

# Actual Research Activities, Applications and Future Prospects for CLT

**G. Schickhofer, K. Ganster, R. Sieder, A. Ringhofer, S. Zimmer**

Institute of Timber Engineering and Wood Technology  
Graz University of Technology

**Engineering construction in wood**

Theme: Time, cost, climate and quality - that's why we choose wood.

Clarion Hotel Sign, Stockholm, Sweden [SE]  
14 November 2019

- **INTRODUCTION**
  - TIMBER at Graz University of Technology – R&D
  - Data & Facts about CLT
- **SELECTED SUB- AND PROJECTS**
  - “**CLT\_standardisation**” for wider use
  - “**PREFAB\_modules**” for densification
  - “**CLT\_follows\_form**” for free-form surfaces
- **FUTURE PROSPECTS**

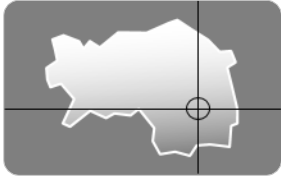
## ■ INTRODUCTION

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## ■ SELECTED SUB- AND PROJECTS

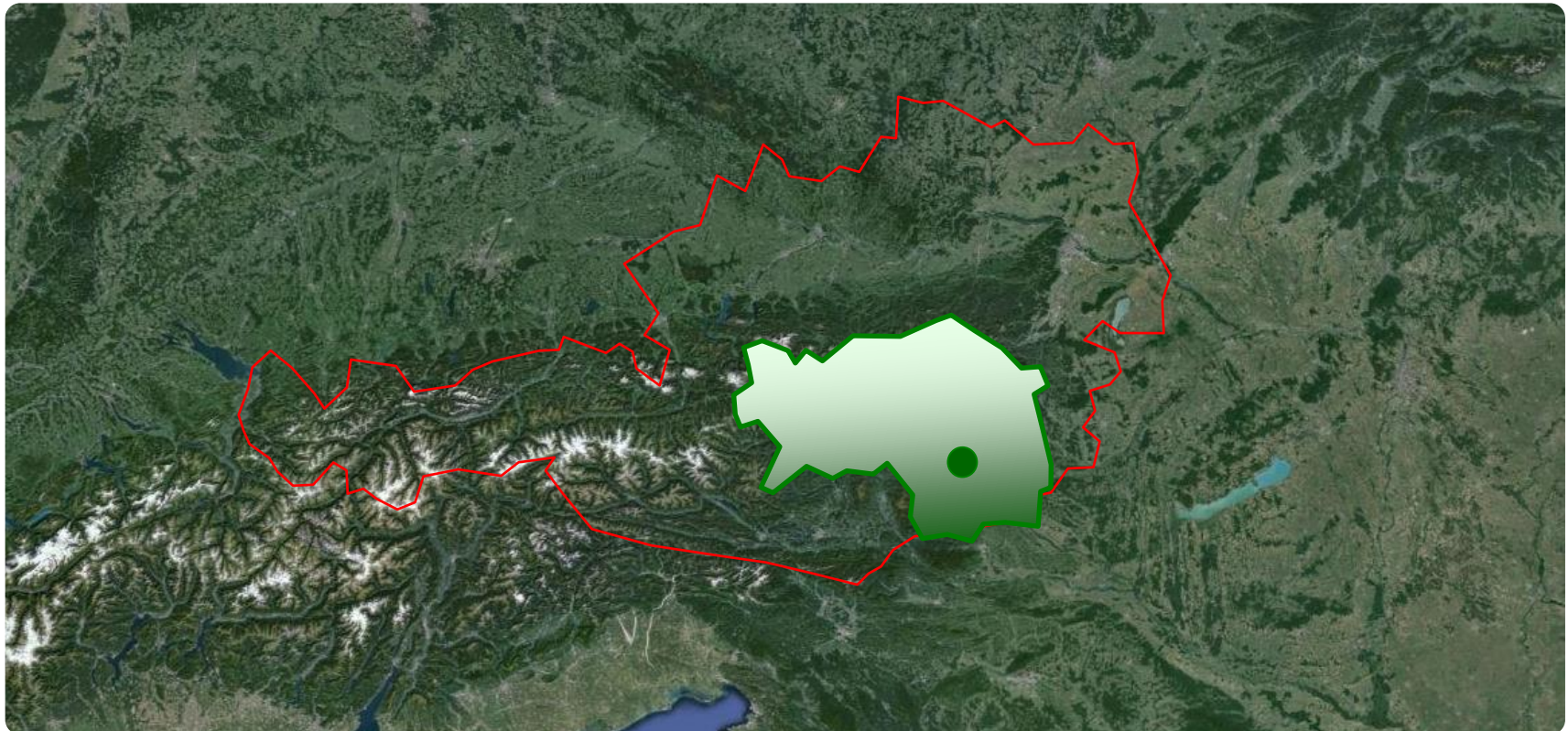
- “CLT\_standardisation” for wider use
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## ■ FUTURE PROSPECTS



# Graz University of Technology

## Styria / Austria



**Styria – 13 districts – 1,24 mill. inhabitants | capitol: Graz**  
**61% forest vegetation**



# Graz University of Technology

7 faculties | 13,800 students | 3,350 staff (2018)  
budget: € 225 Mil. (1/3 is 3<sup>rd</sup> party budget)

## Faculty of Civil Engineering Sciences

15 institutes | about 1,400 students (2018)

### Institute of Timber Engineering and Wood Technology

1991: Chair for Timber Engineering

10|2004: Institute of Timber Engineering and Wood Technology

Scientific staff: **7.5 FTE** | 3<sup>rd</sup> party budget: **€ 425,000** (2018)



source: TU Graz

### Competence Centre holz.bau forschungs gmbh

12|2002: Competence Centre holz.bau forschungs gmbh

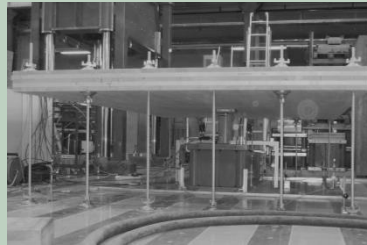
2003 - 2016: three 4-year funded COMET programmes:  
**K\_ind-Projekt, holz.bau, focus\_sts**

Scientific staff: **5.0 FTE** | budget: **€ 700,000** (2019/20)



# R&D topics regarding Timber Engineering and Wood Technology at TU Graz

## Shell and Spatial Timber Constructions (SSTC)



## Innovative and Intelligent Connection Systems (IICS)



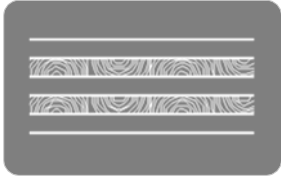
## Lightweight and Hybrid Hardwood Applications (LHHA)



## Evaluation and Maintenance of Historic Structures (EMHS)



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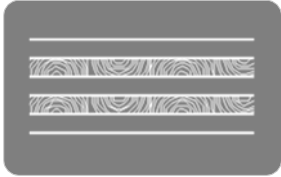


## CLT plants

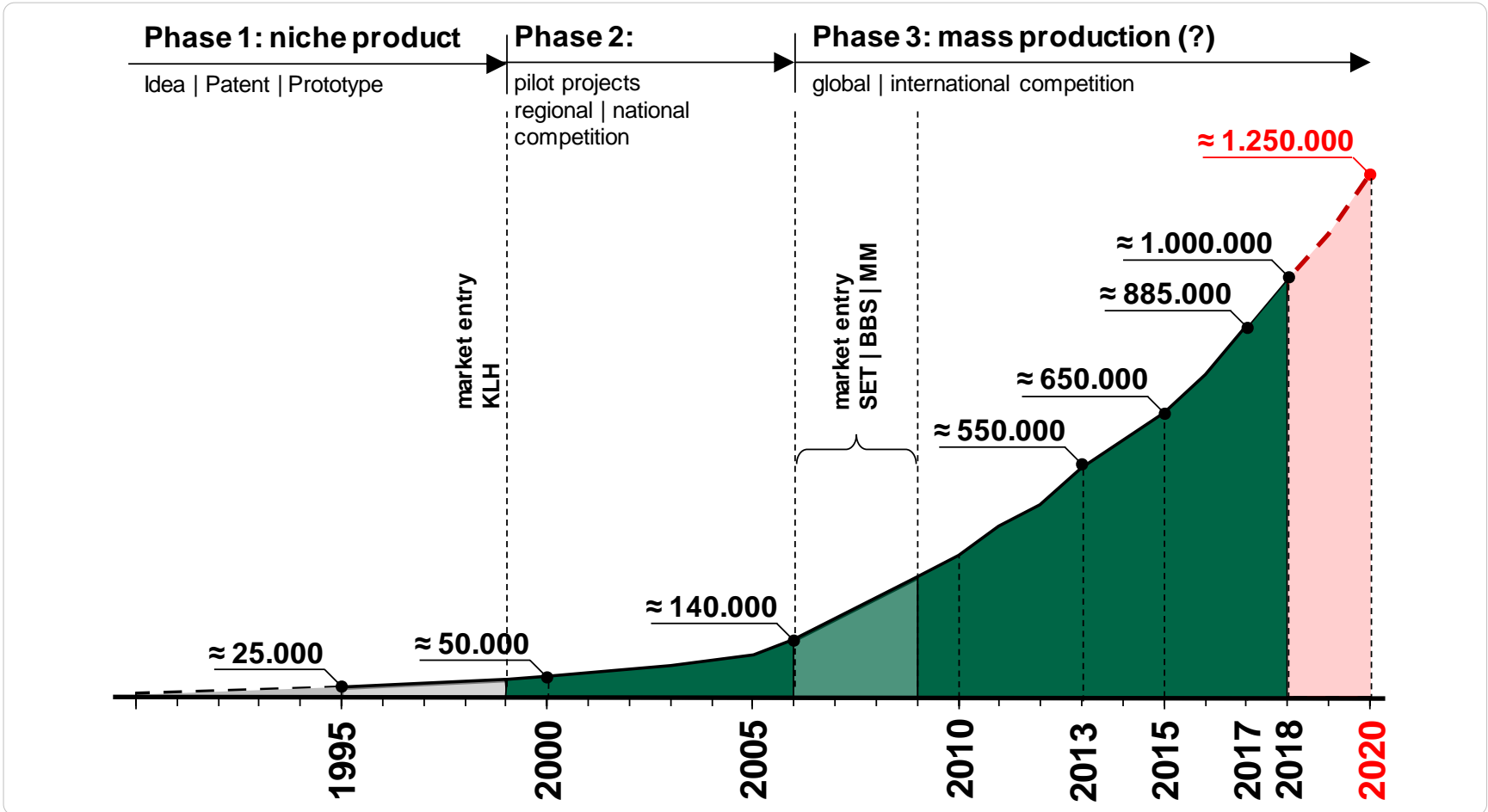


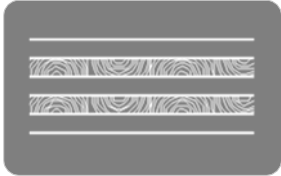
	2019
Europe	~ 45 (8)
NA, JP, AUS NZ	~ 20 (7)
<b>total</b>	<b>~ 65 (15)</b>





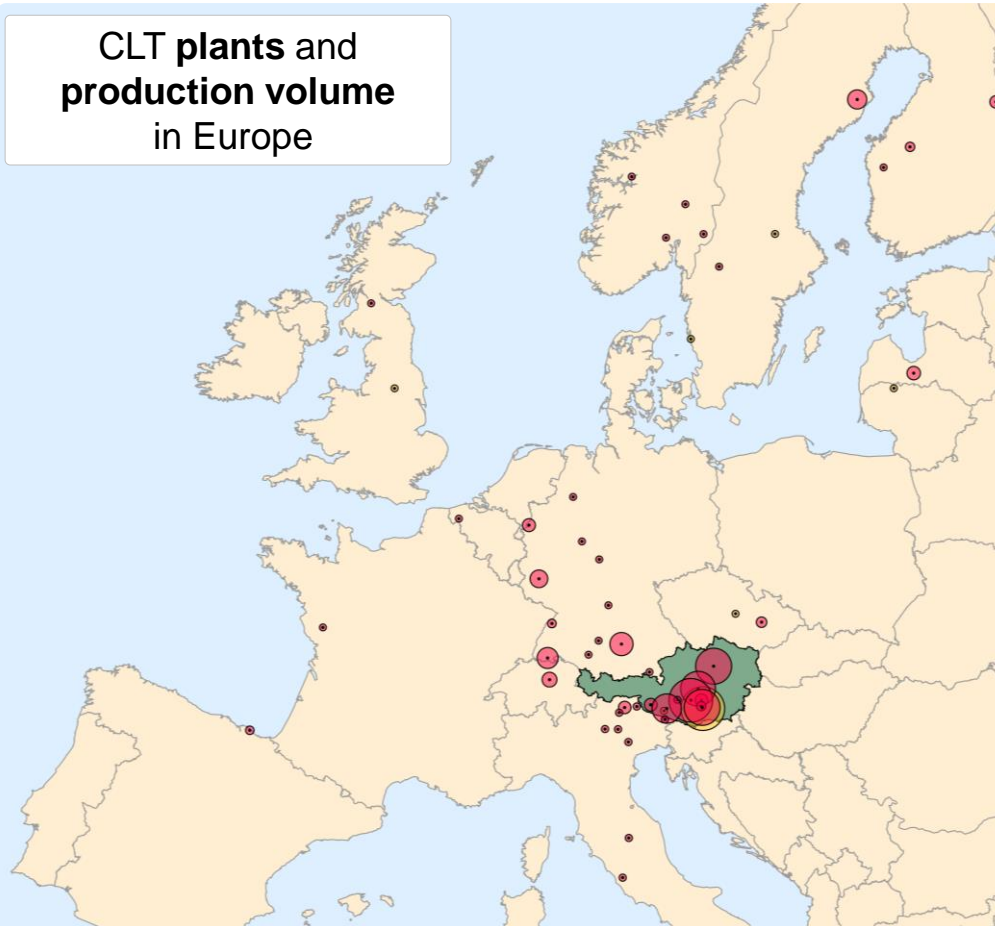
# CLT production





## CLT production

CLT plants and production volume in Europe



- **CLT production 2018**
  - ~ 90 % in Europe
  - ~ 60 % in Austria
  
- **important markets in EU**
  - Scandinavia (SE,FI,NO)
  - UK | France
  
- **important (future) markets worldwide**
  - Japan | USA | Canada
  - (Russia)

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## CLT\_standardisation | wider use

### chapter on CLT in a revised version of Eurocode 5: 2023

- project team of **PT SC5.T1 members:**

A. Brunauer [.at], P. Dietsch [.de], T.Orskaug [.no],  
G. Schickhofer [.at], R. Tomasi [.no], T. Wiegand [.de]

- duration of the project: September **2015** ÷ June **2018**

- prepared documents:

SC5.T1_FIN_DOC_EN1995-1-1	37 pages	<b>[standardisation.doc]</b>
SC5.T1_FIN_BGD_EN1995-1-1	34 pages	<b>[background.doc]</b>



## CLT\_standardisation | wider use

content of the “standardisation.doc” and “background.doc”

- 1 | scope
- 2 | normative references
- 3 | terms, definitions and symbols
- 4 | basis of design
- 5 | material
- 6 | durability
- 7 | structural analysis
- 8 | ultimate limit state
- 9 | serviceability limit state
- 10 | connections → PT SC5.T5
- 11 | components and assemblies



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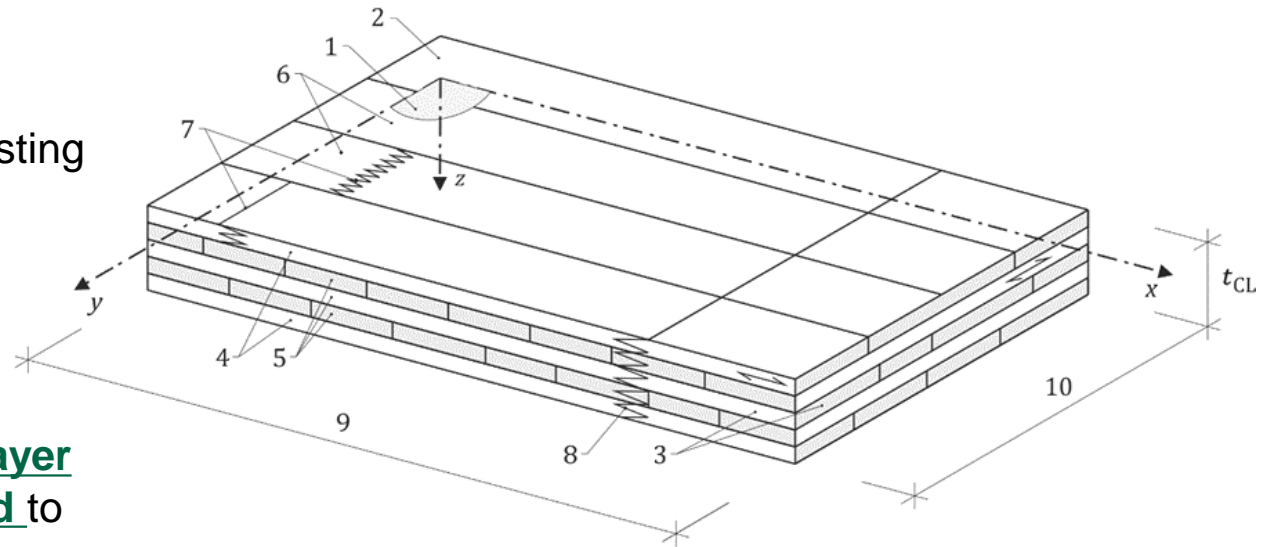


# CLT\_standardisation | wider use

## ad 3 | terms, definitions and symbols

- **Cross Laminated Timber [CLT]**

structural timber consisting of **at least three** face-bonded **layers** which comprise solid timber laminations and may comprise wood-based panels, **at least one layer orthogonally oriented** to the two adjacent layers.



1 plane of the element - **2 wide face** - **3 narrow face** - **4 outer layer** - **5 inner layer** - ...  
 ... - 9 | 10 width  $b_{CL}$  of plate or height  $h_{CL}$  of beam subjected to bending stresses perpendicular (9) | parallel (10) to grain of outermost layers



# CLT\_standardisation | wider use

## ad 4 | basis of design

- partial factor  $\gamma_M$  for CLT (in analogy to GLT)

$$\gamma_M = 1,25$$

## ad 5 | materials

- load-duration and moisture influences on **strength [ULS]**  
values of  $k_{mod}$  for CLT (in analogy to GLT)

service class	duration of load				instantaneous
	permanent	long term	medium term	short term	
1	0,6	0,7	0,8	0,9	1,1
2	0,6	0,7	0,8	0,9	1,1

- load-duration and moisture influences on **deformations [SLS]**  
values of  $k_{def}$  for CLT  
(in analogy to plywood)

service class	1	2	3
$k_{def}$	0,8	1,0	-





# CLT\_standardisation | wider use

## ad 5 | materials

- characteristic values of strength and stiffness

Property		Symbol	Value	Example for cross laminated timber of class CL24 <sup>2)</sup>
Bending strength	for bending moments out of plane, see Figure PT.1-8.13	$f_{m,x,k}$ $f_{m,y,k}$	$3 f_{t,0,k}^{0,8}$	24,0
	for bending moments in plane, see Figure PT.1-8.13	$f_{m,edge,x,k}$ $f_{m,edge,y,k}$	$f_{m,k}^{5)}$	20,5
Tensile strength	in plane	$f_{t,x,k}^{4)}$ $f_{t,y,k}^{4)}$	$1,2 f_{t,0,k}$	16,0
	perpendicular to the plane	$f_{t,z,k}$	0,50	0,50
Compression strength	in plane	$f_{c,x,k}$ $f_{c,y,k}$	$3 f_{t,0,k}^{0,8}$	24,0
	perpendicular to the plane	$f_{c,z,k}$	3,00	3,00
Shear strength out of plane	Longitudinal	$f_{x,k}$	3,50	3,50
	rolling shear	$f_{r,k}$	$\min \left\{ \begin{array}{l} 0,2 + 0,3 \frac{b}{t_1}^{5)}$ 1,4	0,80 <sup>6)</sup>
Shear and torsional shear strength in plane	shear strength of the effective cross-section	$f_{v,xy,k}$ $f_{v,yx,k}$	5,50	5,50
	torsional shear strength of the glued area of crosswise bonded laminations	$f_{tor,node,k}$	2,50	2,50
	rolling shear	$f_{r,k}$	As for shear strength out of plane	
Modulus of Elasticity	loaded in plane	$E_{x,mean}$ $E_{y,mean}$	$1,05 E_{0L,mean}^{7)}$	$11.600^{7)}$
	loaded perpendicular to the plane	$E_{z,mean}$	$450^{7)}$	$450^{7)}$
Shear Modulus	Loaded out of plane	$G_{xz,mean}$ $G_{yz,mean}$	$G_{L,mean}^{7)}$	$650^{7)}$
	loaded in plane	$G_{xy,mean}$ $G_{yx,mean}$ $G_{tor,mean}$	$\min \left\{ \begin{array}{l} \frac{650}{1 + 2,6 \left( \frac{t_1}{b_1} \right)^{12)}$ 450	$450^{6),7)}$
Shear Modulus	rolling shear	$G_{r,mean}$	$\min \left\{ \begin{array}{l} 30 + 17,5 \left( \frac{b_1}{t_1} \right)^{5),7)}$ 100	$65,0^{6),7)}$
Density		$\rho_k$	$1,1 \rho_k^{9)}$	$385^{9)}$
		$\rho_{mean}$	$\rho_{mean}$	420



# CLT\_standardisation | wider use

## ad 5 | materials

- characteristic values of strength and stiffness

property		symbol	value	e.g. cross laminated timber of class <b>CL24</b>
bending strength	out of plane	$f_{m,x,k}; f_{m,y,k}$	$3 f_{t,0,l,k}^{0,8}$	<b>24,0</b>

- strength class:

**CL24**

Cross Laminated

bending strength out of plane



# CLT\_standardisation | wider use

## ad 5 | materials

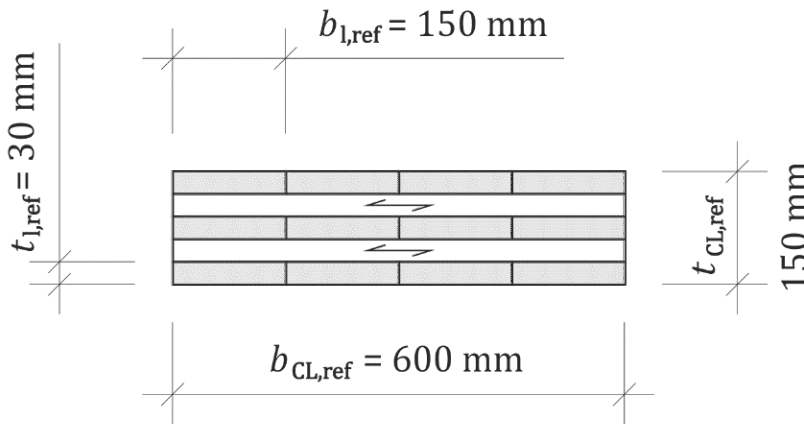
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- strength class:

**CL24**

- bending strength based on tests | reference cross section





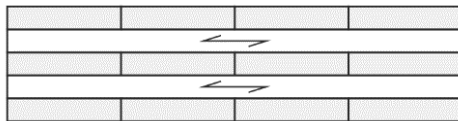
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- strength class: **CL24**
- bending strength based on tests | reference cross section



- bending strength based on calculations | load bearing model

- $$f_{m,x,k} = a_{CL} \cdot f_{t,0,l,k}^{0,8} \qquad a_{CL} = 3,0 \text{ if } COV(f_{t,0,l,k}) = 25 \pm 5$$

$$a_{CL} = k_{sys,m} \cdot k_{CL/GL} \cdot k_{h,CL} \cdot k_{CV}$$

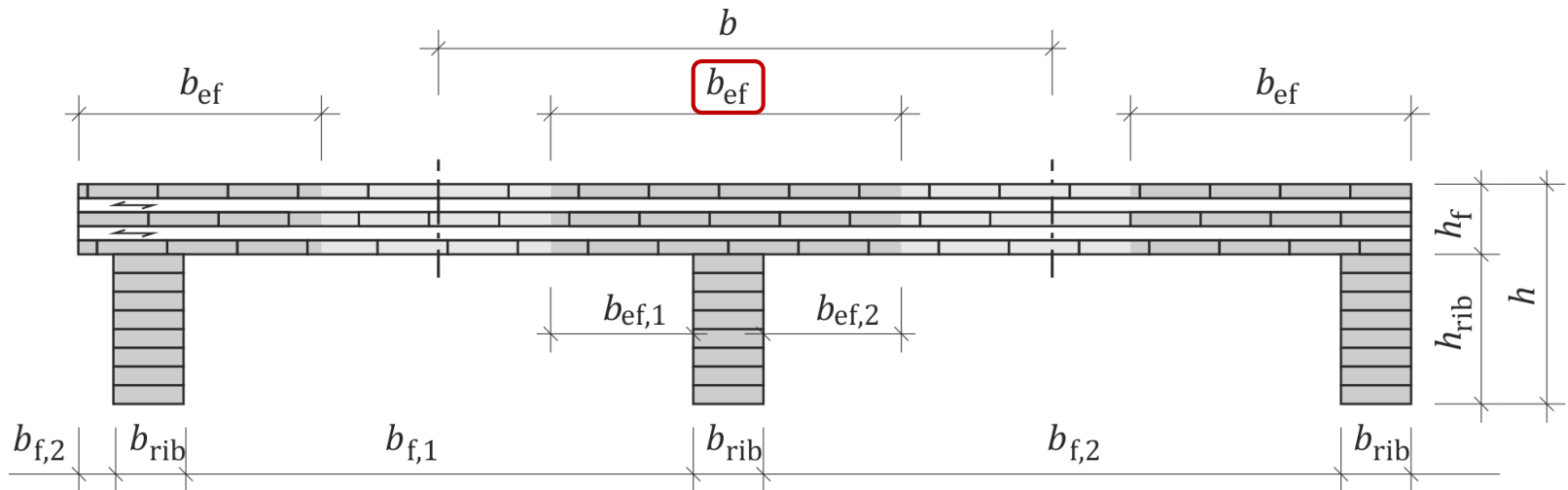


# CLT\_standardisation | wider use

## ad 11 | components and assemblies

- ribbed plates build up from cross laminated timber plates and ribs

$$\rightarrow b_{ef} \leq b_{rib} + \sum b_{ef,i}$$



ribbed plate build up from cross laminated timber plates and glued-on or mechanically jointed ribs



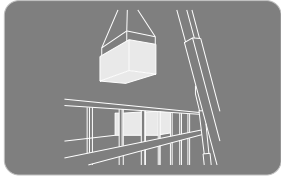
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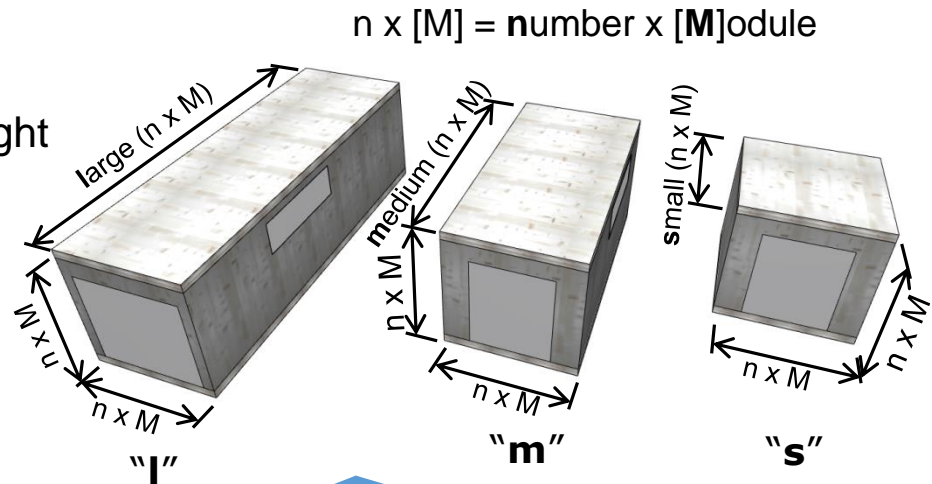
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# PREFAB\_modules

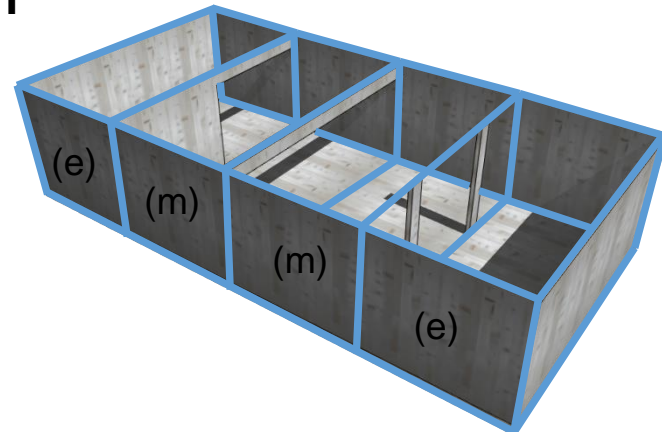
## dimensions of modules

- standardised width, length and height
- but possible steps in length
  - **small** = "s"
  - **medium** = "m"
  - **large** = "l"

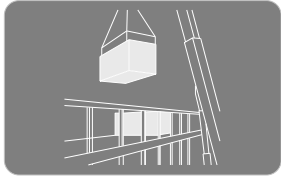


## types of modules

- types according to their **position**
  - edge module (e)
  - middle module (m)



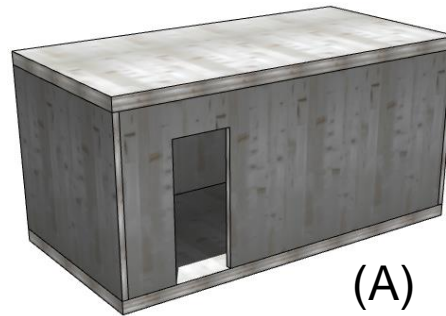




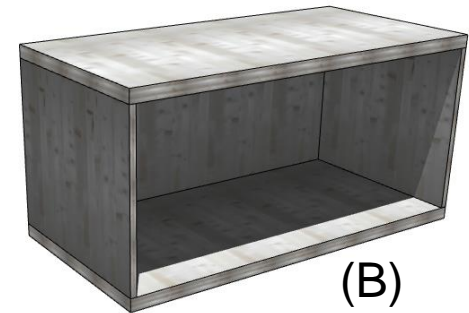
## PREFAB\_modules

### types of modules

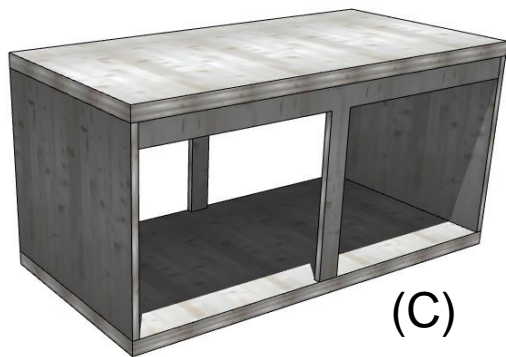
- types according to their **structure**
  - closed on all sides (A)
  - open on one side (B)
  - open on two sides (C)
  - open on three sides (D)
  - open on all sides (E)



(A)



(B)



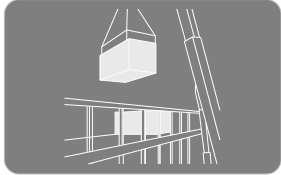
(C)



(D)



(E)



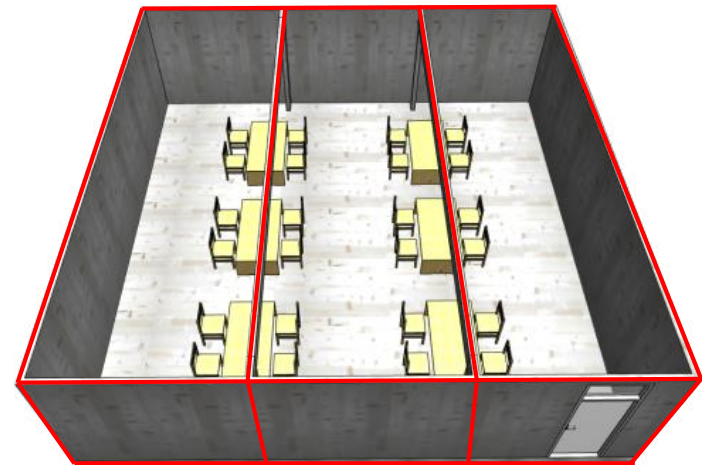
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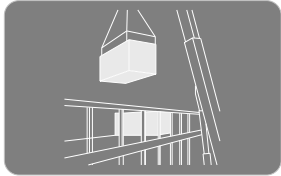
#### single module



#### multi module



- **single modules** usually have an integrated **sanitary unit** and are suitable for hotels, nursing homes and student residences
- the combination of single modules results in **multi modules**, which can be used e.g. for school buildings



# overview of realized projects (hotels, KBS)

source: Kaufmann Bausysteme GmbH

Ammerwald (AT)



Parsdorf (AT)

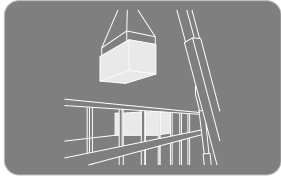


Garching (DE)



Ludwigsburg (DE)





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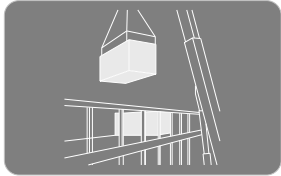


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Ludwigsburg (DE)



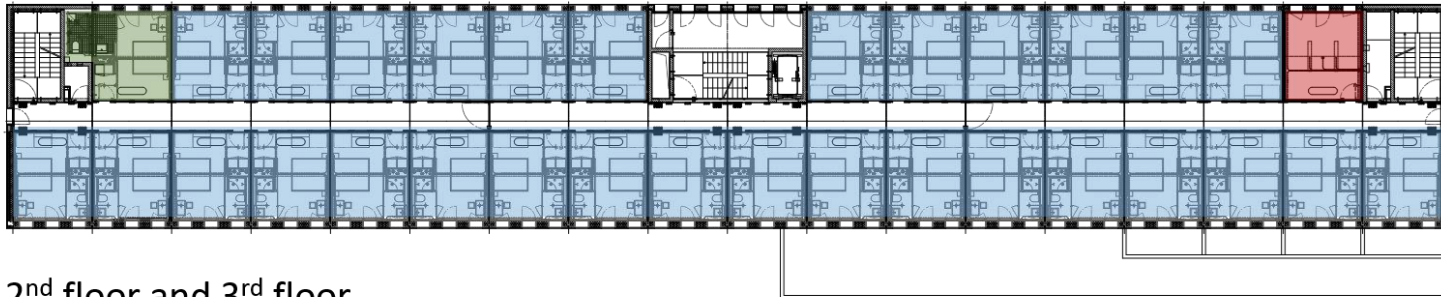


# Hotel Ammerwald, 2008

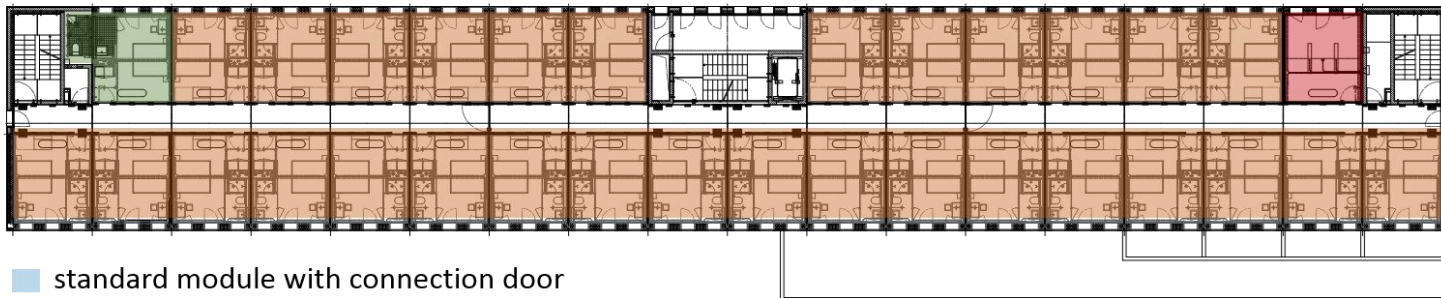
source: Kaufmann Bausysteme GmbH

## floor plan

1<sup>st</sup> floor

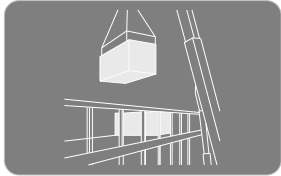


2<sup>nd</sup> floor and 3<sup>rd</sup> floor



- standard module with connection door
- standard module ■ special module (barrier-free) ■ laundry

- 5 storeys | 3 storeys are build in modular design
- 4 different types of modules | a total of 60 modules

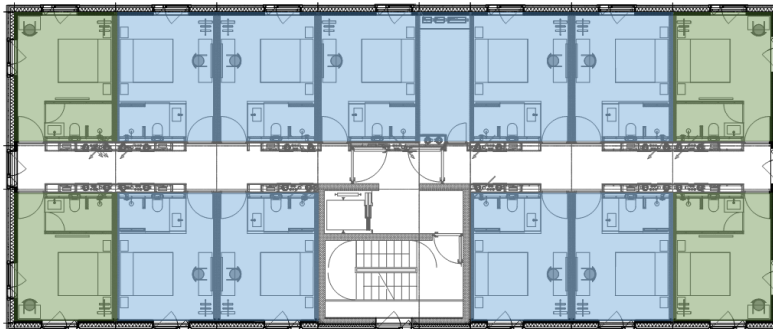


# Hotel Ludwigsburg, 2018

source: Kaufmann Bausysteme GmbH

## floor plan

1<sup>st</sup> floor and 3<sup>rd</sup> floor



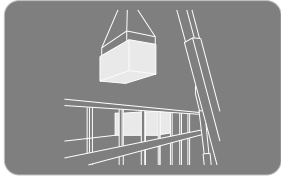
■ standard module 1 ■ standard module 2

attic floor



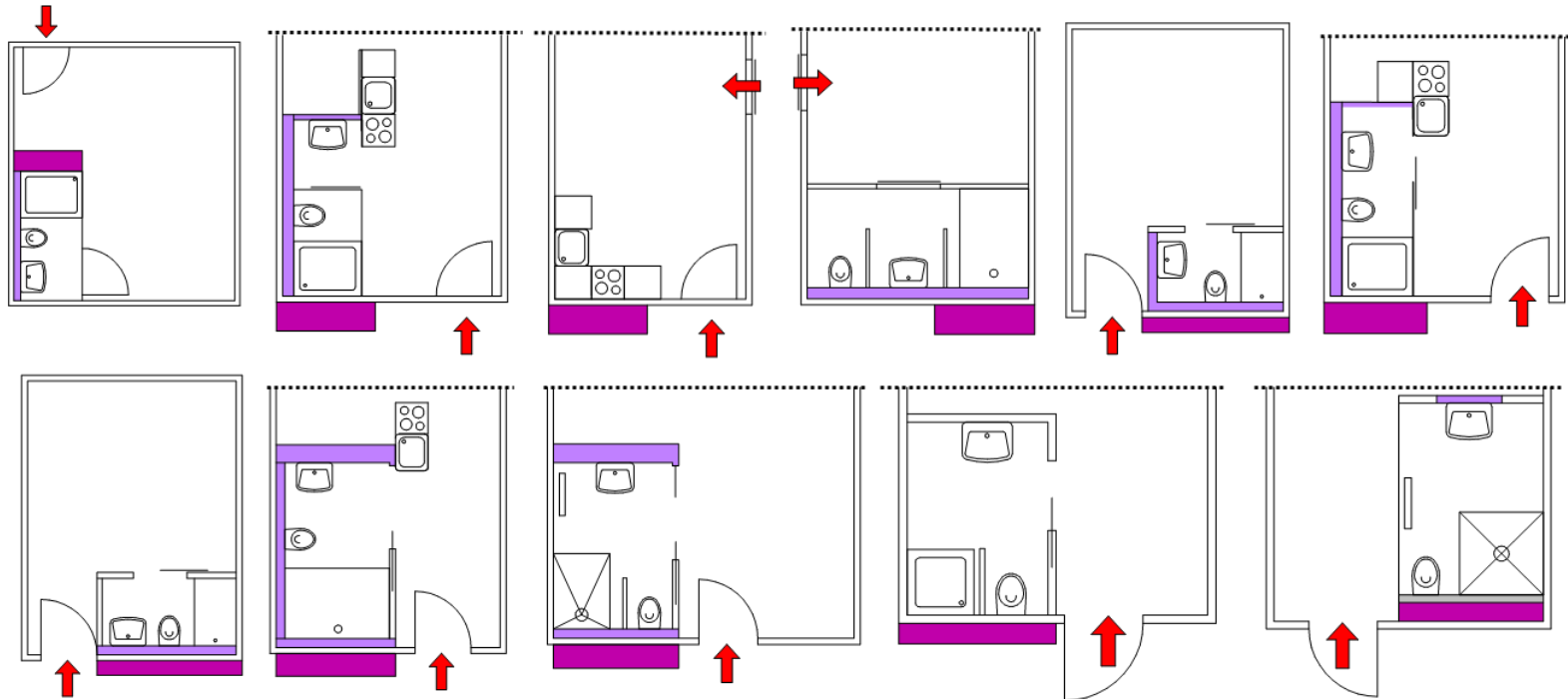
■ special module 1 ■ special module 2 ■ special module 3

- 5 storeys | 4 storeys are build in modular design
- 5 types of modules | a total of 48 modules



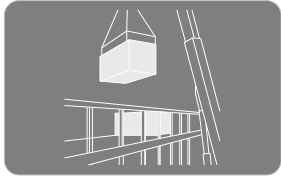
# SensGT: analysis of realized projects (KBS)

source: Kaufmann Bausysteme GmbH



- analysis of MEP systems and bathroom layouts
- main objective: reduction of numbers of different MEP systems and pipe length

MEP...mechanical, electrical and plumbing



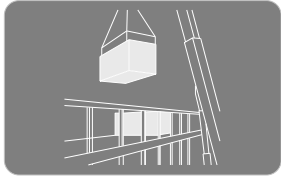
# SensGT: analysis of realized projects (KBS)

source: Kaufmann Bausysteme GmbH

objective: one MEP system and bathroom layout for each category of building





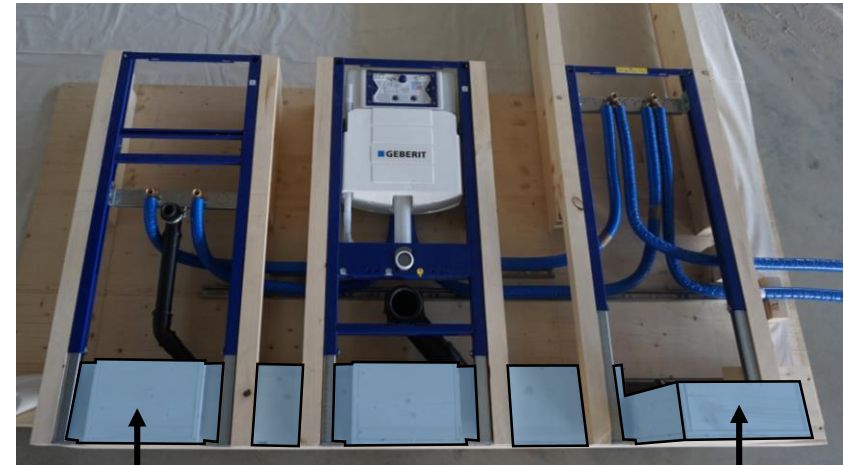


## SensGT: MEP systems – results

status quo



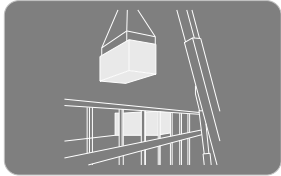
favourable solution



↑ steel basin to catch leakage water (with sensors) ↓

### Resumé

- accessibility in critical regions
- high degree of prefabrication
- coordinated routing and reduction of pipe lengths



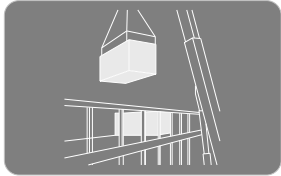
## PREFAB\_modules production

source: Kaufmann Bausysteme GmbH

### production line in Kalwang



- 6 production fields for screed work and 20 for module assembly
- serial implementation of building services at the plant



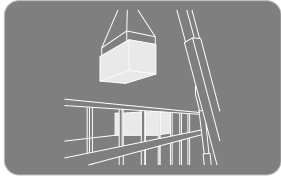
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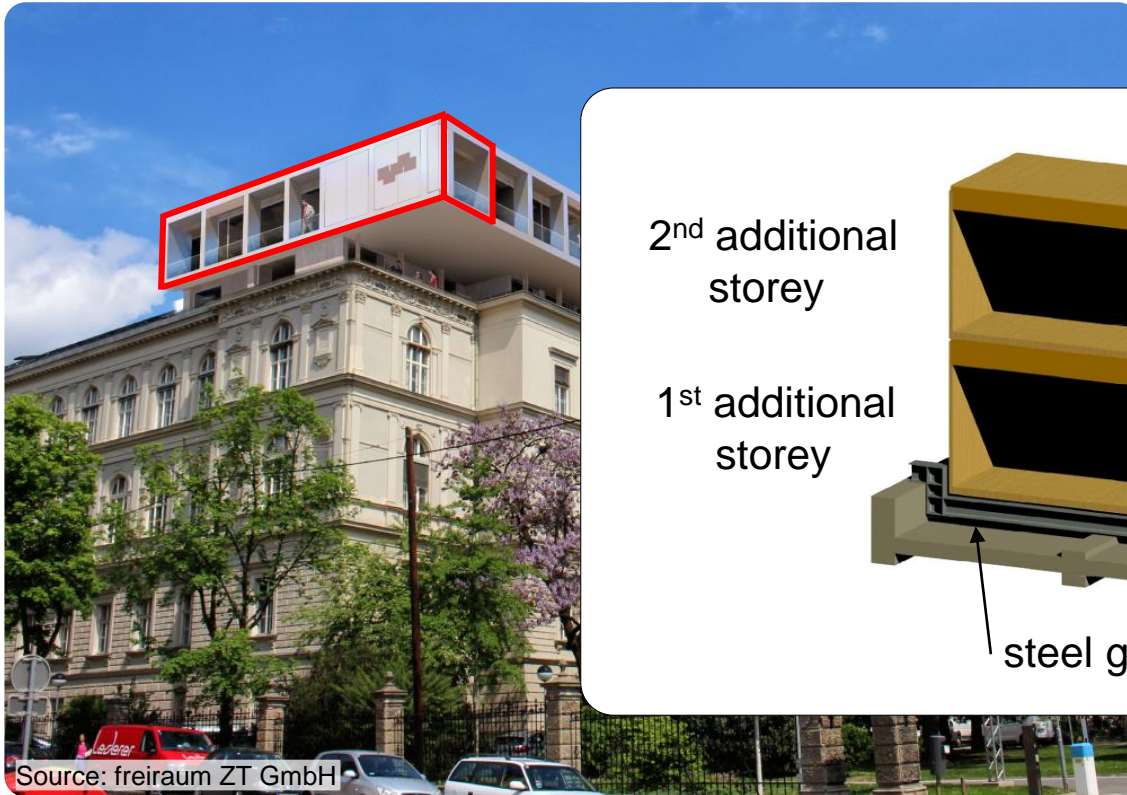


- production up to 6 modules per day
- production per year: single shift 1200 modules | two shifts 2400 modules
- new production line since 02/2019



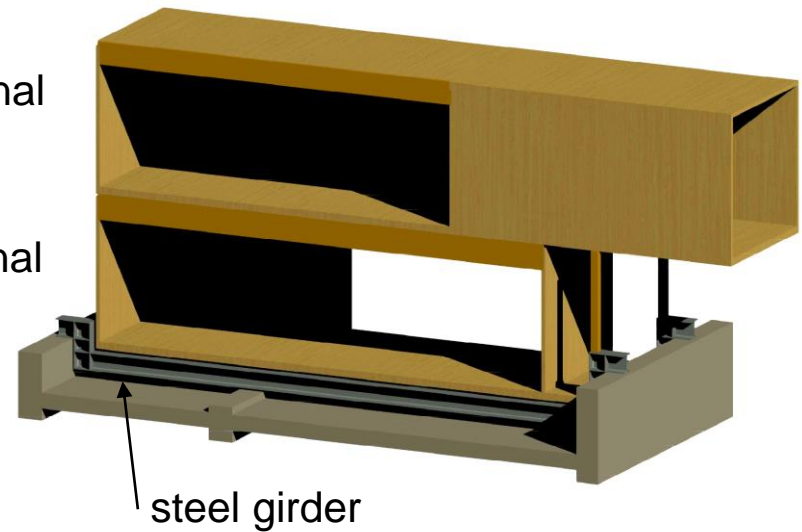
## PREFAB\_modules for densification

study for TU Graz | roof stacking



2<sup>nd</sup> additional storey

1<sup>st</sup> additional storey



steel girder

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**“CLT\_follows\_form”** for **free-form surfaces**

Museum PANEUM

customers' request

architects' idea

engineers' plan

statics/design

production

assembly

product

**museum concerning the history of bread**



Source: kornspitz.com



# “CLT\_follows\_form” for free-form surfaces

## Museum PANEUM

customers' request

**architects' idea**

engineers' plan

statics/design

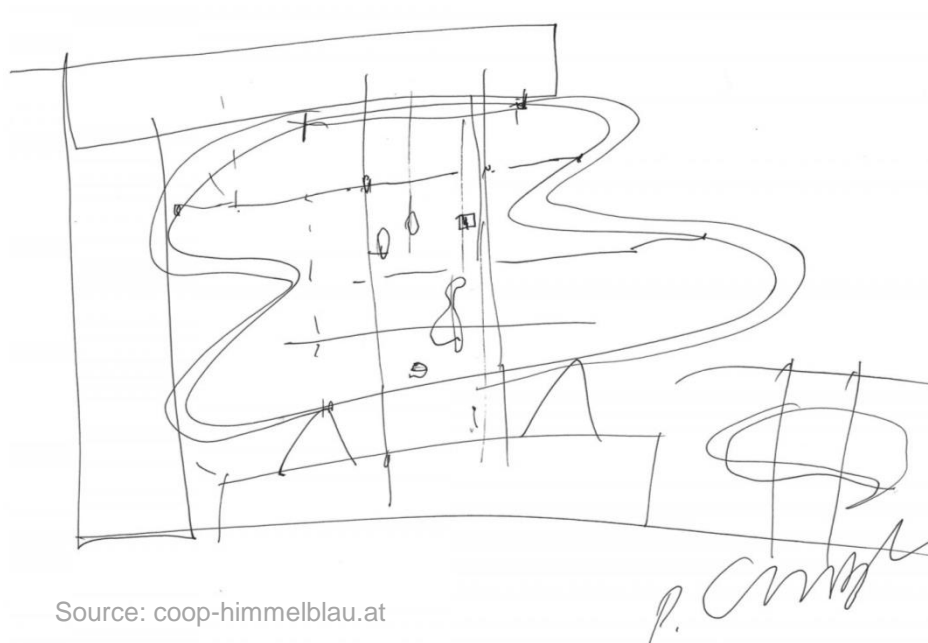
production

assembly

product

### COOPHIMMELB(L)AU

(Wolf D. Prix & Partner)



Source: coop-himmelblau.at



# “CLT\_follows\_form” for free-form surfaces

## Museum PANEUM

customers' request

architects' idea

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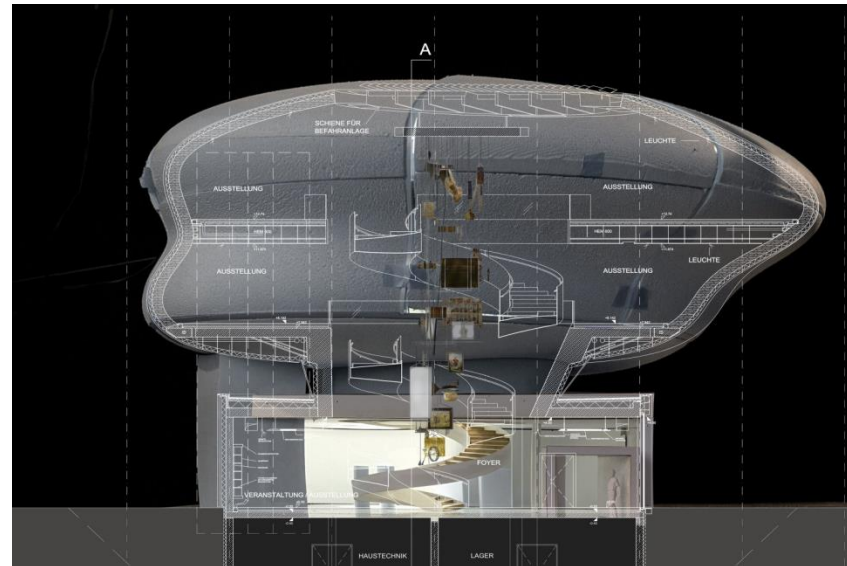
statics/design

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assembly

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### COOPHIMMELB(L)AU (Wolf D. Prix & Partner)



Source: coop-himmelblau.at





# “CLT\_follows\_form” for free-form surfaces

## Museum PANEUM

customers' request

architects' idea

**engineers' plan**

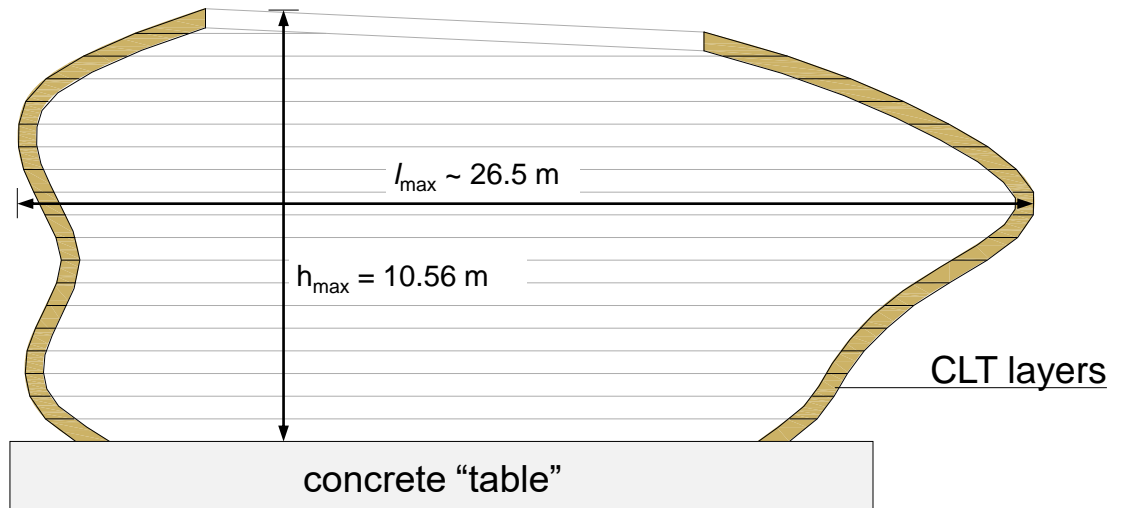
statics/design

production

assembly

product

- composition in layers of CLT
- joining single layers with screw-press gluing
- reinforcement with self-tapping screws





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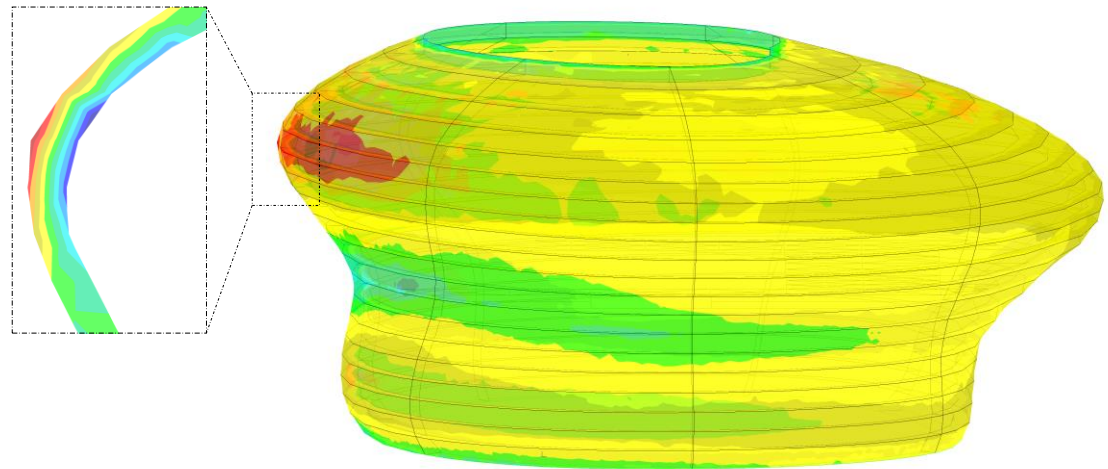
statics/design

production

assembly

product

- simplified model applying beam statics  
(Wernly + Wischenbart + Partner Ziviltechniker GMBH)
- validation by 3D-volume FE analysis  
(Institute of Timber Engineering and Wood Technology, TU Graz)





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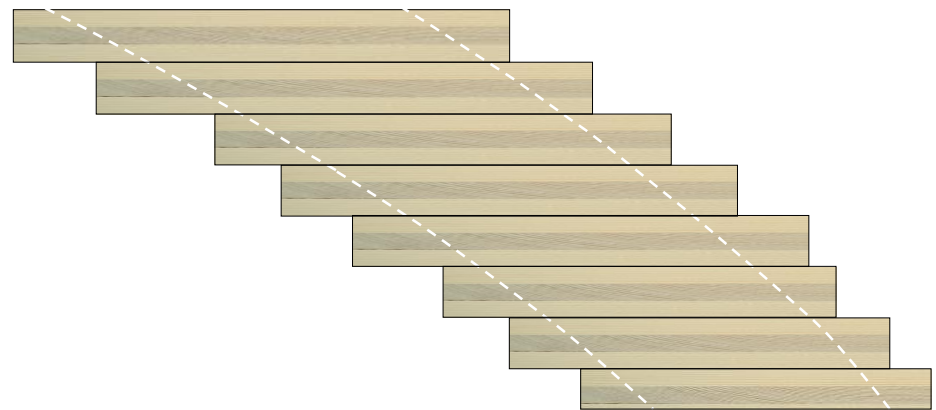
statics/design

**production**

assembly

product

- **CLT raw material: 600 m<sup>3</sup>**
  - 3-, 5-, 7-layered CLT elements





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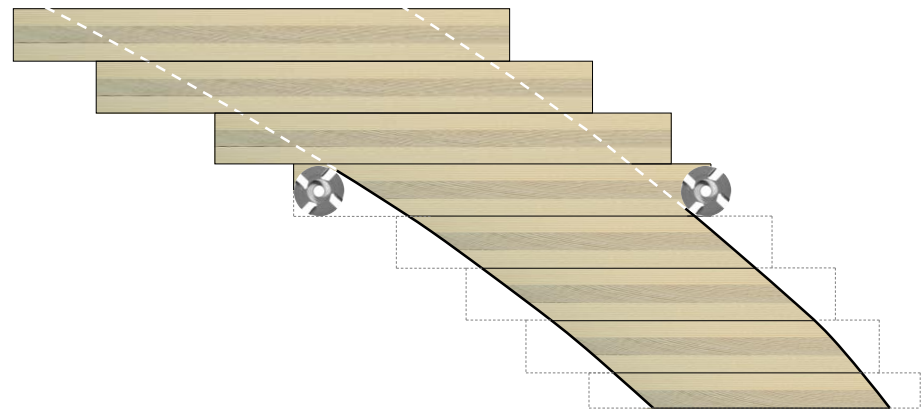
statics/design

**production**

assembly

product

- **CLT raw material: 600 m<sup>3</sup>**
- **milling**





“CLT\_follows\_form” for free-form surfaces

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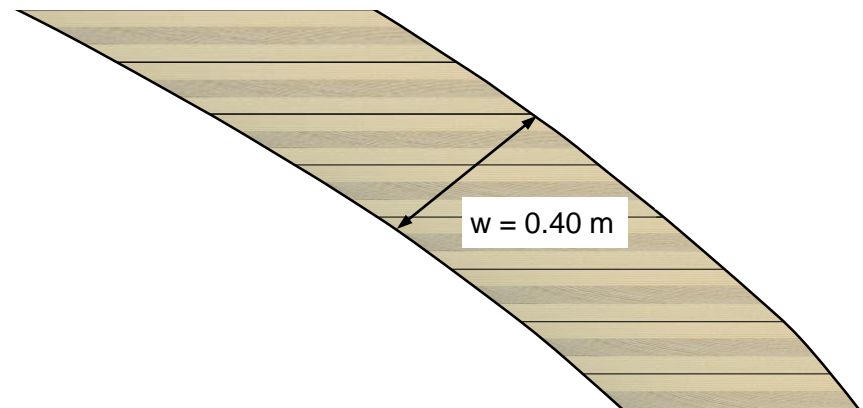
statics/design

**production**

assembly

product

- **CLT raw material: 600 m<sup>3</sup>**
- **milling**
- **CLT final structure: 400 m<sup>3</sup>**
  - 80 “rings” → total height 10.56 m





**“CLT\_follows\_form”** for **free-form surfaces**

Museum PANEUM

customers' request

architects' idea

engineers' plan

statics/design

production

**assembly**

product

- **application of adhesive**
- **positioning of CLT element(s)**
- **screw-press gluing (vertical screws)**
- **load-carrying screws (inclined screws)**





“CLT\_follows\_form” for free-form surfaces

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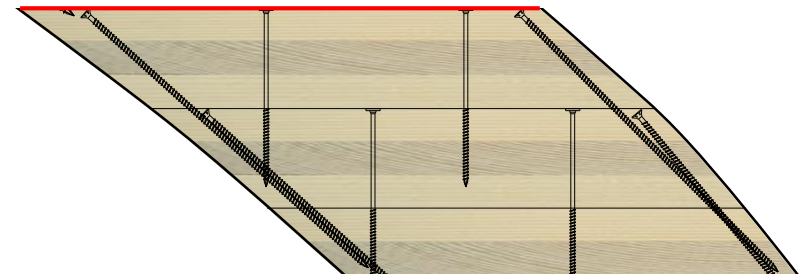
statics/design

production

**assembly**

product

- application of adhesive
  - positioning of CLT element(s)
  - screw-press gluing (vertical screws)
  - load-carrying screws (inclined screws)
- **totally applied screws ~ 120,000 (!)**





# “CLT\_follows\_form” for free-form surfaces

## Museum PANEUM

customers' request

architects' idea

engineers' plan

statics/design

production

**assembly**

product



Source: Wernly + Wischenbart + Partner Ziviltechniker GMBH, 2016





“CLT\_follows\_form” for free-form surfaces

Museum PANEUM

customers' request

architects' idea

engineers' plan

statics/design

production

assembly

product



Source: WILDUNDWUNDERBAR, 2019



“CLT\_follows\_form” for free-form surfaces

Museum PANEUM

customers' request

architects' idea

engineers' plan

statics/design

production

assembly

product



Source: WILDUNDWUNDERBAR, 2019



# “CLT\_follows\_form” for free-form surfaces

## Museum PANEUM

customers' request

architects' idea

engineers' plan

statics/design

production

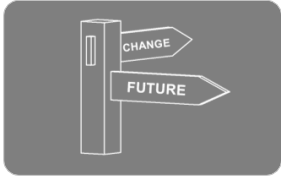
assembly

**product**



Source: WILDUNDWUNDERBAR, 2019

- INTRODUCTION
  - TIMBER at Graz University of Technology – R&D
  - Data & Facts about CLT
- SELECTED SUB- AND PROJECTS
  - “CLT\_standardisation” for wider use
  - “PREFAB\_modules” for densification
  - “CLT\_follows\_form” for free-form surfaces
- **FUTURE PROSPECTS**



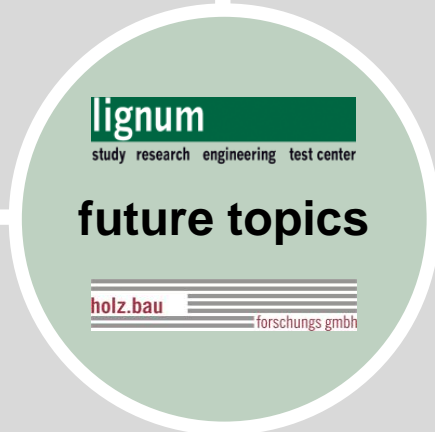
## Relevant CLT research topics

(1)

Development of complete, multifunctional and **optimised production sites** from boards to **prefabricated CLT | GLT** construction.

(2)

Utilisation of **biaxial** load-bearing **capacity** of hybrid **CLT** lay-ups and development of advanced **verification methods**.



(3)

Development of **suitable details** for **CLT** construction to minimise the risk of **moisture-induced** damage within structures.

(4)

Focus on modularisation and **joining** of **CLT modules** with a high degree of **prefabrication** to maximise their scope of application.

# Time for Replacement

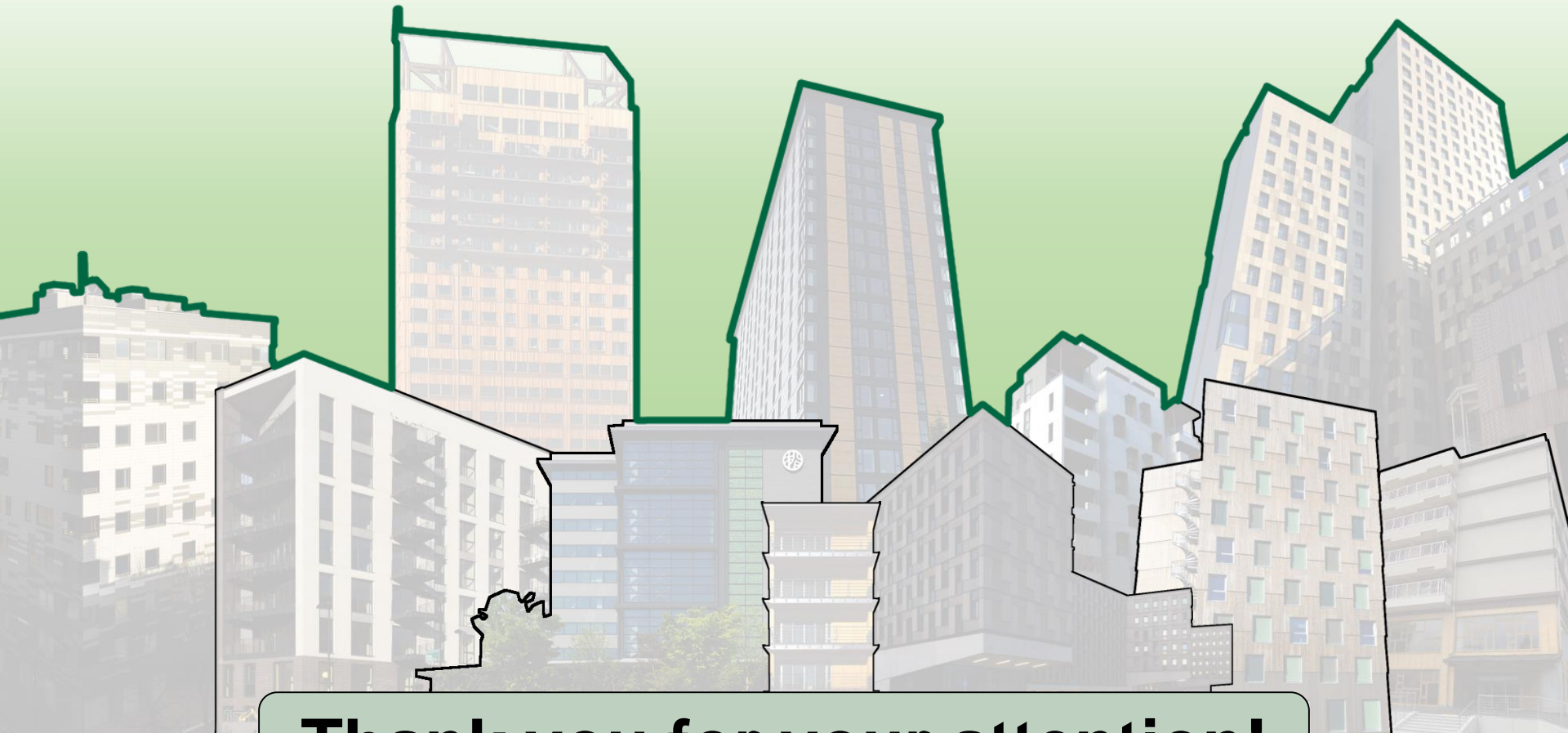
International CLT city skyline

Brumunddal, NO

Vancouver, CA

Melbourne, AU

Vienna, AT



**Thank you for your attention!**

London, UK

NO

sources: (c) Sissi Slotover-Smutny | Stora Enso | Yoh Nakashima | Frank Lam | Kaufmann Bausysteme | KLH | MDH Arkitekti | Woodcon | Woschitzgroup