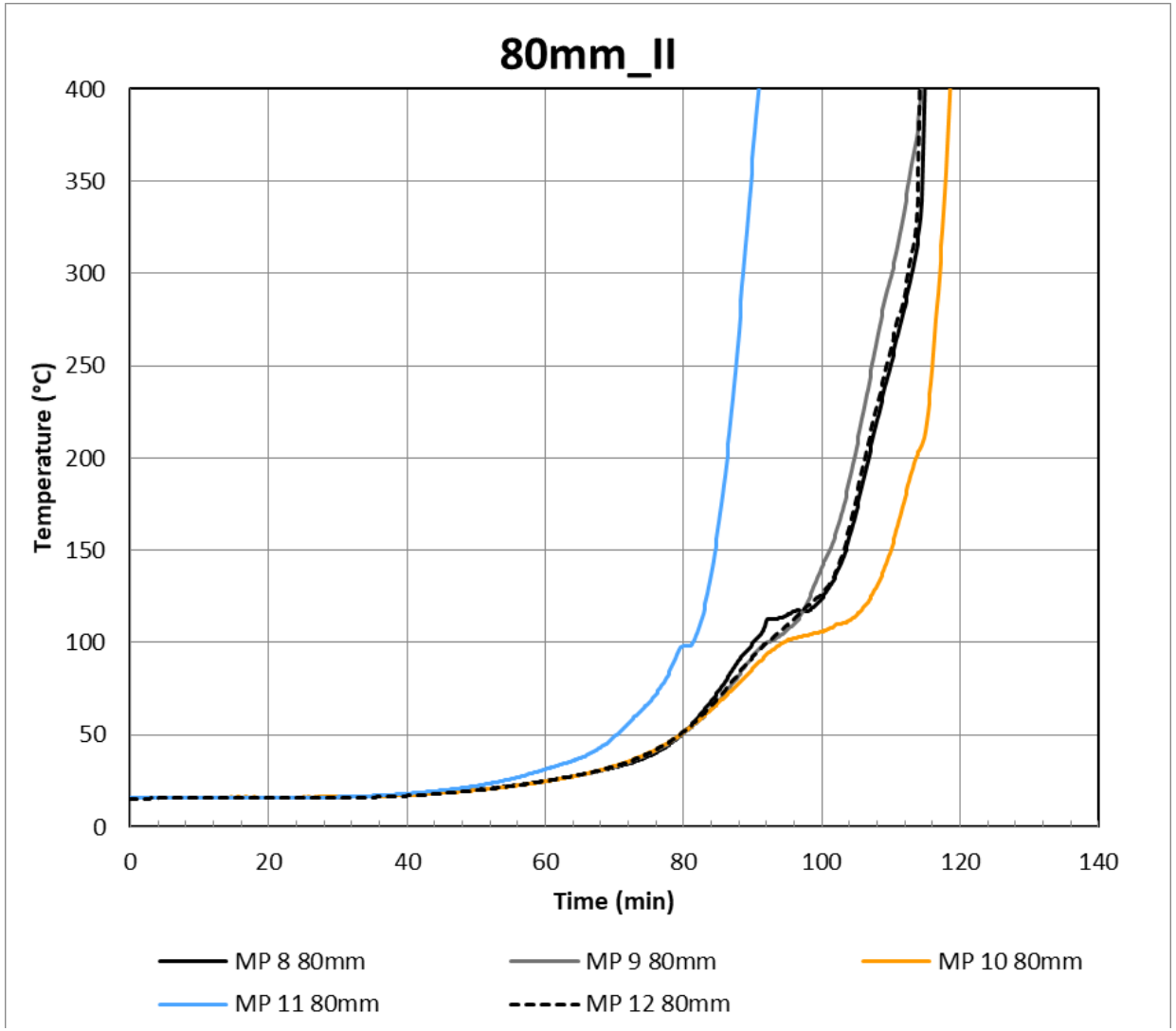
Fire resistance test

(CLT board_Specimen II)

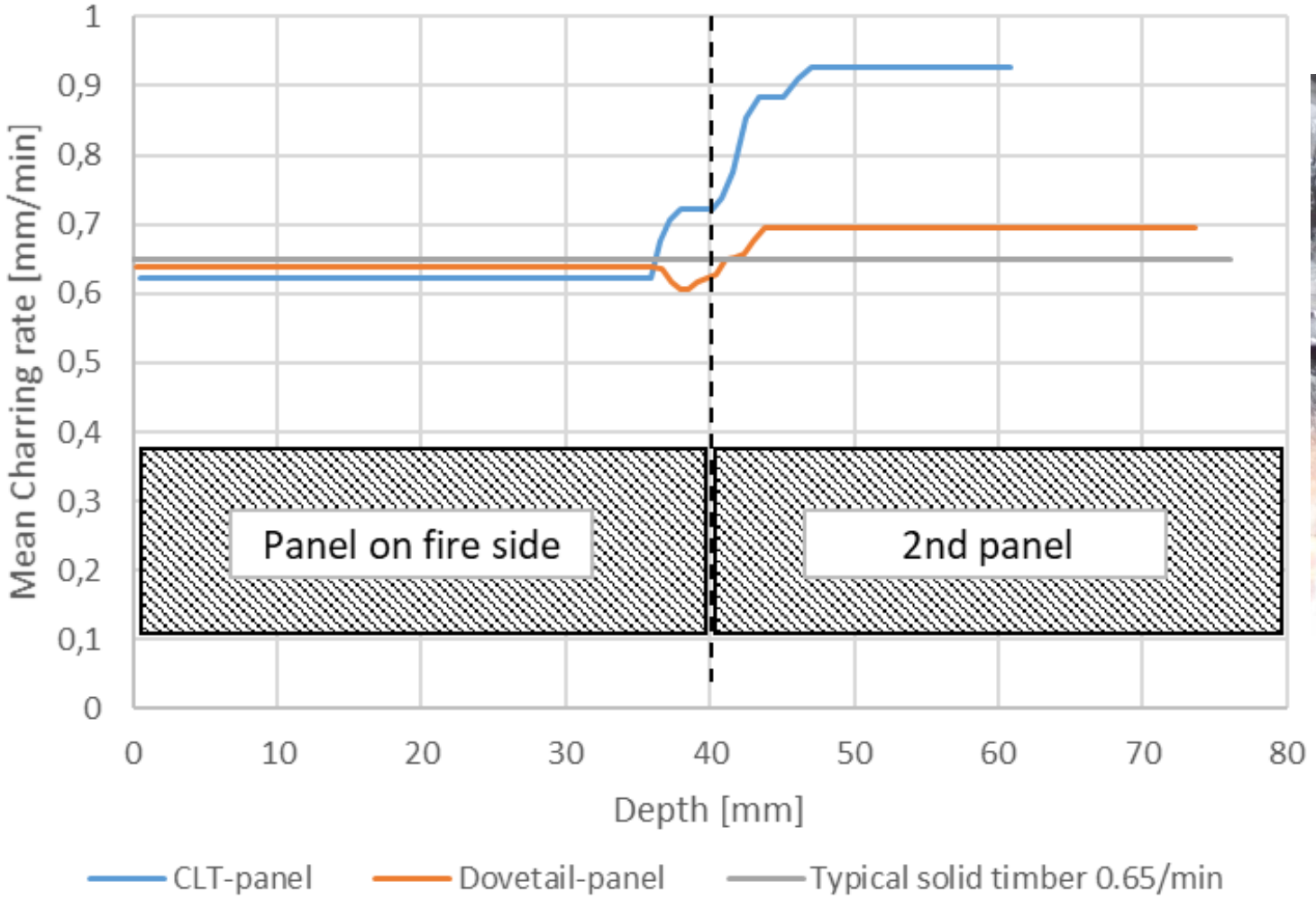




Charring is reached measurement point when the temperature reaches **300°C** ***(1.27 min)***

Tampereen yliopisto
Tampere University

Fire resistance test (char depth)
(CLT vs Dovetail)



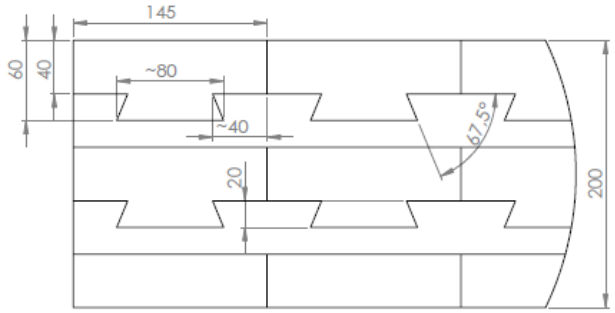
Char rates about **0.92 mm/min *(CLT)*** & **0.70 mm/min *(Dovetail)*** *for second lamella layer*

Dovetail performed **significantly better** than CLT

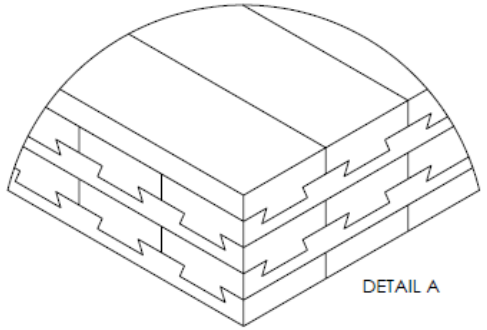
(Typically, acceptable char rates for timber are about 0.50 mm/min for hardwoods and 0.65 mm/min for softwoods)

Airborne sound insulation test specimens

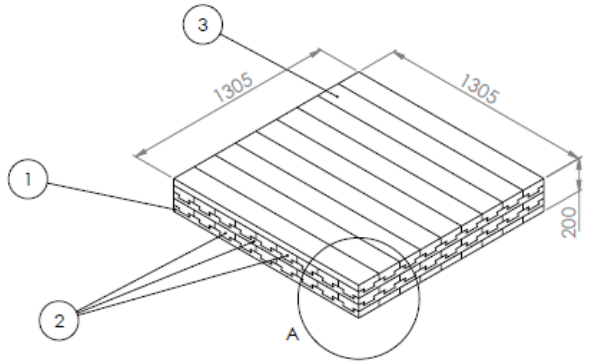
PARAMETRIC DOVETAIL BOARD



Right View



DETAIL A



ITEM NO.	QTY.	CNC-table	LENGTH	SUM (mm)
1	9	1 layer	1305	11745
2	27	2,3,4 layer	1305	35235
3	9	5 layer	1305	11745
			SUM all	58725

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR: | FINISH: | DEBURR AND BREAK SHARP EDGES

Tampereen yliopisto Tampere University | LAPPIA

	NAME	SIGNATURE	DATE
DRAWN	Matti	Yliniemi	
CHK'D			
APP'VD			
MFG			
Q.A			

TITLE: Tampereen yliopisto Arkkitehtuurin yksikkö

MATERIAL: Spruce timber

DWG NO. DW Test 5 layer

A3

WEIGHT: ~150kg

SHEET 1 OF 1

* Test specimens cut in 1160x1190x200 mm

20.05.2022

Tampereen yliopisto
Tampere University

Airborne sound insulation test

CLT and Dovetail boards

(27.05.2022)

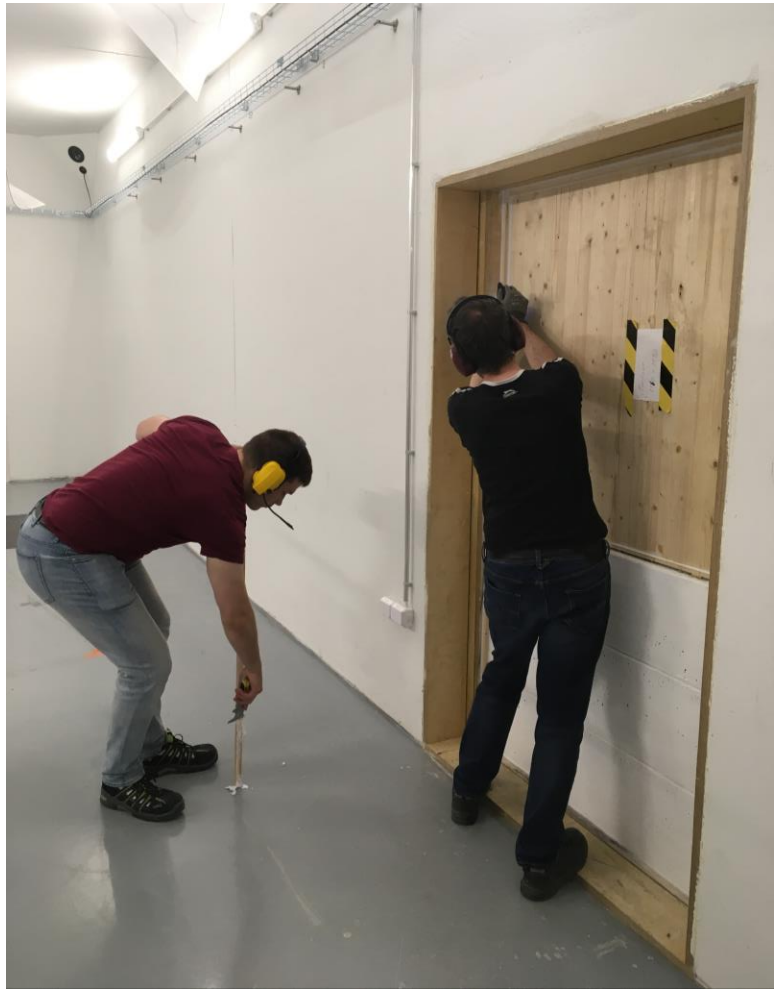
Test settings at Turku University of Applied Sciences

Tampereen yliopisto
Tampere University

Airborne sound insulation test

CLT and Dovetail boards

(27.05.2022)



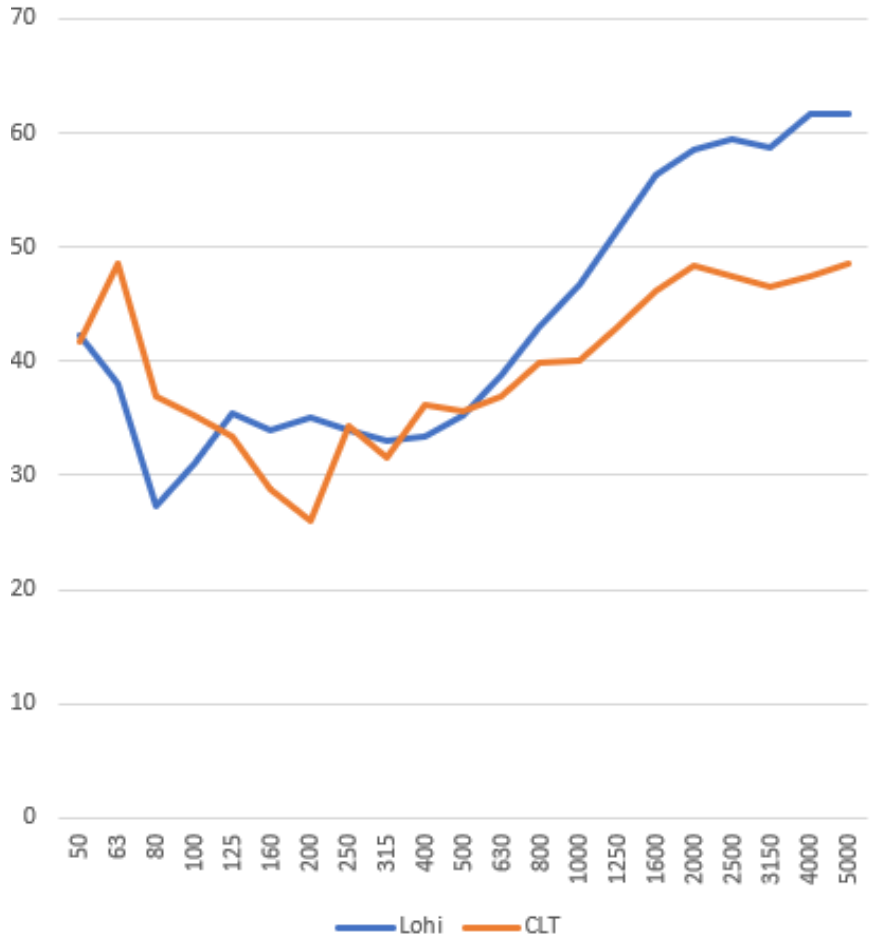
Test settings at Turku University of Applied Sciences

Tampereen yliopisto
Tampere University

Airborne sound insulation test

CLT vs Dovetail boards

Weighted Noise Reduction Index (Rw) / ISO 140-3



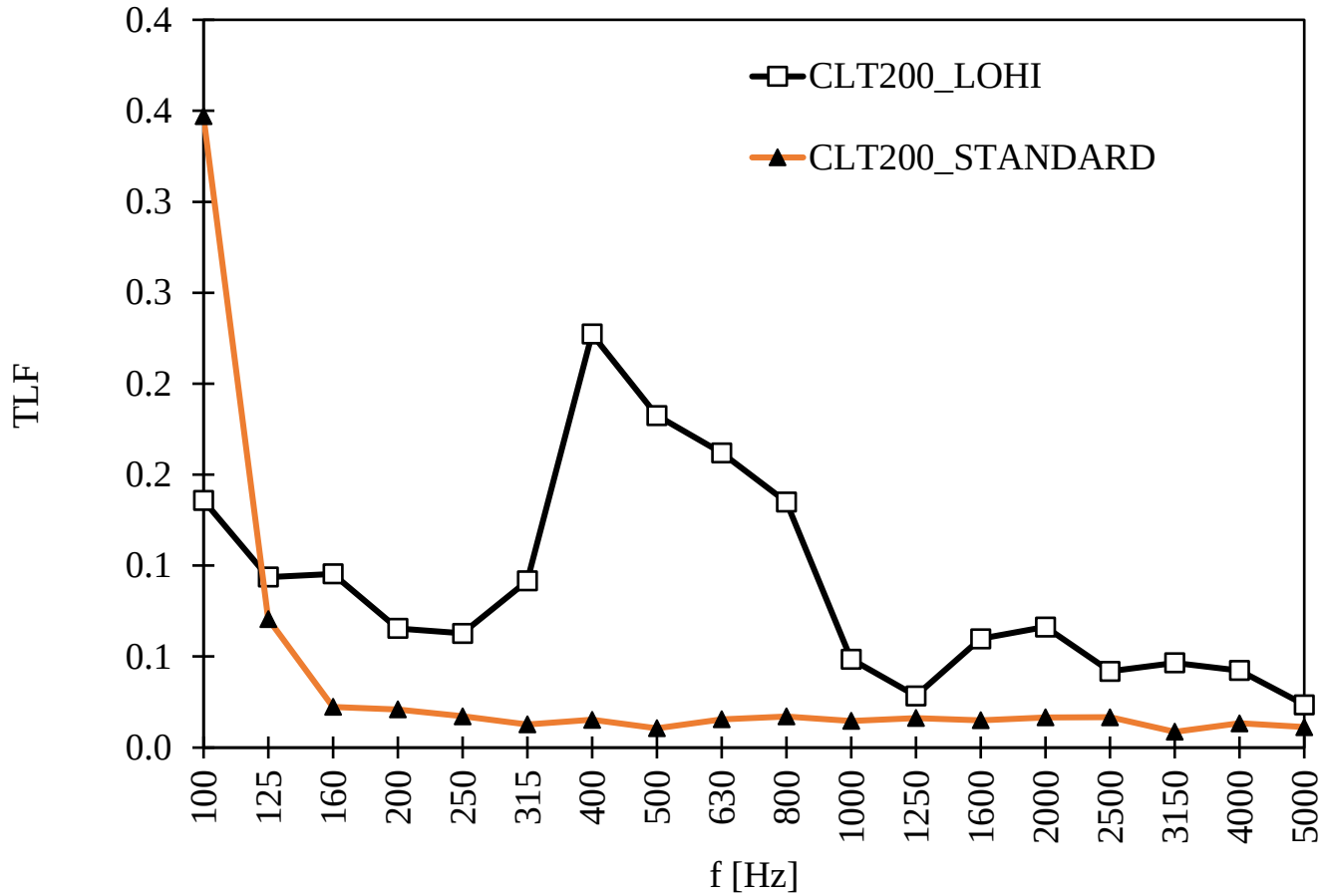
Rw (**Dovetail**) - **43 dB** > Rw (CLT) - 40 dB ... Dovetail performed **significantly better** than CLT

Tampereen yliopisto
Tampere University

Airborne sound insulation test

CLT vs Dovetail boards

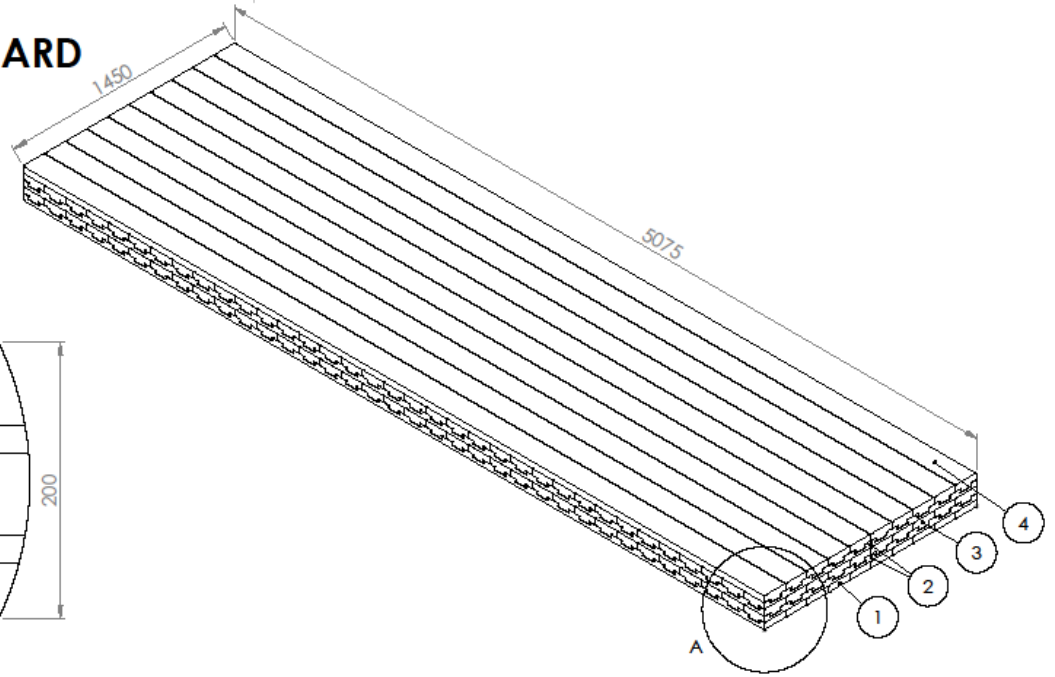
Total Loss Factor (TLF) Analysis

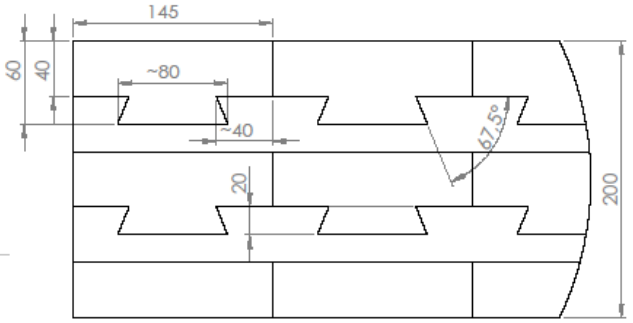


Dovetail performed **significantly better** than CLT in terms of **TLF**, *particularly 315-500 Hz*

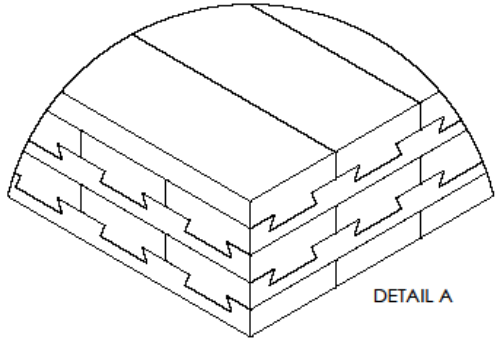
Structural test specimens

PARAMETRIC DOVETAIL BOARD





Right View



DETAIL A

ITEM NO.	QTY.	CNC-table	LENGTH	SUM (mm)
1	10	1 layer	5075	50750
2	70	2 and 4 layer	1450	101500
3	10	3 layer	5075	50750
4	10	5 layer	5075	50750
			SUM all	253750

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR: FINISH: DEBURR AND BREAK SHARP EDGES

Tampereen yliopisto LAPPIA

	NAME	SIGNATURE	DATE
DRAWN	Matti Yliniemi		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Tampereen yliopisto Arkkitehtuurin yksikkö

MATERIAL: Spruce timber

DWG NO. DW Test 5 layer

A3

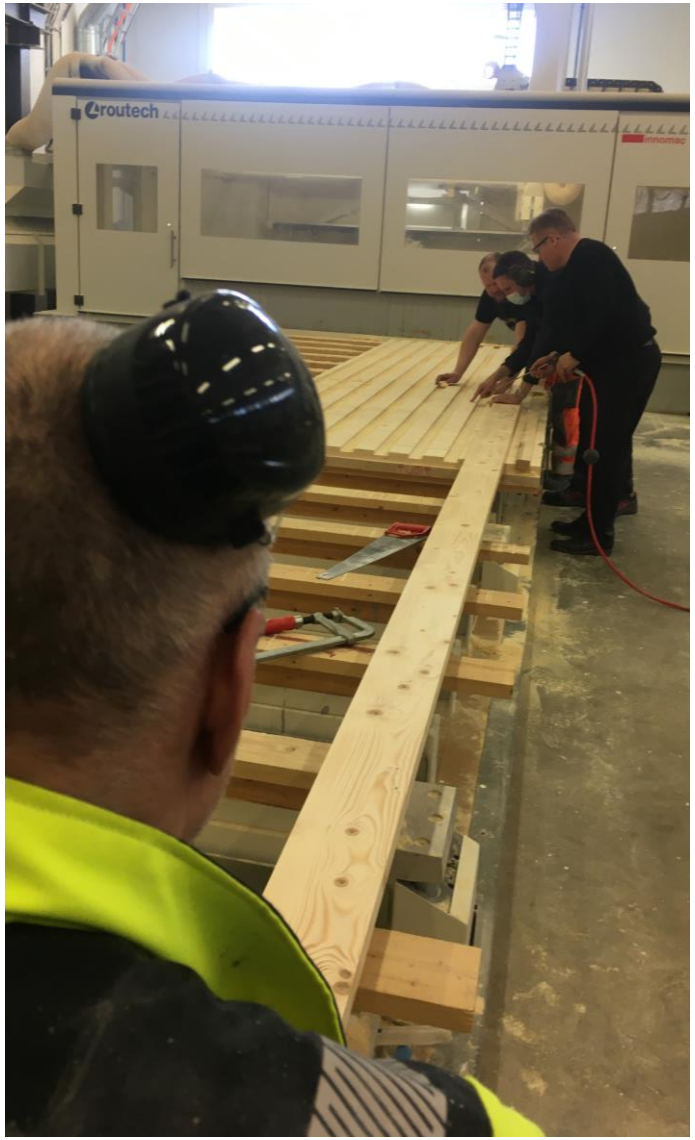
WEIGHT: ~600 kg

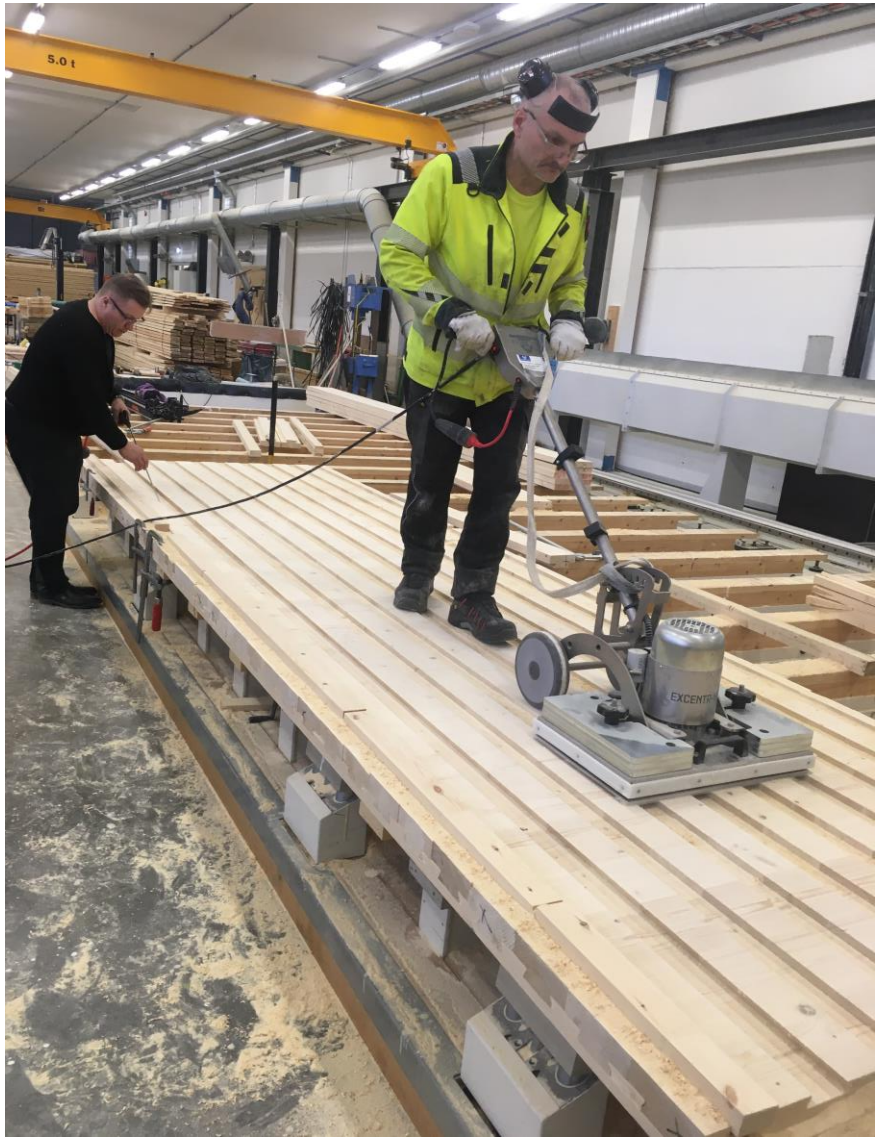
SHEET 1 OF 1

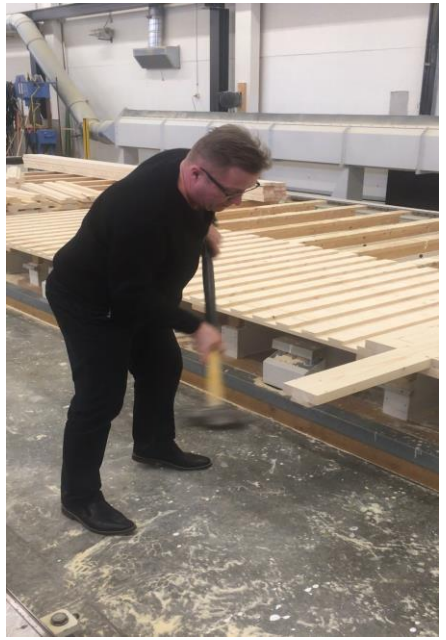
03.05.2022

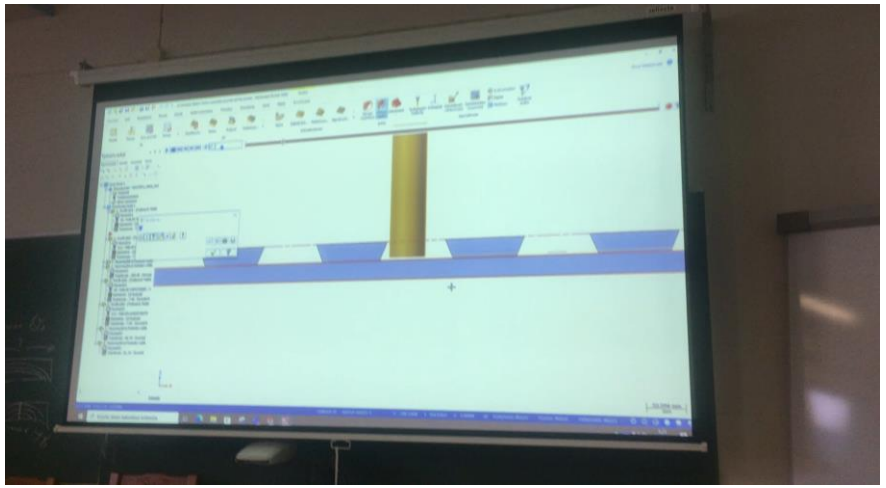
Tampereen yliopisto
Tampere University

Structural test specimens







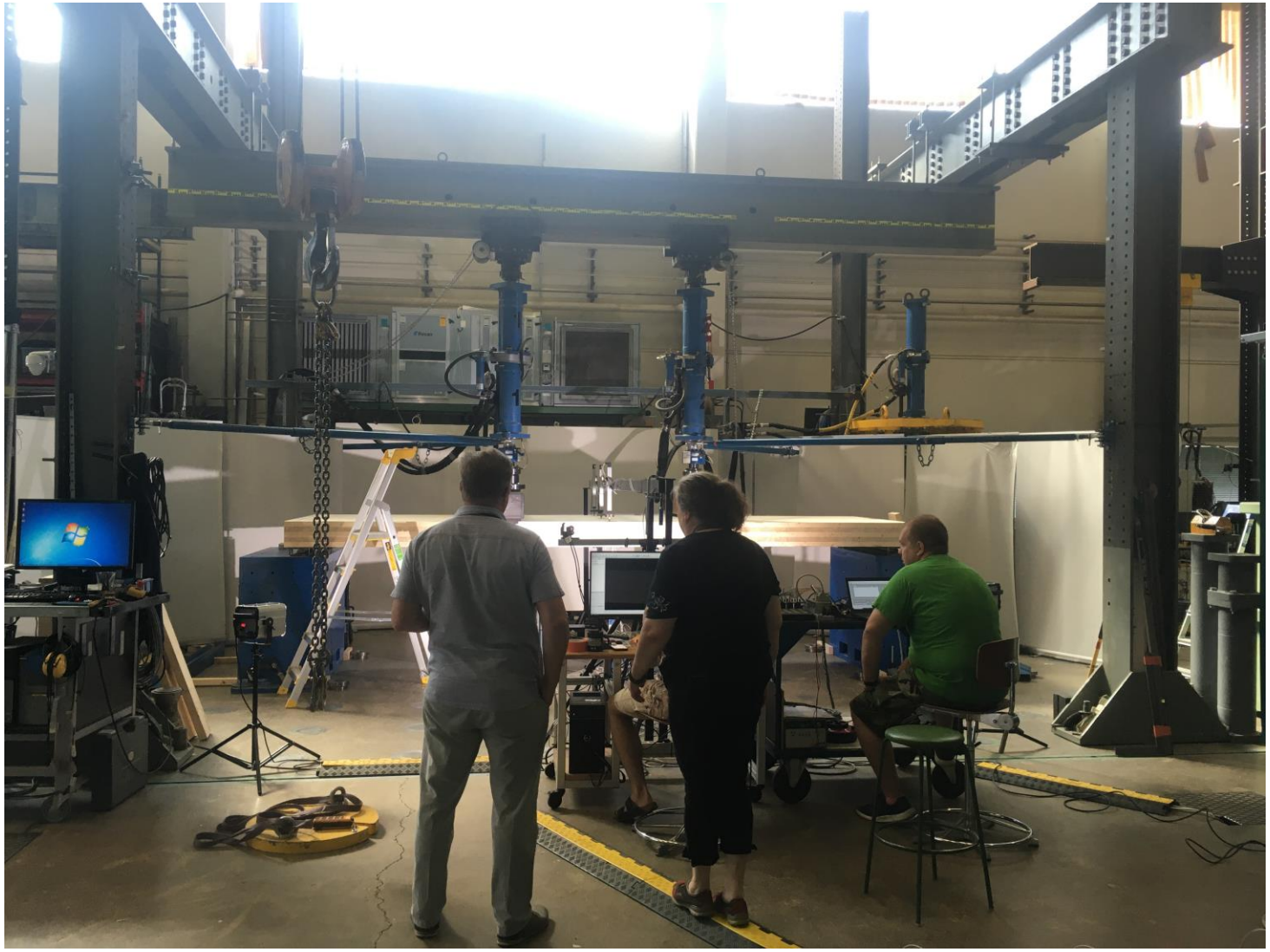


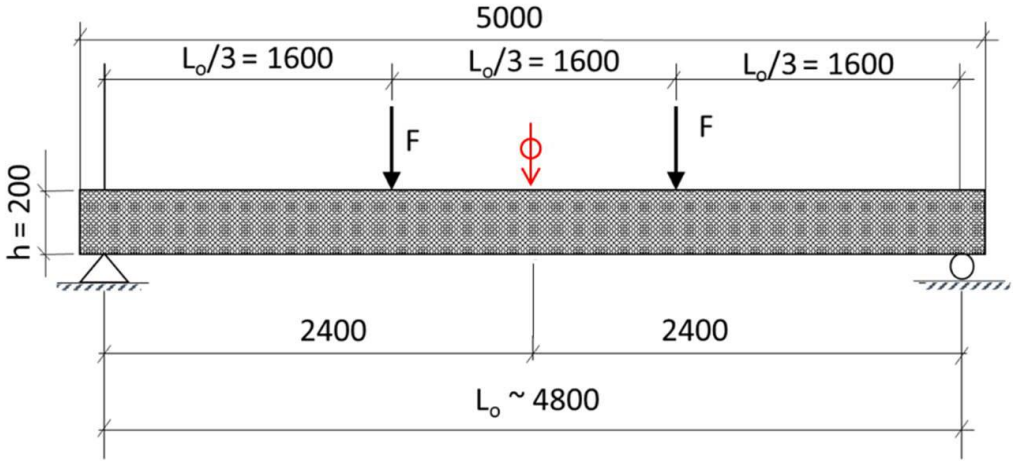
03.05.2022

Tampereen yliopisto
Tampere University

Structural resistance test

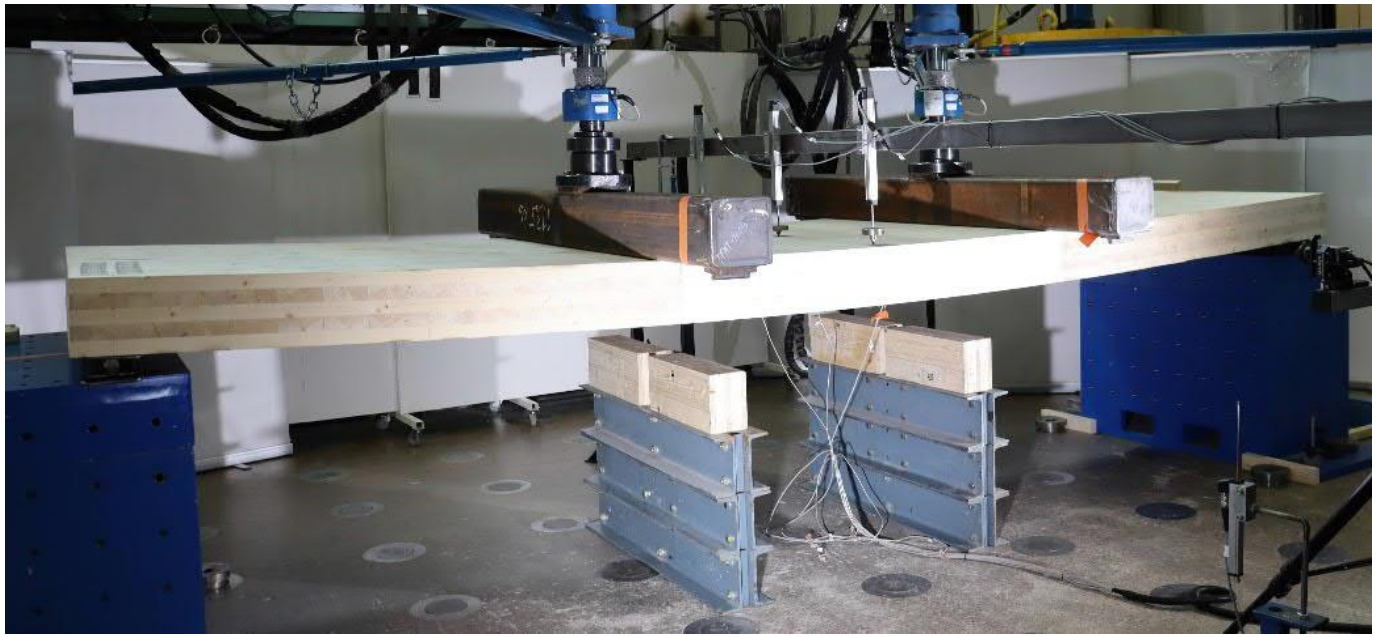
(28.06.2022)

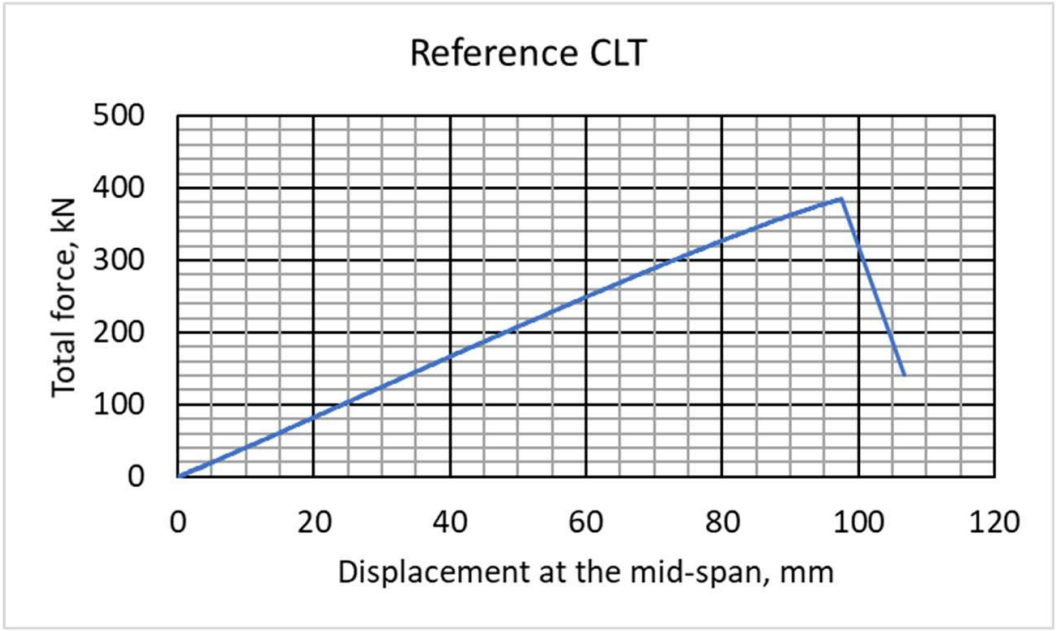


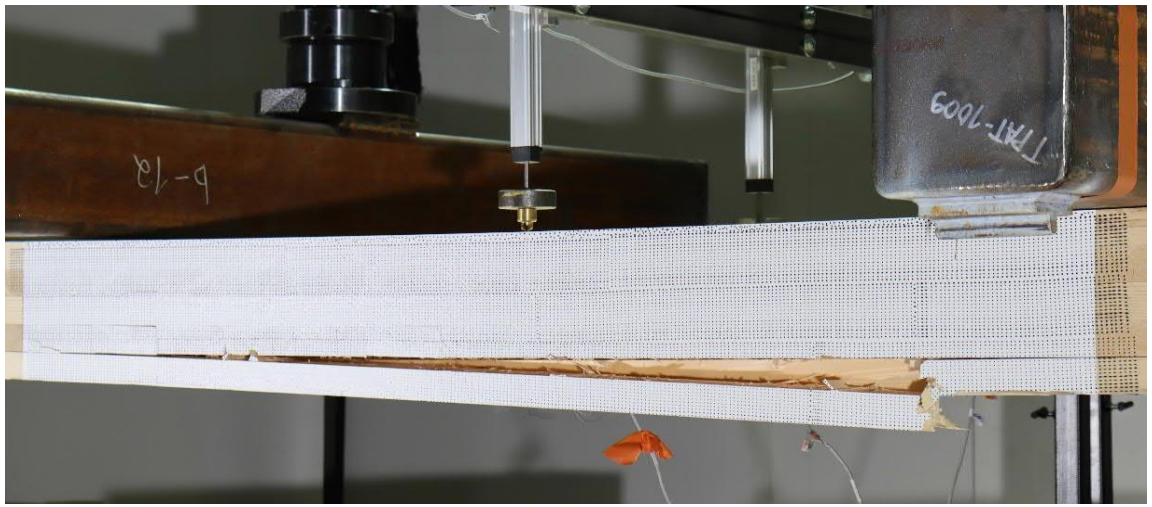


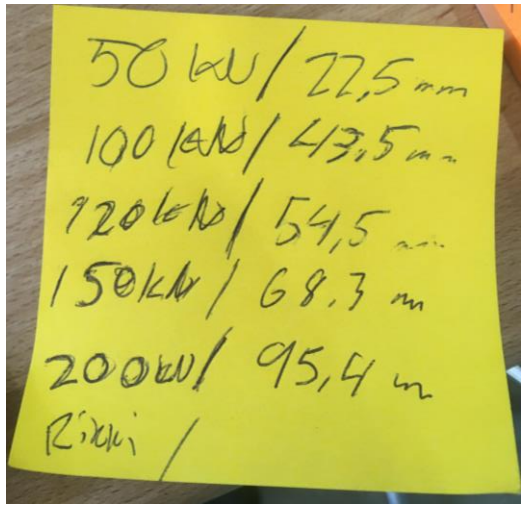
Test settings at Tampere University Structure Laboratory

Bending performance
(CLT board)









The maximum force of reference **CLT sample** in break was **385 kN**

Tampereen yliopisto
Tampere University

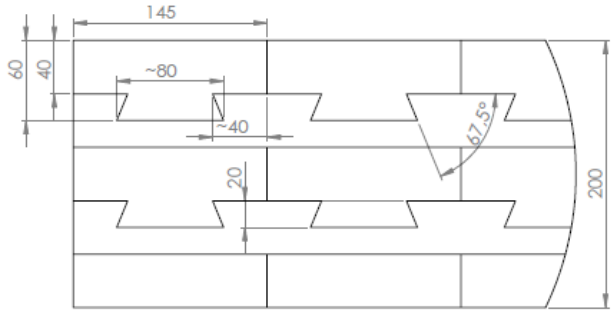
Bending performance

(Dovetail board)

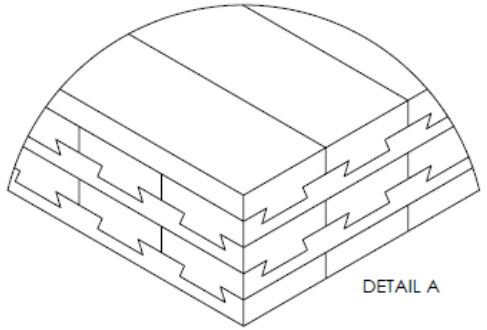
Bended due own weight **45 mm** / Testing duration **90 min /** Max applied force **30 kN**
Max displacement **260 mm** / after removing the force, displacement **53 mm,** thus, ***elastic behaviour***
Withstanding a major bending without breaking, but not suitable for long span use, so to be modified

Airtightness & humidity performance test specimens (test setup)

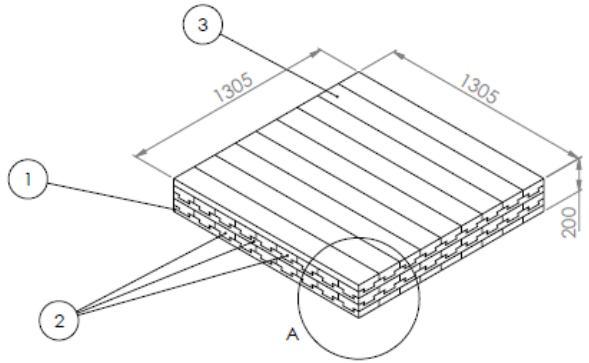
PARAMETRIC DOVETAIL BOARD



Right View



DETAIL A



ITEM NO.	QTY.	CNC-table	LENGTH	SUM (mm)
1	9	1 layer	1305	11745
2	27	2,3,4 layer	1305	35235
3	9	5 layer	1305	11745
			SUM all	58725

	NAME	SIGNATURE	DATE
DRAWN	Matti	Yliniemi	
CHK'D			
APP'VD			
MFG			
Q.A			

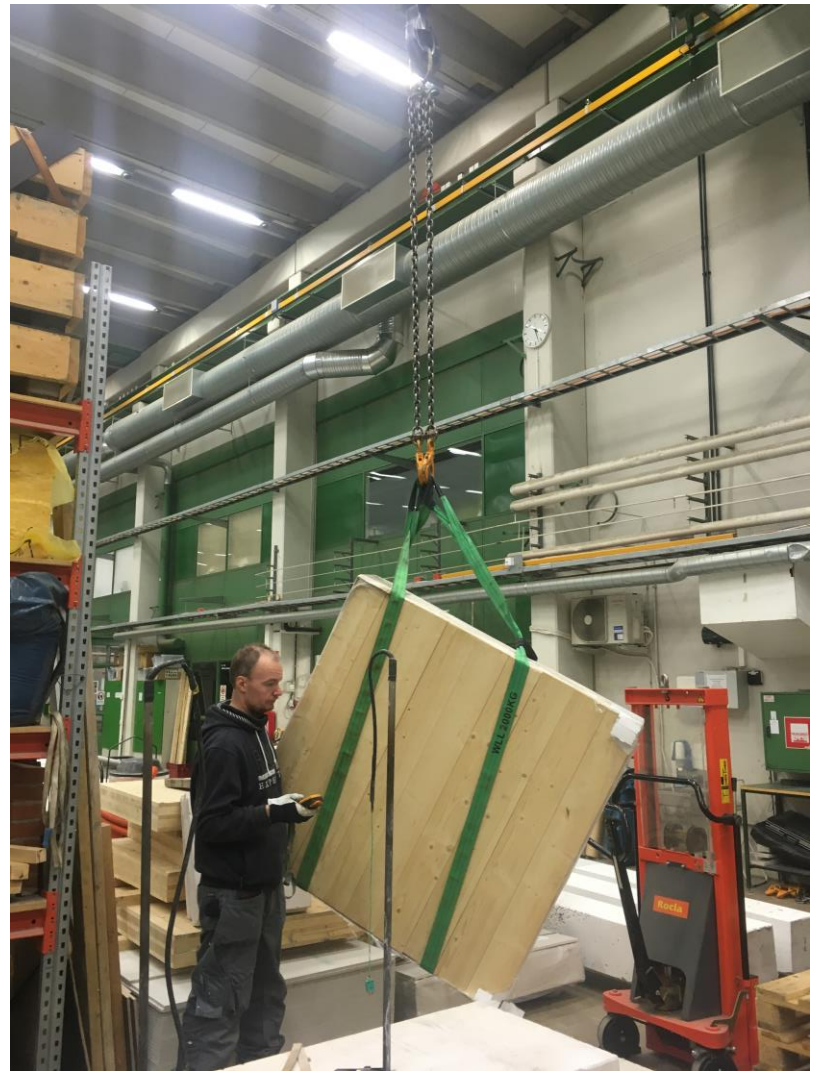
Tampereen yliopisto
Tampere University
LAPPIA

TITLE: Tampereen yliopisto
Arkkitehtuurin yksikkö

MATERIAL: Spruce timber
WEIGHT: ~150kg

DWG NO. DW Test 5 layer
A3

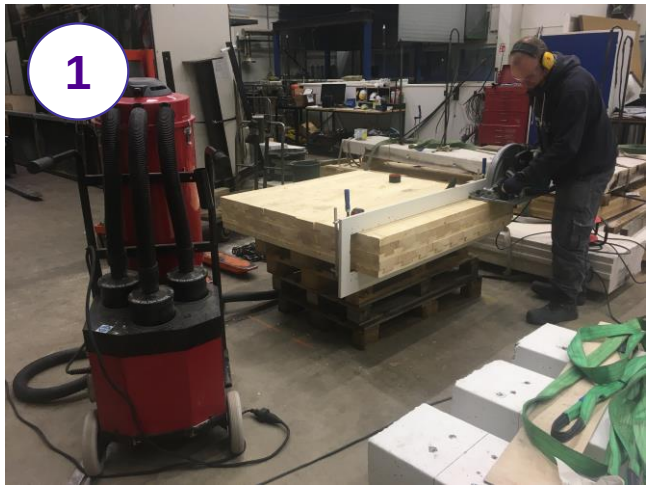
SHEET 1 OF 1

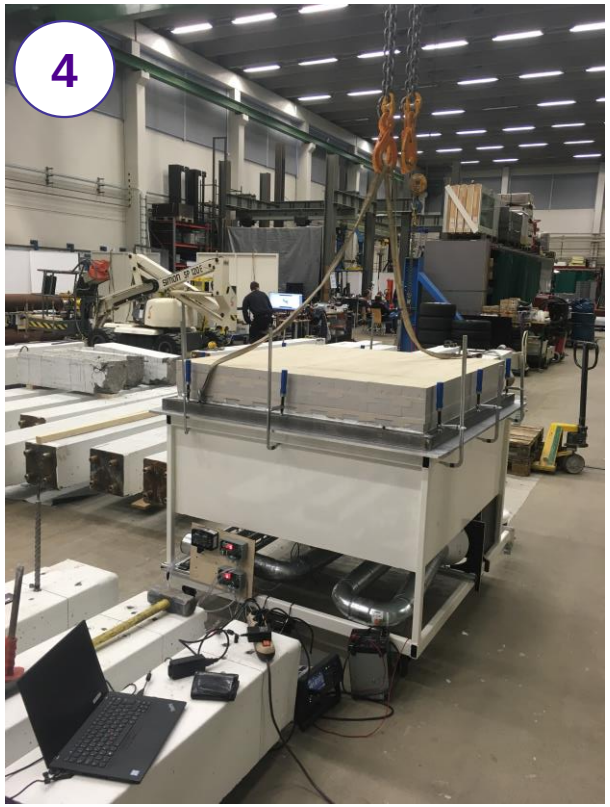


25.11.2022

Tampereen yliopisto
Tampere University

Airtightness & humidity performance test specimens (test setup)





Preparation of dovetail specimens at Tampere University Building Physics Laboratory

(1) **Cutting the test specimen to the size of the measuring frame** (1.2x1.2m); (2) **Primer & waterproof membrane application against air leaks from the sides**; (3) **Calibrating machine** ; (4) **Placing specimen into the machine and sealing of frame edges against air leaks**

Tampereen yliopisto
Tampere University

Airtightness & humidity performance dovetail test specimens

- 50 Mpa
- **2.5 m³/h.m²** (41.7 liter/minute.m²)
  (resulted air permeability)
- **4 m³/h.m²** (66.7 liter/minute.m²)
  (maximum allowable value according to Finnish building code - 1010/2017)

Dovetail board met the standard.

Tampereen yliopisto
Tampere University

Competition - Comparison

	CLT	Dovetail board
Fire resistance performance	Char rate about **0.92 mm/min**	Char rate about **0.70 mm/min**
Sound insulation performance	Rw (**40 dB**)	Rw (**43 dB**)
Structural performance	Break with a force of 385 kN	**Being modified and tested again**
Humidity & air-tightness performance		**2.5** $m^3/h.m^2$ < 4 (building code) **(Dovetail board met the standard)**

Tampereen yliopisto
Tampere University

Dovetailed Massive Wood Board Elements for Multi-Story Buildings *(202,680.96 € + 60,000 €)*

GANTT CHART		2021					2022												2023						
		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
WP1	Designing & building			M1.1			M1.2																		
WP2	**WP2.1** struc. test & opt.									M2.1															
	WP2.2 fire test & opt.												M2.2												
	WP2.3 sound test & opt.															M2.3									
	WP2.4 mois./air-tight. test&opt.																			M2.4					
WP3	Market research															D3.1.1	D3.1.2		D3.2			D3.3		M3.1	M3.2
WP4	**WP4.1** dissemination							D4.1.1			D4.1.2		D4.1.6	D4.1.3			D4.1.4		D4.1.7		D4.1.5		D4.1.8		D4.1.9
	WP4.2 communication									D4.2.1					D4.2.2										
WP5 (Managemet)	Weekly meeting																								
	Quarterly progress evaluation																								
	Steering group meeting																								
	Career development plan																								

Legend	Milestone	Major deliverable	Exact dates will be determined during the action

Updated testing schedule

Fire - *April & May 2022*
Sound - *May 2022*
Structural - *June 2022*
Humidity & air-tightness - *Nov-Dec. 2022*
2nd Structural - *January 2023*
3rd Structural - *March 2023*

Updated lecture schedule

The Oslo School of Architecture and Design - *June 2022*
Iceland University of the Arts - *October 2022*
Aalto University - *October 2022*
University of Oulu - *November 2022*
Royal Danish Academy - *November 2022*
Luleå University of Technology - *February 2023*
Riga Technical University & Vilnius Gediminas Technical University - *March 2023*
Tallinn University of Technology - *Spring 2023 and more ...*

Tampereen yliopisto
Tampere University

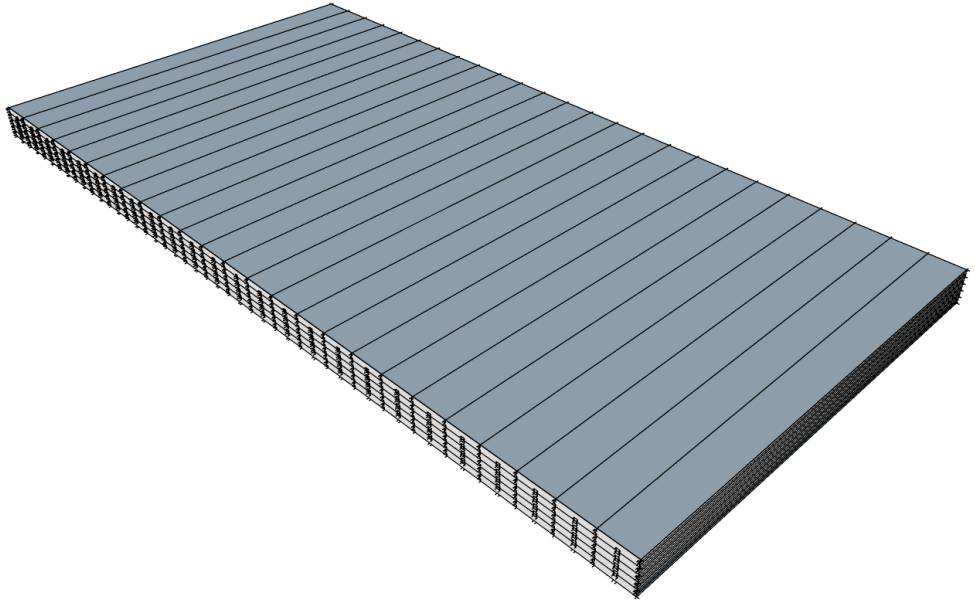
Dovetailed Massive Wood Board Elements for Multi-Story Buildings

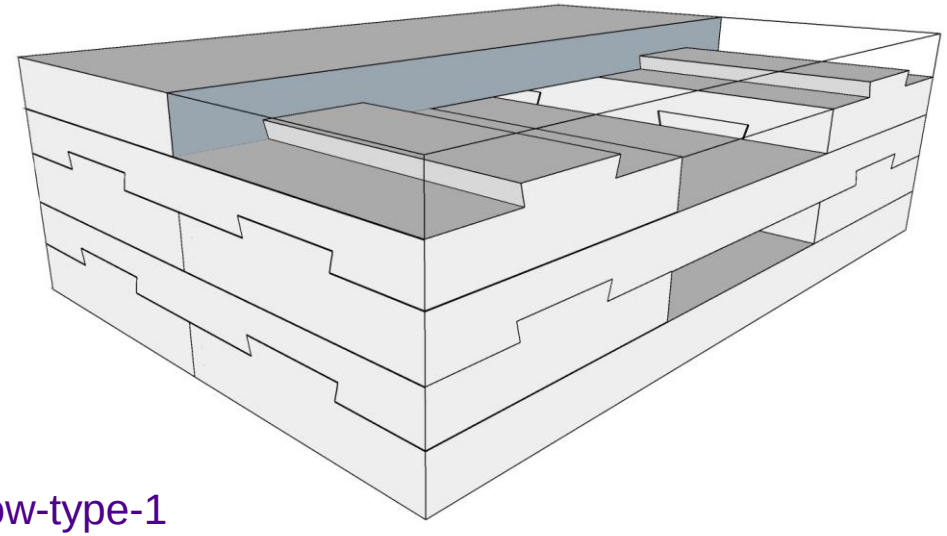
Publications:

1. Ilgın, H.E., Karjalainen, M., Koponen, O. **Review of the Current State-of-the-Art of Dovetail Massive Wood Elements.** IntechOpen: London, UK, 2021
2. Ilgın, H.E., Karjalainen, M., Koponen, O. **Dovetailed Massive Wood Board Elements for Multi-Story Buildings**. In Proceedings of the LIVENARCH VII Livable Environments & Architecture 7th International Congress OTHER ARCHITECT/URE(S), Trabzon, Turkey, 28–30 September 2021; Volume I, pp. 47–60.
3. Ilgın, H.E., Karjalainen, M. **Preliminary Design Proposals for Dovetail Wood Board Elements in Multi-Story Building Construction**. Architecture 2021, 1, 56–68
4. Ilgın, H.E., Karjalainen, M., Koponen, O. **Various Geometric Configuration Proposals for Dovetail Wooden Horizontal Structural Members in Multistory Building Construction.** IntechOpen: London, UK, 2022.
5. Ilgın, H.E., Karjalainen, M., Koponen, O., Soikkeli, A. **A Study on Contractors' Perception of Using Wood for Construction.** IntechOpen: London, UK, 2022
6. Ilgın, H.E., Karjalainen, M. **Massive Wood Construction in Finland: Past, Present, and Future.** IntechOpen: London, UK, 2022.
7. Ilgın, H.E., Karjalainen, M. **Tallest timber buildings: Main Architectural and Structural Design Considerations.** IntechOpen: London, UK, 2022.
8. Ilgın, H.E., Karjalainen, M., Malaska, M., Alanen, M. **Measuring Fire Safety Performance: A Comparative Experimental Study on Dovetail Massive Wooden Board Elements and Cross-Laminated Timber,** WCTE 2023 *(full paper to be submitted by 15 Feb)*
9. Dovetail Massive Wooden Slab Elements: Structural and Fire Resistance Performance *(to be submitted)*
10. Dovetail Massive Wooden Slab Elements: Airtigtness-humidity and Sound Insulation Performance *(to be submitted)*

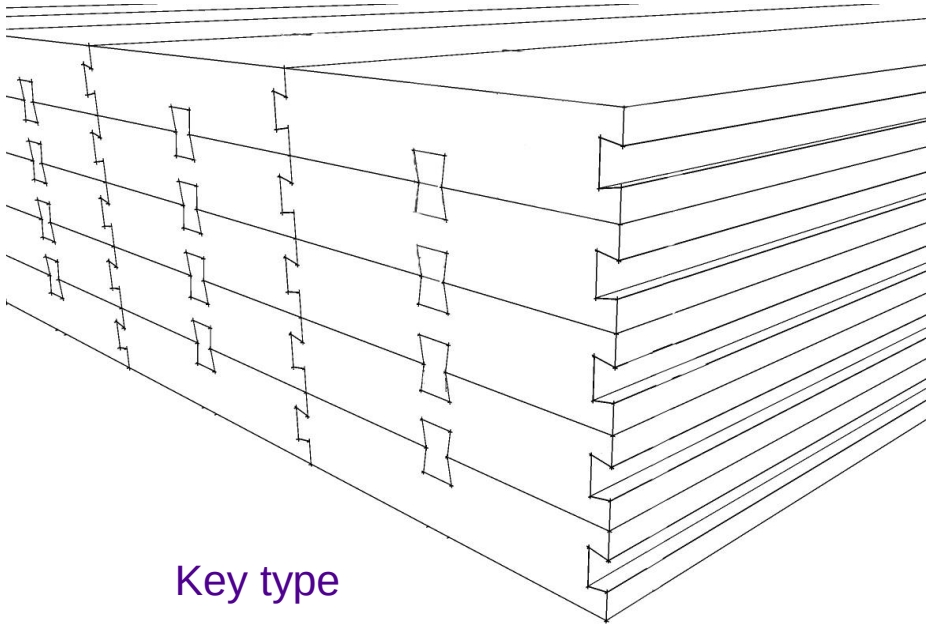
Tampereen yliopisto
Tampere University

Future design alternatives for floor slab

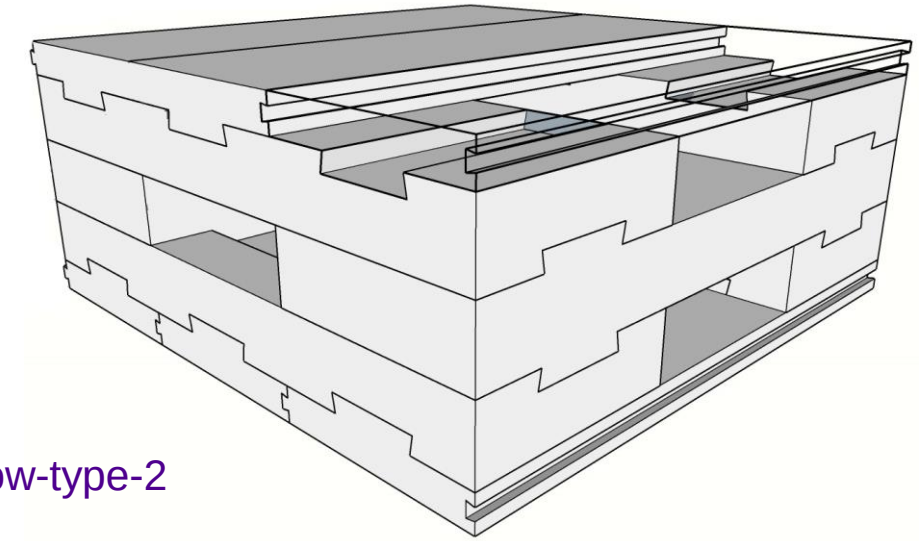




Hollow-type-1



Key type

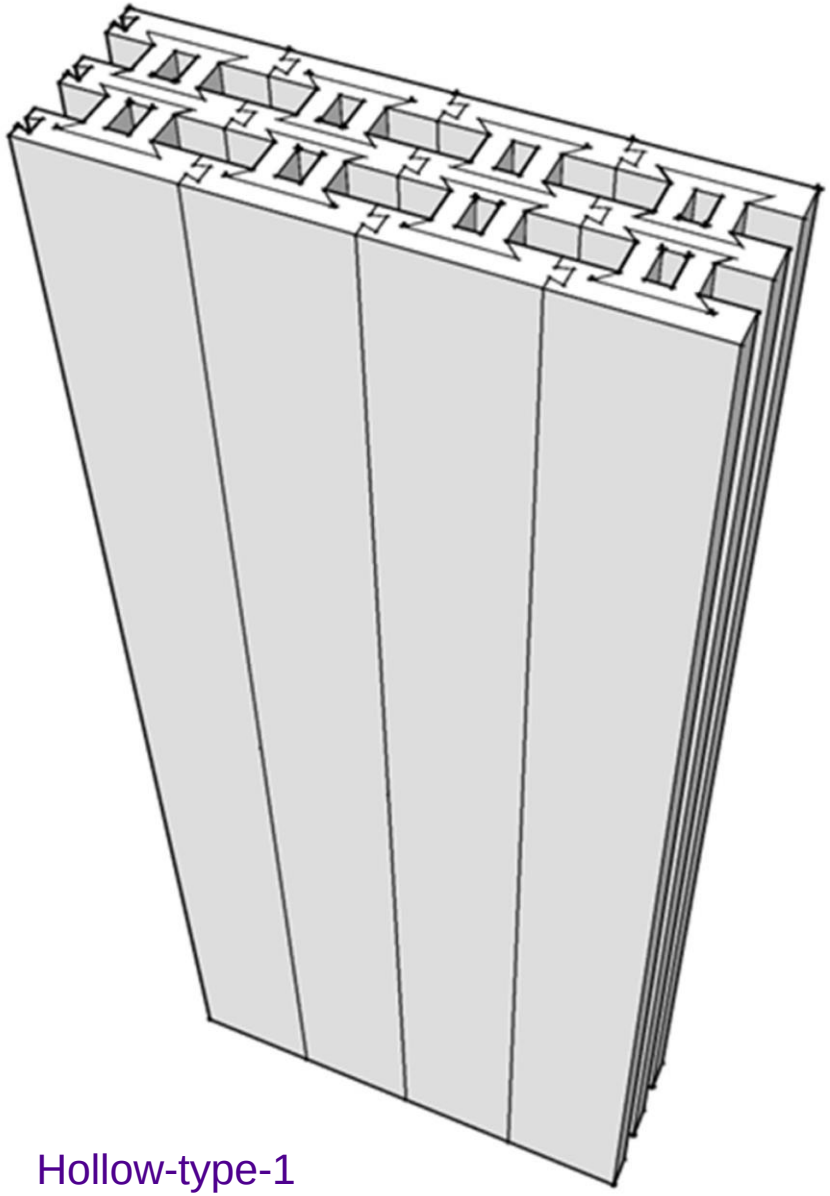


Hollow-type-2

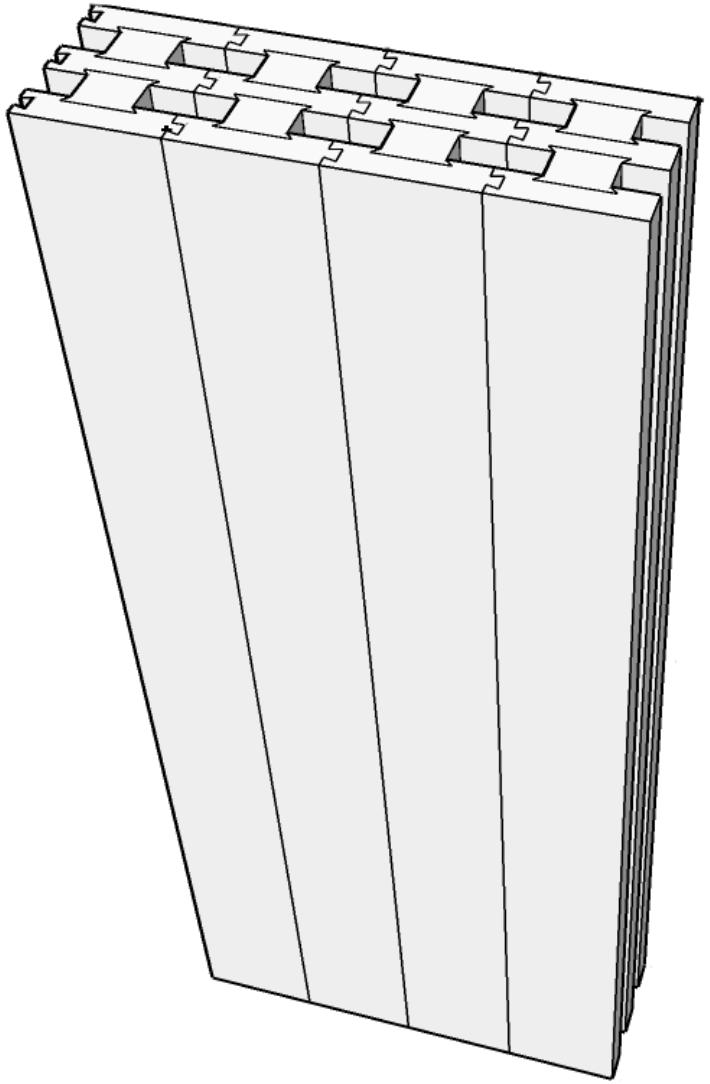
** **ease of HVAC installation and reduction in dead weight***

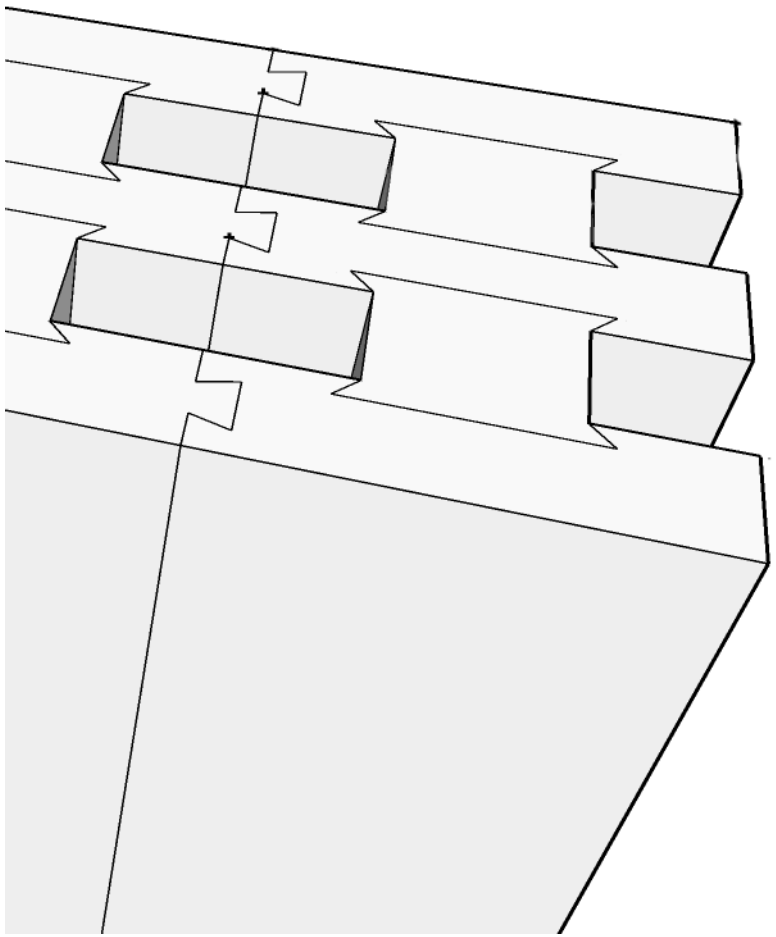
Tampereen yliopisto
Tampere University

Future design alternatives for shear wall



Hollow-type-1





Hollow-type-2

Tampereen yliopisto
Tampere University

Dovetailed Massive Wood Board Elements for Multi-Story Buildings

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No [101024593].

Marjatta ja Eino Kollin SÄÄTIÖ
Lisää mahdollisuuksia

This project has also received funding (60,000 EUR) from the Marjatta and Eino Kolli Foundation for funding the technical performance tests including fire safety, structural, moisture transfer resistance & air-tightness, and sound insulation.

THANK YOU!

Emre Ilgın & Markku Karjalainen

emre.ilgin@tuni.fi

markku.karjalainen@tuni.fi

Website:
https://www.tuni.fi/en/research/dovetailed-massive-wood-board-elements-multi-story-buildings-acronym-domwob