CLT – European Experiences

Cross-Laminated Timber Symposium
Vancouver Convention Center

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Institute for Timber Engineering and Wood Technology, Graz University of Technology | AUT
Competence Centre holz.bau forschungs gmbh Graz | AUT

CONTENT

- „TIMBER“ at the Graz University of Technology
  - Institute for Timber Engineering and Wood Technology (TEWT)
  - Competence Centre holz.bau forschungs gmbh (hbf)
  - R&D Areas
- „Solid Timber Construction (STC)“ – Cross Laminated Timber (CLT)
  - Introduction | History
  - Production | Transport | Assembling
  - Basics of Design (Bending and Rolling Shear)
  - Applications
- Summary | Outlook

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GRAZ UNIVERSITY OF TECHNOLOGY

Austria / Europe

7 faculties | 11,264 students | staff 2,222 (2010)
budget: **€ 150 Mill.** (1/3 3rd party budget)

Faculty of Civil Engineering Sciences

17 institutes | about 1.250 students (2010)
[328 “Diploma”, 672 “Bachelor”, 158 “Master”, 93 “PhD”]

Institute for Timber Engineering and Wood Technology

1991: Chair for Timber Engineering

10|2004: **Institute Timber Engineering and Wood Technology**

Scientific staff: **8.2 FTE** | 3rd party-budget: **€ 320,000** (2010)

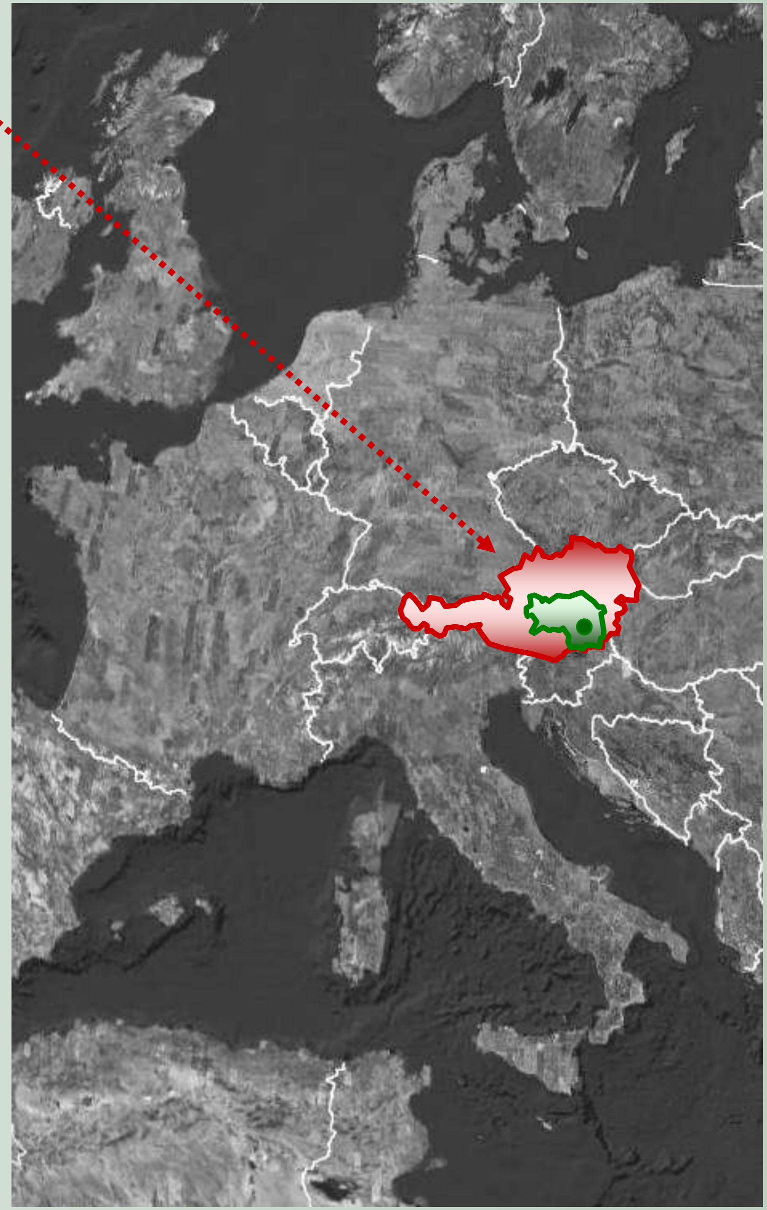
Competence Centre holz.bau forschungs gmbh

09|2002 Acceptance of 4-year-fundings: Competence Center Timber Engineering and Wood Technology

12|2002 **Competence Centre holz.bau forschungs gmbh**

09|2007 Acceptance of 5-year-fundings: K-Project “timber.engineering” | COMET-Programme

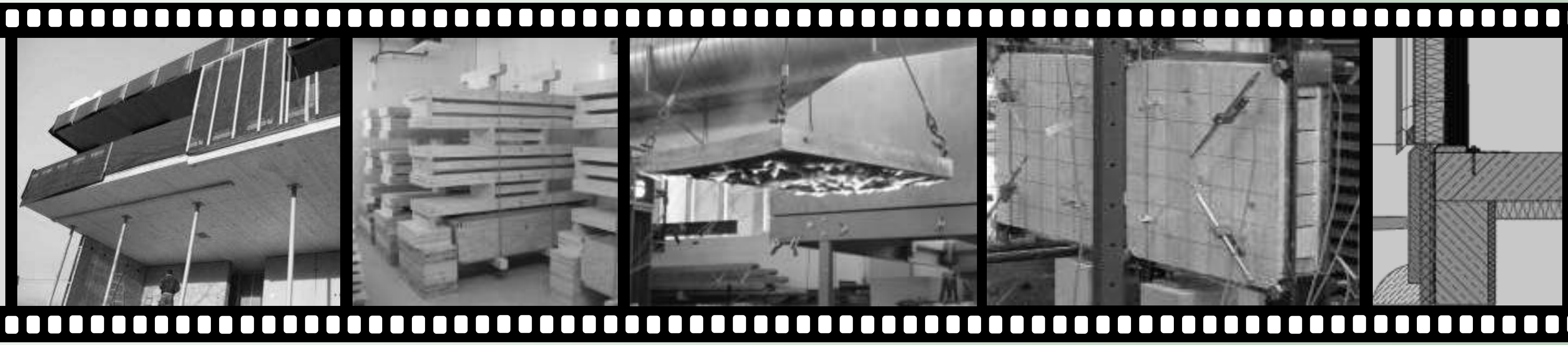
Scientific staff: **7.0 FTE | budget: € 950,000** (2010)



AREA 1

Timber Engineering (TE) – Design and Construction Sciences (DCS)

1.1 Shell and Spatial Timber Constructions (SSTC)

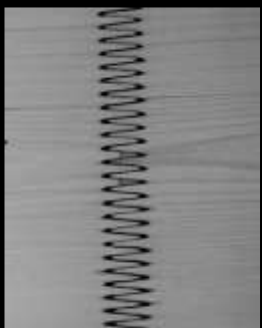


1.2 Innovative and Intelligent Connection Systems (IICS)

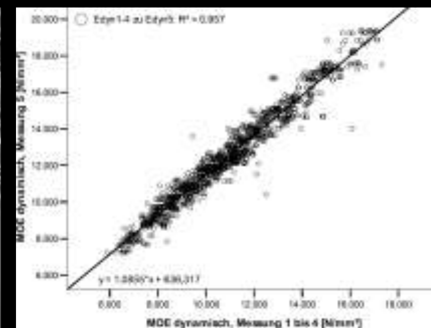
AREA 2

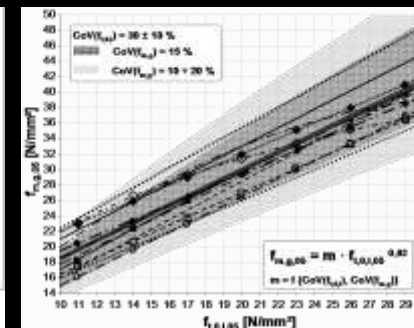
Wood Technology (WT) – Material and Structure Sciences (MSS)

2.1 Advanced Products and Test Methods (APTM)

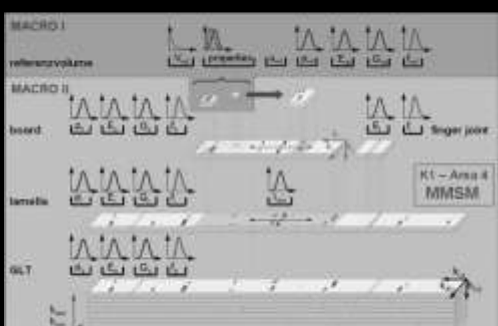


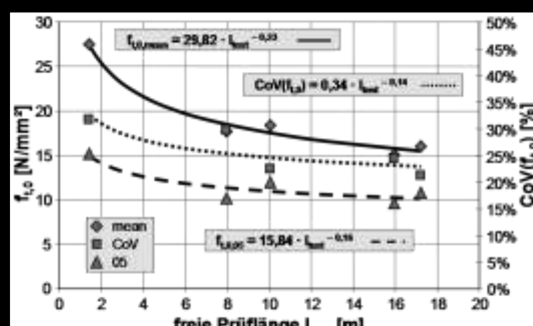


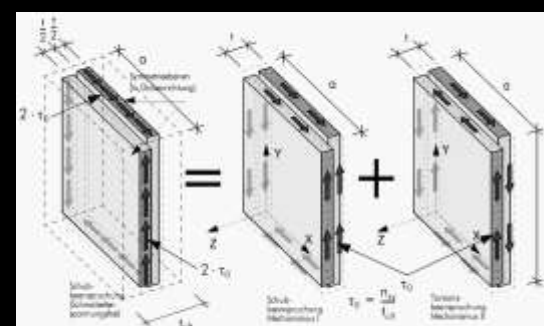
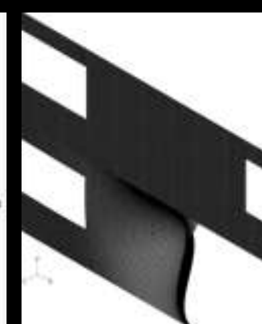




2.2 Material Modelling and Simulation Methods (MMSM)





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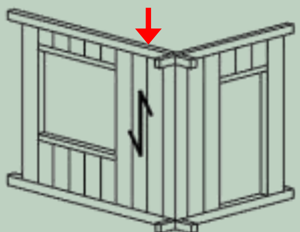
Solid Timber Construction (STC) – INNOVATION based on TRADITION

load transfer

tradition

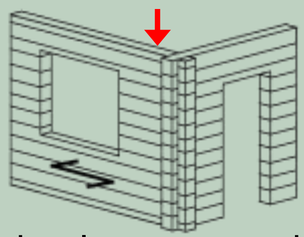
bar-like
(parallel to grain)



timber bar construction
(especially in Scandinavia)

stave church

bar-like
(perp. to grain)

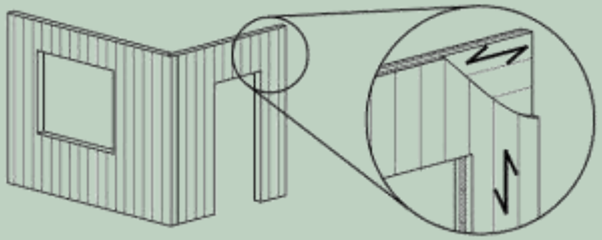


timber log construction
(especially in Alpine Space)

chalet

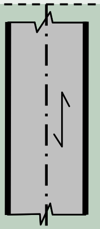
innovation

slab-like
(interaction of “parallel” and “perp.” to grain)



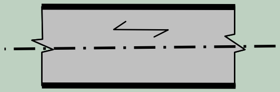
Solid Timber Construction with CLT

detached house Jeitler



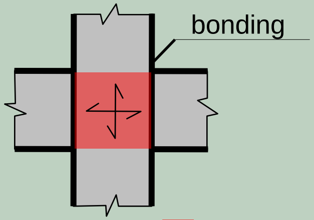
vertical

+



horizontal

=

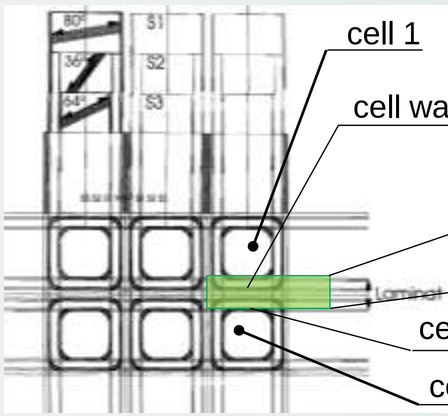


Cross Laminated Timber (CLT)
[rigidly connected]

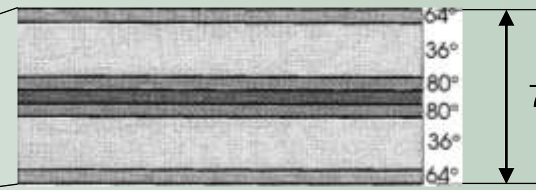
Analogies between Wood and Fibre-Plastic Composites

Scientific Activities [doctoral thesis] | 1989 ÷ 1994

lay-up of the load carrying system of a wood cell…



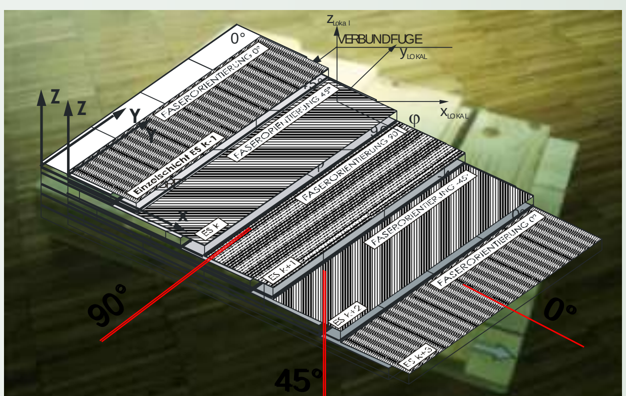
… is similar to the lay-up of fibre plastic composites



ANALOGY

analysis is based on the
`**C**lassical **L**aminate **T**heory´ **(CLT)**
[see also A.P. Schniewind | J.D. Barrett (1969)]

plywood (e.g. 5-layered panel | CLT (…) | 1994 [overlapping text]

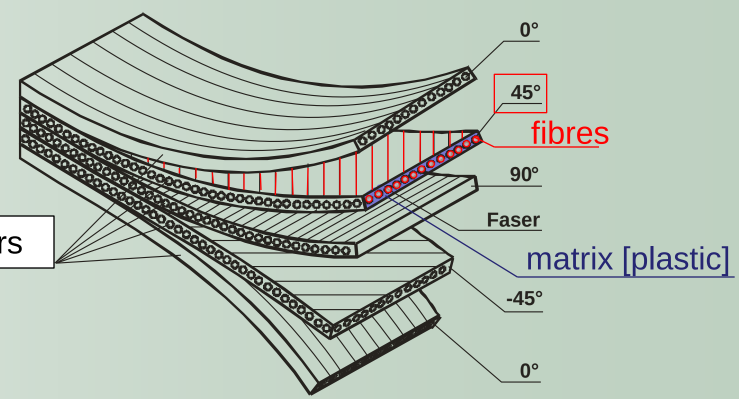


wood fibres + matrix
(lignin + adhesive between the layers)

ANALOGY

fibre plastic composites e.g. 5-layered panel

single layers

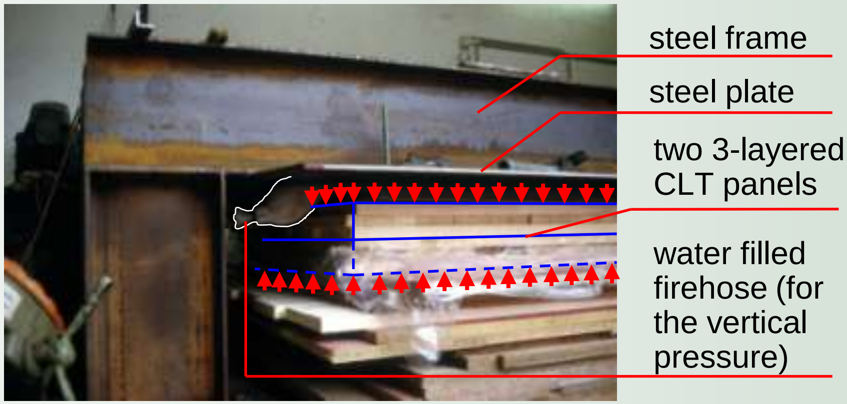


glas-, aramid-, carbon fibres + matrix [plastic]

Product Development

Project between 1995 and 1998

tryout press … and … one of the first CLT panels produced by KLH | Austria, 1996 …



… 15 years later – 2011 – KLH Massivholz GmbH is the world largest CLT producer

www.klh.at | Katsch/Mur | Austria

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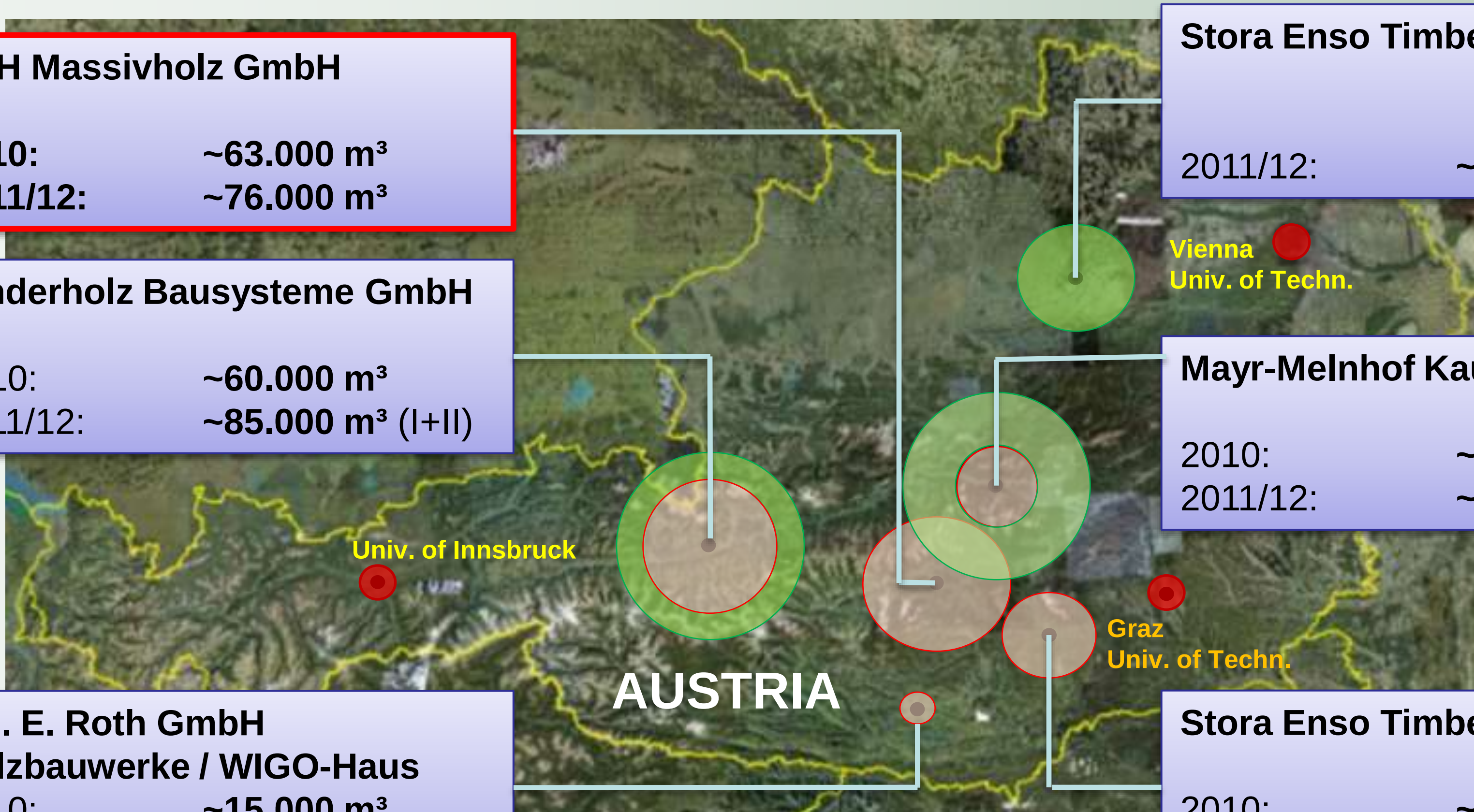
Overview

CLT is a product of well-wooded regions in Europe, e.g. Austria | Germany | Switzerland

AUSTRIA

~8.4 Mio. inhab. / ~84.000 km²



KLH Massivholz GmbH

2010: **~63.000 m³**
2011/12: **~76.000 m³**

Binderholz Bausysteme GmbH

2010: **~60.000 m³**
2011/12: **~85.000 m³** (I+II)

Ing. E. Roth GmbH
Holzbauwerke / WIGO-Haus
2010: **~15.000 m³**
2011/12: **~18.000 m³**

Stora Enso Timber II

2011/12: **~50.000 m³**

Mayr-Melnhof Kaufmann GmbH

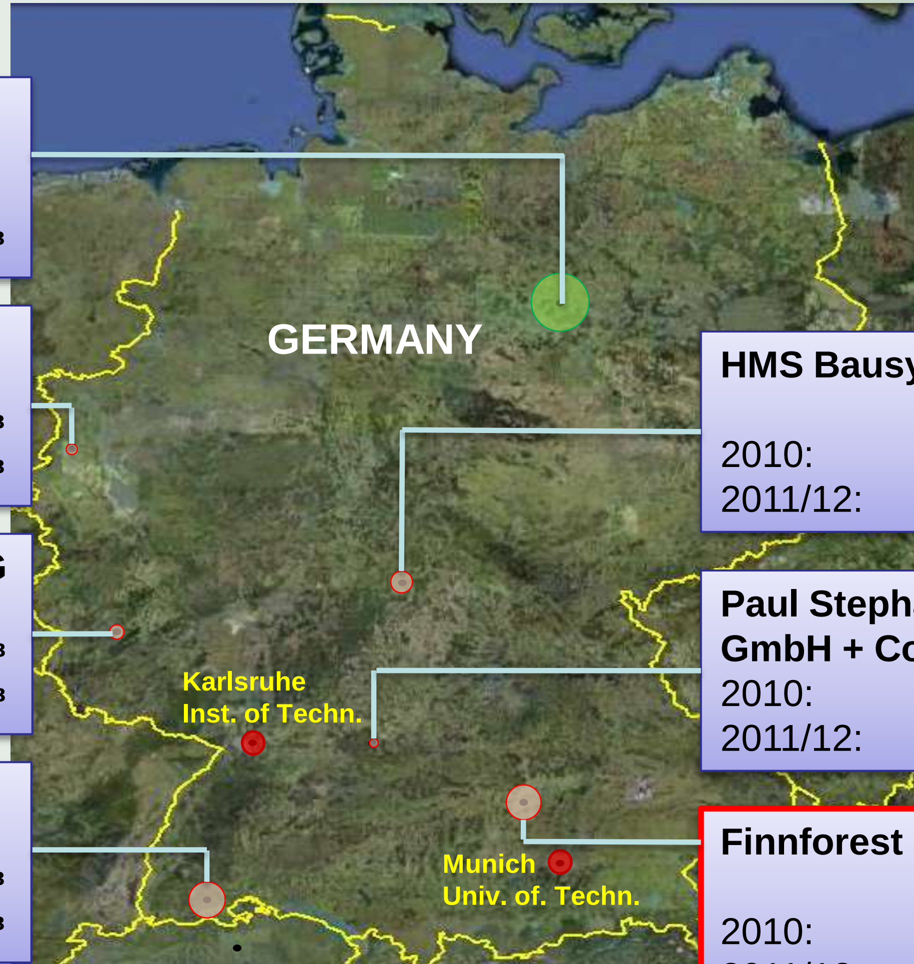
2010: **~36.000 m³**
2011/12: **~85.000 m³** (I+II)

Stora Enso Timber I

2010: **~40.000 m³**
2011/12: **~50.000 m³**

GERMANY

~81.8 Mio. inhab. / ~357.000 km^2



Benken Wood Gardelegen GmbH
2011/12: **~40.000 m^3**

Holzleimbau Derix W. u. J. Derix GmbH & Co.
2010: **~7.500 m^3**
2011/12: **~16.000 m^3**

Eugen Decker Holzindustrie KG
2010: **~10.000 m^3**
2011/12: **~15.000 m^3**

LIGNOTREND Produktions GmbH
2010: **~25.000 m^3**
2011/12: **~30.000 m^3**

HMS Bausysteme GmbH
2010: **~15.000 m^3**
2011/12: **~17.000 m^3**

Paul Stephan Holz GmbH + Co. KG
2010: **~6.000 m^3**
2011/12: **~7.000 m^3**

Finnforest Merk GmbH
2010: **~24.000 m^3**
2011/12: **~28.000 m^3**

SWITZERLAND / ITALY / CZECH REPUBLIC

Schilliger Holz AG

2010:	**~13.000 m³**
2011/12:	**~15.000 m³**

Pius Schuler AG

2010:	**~5.000 m³**
2011/12:	**~6.000 m³**

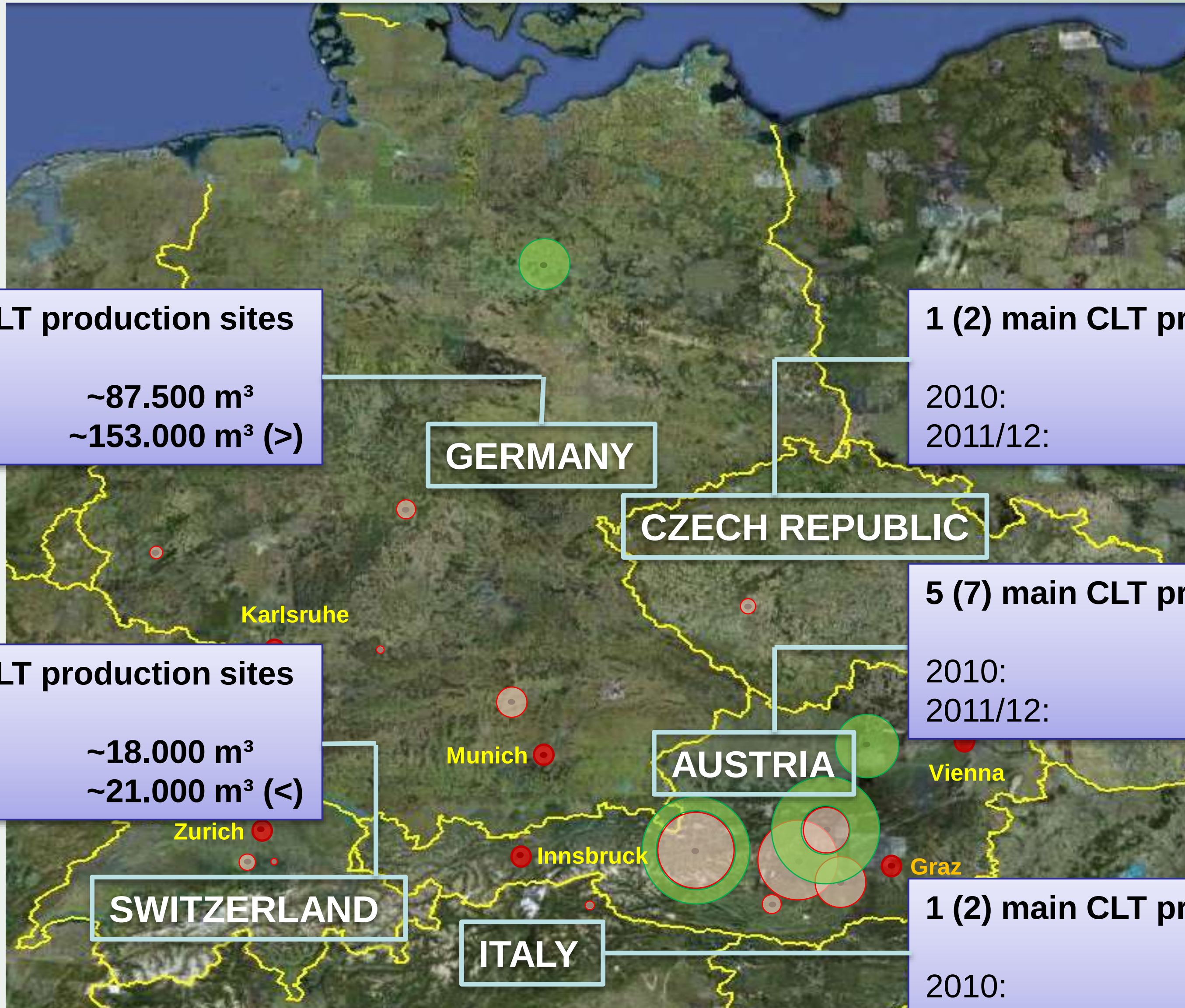
Moser Holzbau GmbH

2010:	**~7.000 m³**
2011/12:	**~8.000 m³**

Haas Group

2010:	**~12.000 m³**
2011/12:	**~15.000 m³**

Production | Transport | Assembling



6 (7) main CLT production sites

2010: **~87.500 m³**
2011/12: **~153.000 m³ (>)**

1 (2) main CLT production sites

2010: **~12.000 m³**
2011/12: **~14.000 m³ (>)**

5 (7) main CLT production sites

2010: **~214.000 m³**
2011/12: **~364.000 m³ (<)**

2 (2) main CLT production sites

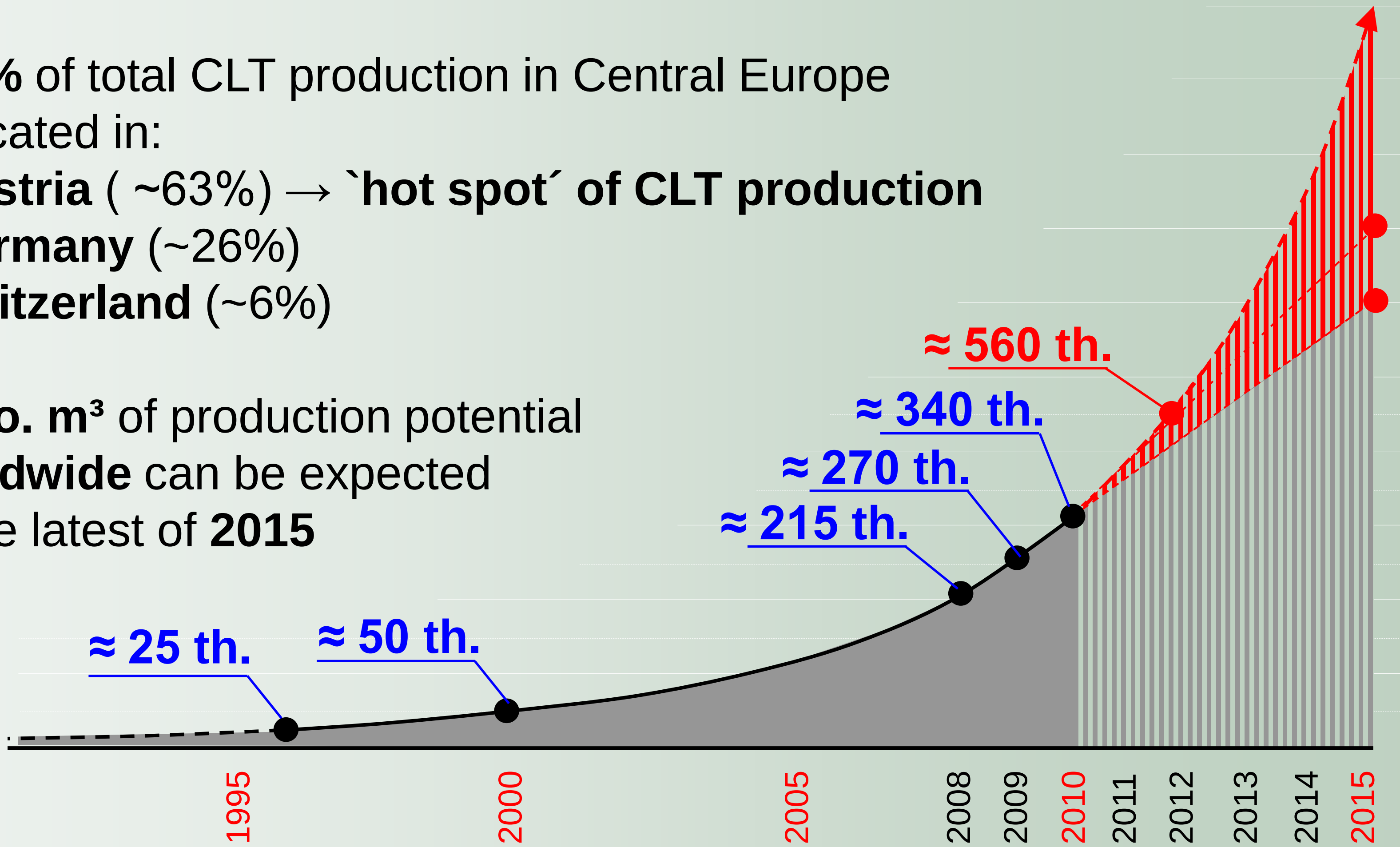
2010: **~18.000 m³**
2011/12: **~21.000 m³ (<)**

1 (2) main CLT production sites

2010: **~7.000 m³**
2011/12: **~8.000 m³ (>)**

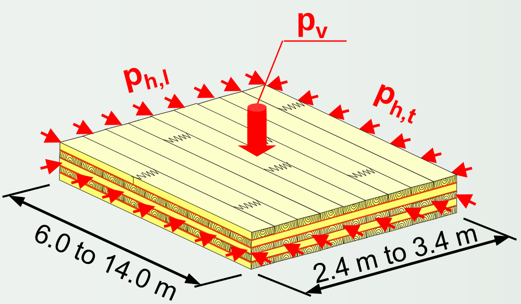
Development of European CLT Production

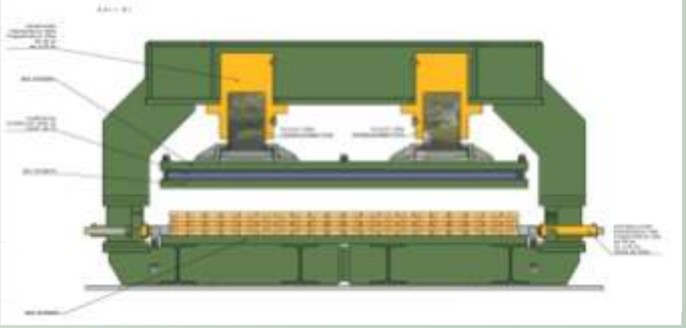
- current **15** main CLT production sites (2011/12: **~20 or more**)
- **~95%** of total CLT production in Central Europe
  is located in:
  - **Austria** (~63%) → **`hot spot´ of CLT production**
  - **Germany** (~26%)
  - **Switzerland** (~6%)
- **1 Mio. m³** of production potential **worldwide** can be expected at the latest of **2015**



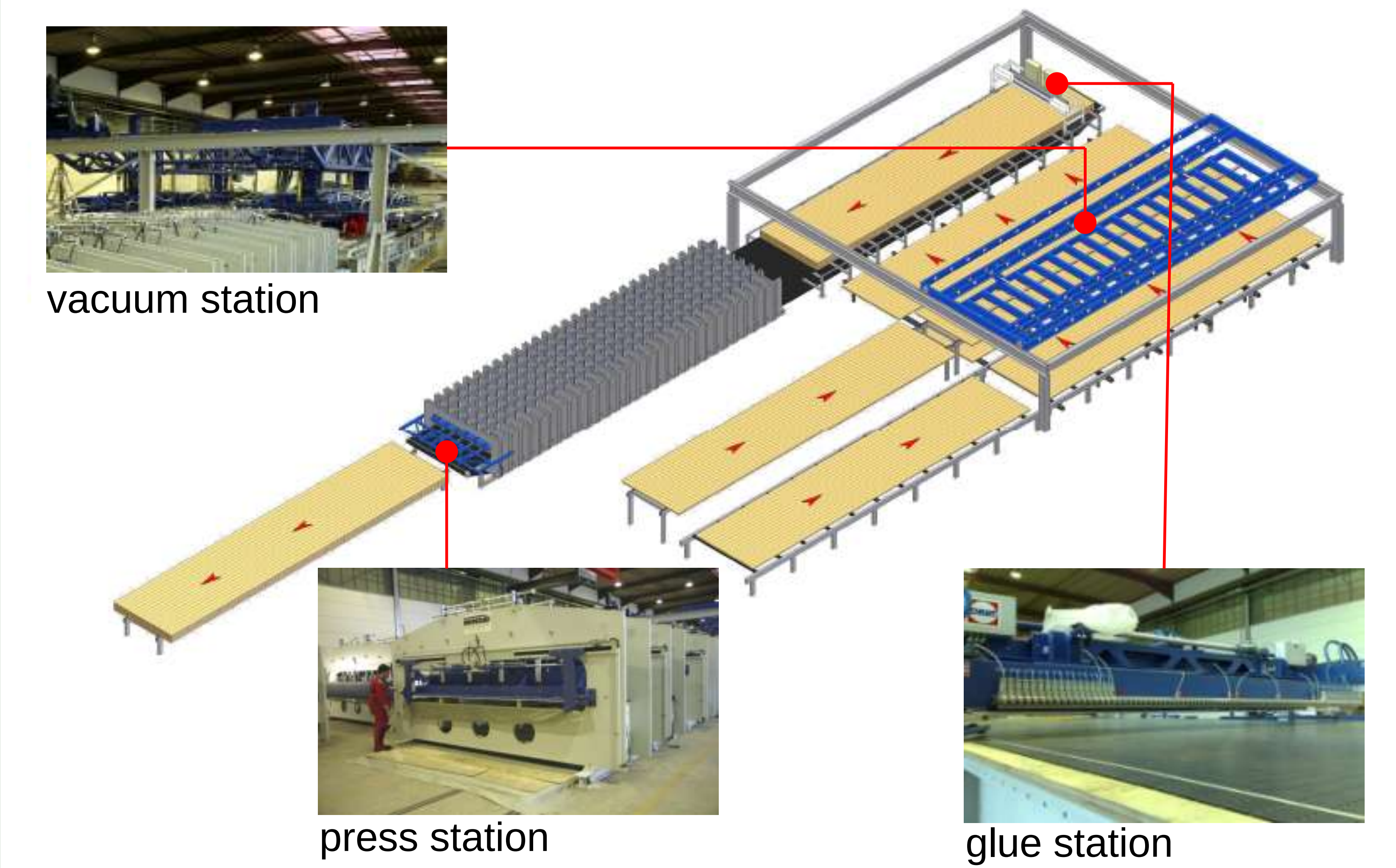
Examples of CLT Press Systems

		MINDA `CLT press´ (GER)	**SPRINGER** `CLT press´ (AUT)
dimensions of CLT		**6.0** m ÷ **14.0** m | **2.4** m ÷ **3.4** m **3 ÷ 9-layers** (≤ ~ 300 mm)	**≤ 14.0** m | **2.5** m ÷ **3.2** m **80** mm ÷ **320** mm
type of press system		hydraulic continuous process	hydraulic continuous process
bonding pressure	vertical, $\mathbf{p_v}$	≤ **0.8** N/mm²	≤ **1.5** N/mm²
	horizontal transverse, $\mathbf{p_{h,t}}$	≤ **0.3** N/mm² (t ~ 300 mm)	~ **0.3** N/mm² (t = 320 mm)
	horizontal lengthwise, $\mathbf{p_{h,l}}$	available	not available



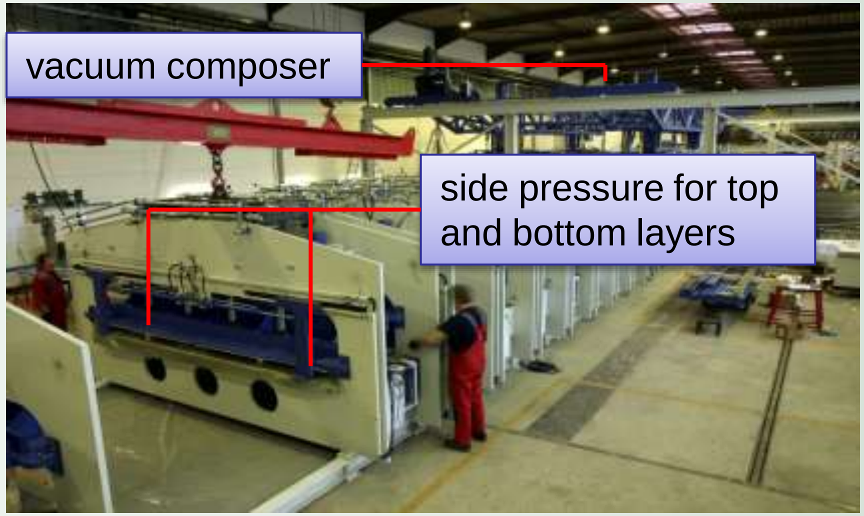


Example of a CLT Press System (e.g. MINDA)



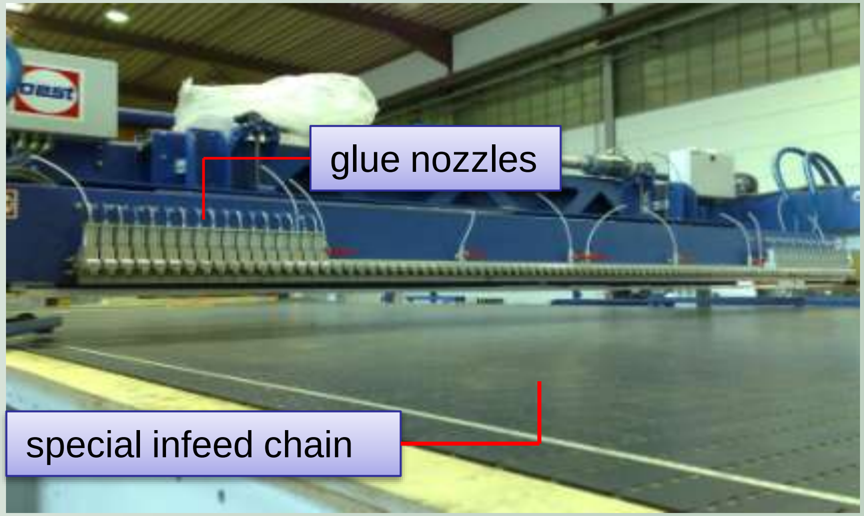
Example of a CLT Press System (e.g. MINDA)

press station and vacuum composer



© Pictures: MINDA

glue station (with infeed chain)



© Pictures: MINDA

- throughfeed system with **simultaneous** charging/discharging
- capacity: 12 pressing cycles/480 min. shift
  → **~ 40 min.** per cycle
  → **~ 20,000 m³**/shift and p.a.
- glue: PUR-HBS modified [open/pressing time: 12´/39´]; approved system by Purbond (CH)

Examples of CLT Press Systems

- further producers of CLT press systems:
  LEISSE (GER) | LEDINEK (SLO) | WEINIG GROUP (GER) | WOODTEC Fankhauser (vacuum press) (CH)
- a high variability regarding the bonding pressure exists between different press systems [0,1 N/mm² (vacuum) to 1,5 N/mm² (hydr.)]

→ development of a process optimized CLT production line | optimization of bonding pressure (ongoing project)

- project partner:
  - MINDA | JOWAT AG
  - TU Graz | UBC
- overall aims of the development of a process-optimized CLT production line are

  ✓ **reduction of production time**

  ✓ **reduction of investment and running costs**

  ✓ **increasing the profitability and competitiveness of CLT**

Optimization of Bonding Pressure

…focus on examination of the influence of the interaction between bonding pressure and adhesive application on CLT properties (e.g. rolling shear, delamination,…)

fixed bonding pressure (0.5 N/mm²)
three adhesive applications
(100 g/m² | 120 g/m² | 150 g/m²)

Nordic spruce, strength class C18 (EN 338) u ~ 12%

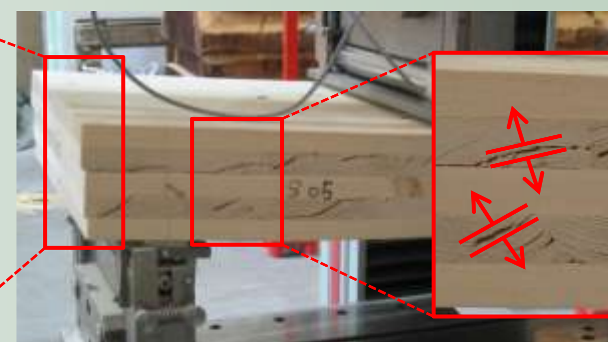
3-layerd CLT plate
pair of par.: 125 g/m² | 0.6 N/mm²
2,5 h pressing time

press at TU Graz

test plan for the project:

- **4-point-bending test configuration (rolling shear)**
- **shear test configuration acc. to EN 408 (small specimen)**
- **delamination test acc. to EN 391 (quality control)**

failure mode:
shear failure
perp. to grain
(`rolling shear´)



failure mode:
tension perp.
to the grain

4-point-bending test config.
→ system property `rolling shear´

Transport | Assembling

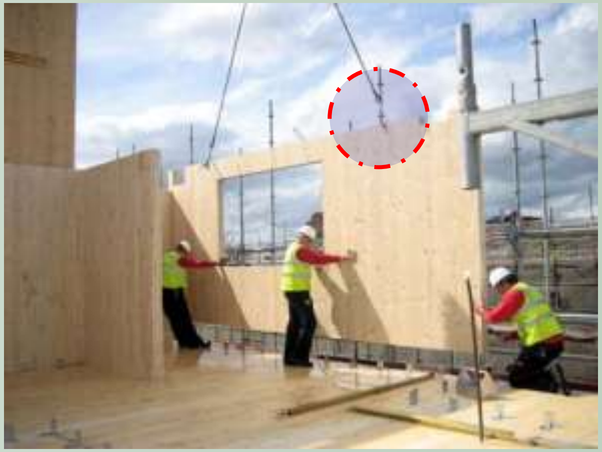
storage of CLT elements (production site)

charging and transport

discharging (building site)

mounting parts for roof elements

mounting parts for ceiling elements



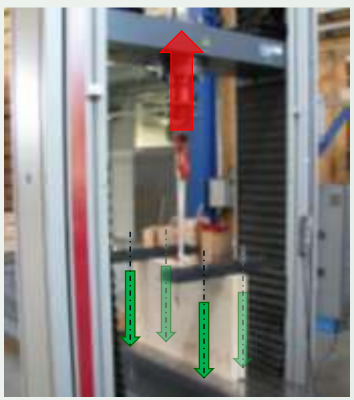
mounting parts for wall elements

Mounting Parts for Transport and Assembling

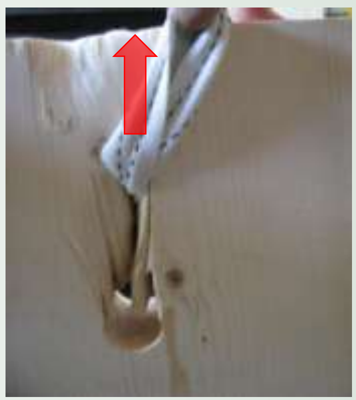
for walls:

- ball-shaped head connected with self-tapping screws
- textile hanger with high strength and ductility

mounting part at the narrow side of a 3-layered CLT element



tension test configuration



failure mode with high deformation [safety factor:7]

in plane

`shear´

`pull out´

out of plane

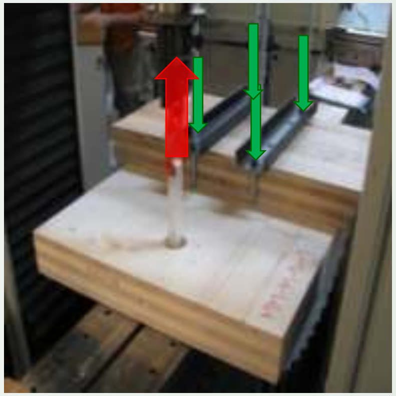
`shear´

failure modes

Mounting Parts for Transport and Assembling

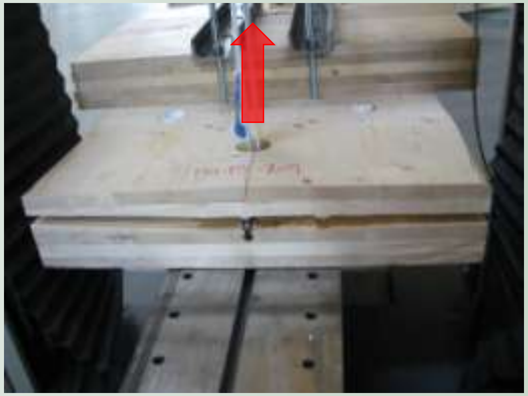
for ceiling and roof elements:

- tapped blind hole connection with dowel and textile hanger



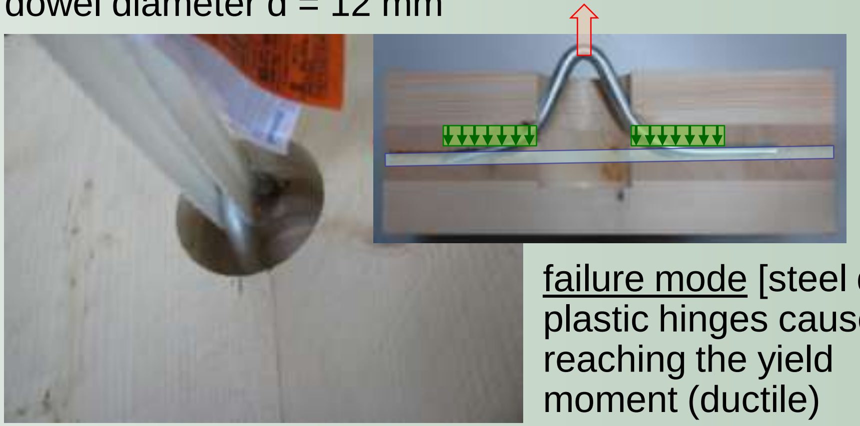
tension test configuration perp. to the grain

dowel diameter d = 16 mm



failure mode [timber] caused by tension perp. to the grain [rigid]

dowel diameter d = 12 mm



failure mode [steel dowel] plastic hinges caused by reaching the yield moment (ductile)

NOTE:

Extension of knowledge regarding the load carrying behavior of mounting parts is required! → Research activities are important!

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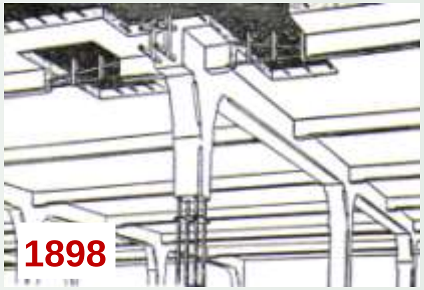
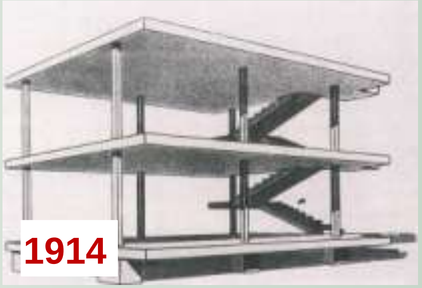
Ceiling Constructions

- development of reinforced concrete related to column-plate-systems



RC frame with secondary concrete elements

RC ceiling on enlarged column heads ("mushroom headed")



point supported RC ceilings

point supported RC ceilings

t i m e l i n e

- development of timber engineering related to column-plate-systems


line supported CLT ceiling (with GLT beam)


CLT/GLT ceiling element as a ripped base plate (span length 8 m)


point supported CLT element (steel or timber column)

because of …

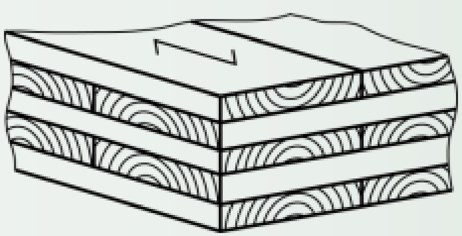
- geometric aspects and boundary conditions, in combination with
- build-up of plates

CLT is mainly used as a building element with one pronounced direction for load transfer.

therefore …

In general, computation models based on 1D-beam theory are mostly sufficient!

design of 2D-load bearing behaviour



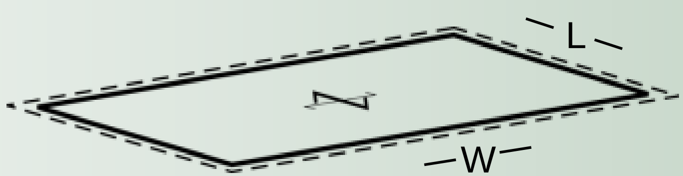
e. g. 5-layered plate with following assembling
34-19-34-19-34 mm
$(EJ)_L = 2{,}42 \cdot 10^{12}$ Nmm²
$(EJ)_Q = 0{,}41 \cdot 10^{12}$ Nmm²

$(EJ)_L : (EJ)_Q \sim 6 : 1$

--- support | load transfer

L : W = 1 : 1

L : W = 1 : 2



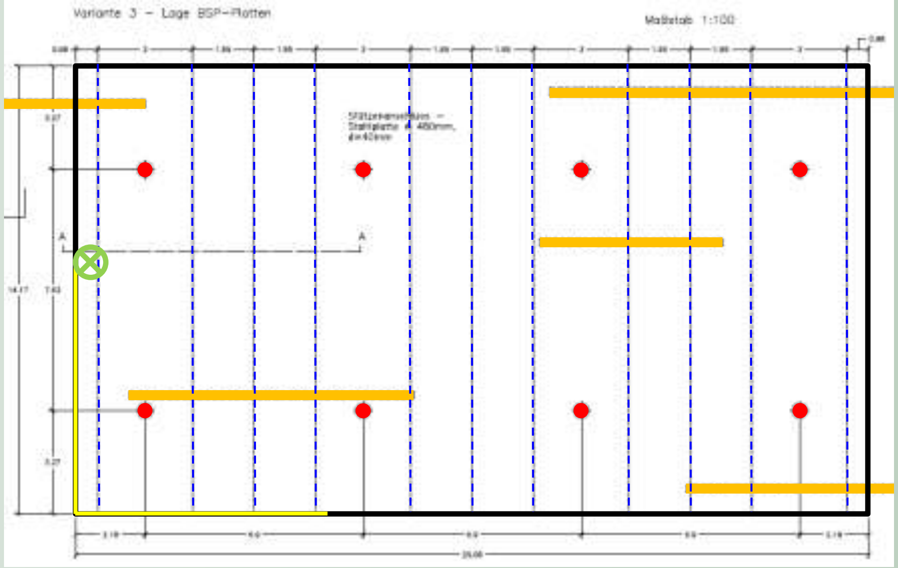
load-bearing capacity
longitudinal : transverse

L : W = 1 : 1 — **factor ~ 6**

L : W = 1 : 2 — **factor ~ 100**

BUT …

2D-effects are relevant and therefore have to be considered for …



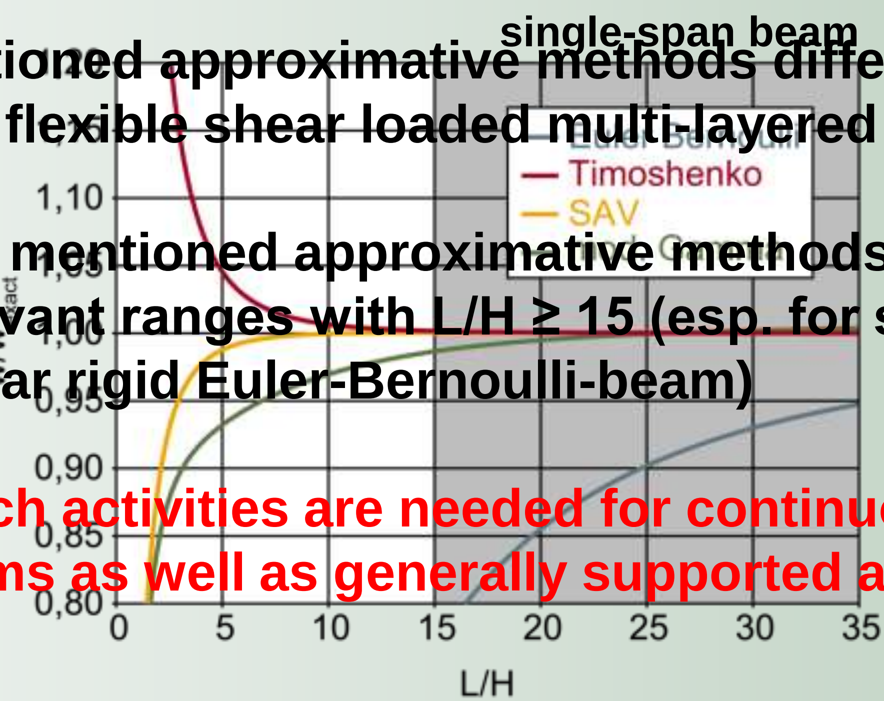
\`DEUTSCHER PAVILLON´ of M. van der Rohe
build:1929 | World Exhibition Barcelona

- point-supported CLT plates | roof elements (1)
- partial area supported CLT plate | roof elements (2)
- cantilever (3)
- butt joints (construction) (4)
- point loads (5)
- etc.

Further research activities on 2D-effects are required!

known approximative methods for the 1D-platestrip:

- **shear-analogy-method**
  anchored in DIN 1052
- **modified γ-method**
  as ‘flexible jointed member’, anchored in EN 1995-1-1 (informativ), DIN 1052, etc.
- **Timoshenko beam theory**
  CLTdesigner of TU Graz | www.cltdesigner.at



➢ **All above mentioned approximative methods differ from the exact solution of the flexible shear loaded multi-layered compound beam!**

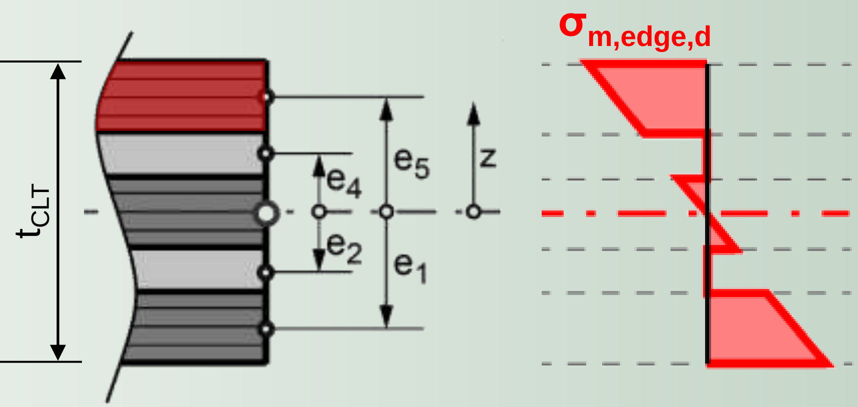
➢ **BUT: All above mentioned approximative methods can be applied for practically relevant ranges with L/H ≥ 15 (esp. for single-span beams; <u>exception:</u> shear rigid Euler-Bernoulli-beam)**

➢ **Further research activities are needed for continuous and/or cantilever beams as well as generally supported and loaded CLT elements!**

BENDING

e.g.: 5-layered CLT element [assumption : $E_{90}=0$]

ES	α			
#5	0	E_0	G_0	t_5
#4	90	E_{90}	G_{90}	t_4
#3	0	E_0	G_0	t_3
#2	90	E_{90}	G_{90}	t_2
#1	0	E_0	G_0	t_1



'saw tooth' - like stress distribution

calculation of the design value for edge-bending-stress $\sigma_{m,edge,d}$

$$\sigma_{m,i=5,edge,d} = \frac{M_{max,d}}{K_{CLT}} \cdot \frac{t_{CLT}}{2} \cdot E_{i=5}$$

bending stiffness of a layered cross section area

$$K_{CLT} = \sum_{i=1}^{n} \left(J_i \cdot E_i \right) + \sum_{i=1}^{n} \left(A_i \cdot e_i^2 \cdot E_i \right)$$

calculation of the design value for bending strength $f_{m,clt,d}$ acc. to load-bearing-model for CLT (TU Graz)

$$f_{m,clt,k} = a_{clt} \cdot f_{t,0,l,k}^{\,0.8} \quad \Rightarrow \quad f_{m,clt,d} = \frac{k_{mod} \cdot f_{m,clt,k}}{\gamma_M}$$

with: $f_{t,0,l,k}$ ... characteristic tension strength of boards (raw material)

a_{clt} ... prefactor to take into consideration

- the coefficient of variation (COV) of the raw material
- the laminating effect
- the system effect
- the size effect
- the structure | assembling effect

The known technical-approvals for CLT differ in the interpretation of this general model approach. The differences are negligible!

load bearing model for CLT in bending according to technical approvals:

- **ETA-09/xxx**

$$f_{m,clt,k} = \text{minimum} \begin{cases} a_{clt} \cdot f_{t,0,k}^{\;0.8} \\ 1.2 \cdot f_{m,k} \end{cases}$$

with: $f_{m,k}$... characteristic bending strength acc. to EN 338
$f_{t,0,k}$... characteristic tension strength acc. to EN 338
a_{clt} = 3.5 ... for visually graded timber

- **DIBt Z-9.1-xxx**

$$f_{m,clt,k} = k_l \cdot f_{m,glt,k}$$

reference depth $d_{ref,clt}$ not defined!
→ need for research
suggestion: $d_{ref,clt}$ = 150 mm

with: $f_{m,glt,k}$... charact. bending strength for GLT ($d_{ref,glt}$ = 600 mm)
k_l … prefactor to take in consideration the system effects (k_l = 1.1, if n ≥ 4)

load bearing models for CLT in bending – a comparison:

example | strength-class C24 acc. to EN 338 or GL24h acc. to DIN 1052

- load bearing model in bending | TU Graz (reference)

$$f_{m,clt,k} = a_{clt} \cdot f_{t,0,l,k}{}^{0,8} = 3.5 \cdot 14.0^{0.8} = 28.9\ N/mm^2$$

- ETA-09/xxx

$$f_{m,clt,k} = \min \begin{cases} a_{clt} \cdot f_{t,0,l,k}{}^{0.8} = 3.5 \cdot 14.0^{0.8} = 28.9\ N/mm^2 \\ 1.2 \cdot f_{m,k} = 1.1 \cdot 24.0 = 28.8\ N/mm^2 \end{cases}$$

- DIBt Z-9.1.-xxx

$$f_{m,clt,k} = k_l \cdot f_{m,glt,k} = 1.1 \cdot 24.0 = 26.4\ N/mm^2$$

Note: system factor k_l conservative | no depth correction, $d_{ref,clt}$ not defined

$$f_{m,clt,d=150,k} = k_h \cdot k_l \cdot f_{m,glt,k} = 1.1 \cdot 1.1 \cdot 24.0 = 29.0\ N/mm^2$$

design

$$\frac{\sigma_{m,edge,d}}{f_{m,clt,d}} \leq 1.0$$

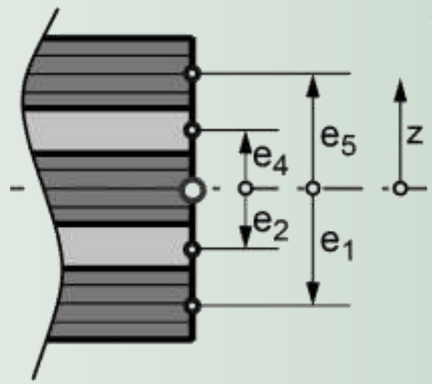
normally very low utilization ratio → seldom relevant

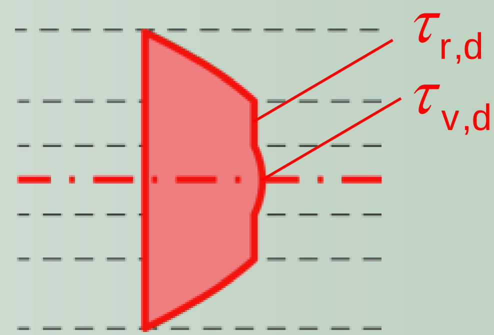
SHEAR | longitudinal | transverse (rolling shear)

calculation of the design value for shear stress

e.g.: 5-layered CLT element [assumtion : E_{90}=0]

ES	α				
#**5**	0	E_0	G_0	t_5	t_{CLT}
#4	90	E_{90}	G_{90}	t_4	
#3	0	E_0	G_0	t_3	
#2	90	E_{90}	G_{90}	t_2	
#1	0	E_0	G_0	t_1	



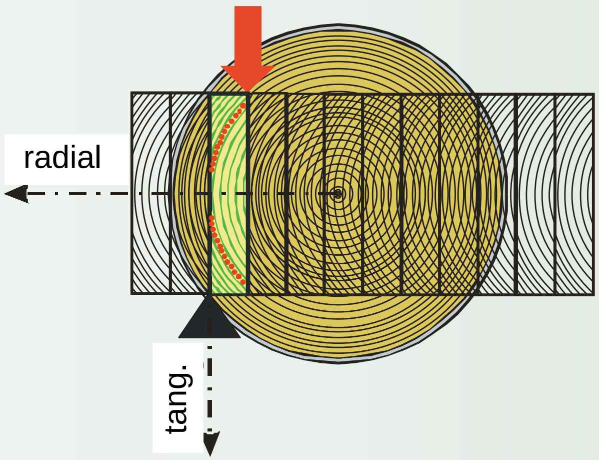


$$\tau(z_0)_d = \frac{V_{z,d} \cdot \int_{A_0} E(z) \cdot z \cdot dA}{K_{clt} \cdot b(z_0)}$$

➡ **$\tau_{v,d}$ (longitudinal) und $\tau_{r,d}$ (transverse)**

Illustration of Rolling Shear

rolling shear: `overturn´ of wood fibers during a shear load perpendicular to the grain



material value for rolling shear (spruce)

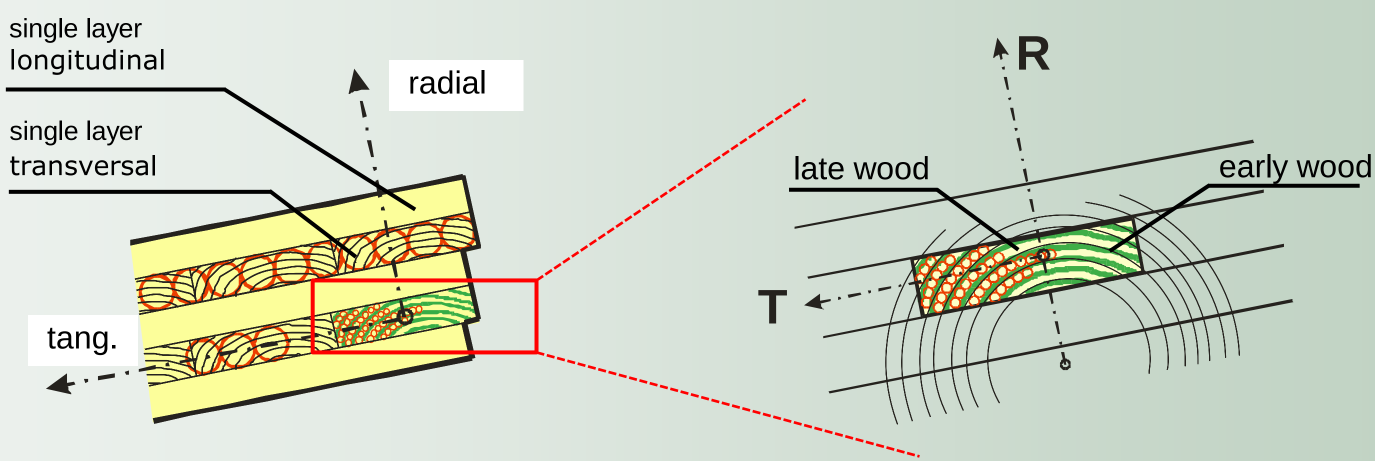
$f_{r,k}$ = 1.0 N/mm²

G_r ~ 40 ÷ 95 N/mm²

$G_r \rightarrow G_{90,mean}$ (acc. to EN 1995-2)

rolling shear of CLT

failure mode in the single lamella:
peel failure in early wood



calculation of the design values of shear strength $f_{v,clt,d}$ and rolling shear strength $f_{r,clt,d}$

$f_{v,clt,k} = 3.0$ N/mm² … **based on $f_{v,k}$ of GLT (approximative)**

Considering the system effect, a 25 % higher value for $f_{r,clt,k}$ compared to GLT is proposed (e.g. \`BSPhandbuch´ | TU Graz).

$f_{r,clt,k} = 1.25$ N/mm² … **based on \`BSPhandbuch´ | TU Graz**

design:

$$\frac{\tau_{v,d}}{f_{v,clt,d}} \leq 1.0 \qquad \frac{\tau_{r,d}}{f_{r,clt,d}} \leq 1.0$$

Both verifications normally result in a low utilisation level. Therefore this terms are seldom relevant.

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- „Solid Timber Construction (STC)“ – Cross Laminated Timber (CLT)
  - Introduction | History
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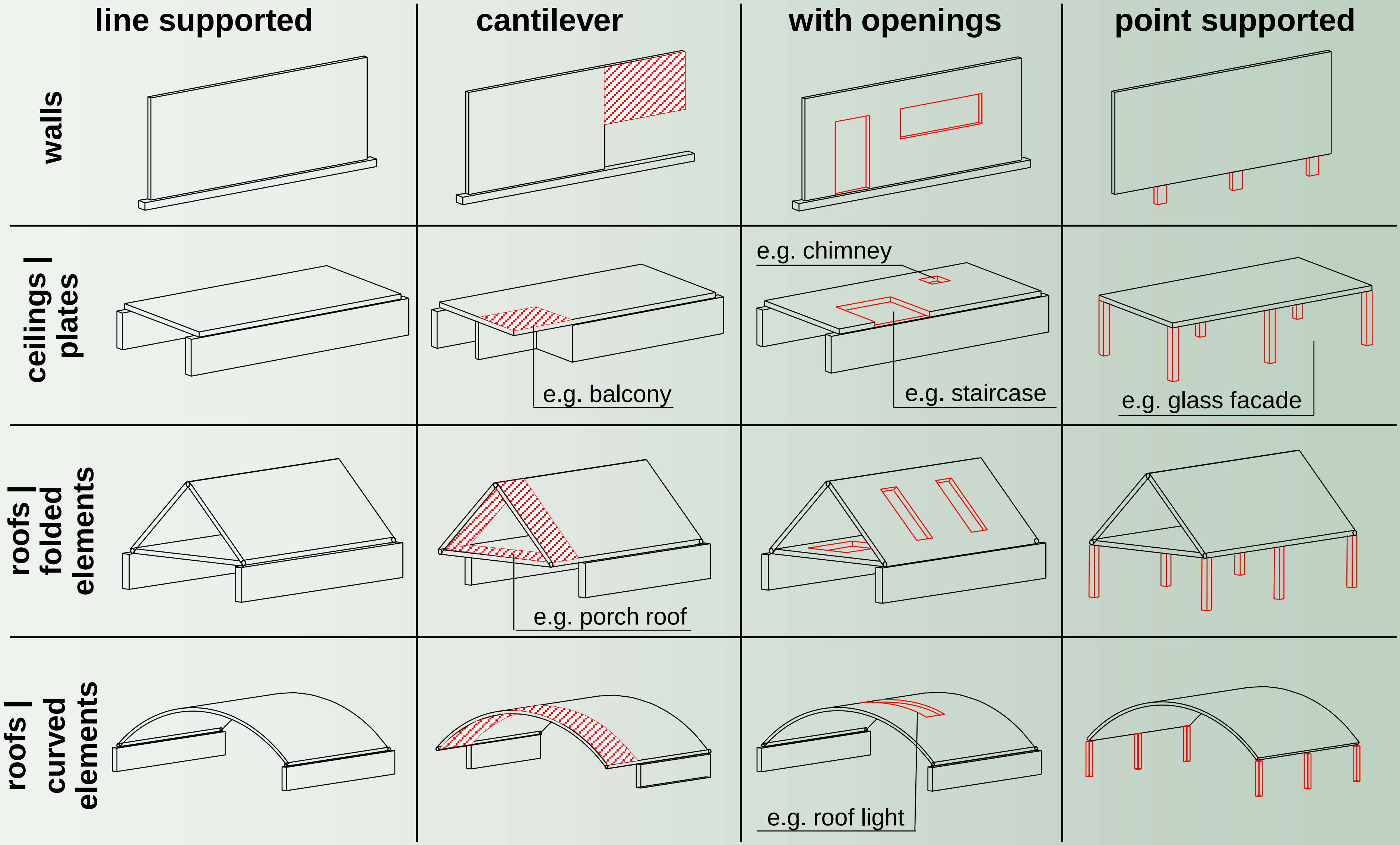
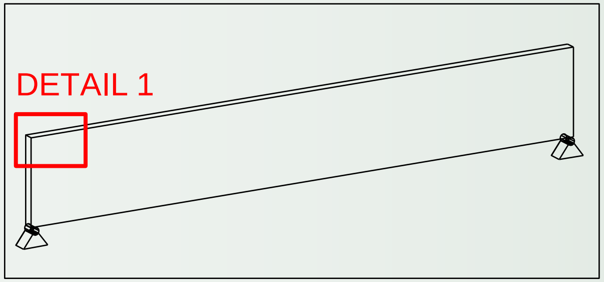
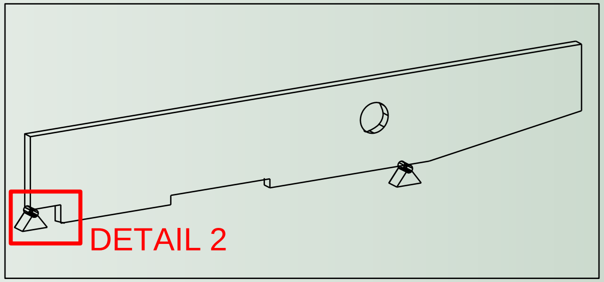
Use of CLT as 2D Elements



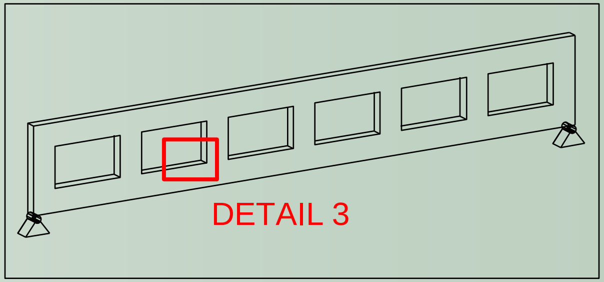
Use of CLT as 1D Elements



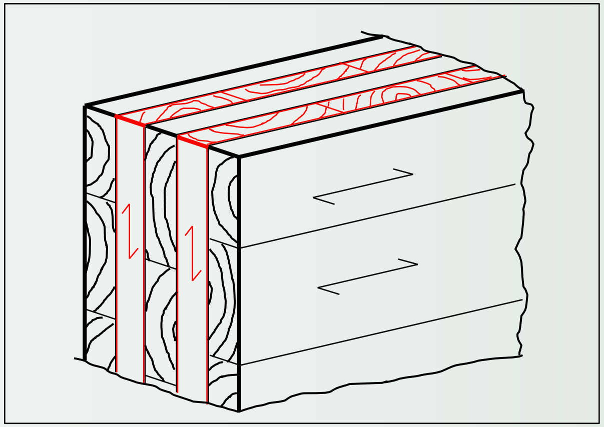
beam
without openings



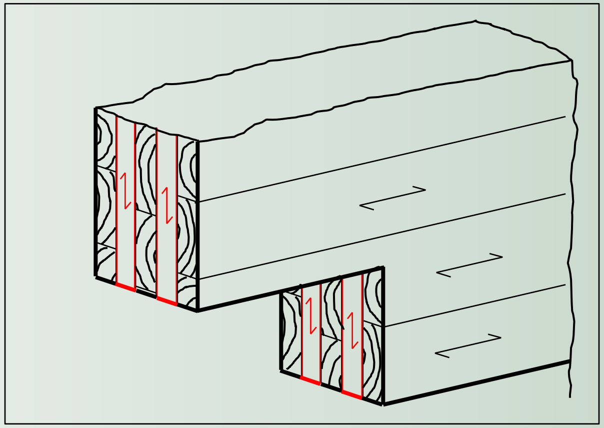
tapered beam with notched support
and openings



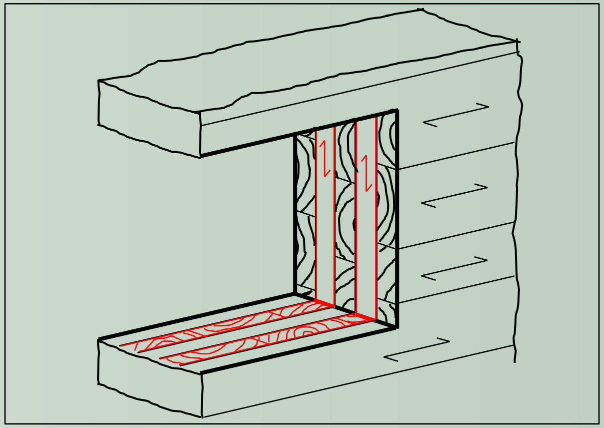
beam as \`Vierendeel system´



detail 1:
built up of a 5-layered
beam element



detail 2:
notched support



detail 3:
opening

vertical (cross) layers as \`reinforcement´ of CLT
(high capacity in shear and tension perp. to grain)

→ Research activities are needed!

Residential Buildings

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Hartberg (AUT) | 2008
CLT by KLH

© Pictures: Paul Ott, Graz

Graz (AUT) | 2007
CLT by Mayr-Melnhof Kaufmann

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Eichgraben (AUT) | 2008
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Residential Buildings

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Multi-Storey Buildings


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3-storey building
Judenburg (AUT) | 2002
CLT by KLH


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4-storey building
Judenburg (AUT) | 2002
CLT by KLH


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5-storey building
Berlin (GER) | 2010
CLT by KLH

Multi-Storey Buildings

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5-storey building
Vienna (AUT) | 2005
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8-storey building
London (UK) | 2008
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8-storey building
London (UK) | 2010
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Kindergarten

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Office Buildings

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Leoben (AUT) | 2008
CLT by Mayr-Melnhof Kaufmann

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Headquarter Binder Holz
Fügen (AUT) | 2007
CLT by Binderholz Bausysteme

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Building Research Center
TU Graz (AUT) | 2006
CLT by Holzleimbau Stingl

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Summary

- **S**olid **T**imber **C**onstructions (**STC**) with **C**ross-**L**aminated **T**imber (**CLT**) is an already well-established building system in Central Europe.

- The production and consumption potential of CLT in Europe, already on a high level, creates a fast growing market [~ **+ 25 % p.a.**].

- The timber product CLT has the potential to become **THE new \`green´** and **CO_2-active** solution to replace current reinforced concrete as prefabricated 2D element (e.g. ceiling constructions).

- The **universal application of CLT** – residential houses, multi-storey and communal buildings, bridges, etc. – leads to the **increasing interest** of engineers and architects.

Outlook Regarding the Presentation

CLT – Research and Testing at TU Graz

Day 2 – Wednesday, Feburary 9, 2011, 10:10 ÷ 10:50

- **point supported ceilings and roofs**
  → determination of compression perp. to the grain capacity of CLT panels
- **verifications regarding serviceability limit state (SLS)**
  → behaviour of CLT ceiling systems in case of vibrations
- **in-plane shear capacity and verification methods**
  → determination of in plane shear strength properties and design models
- **CLT designer – software tool for designing CLT elements**
  Concept | Applications | News [A. Thiel]
- **summary | outlook**

Swimming pool | Hagenberg i.M. / AUT

Swimming pool | Hagenberg i.M. / AUT

Swimming pool | Hagenberg i.M. / AUT

THANK YOU FOR YOUR ATTENTION

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