„Cross Laminated Timber“ – an innovative product for the „European Timber Massive Construction“ principle

Building with Wood – SEMINAR
Modern Technologies and sustainable Solutions for the Mediterranean Area

Univ.-Prof. Dipl.-Ing. Dr.techn. Gerhard Schickhofer
Institute for Timber Engineering and Wood Technology, Graz University of Technology | AT
Competence Centre holz.bau forschungs gmbh Graz | AT
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  - R&D Areas
- „European Timber Massive Construction“ – Cross Laminated Timber
  - Introduction | History
  - Use | Application Examples
  - Technology
  - Modelling and Verification (Design Process)
  - Building Physics | Leading Details
  - Future Developments
- Summary
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GRAZ UNIVERSITY OF TECHNOLOGY
Austria / Europe

Faculty of Civil Engineering Sciences
17 institutes | about 1,140 students
[207 “diploma”, 693 “Bachelor”, 146 “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: 7.0 FTE | third-party-budget: € 250.000 (2008)

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: 7.1 FTE | budget: € 1.000.000 (2008)
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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- Summary
Timber Massive Construction (TMC) define Culture in Constructions in well-wooded regions of Europe, e.g.:

- **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

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<table>
<thead>
<tr>
<th><strong>Past and Current</strong></th>
<th><strong>Tradition</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bar-like</strong></td>
<td><strong>Bar-like</strong> (parallel to grain)</td>
</tr>
<tr>
<td>Indoor</td>
<td>Indoor</td>
</tr>
<tr>
<td>Insulation bearing</td>
<td>Bearing</td>
</tr>
<tr>
<td>Indoor</td>
<td>Indoor</td>
</tr>
<tr>
<td>Outdoor</td>
<td>Indoor</td>
</tr>
<tr>
<td>Insulation</td>
<td>Bearing</td>
</tr>
</tbody>
</table>

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**Timber Lightweight Construction (TLC)**

- **Bar-like** (bracing)
  - Timber truss construction

- **Slab-like**
  - Timber frame construction

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**Institute for Timber Engineering and Wood Technology**

Gerhard Schickhofer

Athens, Greece, 06th November 2009

Institute for Timber Engineering and Wood Technology
Timber Massive Construction (TMC) – INNOVATION based on TRADITION

Load transfer

**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

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

- Timber Massive Construction with CLT (new “European Timber Massive Construction”)
- detached house Jeitler


bonding
product innovation Cross Laminated Timber (CLT)

≈ 20 years: from idea to approvals …

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>G. Dröge</td>
</tr>
<tr>
<td>1989</td>
<td>A. Steurer: “CLT” as slab- and plate-stressed deck-bearing-structure</td>
</tr>
<tr>
<td>1995</td>
<td>K. Moser: multi-storey residential building out of “Merk-Dickholz” (MDH)</td>
</tr>
<tr>
<td>1998</td>
<td>KLH Massivholz GmbH (A) &amp; Merk-Holzbau GmbH (D): 1st national technical approvals for the product “CLT”</td>
</tr>
</tbody>
</table>

≈ 10 years: international R&D, further approvals, distribution of CLT-TMC …

<table>
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<tr>
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<tr>
<td>2000</td>
<td>G. Schickhofer: branding the term “Cross Laminated Timber” (CLT), based on G→E translation of “BrettSperrHolz” at the COST E5-Meeting in Venice (I)</td>
</tr>
<tr>
<td>2000 –</td>
<td>intensive R&amp;D in German-speaking regions (A</td>
</tr>
<tr>
<td>2006 –</td>
<td>first European Technical Approvals (ETZs) for CLT (current 5)</td>
</tr>
<tr>
<td>2009</td>
<td>intensifications of national and international transfer-activities</td>
</tr>
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CLT – use | application examples

„Wandritsch“-road bridge (view)

„Wandritsch“-road bridge (1998)
St. Ruprecht / Styria (A)

pre-fabricated bridge deck plate

surface course 30 mm
melted asphalt 50 mm
sealant 5 mm
plywood 6 mm
"KLHmasive" (9 layers à 19 mm) 171 mm
BS18-ribbs (GL36) 160 mm

timber-timber composite

160 160 160 160 160

6
171

30 mm
melted asphalt
50 mm
5 mm

171 mm

6 mm

"KLHmasive" (9 layers à 19 mm)

160 mm

160 160 160 160 160

6 mm

"KLHmasive" (9 layers à 19 mm)

160 mm

160 160 160 160 160

6 mm

"KLHmasive" (9 layers à 19 mm)
CLT – use | application examples

building technology centre (section 1)

under-stressed framework

building technology centre
section 1 (2001)
Graz / Styria (A)

innovative connection technique

production of CLT-elements
CLT – use | application examples

„Austria-House“ (2006)
Turin / Italy
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# CLT – technology

## Production Process of Cross Laminated Timber (CLT) Elements

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<tr>
<th>Step</th>
<th>Intermediate Product</th>
<th>Intermediate Production Process</th>
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<tbody>
<tr>
<td><strong>STEP I:</strong> Log</td>
<td></td>
<td>Cross cut</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 to 600 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 150 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 mm</td>
</tr>
<tr>
<td><strong>STEP II:</strong> Board</td>
<td></td>
<td>Grading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trimming</td>
</tr>
<tr>
<td><strong>STEP III:</strong> Finger-Jointed Lamella</td>
<td></td>
<td>Finger jointing</td>
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<tr>
<td>finger-joint.</td>
<td>lamella</td>
<td></td>
</tr>
<tr>
<td>intermediate</td>
<td>STEP: single-layer</td>
<td>edge gluing</td>
</tr>
<tr>
<td>STEP IV:</td>
<td>Cross Laminated</td>
<td>face gluing</td>
</tr>
<tr>
<td>CLT</td>
<td>Timber (CLT)</td>
<td></td>
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<td><strong>Intermediate STEP:</strong> single-layer panel</td>
<td>edge gluing</td>
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#### Bonding Pressure
- Horizontal:
  - Approx. 0.2 N/mm²
- Dimensions:
  - 1.25 m to 3.0 m
  - Up to 16.5 m (or longer)
## Production Process of Cross Laminated Timber (CLT) Elements

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<td>face gluing</td>
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### Bonding Pressure Vertical:
- approx. 0.6 N/mm² with hydraulic equipment
- < 0.1 N/mm² with vacuum
- approx. 0.1 N/mm² with clip connection

![Diagram of face gluing with or without horizontal bonding pressure](image)
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design acc. limit states of …

- ultimate bearing capacity (ULS-design)
- serviceability (SLS-design)

**for the CLT-slab (roof | ceiling)**
e.g. 5- or 7-layered CLT ceiling-element

**for the CLT-plate (wall)**
e.g. 3- or 5-layered CLT-wall element

---

**action vertical**
to plane of slab

- $V_{\text{max}}$
- $P_{\text{max}}$
- $M_{\text{max}}$
- $l_1$
- $l_2$
- $l_3$
- element width
- element length

---

**action in plane**
of panel

- storey width
- storey height
ULS design ...

- $M_{\text{max}}$ bending
- $V_{\text{max}}$ shear due to transverse force
- $P_{\text{max}}$ compression perpendicular | bearing pressure

\[
\frac{\sigma_{m,\text{edge},d}}{f_{m,\text{CLT},d}} \leq 1.00
\]

design value of the consequences of the governing combinations of actions \(\leq 1.00\)

design value of the resistance

Gerhard Schickhofer
Athens, Greece, 06th November 2009
Institute for Timber Engineering and Wood Technology
design value of the consequences of the governing combinations of actions …

BENDING STRESS $\sigma_{m,\text{edge,d}}$

stress distribution within the cross section

basis: model of the classical “Timoshenko-bar” | “transversal shear-flexible bar”

$\rightarrow$ sufficient accurate for practical applications $[15 < L/H < 30]$

e.g.: 5-layer CLT-element

\[
\bar{\sigma}_{m,\text{edge,d}} = \frac{M_{\max,d}}{K_{\text{CLT}}} \cdot \frac{t_{\text{CLT}}}{2} \cdot E_{i=5}
\]

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

\(t_{\text{CLT}}\) normal stress distribution within the cross section

$\rightarrow$ shape like “saw teeth”
design value of the resistance ... BENDING STRENGTH $f_{m, CLT, d}$

Two primary system effects:

- laminating effect (vertical layered, akin to GLT)
- system effect (horizontal, mutual acting elements)

$$f_{m,c,05} = m \cdot f_{t,0,l,05}^{0.80} \cdot k_{sys, CLT} (n) \cdot k_{CLT/CLT} \cdot k_{d, CLT}$$

Bearing model for GLT in bending $\cdot 1.06$ ($f^{0.82} \rightarrow f^{0.80}$)

- laminating effect
- system effect
- structure / assembling effects

$$k_{sys, CLT} (n \geq 4) = 1.10$$

$$k_{d, CLT} = \left( \frac{600}{150} \right)^{0.1} = 1.15$$

$$f_{m,c,05, n \geq 4, d_{CLT, ref}} \approx 1.25 \cdot m \cdot f_{t,0,l,05}^{0.80}$$

With $m = 2.8$ for GLT (vis.)

$$f_{m,c,k}^{1)} = 3.0 \cdot f_{t,0,l,k}^{0.8} \text{ for CoV}(f_{t,0,l}) = 25\% \pm 5\%$$

$$f_{t,j,k} \geq 1.2 \cdot f_{t,0,l,k}$$

$$f_{t,j,k} \geq 1.4 \cdot f_{t,0,l,k} \text{ for CoV}(f_{t,0,l}) = 35\% \pm 5\%$$

$1)$ characteristic bending strength of CLT, referred to a reference depth of $d_{c, ref} = 150$ mm
CLT – modelling and verification \([f_{m,\text{CLT}}]\)

**CLT, boards C24+(vis.): GLT:** 
\[ f_{m,g,05,d=600} = 24 \text{ N/mm}^2; \text{ timber: } f_{t,0,l,05} = 14.7 \text{ N/mm}^2; f_{m,05,d=150} = 24 \text{ N/mm}^2 \]

**acc. design model:**
\[ f_{m,c,05,d=150} = 3.5 \cdot f_{t,0,l,05}^{0.8} = 3.5 \cdot 14.7^{0.8} = 30.06 \text{ N/mm}^2 \]

**acc. DIBt Zxxx:**
\[ f_{m,c,05,d=150} = 1.1 \cdot f_{m,g,05,d=600} \cdot \min\{(600/150)^{0.14}; 1.1\} = 1.1 \cdot 24 \cdot 1.1 = 29.04 \text{ N/mm}^2 (-3\%) \]

3.2 Bemessung
3.2.1 Beanspruchung rechtwinklig zur Bauteilebene
3.2.1.1 Der Nachweis der Spannungsverteilung und der Schnittrögen eines “HMS-Elementes” rechtwinklig zur Bauteilebene ist nach der Verbundtheorie unter Berücksichtigung von Schubverformungen zu führen.

Beim Biegespannungsnachweis ist nur die Normalspannung der Bretter am Querschnittsrand nachzuweisen, der Nachweis der Scherzenträgheit im Brott wird unberücksichtigt bleiben.

Beim Biegespannungsnachweis darf die zulässige Biegespannung bzw. der Bemessungswert der Biegefestigkeit mit einem Systembeiwert \(k\) multipliziert werden:

\[ k \cdot \min\{1+0.025 \cdot n; 1\} \leq 1 \]

mit \(n\) ist Anzahl der nebeneinander liegenden Bretter.

**acc. ETA-09/xxx:**
\[ f_{m,c,05,d=150} = \min\{3.5 \cdot f_{t,0,l,05}^{0.8}; 1.2 \cdot f_{m,05,d=150}\} = \min\{30.06; 28.80\} = 28.80 \text{ N/mm}^2 (-4\%) \]
... further ULS and SLS-design procedures:

for the CLT-slab (roof | ceiling | …)

**ULS**
- shear due to transversal force
  - in the governing layer lengthwise
    with \( f_{v,CLT,k} = 3.0 \text{ N/mm}^2 \) (\( \equiv f_{v,GLT,k} \))
  - in the governing layer perp.
    with \( f_{r,CLT,k} = 1.25 \text{ N/mm}^2 \) (\( \equiv \text{approvals} \))
- compression perp. at bearings
  - with \( f_{c,CLT,90,k} \) and \( k_{c,CLT,90} \)
- fire design
  - without gaps: \( \beta_0 = 0.65 \) (1.30) mm/min
  - with gaps: \( \beta_n = 0.80 \) (1.60) mm/min

**SLS**
- deformations | deflections
  - creep factor: \( k_{\text{def}} = 0.80 \div 0.90 \) (SC1)
    \[ k_{\text{def}} = 1.00 \div 1.10 \] (SC2)
  - shear correction factor \( \kappa \approx 0.25 \) (!)
- vibration design
  - with Lehr’sche damping coefficient
    \[ D = 0.025 \div 0.040 \]

for the CLT-plate (wall | …)

**ULS**
- shear in plane direction
  - mechanism I “shear”
    with \( f_{v,CLT,k} \approx 5.0 \text{ N/mm}^2 \) (\( \equiv \text{approvals} \))
  - mechanism II “torsion”
    with \( f_{t,CLT,k} = 2.5 \text{ N/mm}^2 \) (\( \equiv \text{approvals} \))
- tension and compression
- stability design
  - buckling

**SLS**
- deformations | deflections in plane
  - without openings:
    \( G^* \approx 450 \div 500 \text{ N/mm}^2 \)

⇒ for further information and details

CLThandbook | 11.2009
connection techniques within the Timber Massive Construction …

connections of in general large-sized CLT-wall, -ceiling, -roof elements with …

- self drilling screws
- dowel type fasteners
- glued in rods
- nails
- system connector

at the contact gap …

- foundation | wall
- wall | wall
- wall | ceiling | wall
- ceiling | ceiling

exposure in the contact gaps in …

- all three main axes
- static and dynamic (earthquakes)
**contact gap “foundation | wall”**
connection technique:
- steel plate – timber with nails

5-layered CLT-wall element
- steel angle (outside)
- sealant and altitude compensation
- reinforced concrete foundation
- bandings due to wood protection (e.g. oak, black locust)

nails (attention to gaps!)

wall:foundation
contact gap “wall | wall”
connection techniques:
- self drilling, partly or full threaded screws
- system connector | steel core and glued in rods
- system connector | hook connector

5-layered CLT-wall element
sealing tapes (compression band)
self drilling screws

e.g. bearing 5-layered CLT-wall element (outdoor)
sealing tapes (optional)
e.g. bearing 5-layered CLT-wall element (indoor)
hook connector (self-centring assembling)

corner joint T-joint

wall:wall

sealing tapes
embedded steel core
glued in rods

longitudinal joint
**contact gap “wall | ceiling | wall”**

**connection techniques:**
- self drilling screws
- steel angle | nailing

- sealing tapes (compression band)
- positively tied by screws (screws in grain shall be avoided!)
- noise insulation and / or separation (impact sound insulating interlayer | elastic support in combination with a ceiling construction of:
  - floating floor
  - impact sound insulation
  - fill (split)
  - detached ceiling

- e.g. 5-layered CLT-wall element (outdoor)
- e.g. 5-layered CLT-ceiling element
Contact gap “ceiling | ceiling”

Connection techniques:
- Self drilling screws
- Bonded joint
- Overlapping / interlocking joint

- E.g. 5-layered CLT-ceiling element
- Overlapping / interlocking joint
- Positively tied by screws
- Sealing tapes (compression band)

Transverse force joint

- E.g. 5-layered CLT-ceiling element
- Screwing under angle (e.g. 45°)

Transverse force joint

- E.g. 5-layered CLT-ceiling element
- On the top and underneath strapping (adhesion by screwing pressure)

Bending stiff joint
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building physics aspects …

- **thermal insulation**
  - wintry thermal insulation
  - summery thermal insulation (over warming of indoor climate)

- **moisture protection | airtightness** → tests at TU Graz and on-site
  - condensate formation

- **noise insulation**
  - noise indoor | airborne noise | footfall noise | → requirements

- **fire protection** (tests in cooperation with ETH Zurich | EMPA Dübendorf)

… leading details

in cooperation with the Institute for Building Construction and Building Physics at TU Graz → see CLThandbook | Annex “Leading Details”
noise protection aspects – leading detail “wall | ceiling | wall”

- noise protected support (ext. wall)
- airtight plain
- sealing tapes
- detached floor (vibration bracket)
- noise protected support (load bearing wall)
- noise protected support (flat separating wall)
- noise protecting support construction
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building systems with CLT …

folded panels with CLT

- principles concerning folded panels → construction principle from nature
- “plane-active bearing systems” acc. bionic principles
- variety of folded panel constructions and applications

half prismatic

prismatic

pattern of parallel straight lines

pyramid

raised planes

capped top

antidromic folded panels
clarification of the difference between “decisive “ and “non decisive” modification: attics upgrading and expansion of Wilhelmina style houses

- reinforced concrete vs. CLT-European Timber Massive Construction (ETMC)

earthquake actions acc. to “simplified response spectrum” acc. EN 1998-1
folded panels with CLT: field of application up to 20 m free span

- column-free overspan of roof space
- short erection time and immediately usability
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after 20 years from idea to **first national technical approvals and prototypes in 1998** followed further 10 years of intensive R&D beside **more approvals in Europe** and the **establishment and distribution of the European Timber Massive Construction technique (ETMC)**

the next 5 to 10 years indicate **industry sector projects** in regard to **standardisation, R&D, marketing and transfer**

- **standardisation**
  - standardisation portfolio consisting of regulations concerning test-, product-, design- and construction procedures

- **R&D**
  - development of construction systems
  - design procedures for special cases
    - pin-supported slabs | special design procedures for supports
    - earthquake design acc. EN 1998 | preparation for practice
  - building physics in regard to CLT
    - non-stationary moisture transport through a CLT cross section
    - fire design | standardisation of charring rates

- **marketing and ”know how”-transfer**
  - technical meetings | seminars | workshops

CLT – summary | outlook
THANK YOU FOR YOUR ATTENTION
Contact:

Univ.-Prof. Dipl.-Ing. Dr.techn. Gerhard Schickhofer
Institute for Timber Engineering and Wood Technology, Graz University of Technology | AT
Competence Centre holz.bau forschungs gmbh Graz | AT
Inffeldgasse 24/l
A-8010 Graz
gerhard.schickhofer@tugraz.at
phone.: +43 316 873 4600