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Kurse 2017

Brettsperrholz Seminar

# Brettsperrholz: Einführung, Übersicht und Grundlagen der Berechnung

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Wood Technology, TU München, Germany
Timber Structures & Wood Technology, TU Delft, The Netherlands

*Parasite, Rotterdam. Material: Dickholz , Merk Holzbau.*
*Quelle: Architect Korteknie Stuhlmacher - Rotterdam*



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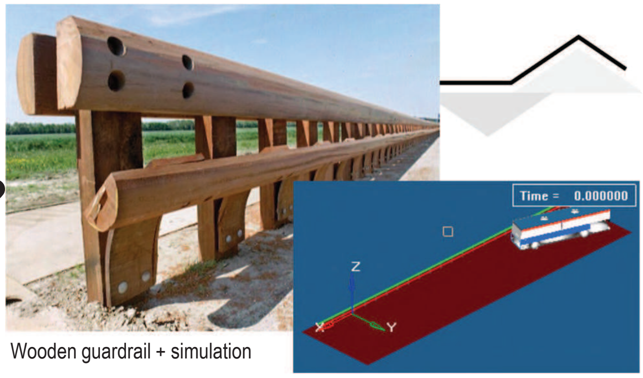
## Who am I?

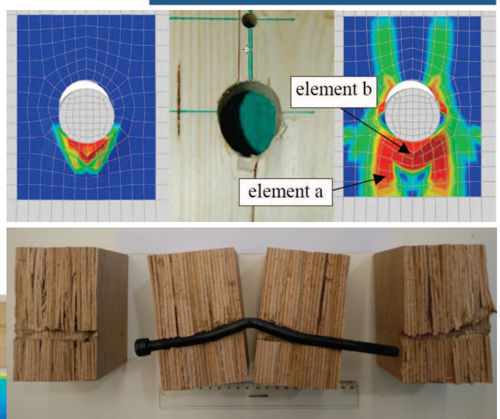
- Born 1965, Rotterdam
- Study: Civil engineering TU Delft 1983 – 1989
- TNO 1989-2000 (Part-time Ph.D. TU Delft); TU Delft 2000-2009
- In between: 2003 – 2008 CNR – Italy
- Current: Prof. Wood Technology – TU Munich

Research subjects:

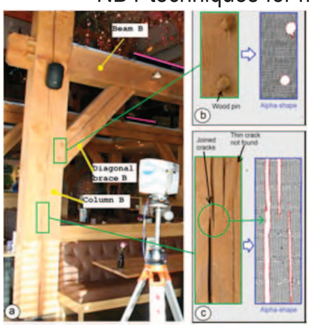
- Dowel type connections with EWP´s
- Gluing of wood and wood products
- Quality of wood and biobased materials (p.e. bamboo)
- Numerical modelling of wood and wood products
- Service life modelling and climate variations of timber structures
- NDT techniques for material parameters and building assessment



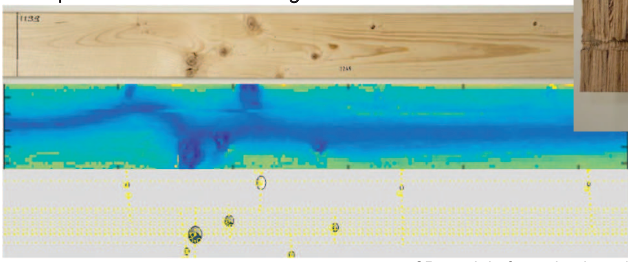

Wooden guardrail + simulation




Steel yielding, Grade 12.9, $f_y$ = 1400 MPa, numerical model for connections



Crack analysis by Laserscanning



3D-model of wooden boards

## ÜBERBLICK

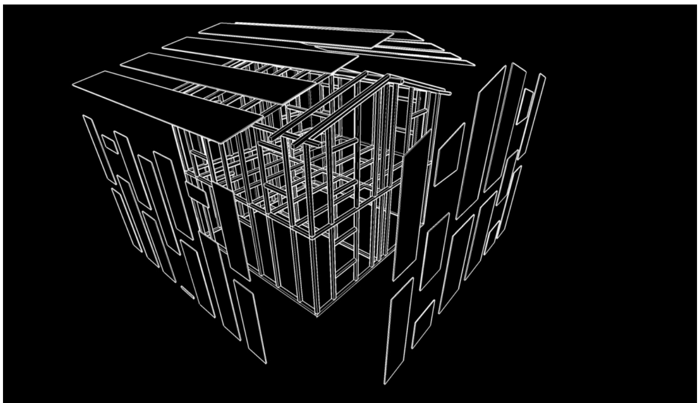
## INHALTSVERZEICHNIS

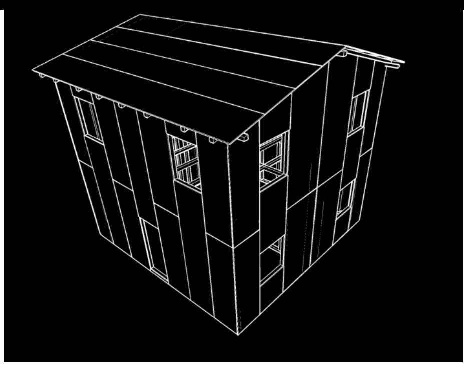
- Geschichte und erste Entwicklung von CLT
- Material, Herstellung
- Aufbau von Querschnitten
- Mechanische Eigenschaften
- Berechnungsgrundlagen
  - Biegung, Schub (Ultimate Limit State)
  - Steifigkeit (Verformung, Kriechen)
  - Erdbeben



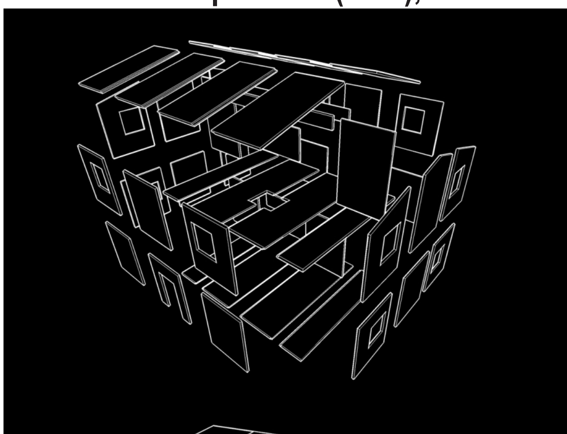


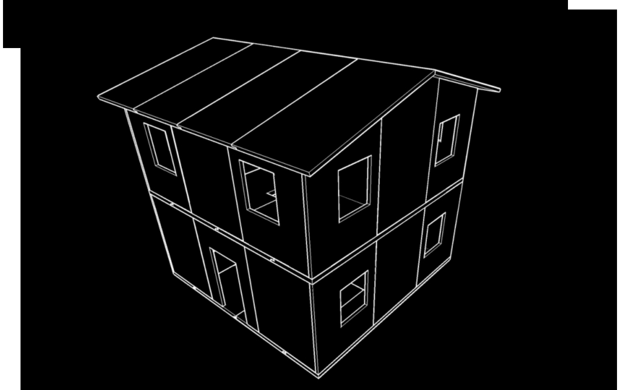
## Timber Frame - Holzrahmenbau





## CLT – Brettsperrholz (BSP), Vollholzbau



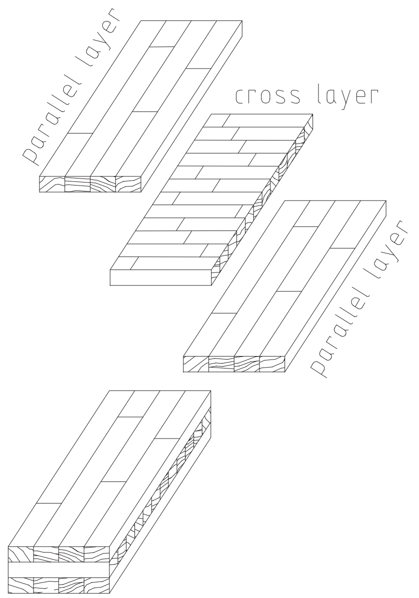


## INHALTSVERZEICHNIS

### CLT: GESCHICHTE UND ERSTE ENTWICKLUNG

- Anfang ´90 Jahren: Dickholz (Merk Holzbau)
- TU Graz

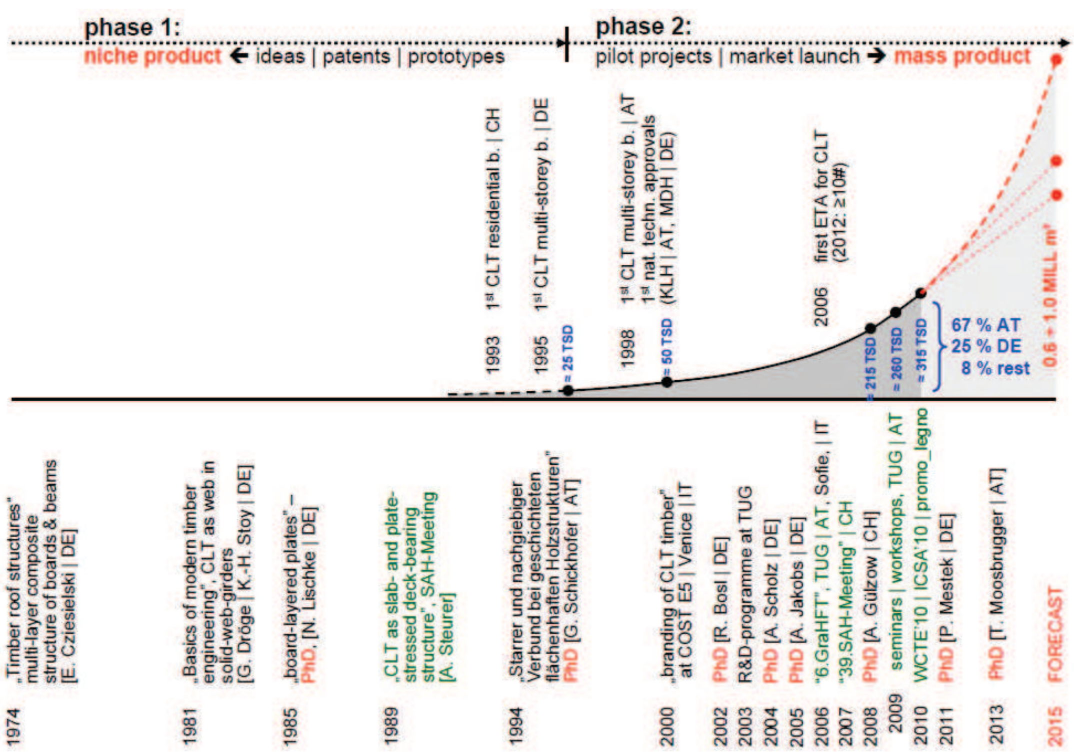
- Holzqualität
- Vakuumpresse
- Seitenverklebung
- Brettdimensionen




*Prinzipaufbau von CLT, 3-Lagig*

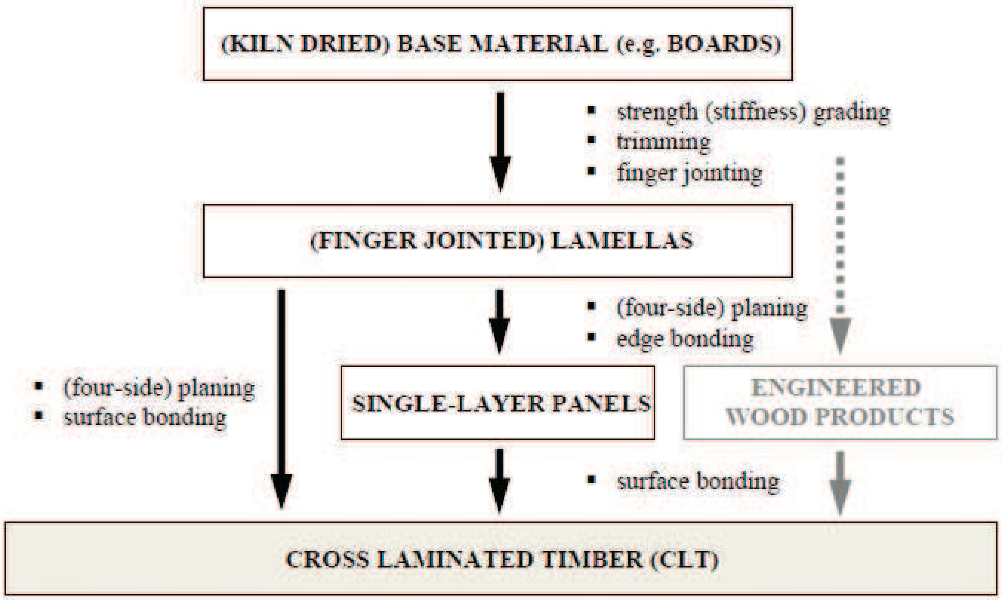







*Brandner, Schickhofer, TU Graz*

Patent application:
Vakuumverleimte schichtholzplatte, EP 0881965 A1
Patentinhaber: Karl Moser
Datum: 9.12.1998




EN 14081 Bauholz
(DIN 4074 / UNI 11035)

EN 15479 Keilgezinktes Vollholz für tragende Zwecke

prEN 16351 Brettsperrholz

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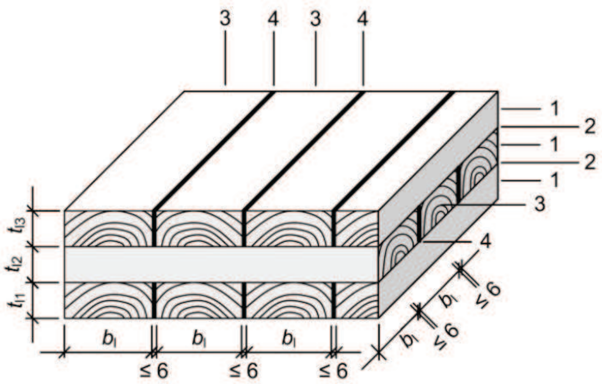
prEN16351

Dimensions in millimetres



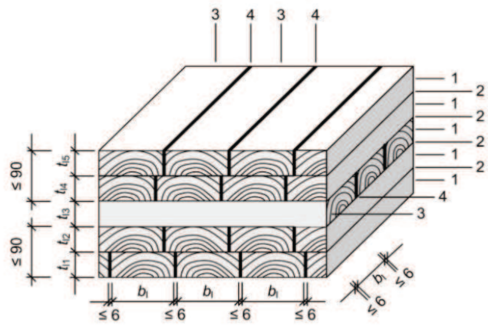

**Key**

| | | | | |
|---|---|---|---|---|
| 1 | timber layer | $6 \le t_{l1,3} \le 45$ | $6 \le t_{l,2} \le 60$ | $40 \le b_l \le 300$ |
| 2 | bondline between layers | | | |
| 3 | lamination | | | |
| 4 | gap between lamination | | | |

**Figure 6 — Example for a layup made of three timber layers**

Dimensions in millimetres

- prEN16351




**Key**

1 timber layer $6 \leq t_l \leq 45$ $40 \leq b_l \leq 300$

2 bondline between layers

3 lamination

4 gap between lamination

**Figure 7 — Example for a layup with five timber layers outermost layers bonded parallel to the grain**

*Latest Draft prEN 16351 (2016): Aufbau von CLT*



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## BRETTER UND VERKLEBUNG

- Bretter sollen Festigkeitsklasse C24 zugeordnet sein (ggf. auch C16 / C18 möglich für Zwischenlagen)
  - Visuell oder maschinell sortiert (CE Kennzeichnung nach 14081)
  - Keilzinkenverbindiungen nach EN 15497
- Klebstoffen nach EN 301 (PU – Polyurethanklebstoffe, MUF – Melamine-Urea-Formaldehyd)
- Verklebung durch Vacuumdruck oder mechanische Presse
- Bretter können eine Entlastungsfuge enthalten.
- Seitenverklebung nicht immer vorhanden

- Qualitätskontrolle des Produktes:
- CE – Kennzeichnung nach prEN 16351
- Verklebung durch Delaminierungsversuchen

- Kein hEN
- Zulassungen / ETA

*Quelle: Architect Korteknie Stuhlmacher - Rotterdam*

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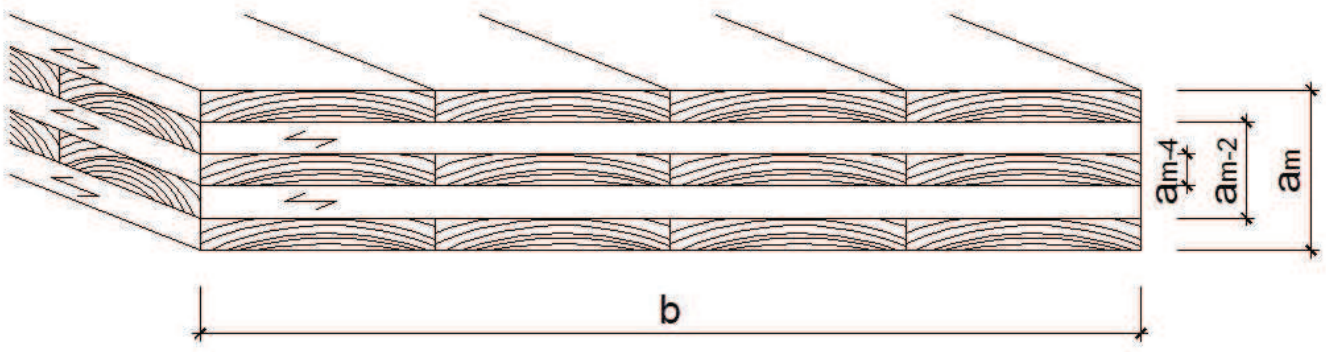


*Typischer Aufbau von BSP / CLT / XLAM*
*(Parameter für Spannungs/Steifigkeitsberechnungen)*

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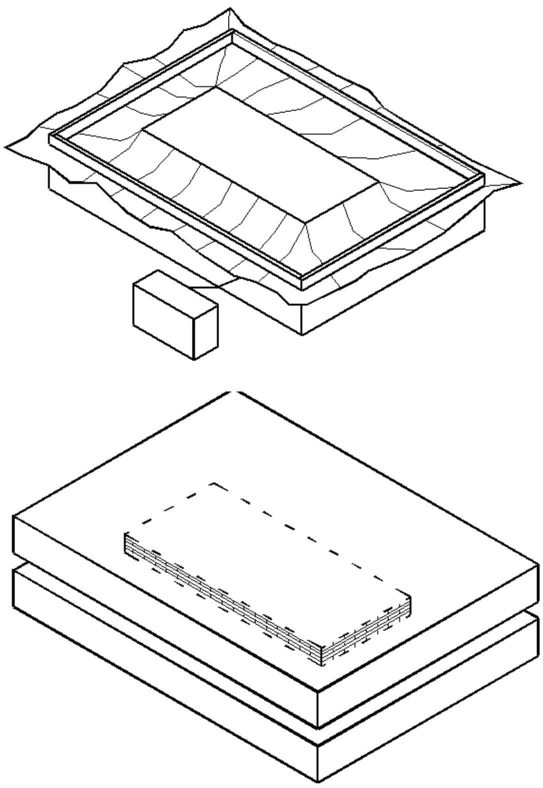

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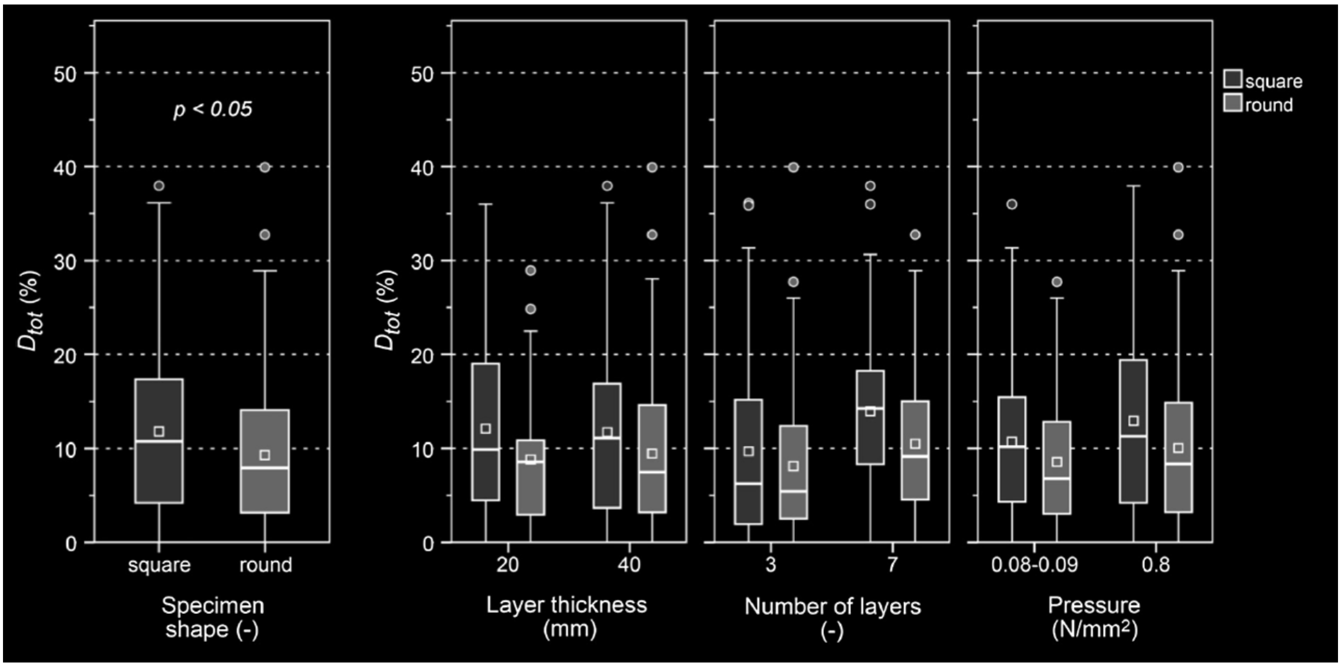
# Delamination of CLT



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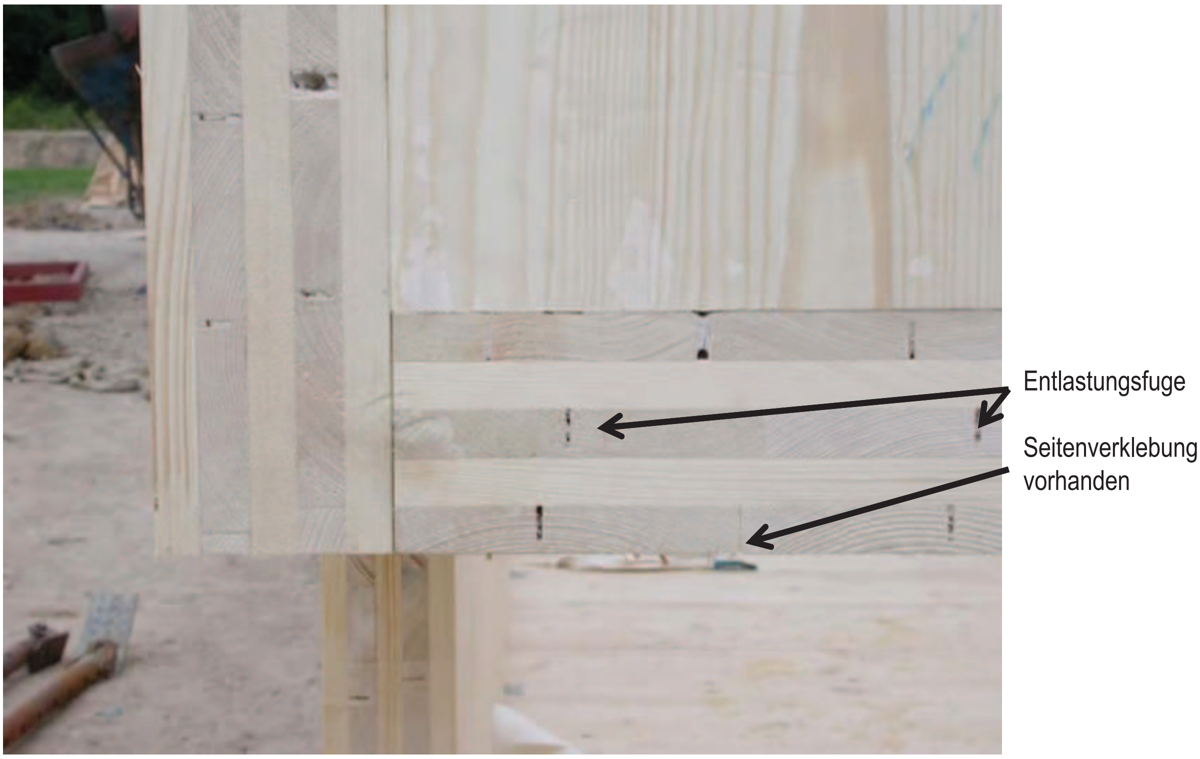


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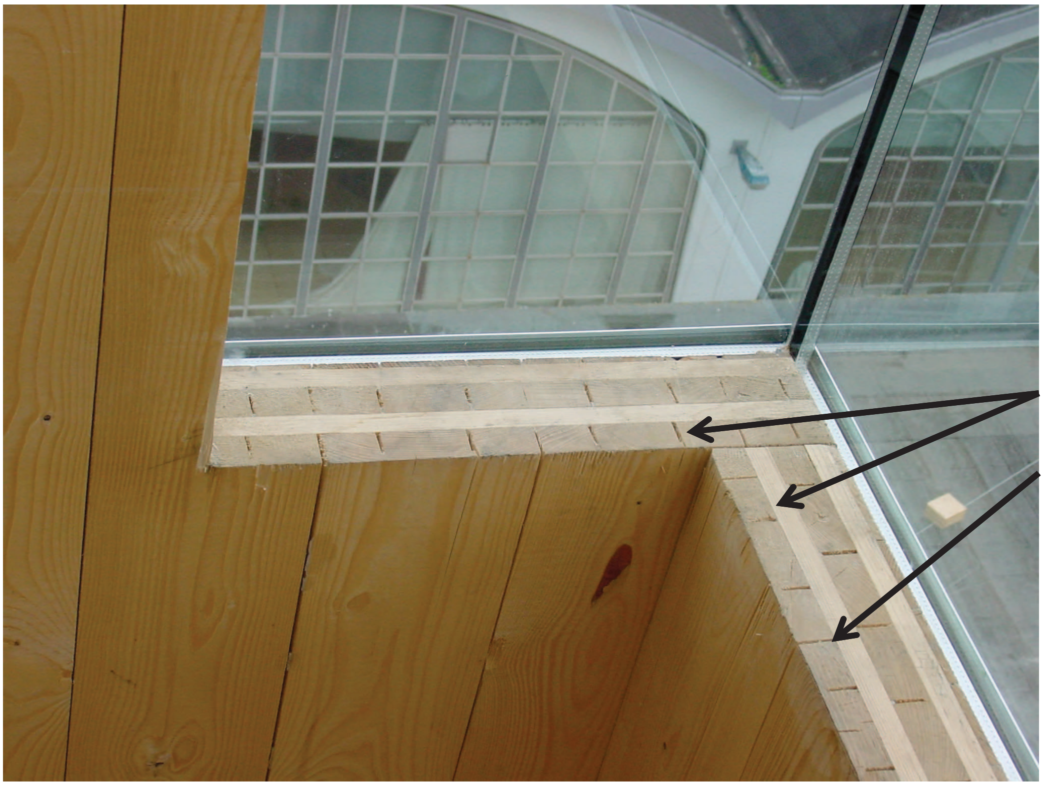


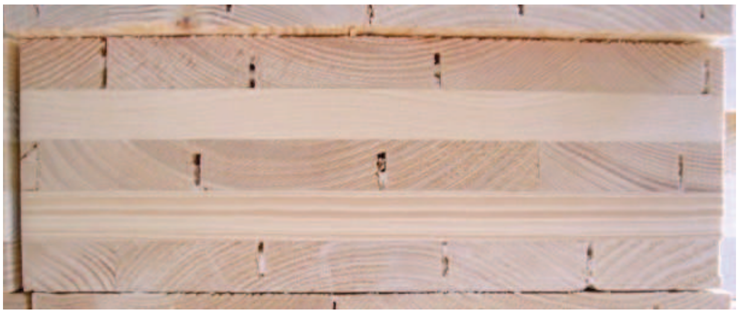
Entlastungsfuge

Seitenverklebung nicht vorhanden





## CLT (XLAM): Examples of lay-up



*XLAM 5-strati 3+2*

*XLAM 3-strati 2+1*

*XLAM 5-strati 4+1*

## CLT + LVL-S / Q: Examples of boards with wood-based panels

*3 Strati:*
*Legno - Kerto® S - Legno*

*3 Strati:*
*Legno- Kerto® Q - Legno*



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| | |
|---|---|
| CE<br>**0797** | *CE-marking symbol given in Directive 93/68/EEC*<br>*Identification number of the notified certification body* |
| **AnyCo Ltd**<br>**11**<br>01234-CPD-00234 | *Name or identifying mark of the manufacturer*<br>*NOTE Registered address of the manufacturer may also be added.*<br>*Last two digits of the year in which the marking was affixed*<br>*Number of the EC certificate of conformity* |
| **WI 124.128**<br>Cross laminated timber | *Number of EN*<br>*Description of the product* |
| Member size *l* x *w* x *d*: 16 000 x 2 450 x 211<br>Layup: 42l – 42w – 43l – 42w – 42l<br>Strength class of all Layers: C 24<br>PUR: Type I | *Performance of some of the mandated characteristics* |

**Figure ZA.1 — Example of the CE marking affixed on the cross laminated timber**

*Example of possible CE-marking for Cross Laminated Timber – Brettsperrholz (subject to change!)*

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## HINTERGRÜNDE UND EUROCODE SYSTEM

- Belastungen
  - EN 1991-1-1 Densities, self-weight and imposed loads
    (Wichten, Eigengewicht und Nutzlasten im Hochbau)
  - EN 1991-1-3 Snow loads (Schneelasten).
  - EN 1991-1-4 Wind actions (Windlasten)
  - EN 1991-1-5 Thermal actions (Temperatureinwirkungen)
  - EN 1991-1-6 Actions during execution (Einwirkungen während der Bauausführung)
  - EN 1991-1-7 Accidental actions (Außergewöhnliche Einwirkungen)

- EN 1995: NDP (Nationally Determined Parameters):
- Wichtig für XLAM:
  - 2.3.1.2(2)P Assignment of loads to load-duration classes
  - 2.3.1.3(1)P Assignment of structures to service classes
  - 2.4.1(1)P Partial factors for material properties
  - 9.2.4.2.1(7) Design method for wall diaphragms



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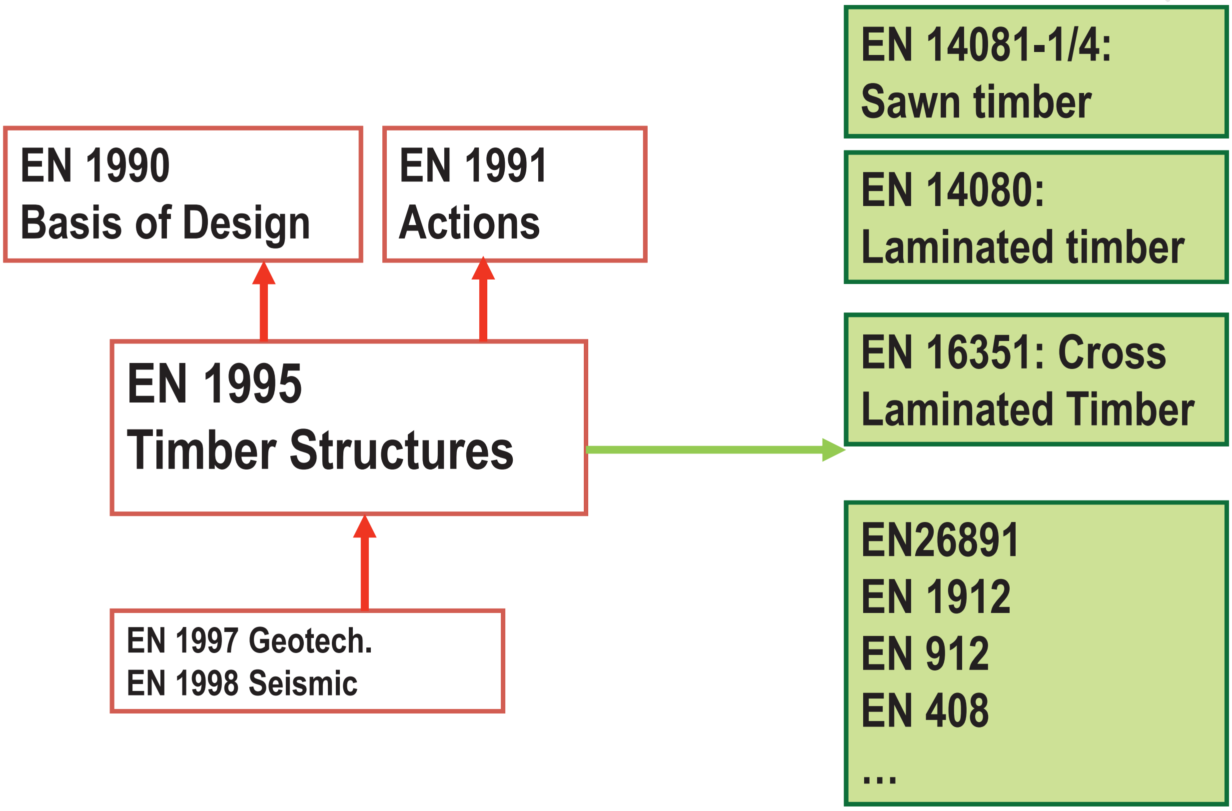
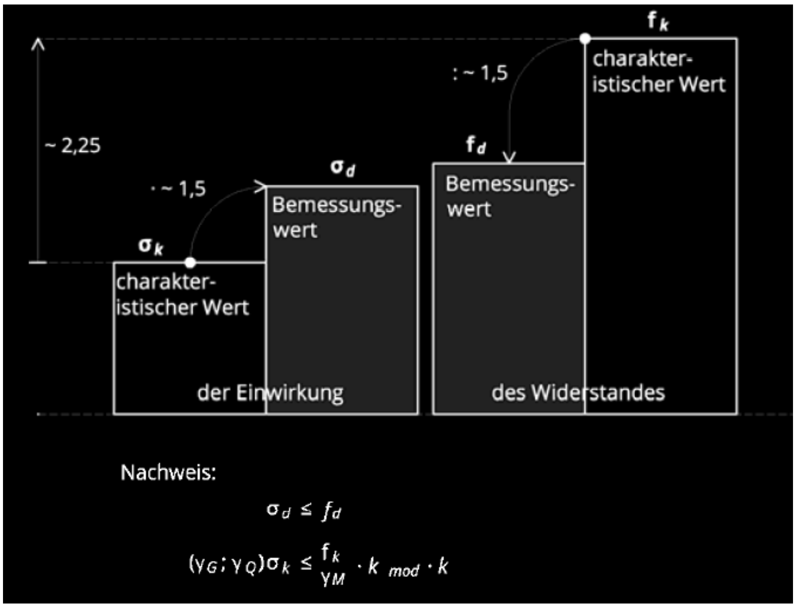



(harmonisierte) Europäische Normen

## Eurocode-system





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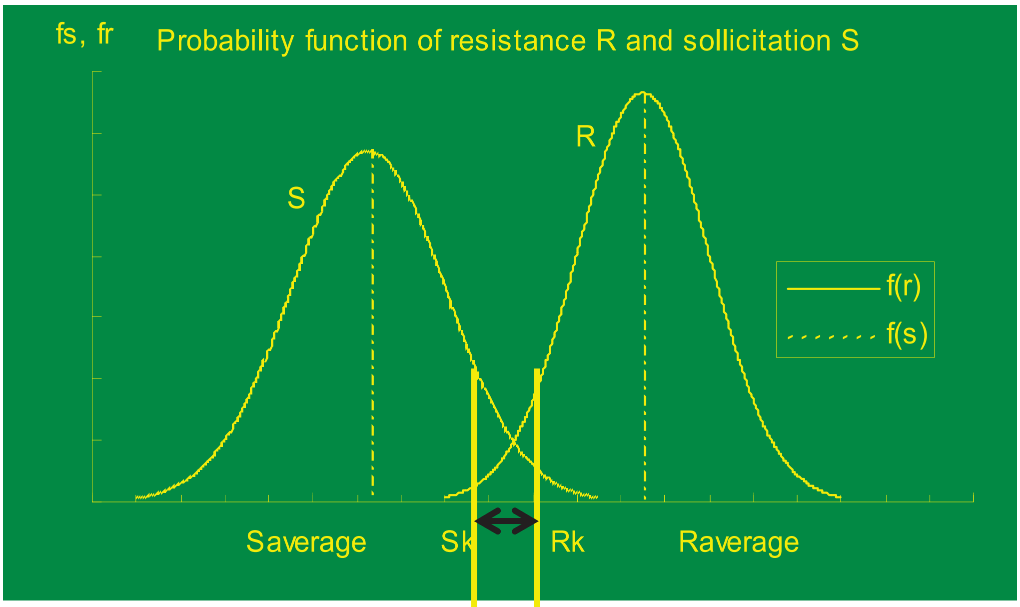



The safety factors determine how far R and S are separated!
They depend on the reliability index required by the legislation.

$$\gamma_{p,q} \leftrightarrow \gamma_M$$

$$Z = \frac{R_k}{\gamma_M} - \gamma_{p,q} S_k \geq 0$$

## Generell nach EC5:

$$f_{m;d} = \frac{f_{m;c} k_{mod}}{\gamma_M} k_h k_{ls}$$

$f_{m,c}$ = characteristic value of strength (m=bending, c=compression,...

$f_{m,d}$ = design value value of strength (m=bending, c=compression,...

$k_h$ = the depth factor (= 1.0)
$k_{ls}$ = the load-sharing factor (auch $k_{sys}$ genannt)
$k_{mod}$ = the modification factor (Tabel 2.2 / Tabel
- load duration (Lasteinwirkungsdauer)
- service class (Nutzungsklasse)

$\gamma_m$ = safety factor (teilsicherheitsbeiwert, (NDP)
$\gamma_m$ = 1.25 (Üblicherweise, Nationale Anhang zu beachten!)
$\gamma_m$ = 1.3 für Verbindungen

Nutzungsklasse 1: T=20ºC, RH = 65% (ω ≈ 12%)
Nutzungsklasse 2: T=20ºC, RH = 85% (ω ≈ 18%)

Nutzungsklasse 3 nicht erlaubt!





2.3.1.2(2)P Assignment of loads to load-duration classes

## ZUORDNUNG BELASTUNGEN (Nationale Regelung)

**Tabelle 2.2 — Beispiele für die Zuordnung zu Klassen der Lasteinwirkungsdauer**

| Klasse der Lasteinwirkungsdauer | Beispiele für die Lasteinwirkung |
|---|---|
| ständig | Eigengewicht |
| lang | Lagerstoffe |
| mittel | Verkehrslasten, Schnee |
| kurz | Schnee, Wind |
| sehr kurz | Wind und außergewöhnliche Einwirkungen |

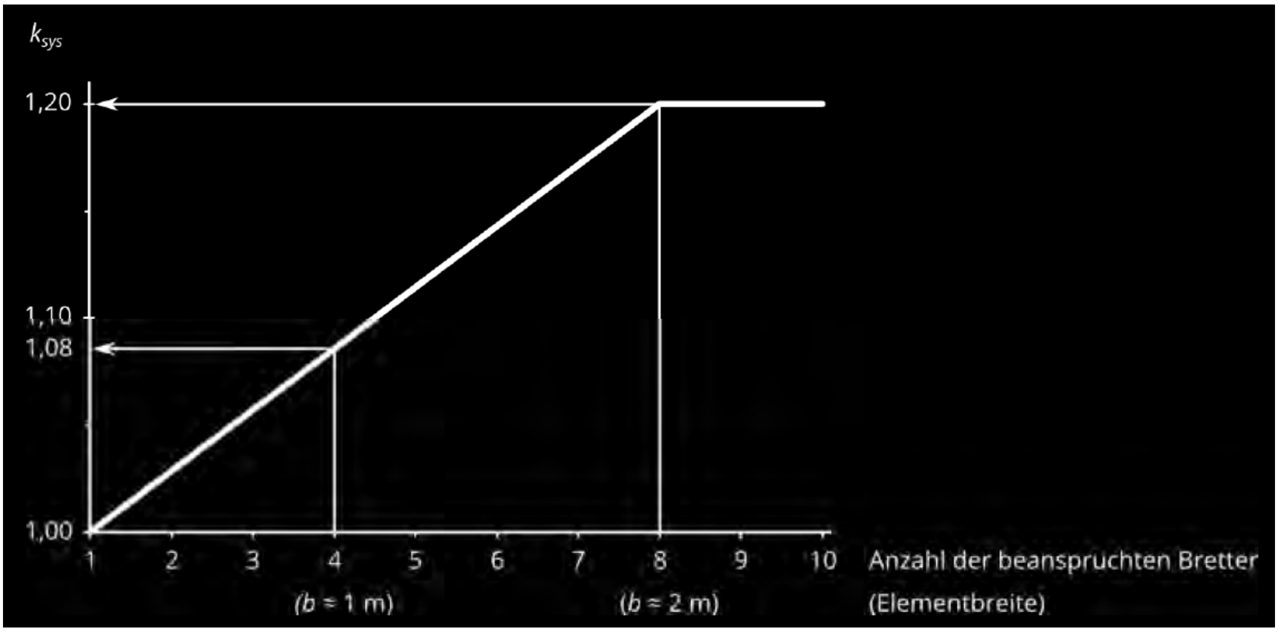
*EN 1995 - Eurocode 5*

*Eurocode 5, Table for $k_{mod}$*

| Material | EN-Standard | Service class | Load-duration class | | | | |
|---|---|---|---|---|---|---|---|
| | | | Permanent | Long term | Medium term | Short term | Instantaneous |
| **Solid timber / GLT** | EN 14081 EN 14080 | 1 | 0.60 | 0.70 | 0.80 | 0.90 | 1.10 |
| | | 2 | 0.60 | 0.70 | 0.80 | 0.90 | 1.10 |
| | | 3 | 0.50 | 0.55 | 0.65 | 0.70 | 0.90 |
| **CLT** | prEN16351 | 1 | 0.60 | 0.70 | 0.80 | 0.90 | 1.10 |
| | | 2 | 0.60 | 0.70 | 0.80 | 0.90 | 1.10 |








*Systemeffekt für CLT bei einer Brettbreite van 250 mm*

*©ProHolz*

Table 7.1 - Example of strength and stiffness properties for proprietary European CLT products

| Property | | Strength class of timber in laminates | |
|---|---|---|---|
| | (MPa) | C16 | C24 |
| **Strength properties** (5 percentile characteristic values based on short-term load) | | | |
| Bending | $f_{m,k}$ | 16 | 24 |
| Tension parallel to grain in face layers | $f_{t,0,k}$ | 10 | 14 |
| Tension perpendicular to grain in face layers | $f_{t,90,k}$ | 0.4 | 0.4 |
| Compression parallel to grain in face layers | $f_{c,0,k}$ | 17 | 21 |
| Compression perpendicular to grain in face layers | $f_{c,90,k}$ | 2.2 | 2.5 |
| Shear in the plane of the plate | $f_{v,k}$ | 1.8 | 2.5 |
| Shear through thickness of the plate | $f_{r,k}$ | 0.7 | 0.7 |
| **Stiffness properties** (mean values) | | | |
| Modulus of elasticity in bending parallel to grain in face layers | $E_{0,mean}$ | 8,000 | 11,000 |
| Modulus of elasticity in bending perpendicular to grain in face layers | $E_{90,mean}$ | 270 | 370 |
| Shear in the plane of the plate | $G_{v,mean}$ | 500 | 690 |
| Shear through thickness of the plate | $G_{r,mean}$ | 50 | 50 |

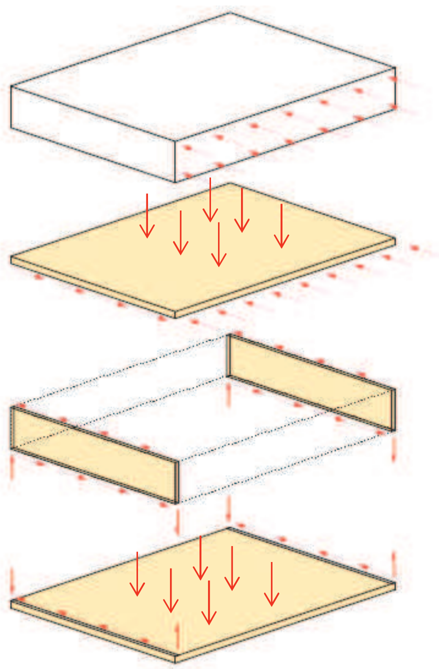




Anwendungsmöglichkeiten von CLT Elementen

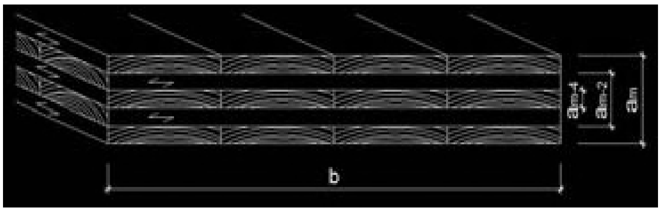
Beanspruchung:

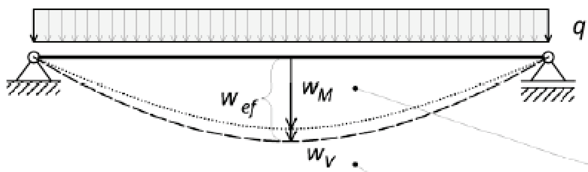
- quer zur Plattenebene
- in Plattenebene (Scheibe)

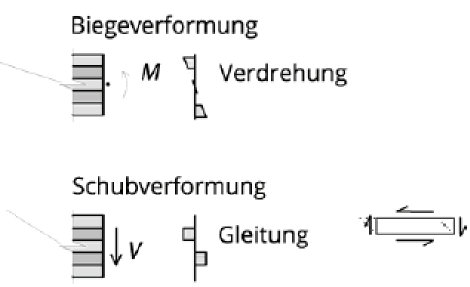


## Anwendungsmöglichkeiten und Berechnungsgrundlagen für CLT

- **Gamma Theory – Gamma (γ)-verfahren**
- Shear Analogy – Schubanalogie
- **Timoshenko Theory - Biegemodel**
- Finite Element Analysis





*Biege- und Schubspannungen bei Plattenbeanspruchung*

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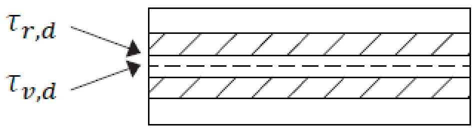
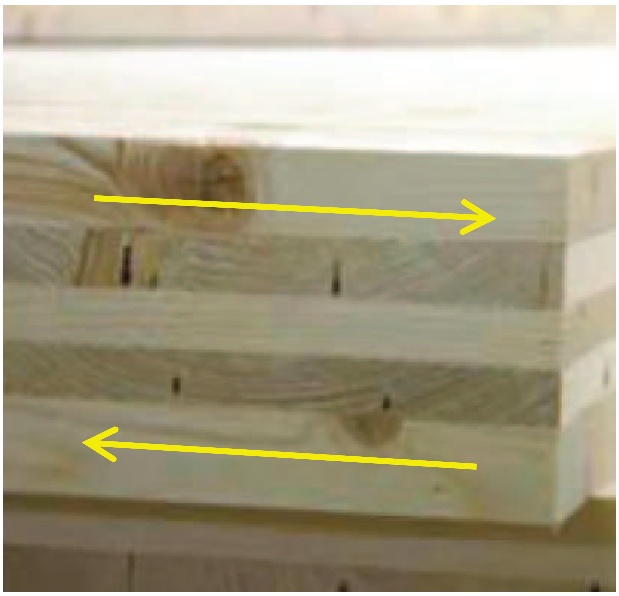
## Shear + Rolling shear in plane




$$\tau_d = \frac{V_d \cdot S(E_i \cdot z_i)}{EI_{ef} b} \leq f_{v,d} \text{ and } f_{r.d}$$

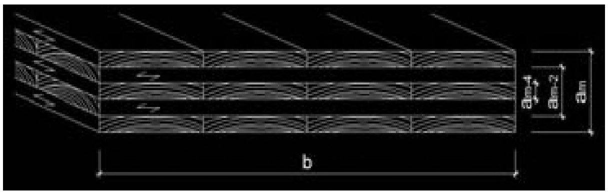


*Rollschub – Rolling shear*
*$f_{v,c}$ = 0.7 N/mm², $G_{r,mean}$ = 50 N/mm²*

Timoshenko beam

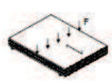
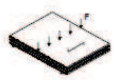
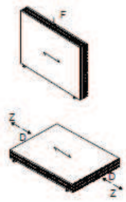
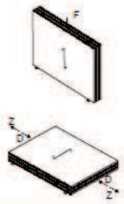
$L/a_m$ > 30 (Spannungen parallel zur Faser)

$L/a_m$ > 20 (Spannungen quer zur Faser)




$$EI_{ef} = \sum E_i I_i + \sum E_i A_i e_i^2$$

$$\sigma_{m,d} = \frac{M \cdot E_0}{EI_{eff}} \cdot \frac{a_m}{2}$$

| | $k_i$ |
|---|---|
|  | $k_1 = 1 - \left[1 - \frac{E_{90}}{E_0}\right] \cdot \frac{a_{m-2}^3 - a_{m-4}^3 + \ldots \pm a_1^3}{a_m^3}$ |
|  | $k_2 = \frac{E_{90}}{E_0} + \left[1 - \frac{E_{90}}{E_0}\right] \cdot \frac{a_{m-2}^3 - a_{m-4}^3 + \ldots \pm a_1^3}{a_m^3}$ |
|  | $k_3 = 1 - \left[1 - \frac{E_{90}}{E_0}\right] \cdot \frac{a_{m-2} - a_{m-4} + \ldots \pm a_1}{a_m}$ |
|  | $k_4 = \frac{E_{90}}{E_0} + \left[1 - \frac{E_{90}}{E_0}\right] \cdot \frac{a_{m-2} - a_{m-4} + \ldots \pm a_1}{a_m}$ |

*Systemaufbaufactoren, (Blass & Fellmoser),*





| Loading | To the grain of outer skins | Effective strength value | Effective stiffness value |
|---|---|---|---|
| Perpendicular to the plane loading | | | |
| Bending | Parallel | $f_{m,0,ef} = f_{m,0} \cdot k_1$ | $E_{m,0,ef} = E_0 \cdot k_1$ |
| | Perpendicular | $f_{m,90,ef} = f_{m,0} \cdot k_2 \cdot a_m / a_{m-2}$ | $E_{m,90,ef} = E_0 \cdot k_2$ |
| In-plane loading | | | |
| Bending | Parallel | $f_{m,0,ef} = f_{m,0} \cdot k_3$ | $E_{m,0,ef} = E_0 \cdot k_3$ |
| | Perpendicular | $f_{m,90,ef} = f_{m,0} \cdot k_4$ | $E_{m,90,ef} = E_0 \cdot k_4$ |
| Tension | Parallel | $f_{t,0,ef} = f_{t,0} \cdot k_3$ | $E_{t,0,ef} = E_0 \cdot k_3$ |
| | Perpendicular | $f_{t,90,ef} = f_{t,0} \cdot k_4$ | $E_{t,90,ef} = E_0 \cdot k_4$ |
| Compression | Parallel | $f_{c,0,ef} = f_{c,0} \cdot k_3$ | $E_{c,0,ef} = E_0 \cdot k_3$ |
| | Perpendicular | $f_{c,90,ef} = f_{c,0} \cdot k_4$ | $E_{c,90,ef} = E_0 \cdot k_4$ |

Gamma-verfahren

Einfach: nur Biegeberechnungen

Schubverformung durch Faktor **γ**

Effekt: reduzierte Biegesteifigkeit:

1. Höhere Biegespannungen
2. Höhere Durchbiegung

$$EI_{ef} = \sum E_i I_i + \sum \gamma_i E_i A_i e_i^2$$

$$\sigma_{m,i,d} = \frac{M \cdot E_0}{EI_{eff}} \cdot (\gamma_i a_i + \frac{h_i}{2})$$

$$\gamma_1 = \frac{1}{\left(1 + \frac{\pi^2 E_{//} b h_1}{\ell_{ef}^2} \cdot \frac{h_{1,2}}{b G_{R,12}}\right)}$$





Verformungsbeiwerte $k_{def}$ für Brettsperrholz

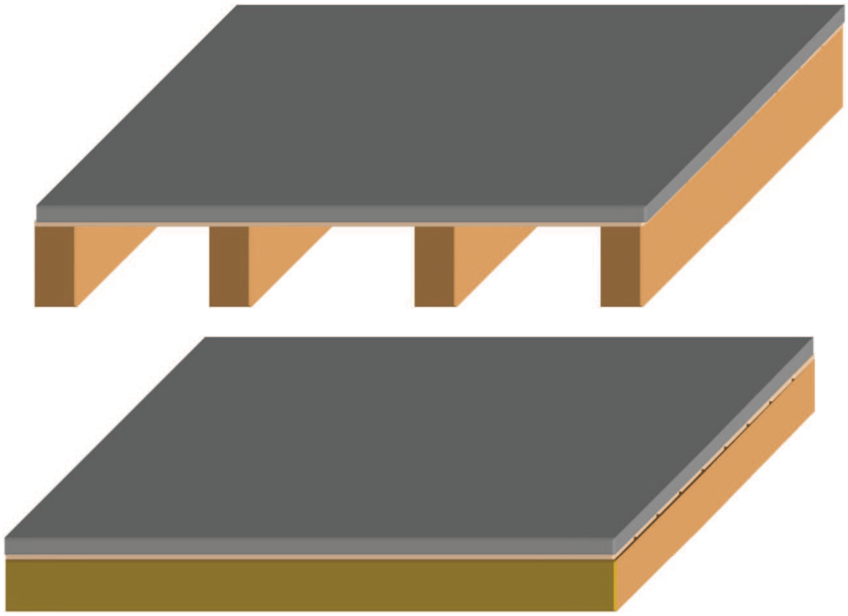
| Baustoff | $k_{def}$ für Nutzungsklasse | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Vollholz | 0,60 | 0,80 | 2,00 |
| Brettschichtholz | 0,60 | 0,80 | 2,00 |
| Brettsperrholz[1] | 0,80 | 1,00 | nicht zugelassen |

| **Baustoff** | **$k_{def}$ für Nutzungsklasse** | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| Sperrholz nach EN 1995-1-1:2009 | 0,80 | 1,00 | 2,50 |
| Brettsperrholz nach DIN 1052:2008 | 0,60 | 0,80 | – |
| Brettsperrholz TU Graz 3 bis 7 Schichten | 0,80 | 1,00 | – |
| Brettsperrholz TU Graz mehr als 7 Schichten | 0,85 | 1,10 | – |



*Quelle: BBS Bemessung*

Timber-concrete composite floors





Statically Determinate (S.D.) or Statically Indeterminate (S.I.):

S.D.: creep influences only the deformation

S.I.: creep also influences the load distribution in the system.

- Beam with rigid supports or hinged
- Stressed skin panels
- Timber-concrete composites
- Use:

$$E_{c,\infty} = \frac{E_{c,0}}{1+\psi_{cr,c}} \qquad E_{j,\infty} = \frac{E_{j,0}}{1+\psi_{cr,j}} \qquad E_{t,\infty} = \frac{E_{t,0}}{1+\psi_{cr,t}}$$

## Load-slip behaviour of joints: stiffness values

Dowels, Bolts (without clearance), Screws and Nails (predrilled)

$$k_{ser} = \frac{\rho_m^{1.5} d}{25}$$

Nails (without pre-drilling):

$$k_{ser} = \frac{\rho_m^{1.5} d^{0.8}}{30}$$

Stahl-Holzverbindung, Beton-Holz verbindung: 2 x $k_{ser}$

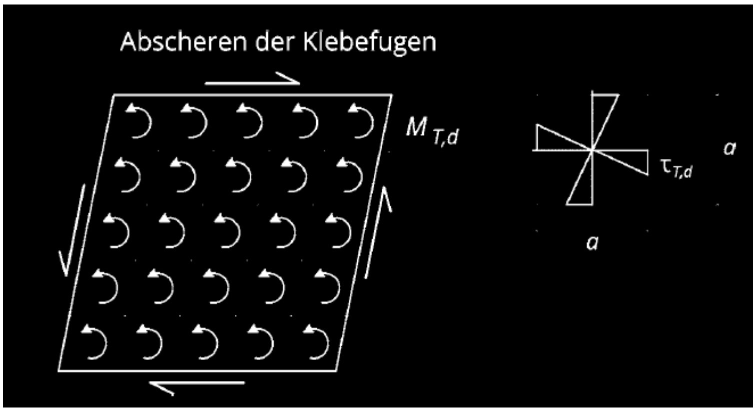
Der Entwurf wird gerechnet mit der effektiven Biegesteifigkeit $EI_{eff}$ für t=0 und t=∞





*Holzbetonverbundsystem,*
*Raadschelders Bouwadvies, NL*

## Anforderungen an der Klebfuge bei fehlender Seitenverklebung - Scheibenanwendung




$$\tau_{T,d} \leq f_{V,T,d}$$

$$\tau_{T,d} = \frac{M_T}{\sum I_P} \cdot \frac{a}{2} = \frac{M_T}{n_k \cdot \frac{a^4}{6}} \cdot \frac{a}{2} = \frac{3 \cdot M_T}{n_k \cdot a^3}$$

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## Creep deformation

Eurocode 5: $w_{tot} = w_{inst} + w_{creep}$

$$w_{inst} = \sum_{j \geq 1} w_{inst,G,j} + w_{inst,Q,1} + \sum_{i>1} \psi_{Q,i} \cdot w_{inst,Q,i}$$

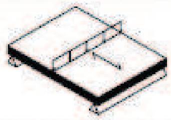
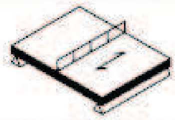
$k_{def}$ depends on load duration and material

Each load contribution shall be calculated: *G* (long term) and *Q* (short term), in combination with $\psi_2$

| Rechenwerte der Durchbiegungen | | Grenzwerte der Durchbiegungen | |
|---|---|---|---|
| | | Biegeträger (Stützweite ℓ) | Kragträger (Kraglänge $\ell_k$) |
| charakteristische Bemessungssituation | $w_{Q,inst}$ | ℓ/300 | $\ell_k$/150 |
| | $w_{fin} - w_{G,inst}$ | ℓ/200 | $\ell_k$/100 |
| quasi-ständige Bemessungssituation | $w_{fin} - w_c$ | ℓ/250 | $\ell_k$/125 |

$w_{Q,inst}$ Anfangsdurchbiegung infolge veränderlicher Einwirkungen
$w_{fin}$ Enddurchbiegung
$w_{G,inst}$ Anfangsdurchbiegung infolge ständiger Einwirkungen
$w_c$ Überhöhung

## Unterstützung bei der Bemessung durch CLT Hersteller:

| BEANSPRUCHUNG ALS PLATTE DIN 1052: 2008-12 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | PARALLEL ZUR FASERRICHTUNG DER DECKLAGEN | | | | SENKRECHT ZUR FASERRICHTUNG DER DECKLAGEN | | | |
| |  | | | |  | | | |
| BEZEICHNUNG | $E_{mean}$ | STEIFIGKEIT | $f_{m,k}$ | $f_{v,k}$ | $E_{mean}$ | STEIFIGKEIT | $f_{m,k}$ | $f_{v,k}$ |
| LEND | N/mm² | E x I $E_{mean}$+12 Nmm² | N/mm² | N/mm² | N/mm² | E x I $E_{mean}$+12 Nmm² | N/mm² | N/mm² |
| 51 | 10590 | 0,117 | 23,11 | 0,92 | 410 | 0,005 | 2,67 | 0,67 |
| 61 | 10050 | 0,190 | 21,93 | 0,97 | 950 | 0,018 | 4,68 | 0,89 |
| 71 | 10850 | 0,324 | 23,67 | 0,89 | 150 | 0,004 | 1,37 | 0,48 |
| 81 | 10590 | 0,469 | 23,11 | 0,92 | 410 | 0,018 | 2,68 | 0,67 |
| 85 | 8710 | 0,446 | 19,00 | 1,05 | 2290 | 0,117 | 8,33 | 0,55 |
| KIL 85* | 10470 | 0,536 | 22,84 | 0,93 | 490 | 0,025 | 2,93 | 0,67 |
| 93 | 10730 | 0,719 | 23,41 | 0,91 | 270 | 0,018 | 2,03 | 0,58 |
| 95 | 8340 | 0,596 | 18,20 | 1,10 | 2660 | 0,190 | 9,04 | 0,62 |

| KNICKZAHLEN LEND | | |
|---|---|---|
| λ | ω | $k_c$ |
| 0 | 1,00 | 1,00 |
| 10 | 1,00 | 1,00 |
| 20 | 1,00 | 1,00 |
| 30 | 1,00 | 0,98 |
| 40 | 1,03 | 0,96 |
| 50 | 1,11 | 0,92 |
| 60 | 1,25 | 0,85 |
| 70 | 1,45 | 0,74 |
| 80 | 1,75 | 0,61 |
| 90 | 2,22 | 0,50 |
| 100 | 2,74 | 0,42 |
| 110 | 3,32 | 0,35 |
| 120 | 3,95 | 0,30 |
| 130 | 4,63 | 0,25 |
| 140 | 5,37 | 0,22 |
| 150 | 6,17 | 0,19 |
| 160 | 7,02 | 0,17 |
| 170 | 7,93 | 0,15 |
| 180 | 8,88 | 0,14 |
| 190 | 9,89 | 0,12 |
| 200 | 10,96 | 0,11 |

| QUERSCHNITTSWERTE LEND-WÄNDE | | |
|---|---|---|
| BEZEICH-NUNG | TRÄGHEITS-RADIEN i | NETTO-QUERSCHNITT $A_{netto}$ |
| LEND | cm | cm² |
| 51 | 1,77 | 340 |
| 61 | 2,25 | 340 |
| 71 | 2,33 | 540 |
| 81 | 2,81 | 540 |
| 85 | 2,82 | 510 |
| KIL 85* | 3,00 | 540 |
| 93 | 3,15 | 660 |
| 95 | 2,98 | 610 |





## Bemessungsdiagramme

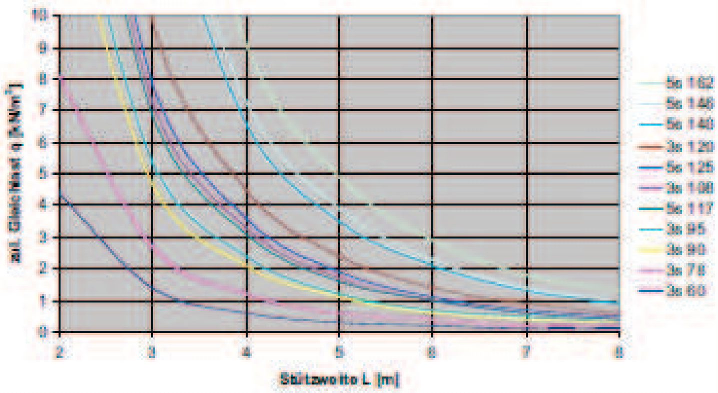

Orientierung der Decklage längs zur Produktionslänge -> DL

### KLH ALS DECKE

(L/400, Vollast)

**ANMERKUNG:**

Bei großen Stützweiten ist auch das Schwingungsverhalten der Decke zu untersuchen.
Bei Dimensionierung mit L/400 hat die Deckenplatte aber üblicherweise eine ausreichende Steifigkeit.




Knick + Stabilität von Wänden

Netto Querschnitt:

$$\lambda = \frac{\ell_{ef}}{i}$$

$$i_y = \sqrt{\frac{I_{ef}}{A_{net}}}$$

$$\sigma_{c,0,d} = \frac{N_{c,0,d}}{A_{net}}$$

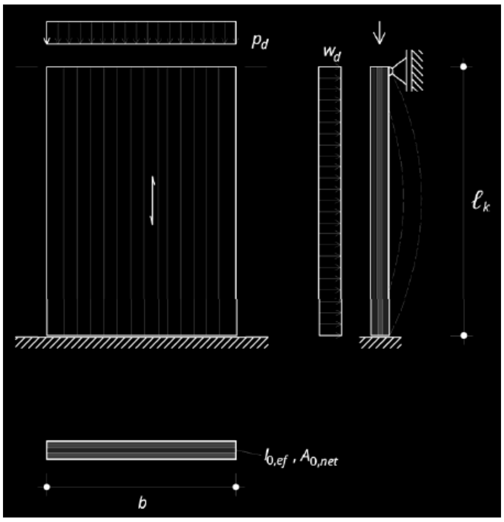
$$\frac{\sigma_{c,0,d}}{k_c f_{c,0,d}} \leq 1$$

Brutto Querschnitt:

$$i_y = \sqrt{\frac{I_{full}}{A_{gross}}}$$

$$\sigma_{c,0,d} = \frac{N_{c,0,d}}{k_3 A_{gross}}$$

$$\frac{\sigma_{c,0,d}}{k_c k_3 f_{c,0,d}} \leq 1$$



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$$k_{c,y} = \frac{1}{k_y + \sqrt{k_y^2 + \lambda_{rel,y}}} \qquad k_y = 0.5\left[\left(1+\beta_c(\lambda_{rel,y} - 0.3) + \lambda_{rel,y}^2\right)\right] \qquad \beta_c = 0.1$$

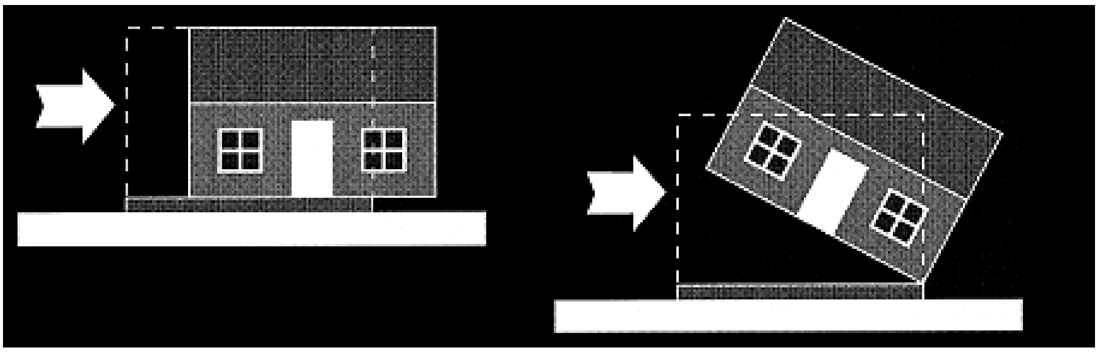
$$\lambda_{rel,y} = \frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0.05}}}$$

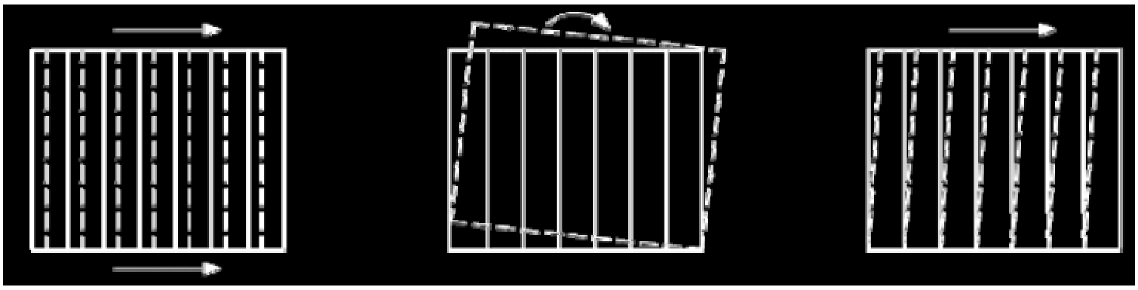
Gegebenerfalls Biegung addieren: $\frac{\sigma_{c,0,d}}{k_c f_{c,0,d}} + \frac{\sigma_{m,d}}{f_{m,d}} \leq 1$



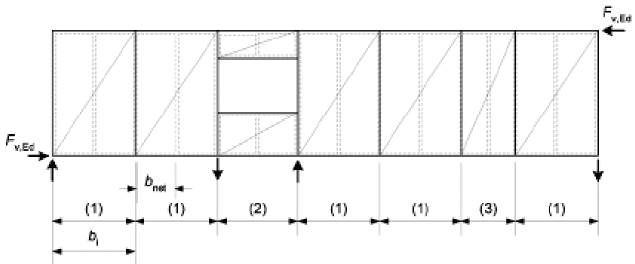


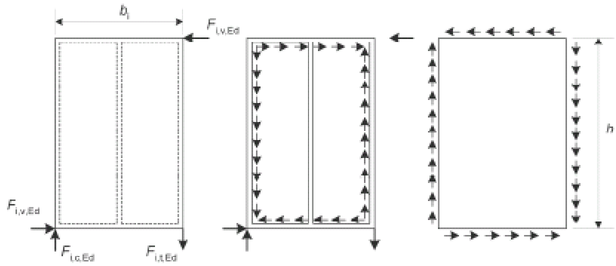
Stabilität





Funktionen einer Wand bei Horizontalbeanspruchung in der Plattenebene (Wind / Erdbeben)





(1) Standardelement
(2) Element mit Öffnung
(3) Element (Schmal)



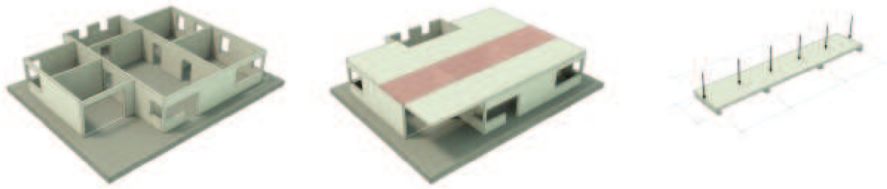


*Figure 10: Floors design is usually performed neglecting any possible 2D plate effect.*

rib stiffened plate

double-skin plate

**Fig. 7.5** - Long span floor plates

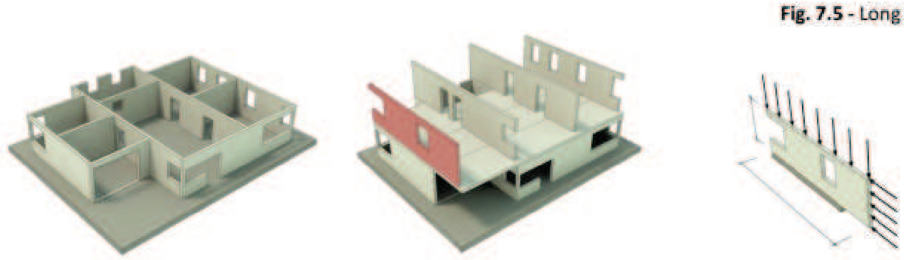


*Figure 12: In-plane use of cross-lam panels allows for very large overhangs*

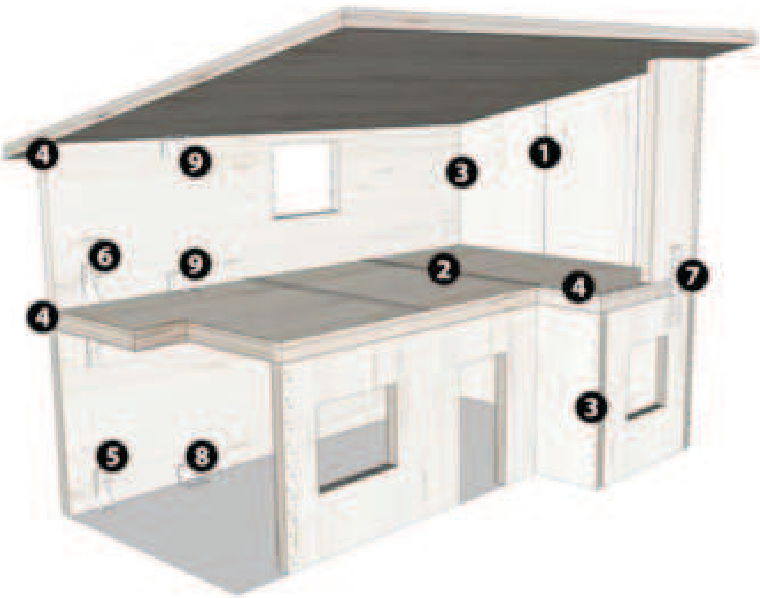



*Figure 13: Points where design of connections must be undertaken:*

- screws

*1 wall-wall*
*2 floor-floor*
*3 wall-corner wall*
*4 floor-wall*

- hold-downs

*5 wall-foundation*
*6 wall-floor/floor-wall*

- steel straps

*7 wall-wall*

- steel angles

*8 wall-foundations*
*9 wall-floor/ wall-wall (in vertical)*



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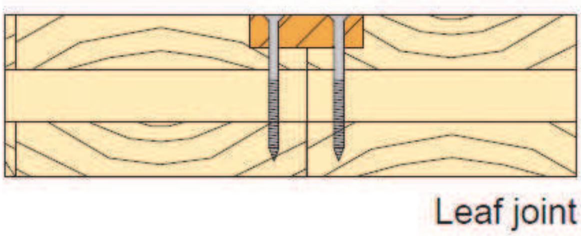
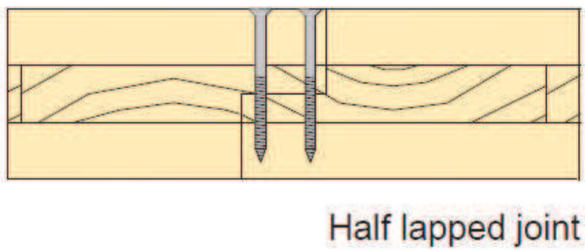
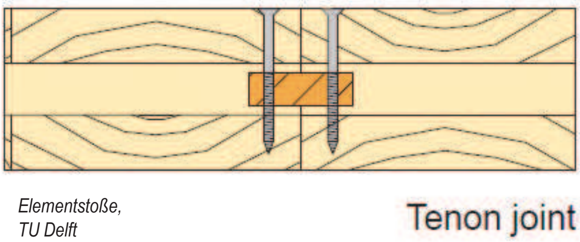
## CLT-Elementstoße



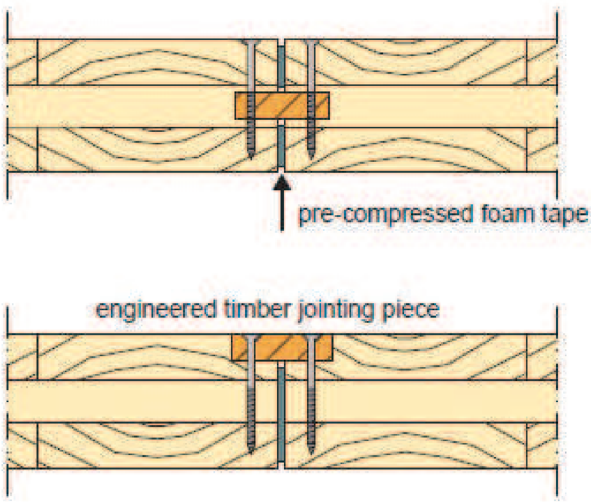



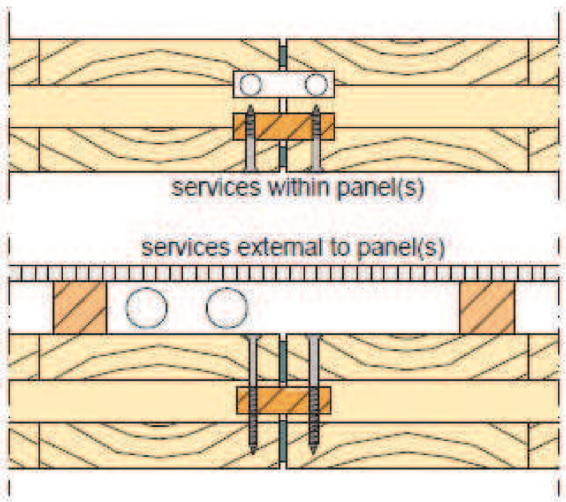

*Elementstoße, TU Delft*

*Elementstoße, Binderholz*









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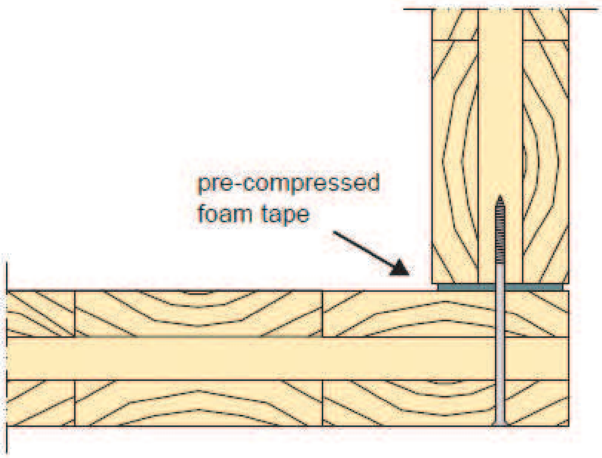


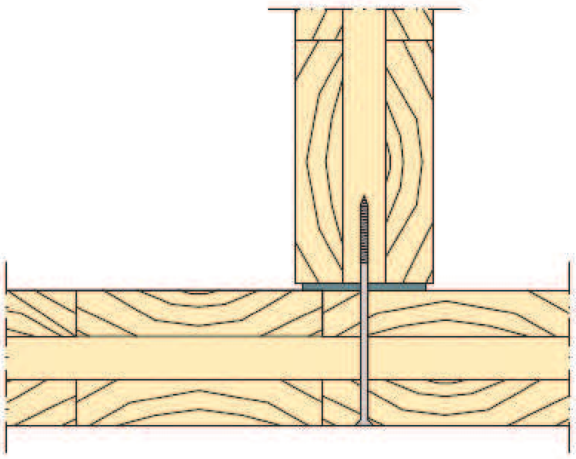

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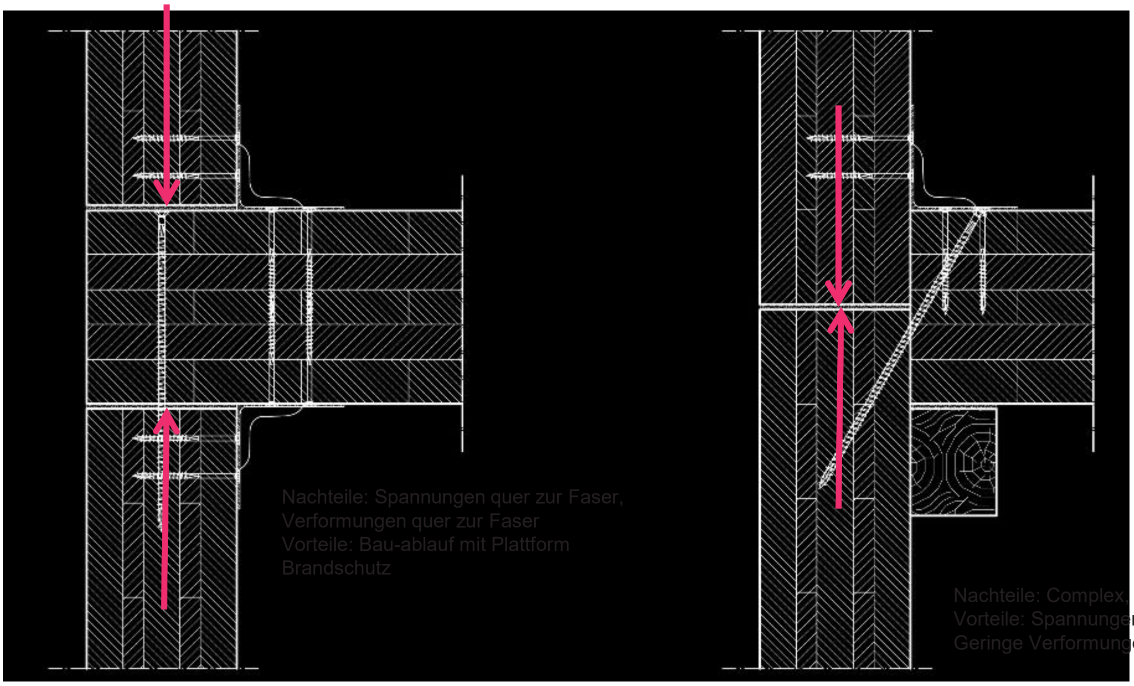
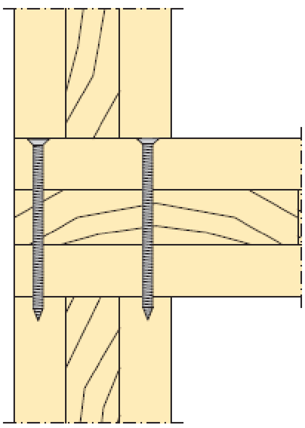


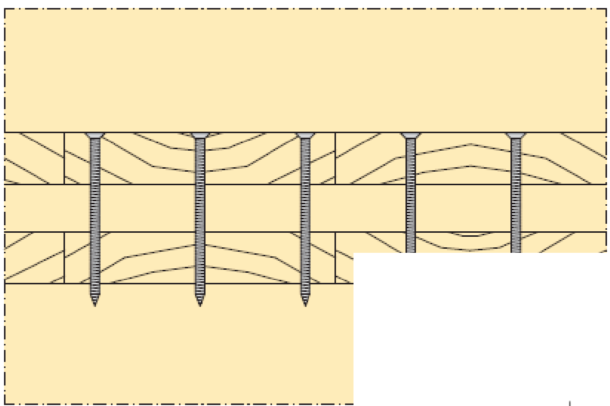

*Platform frame vs. Balloon frame*



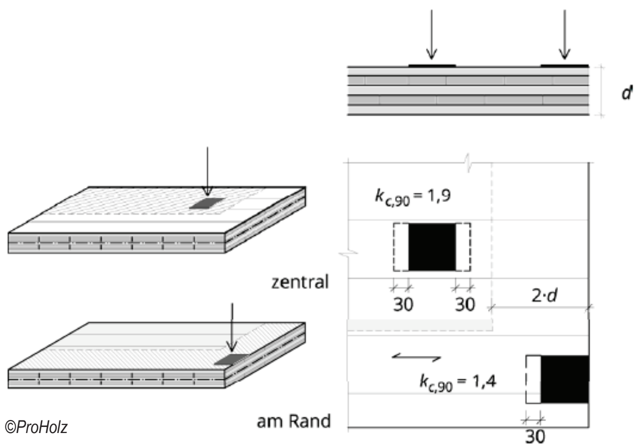


## Platform frame: reinforcement against perp. to grain stresses





*Verstärkung von Quer zur Faser beanspruchten Bodenelementen; Knick von Schrauben!*

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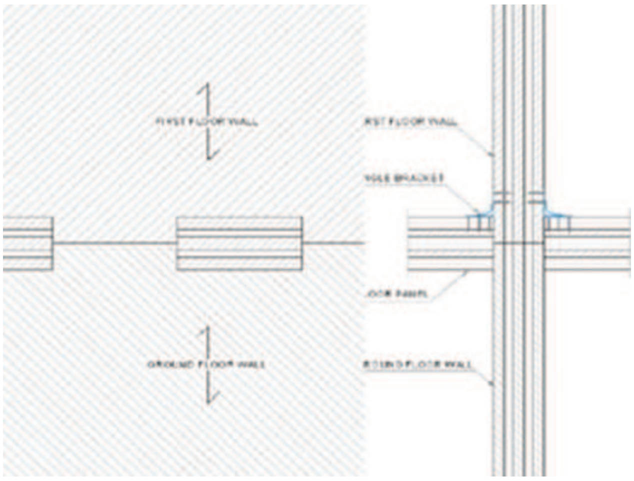

Detail for floor-floor / wall-wall connection
Source: klh





## Erdbeben mit EC8 + EC5

- Global structure
  - The entire system of connections, elements, masses etc. determines the behaviour in an earthquake
- Element ductility (floors / walls):
  - Behaviour of the main structural (connected) elements.
    Wood is brittle!
- Local ductility (joints, materials)
  - Ductility (= $v_u/v_y$)
  - Steel is ductile, but not all timber joints with steel are.

When can we apply Eurocode 8?

## Eurocode 8 - approach of the design of structures in seismic regions

- Based on principle of Limit States Design.
- Operates with the so-called "service" earthquake, "moderate" but not "likely", which has PGA with an average return period of 50 years.
- The "ultimate" earthquake, "severe" but "accidental" has a return period of 475 years.
- Timber elements exhibit a generally elastic behaviour under alternate loading, with brittle failure primarily due to natural defects like knots.
- Plasticity and capacity to dissipate energy are taken into account in the connections between the various structural elements provided that they are "semi-rigid".



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## Eurocode 8 – continued

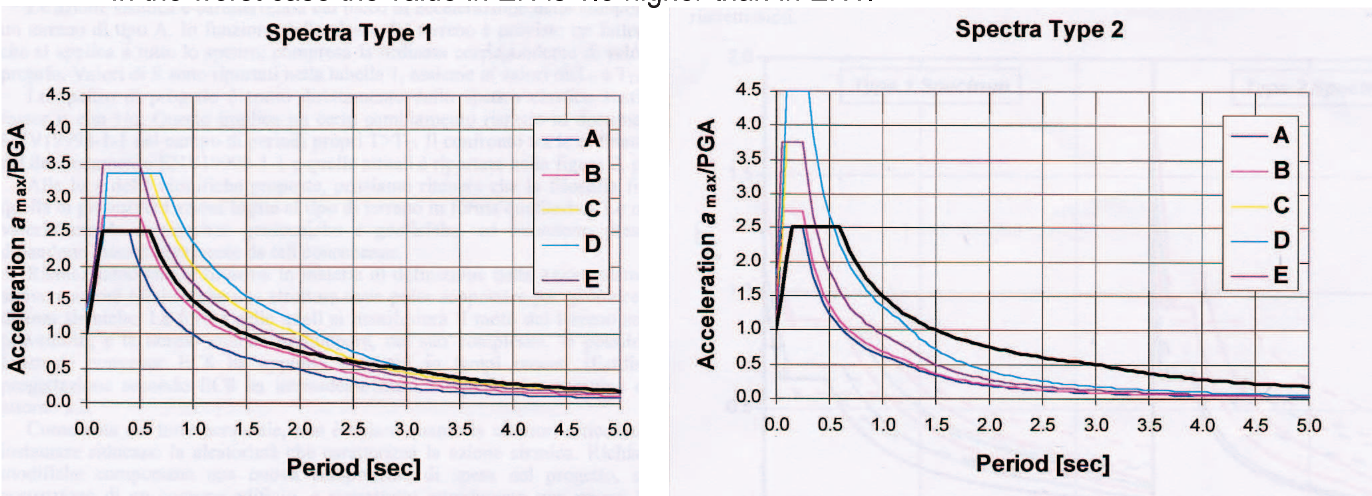
- Structures are classified into categories taking into account their plastic behaviour and their ability to dissipate energy.
- the earthquake design base shear load Ed :

$$E_d = \frac{M \cdot R(T_o, \nu) \cdot A_u}{q}$$

- **M** is the mass of the structure,
- ***R(T**$_{o,}$**n)*** is the amplification factor of the PGA ,
- **A**$_u$ is the design PGA depending on the seismicity of the site,
- ***q*** is the design Action Reduction Factor (ARF).

Amplification factor R ($T_o$,$\nu$)

- In the EN version the soil conditions from A to E are considered instead of three classes (from A to C) as in ENV.
- Also two different types of quakes are considered for each soil condition: Type 1 ($M_s$>5.5) and Type 2 ($M_s$<5.5).
- In the worst case the value in EN is 1.8 higher than in ENV.








Behaviour factor - q

- q is the design Action Reduction Factor (ARF), i.e. "simply the factor to be used in calculating design inertia forces so that a structure designed linearly elastic using the static code strength values can survive the design quake intensity, even if heavily damaged, but without its ruin" .
- In order to take into account the so-called over-strength, q factors have been changed with an average increase of 1.5 times according to the previous values in ENV.

Determination of the suitability of a chosen ARF value:

- design the structure using the ARF according to the code,
- using a suitable non-linear analysis programme capable of following the displacement history of the building under a quake in the time domain,
- the $\mathbf{PGA_u}$ that the building will survive without exceeding a failure limit can be determined,
- this $\mathbf{PGA_u}$ can be compared against $\mathbf{PGA_{code}}$ prescribed by the code,
- if $\mathbf{PGA_u > PGA_{code}}$ the previously chosen design ARF value is good enough.

## q factors according to ENV version

| | | |
|---|---|---|
| **Type A** Non-dissipative structures | **q = 1** | Without or with only a few joints with mechanical fasteners beyond the dissipative zones (e.g. arches with hinged joints), cantilever structures with rigid connections at the base, buildings with wall-diaphragms without mechanical fasteners for interconnection, between sheathing and timber framing |
| **Type B** Low-dissipative structures | **q = 1.5** | With few but effective dissipative zones, structures with semi-rigidly fixed-based columns. |
| **Type C** Medium-dissipative structures | **q = 2** | Frames or beam-column structures with semi-rigid joints between all members, braced frame structures with mechanical fasteners in the joints of the frame and/or the connections of the bracing system; vertical diaphragms, where sheathing is glued to the framing. |
| **Type D** Well-dissipative structures | **q = 3** | Buildings with vertical diaphragms resisting the horizontal forces, where sheathing is fixed to the framing by mechanical fasteners a well as the interconnection of the wall-elements (horizontal diaphragms may be glued or nailed). |



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## q factors according to EN version

| | | |
|---|---|---|
| **Type DCL** Structures having low capacity to dissipate energy | **q = 1.5** | Cantilevers; beams; arches with two or three pinned joints; trusses joined with connectors. |
| **Type DCM**, Structures having medium capacity to dissipate energy | **q = 2** | Glued wall panels with glued diaphragms, connected with nails and bolts; trusses with doweled and bolted joints; mixed structures consisting of timber framing. |
| | **q = 2.5** | Hyperstatic portal frames with doweled and bolted joints. |
| **Type DCH**, Structures having high capacity to dissipate energy | **q = 3** | Nailed wall panels with glued diaphragms, connected with nails and bolts, trusses with nailed joints. |
| | **q = 4** | Hyperstatic portal frames with doweled and bolted joints. |
| | **q = 5** | Nailed wall panels with nailed diaphragms connected with nails and bolts. |

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# factors *(ENV versus EN)*

- In the ENV version the mechanical connections loss of strength due to differences from static to cyclic behaviour, was taken into account by using the partial safety factor for fundamental load combination, i.e. $g_m$=1.3, instead of the classical $g_m$=1 for accidental load combination. On the contrary, for non-dissipative structures $g_m$ = 1 was retained.
- In the EN version this point has been reversed: in case of non-dissipative structures the fear of brittle failure has been privileged and the safety coefficient increased, i.e. $g_m$=1.3, while in the case of dissipative structures, the cyclic impairment of strength has been considered limited and the safety coefficient for accidental load combination is used, i.e. $g_m$=1.

| **Structural type and** $\gamma_M$ (ENV) | | **Structural type and** $\gamma_M$ (EN) | |
|---|---|---|---|
| A | 1.0 | DCL | 1.3 |
| B | 1.3 | DCM | 1.0 |
| C | 1.3 | DCH | 1.0 |





Comparisons between ENV and EN

$$R(T_0,\nu)\frac{\gamma_M}{q}$$

- The factor well detects the differences in the design base shear evaluation for the **worst** possible soil and quake type combination:

| ENV | | | EN | | | difference |
|---|---|---|---|---|---|---|
| A | $2.5\frac{1.0}{1} =$ | **2.50** | DCL | $4.5\frac{1.3}{1.5} =$ | **3.90** | ***+56%*** |
| B | $2.5\frac{1.3}{2} =$ | **1.63** | DCM | $4.5\frac{1.0}{2.5} =$ | **1.80** | ***+10%*** |
| C | $2.5\frac{1.3}{3} =$ | **1.08** | DCH | $4.5\frac{1.0}{5} =$ | **0.90** | ***-17%*** |

EN 1998-1 (EC8)

$$F_b = S_d(T_0) \cdot W \qquad \text{if } T_b<T_o<T_c \qquad S_d = \alpha \; S \frac{2.5}{q}$$

- $S_d$ is the ordinate of the design spectrum,
- W is the total weight of the building.
- α is the design peak ground acceleration value/acceleration of gravity *g*,
- *S* is the soil parameter factor (>1) depending on $T_0$

Distribution of the base shear force in elevation:

$$F_i = F_b \frac{z_i W_i}{\sum_j z_i W_i}$$

The mass in seismic design:

$$W = \sum G_{kj} + \sum \psi_{EI} Q_{ki}$$





Example: calculation of the seismic load according to EN-1998

Some introduction points:

- The seismic design of a building starts with an evaluation of the regularity of the building in both layout and elevation.
- Generally regularity increases the seismic resistance of the building.
- If the building is non-regular in elevation the above q-values should be reduced by 20 %, but need not be lower than 1.5.
- Usually timber residential buildings are regular in height and in plan.
- The base shear force acts in both principal directions of the building.
- To ensure the classification of structures, the dissipative zones should be able to deform plastically for at least three fully reversed cycles at a static ductility ratio 4 for type DCM structures and 6 for type DCH structures, without more than 20 % reduction of their resistance.

Determination of vertical load

- The seismic load is determined considering the vertical loads present in the different storeys of the building.
- $G_{kj}$ is the characteristic dead load
- $\psi_{EI}Q_{ki}$ is the probable live load during a seismic event.
- Combination coefficient:
  - $\psi_{2i}$ is 0.3 (the quasi-permanent value of the live load (EC1 and EC5)
  - $\varphi$ is 0.5 except for the top storey for which it is 1.0 (EC8)

$$\psi_{EI} = \varphi \psi_{2i}$$

$$\sum G_{kj} + \sum \psi_{EI} Q_{ki} = 0.75 + 1.60 + 1.30 + 1.30 = 4.95 \text{ KN/m}^2$$





According to Eurocode 8, the base shear force is calculated using the following equation:

$$F_b(T_1) = S_d(T_1) \times W \qquad (1)$$

where $S_d$ $(T_1)$ is the ordinate of the design spectrum at period $T_1$ and $W$ is the total mass of the building.

From the outcomes of the tests, the period $T_1$ of the building is 0,20 s, therefore the ordinate of the design spectrum is

$$S_d(T_1) = a_g \times S \times \frac{2,5}{q} \qquad (2)$$

where:

$a_g$ is the design ground acceleration corresponding to the seismic zone. According to the Italian Seismic Building Code, $a_g$ is taken equal to 0,35 g, CLT building calculation example according to EN-1998:three storey house

*Fig. 5: Three-storey test building on the shaking table at NIED Laboratory in Tsukuba, Japan (configuration C)*



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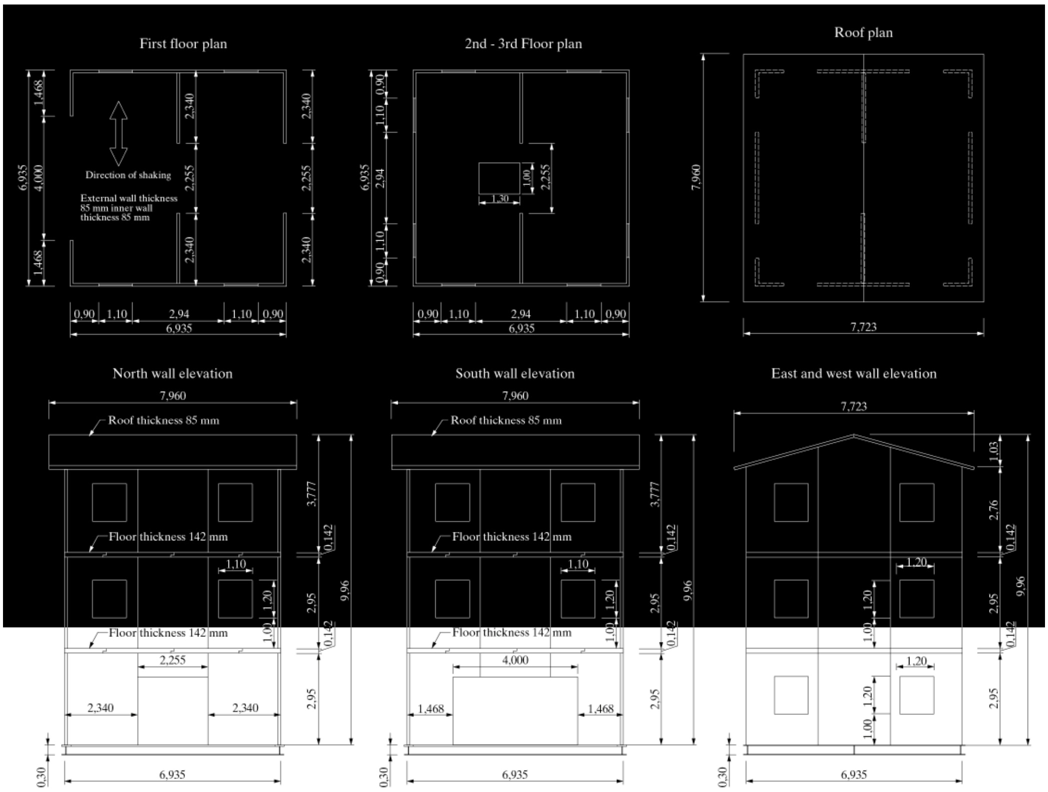


*Fig. 6: Plans and elevation of the test building (Units: m)*

| | |
|---|---|
| **Total weight** | |
| Roof | 45 kN |
| Second floor | 210 kN |
| First floor | 210 kN |
| **Total** | **465 kN** |
| **Seismic action** | |
| **Base shear** | |
| zone 1; $a_g$ | 0,35 |
| $T_1$ | 0,20 |
| soil B S | 1,25 |
| *q* | 1 |
| $F_b = 2{,}5*(W*S*a_g)/q$ | **509 kN** |
| **Distribution on storeys** | |
| height | |
| Hr (roof) | 9,40 m |
| H2 (2nd floor) | 6,18 m |
| H1 (1st floor) | 3,09 m |
| Horizontal forces at each floor | |
| Fr (roof) | 91 kN |
| F2 (2nd floor) | 279 kN |
| F1 (1st floor) | 139 kN |
| shear at each floor | |
| Tr (roof) | 91 kN |
| T2 (2nd floor) | 370 kN |
| T1 (1st floor) | 509 kN |

*Table 2: The calculation of the seismic forces and the shear at each floor*

| Floor | Dead (kN) | Additional (kN) | Total (kN) |
|---|---|---|---|
| 1st | 60 | 150 | 210 |
| 2nd | 60 | 150 | 210 |
| Roof | 45 | 0 | 45 |
| Total | 165 | 300 | 465 |

*Table 1: Load distribution at each floor*



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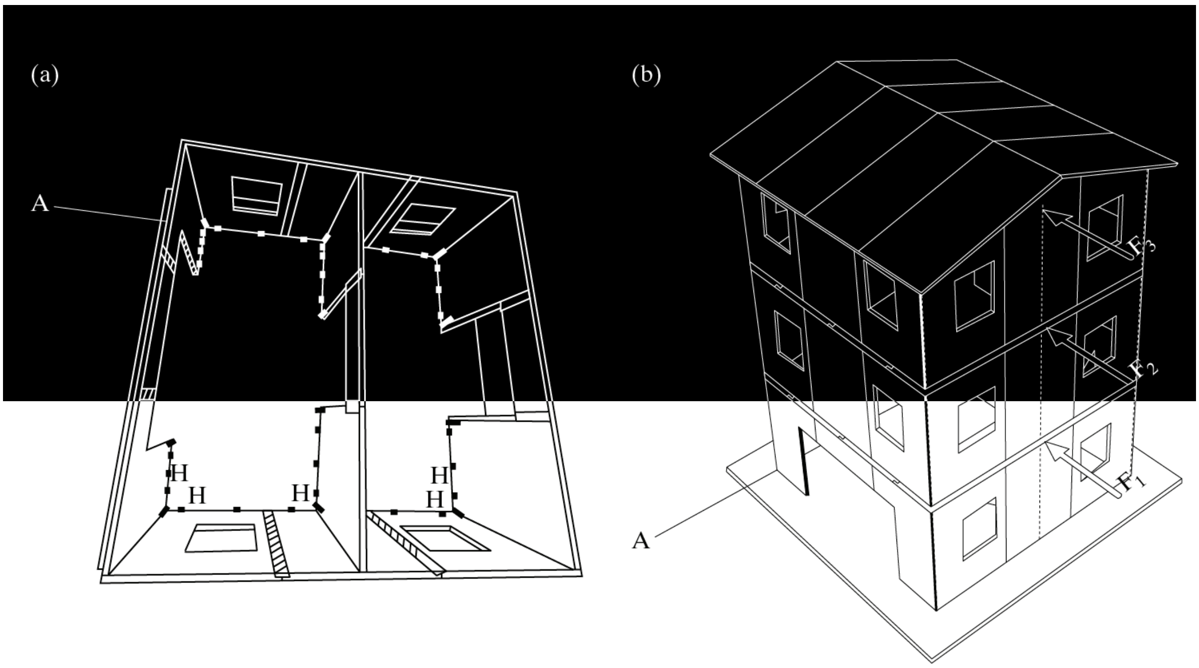


*Fig. 8: Distribution of hold-down anchors and steel angles at ground floor and distribution of seismic forces at each floor. In the left figure, the hold-down anchors marked with H are those taken into account in the design*

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$$F_r \times h_r + F_2 \times h_2 + F_1 \times h_1 - W \times \frac{6,93}{2} -$$
$$-5 \times H \times 6,93 = 0$$

$$91 \times 9,40 + 279 \times 6,18 + 139 \times 3,09 -$$
$$-465 \times \frac{6,93}{2} - 5 \times H \times 6,93 = 0$$

$\Rightarrow$ H = 40,34 kN

$$R_d = \frac{R_k \times k_{mod}}{\gamma_M} = \frac{4 \times 1,1}{1,3} = 3,38\ kN$$



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$H_r$ = 12 × 3,38 = 40,56 kN > H =
= 40,34 kN (6)

$$N_r = \frac{A_{res} \times f_y}{\gamma_M} = \frac{157 \times 640}{1000 \times 1,1} = 91,35 \text{ kN}$$

which is greater than $H_r$ (7)

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# Connecting Devices

Connectors included steel brackets with screws and custom made hold-downs with screws



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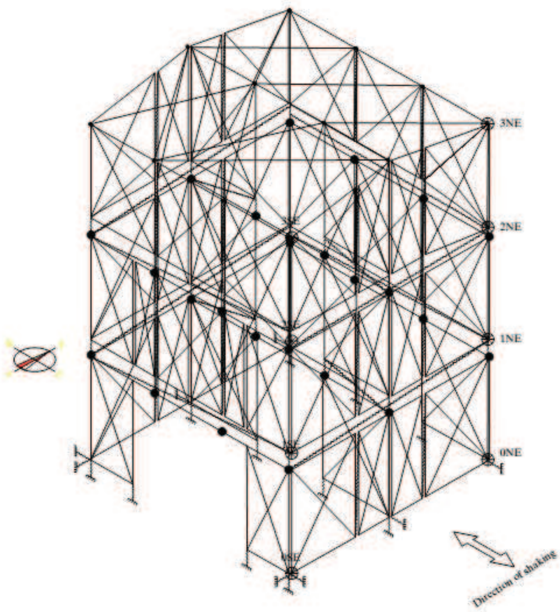
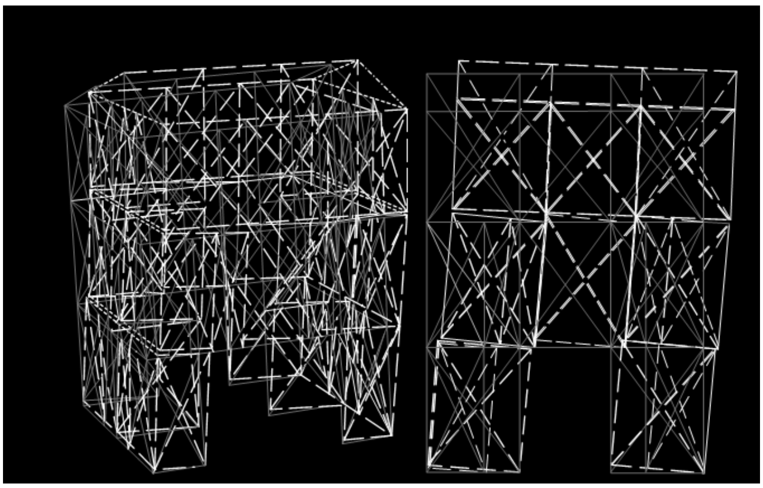
Modellierung



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BEISPIELE


*Faro architecten, Amsterdam*



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*House Nr. 19, Korteknie Stuhlmacher Architecten.*

## DANKE
## FÜR DIE AUFMERKSAMKEIT

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Lenotec



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Benjamin Benschneider/The Seattle Times.

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## Medium rise (and High rise)

9 Stockwerke / 9 floors – 8 CLT

Brettsperrholz / XLAM

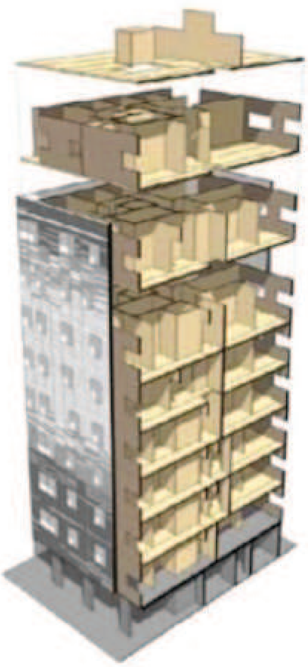
Aufzug Holz / Elevator shaft timber

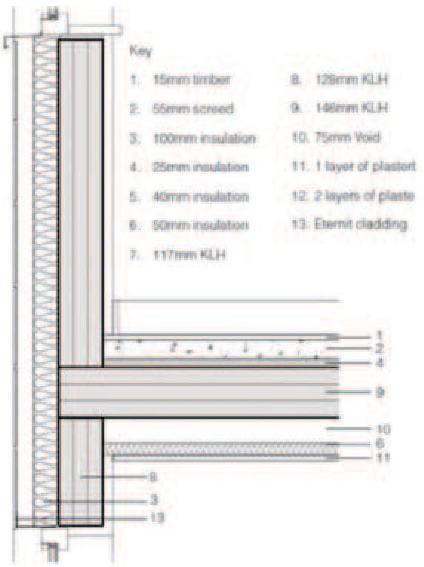
4 app./ storey

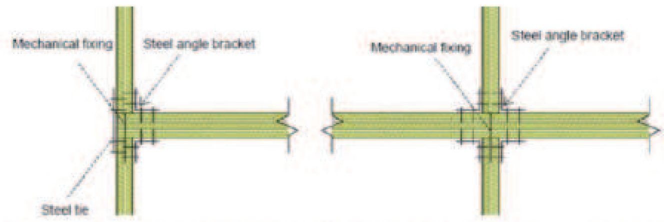
www.klh.at














**Murray Grove London, Neun Stockwerke, CLT (inkl. Aufzugschacht)**

Wohnhaus, Val di Fassa



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*Wohnhaus, Val di Fassa*

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*Vorgefertigte Elementen, Kurze Bauzeit der Tragkonstruktion*





Runde Bauten

Gekrummte Elemente, Merk Aichach





Projekt: Via Cenni, Milano,
E.Gasparri

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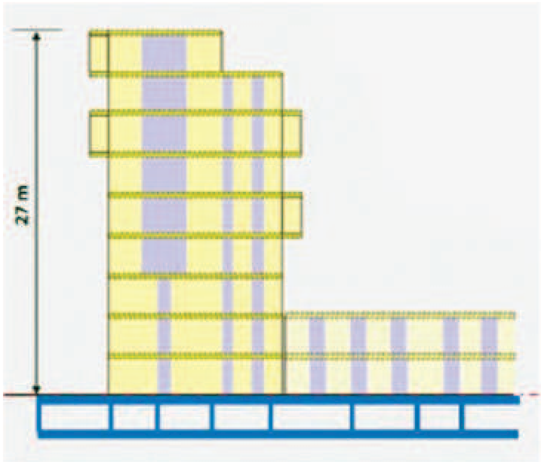


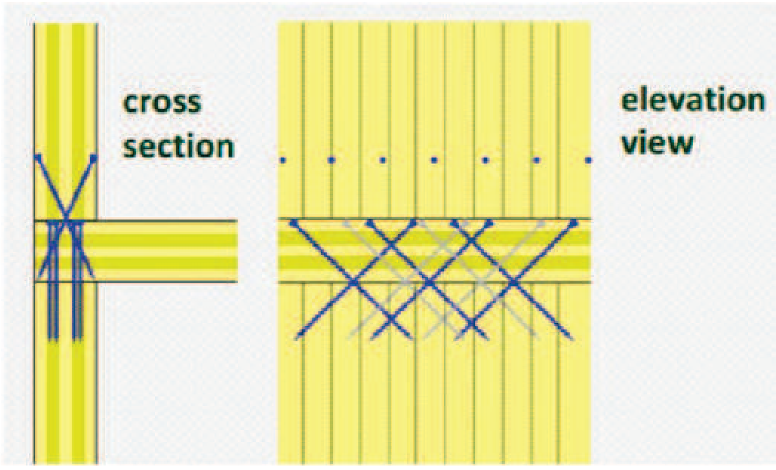


Building does not fulfil EC8  regulatrity criterion



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UBC – Wood Innovation Design Centre,

CLT-Core structure + Post and Beam + CLT floors (double layer)



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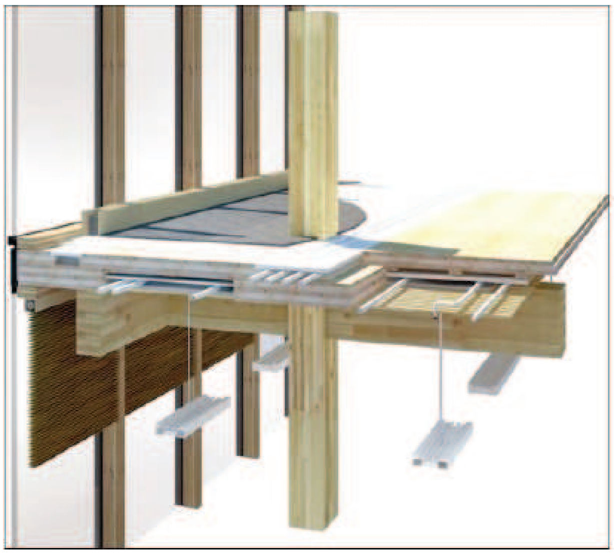

UBC – Wood Innovation Design Centre - Column-Beam system,

No compression stresses perpendicular to the grain from higher storeys

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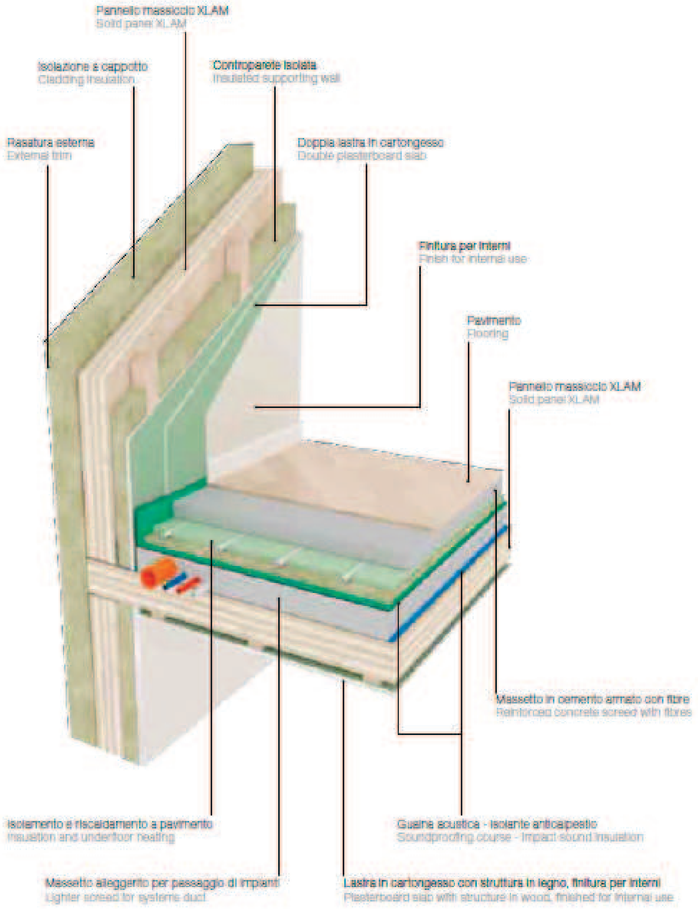
Weitere Anforderungen:

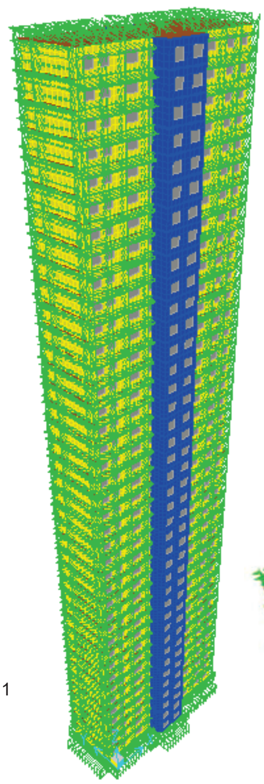
- Wärmedämmung
- Schallschutz
- Brandschutz
- Schwingung
- Luftqualität

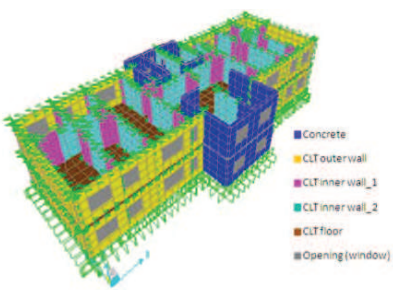




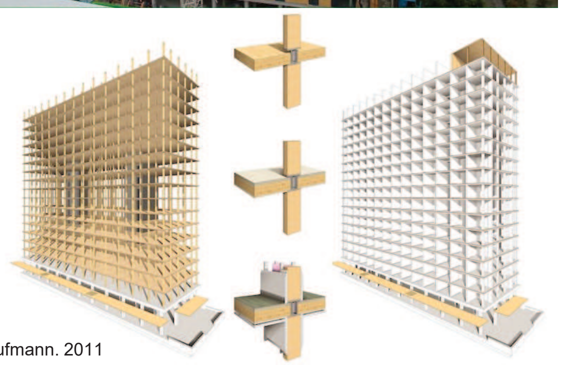



# Composite structures: high rise systems






Xia et al. 2011



Kaufmann. 2011