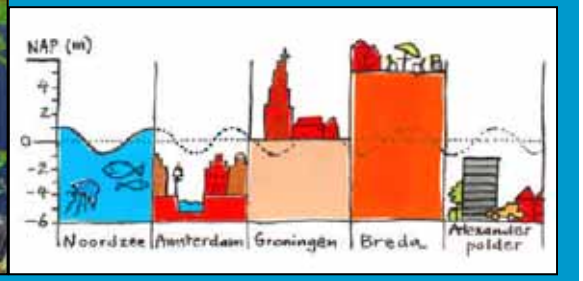
International School
Recent Trends in the EcoConstruction of Buildings (and Structures)

International School, 27-28 Sep. 2017 Anglets / Biarritz France



Jan-Willem van de Kuilen
TU Munich / TU Delft

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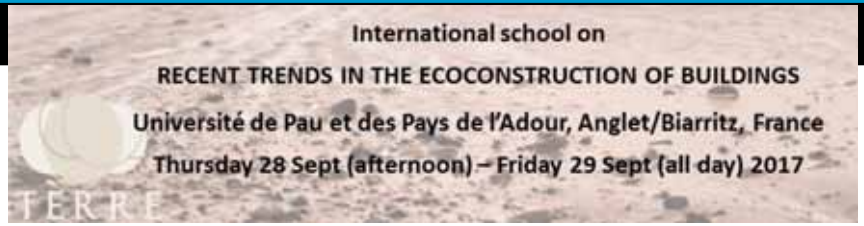

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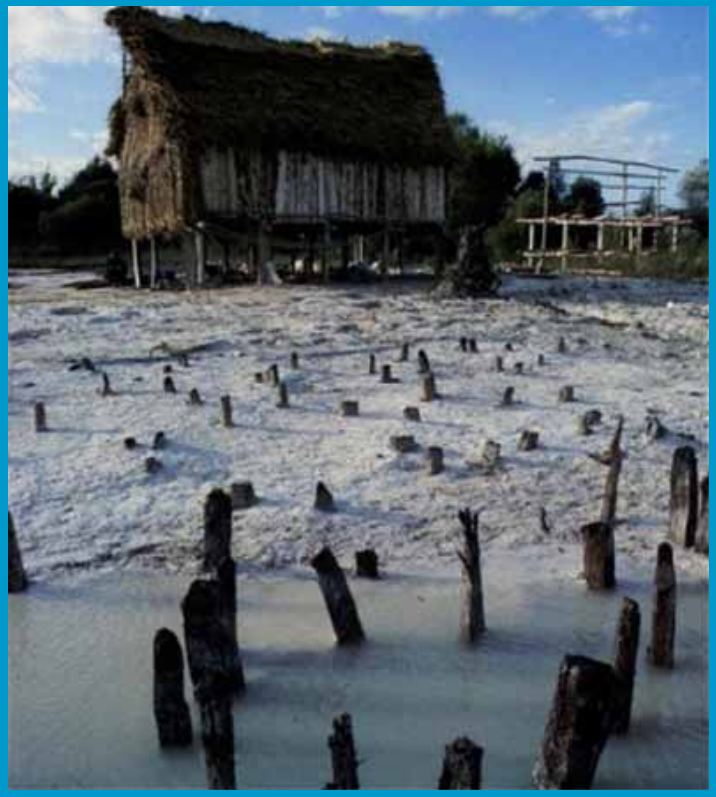
Timber piles in France

thousands of years ago…



piles from a Neolithic village, lac de Chalain (Bronze Age ar. 5,000 BC) [UNESCO, 2009]

well preserved piles from the roman circus of Arles (ar. 150 AD)

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Timber piles in France

used in marshy zones

oak piles support the Strasbourg cathedral (1014 - 1029)

Collège des Bernardins, Paris, built on oak piles (1254) [CQL, 2012]

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Timber piles in France

used in marshy zones

Château de Chambord built on oak piles (ar. 1520)

timber pile

[BRYANT et al., 2007]

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Timber piles in France

used until the 20th century

Grand Palais on oak piles, Paris (1897-1900)

Viaduc des Cent Arches, Libourne (1848-1850) _ built on pine piles

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Timber piles in France

many bridges are standing on timber piles (see Christin, 2013)

Pont Neuf, Paris (1578-1607)

Pont de Pierre, Bordeaux (1820-1822)

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Timber piles in France

Today, timber piles are only used in water for specific works

Fungal attack of beech piles and caps, Rouen Harbor

Oak timber breakwater, Saint-Malo

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Venice is built on piles!

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Venice is built on piles!

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Inspection of foundations
- structure
- species
- quality

Assessment and improvement

Château de Chambord built on oak piles (ar. 1520)

Royal Palace in Amsterdam: 13659 wooden pile foundation, opened in 1655 (362 years old…)

13659 spruce piles

Durability is proven!!!

(Under the right circumstances)

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How to estimate the value...

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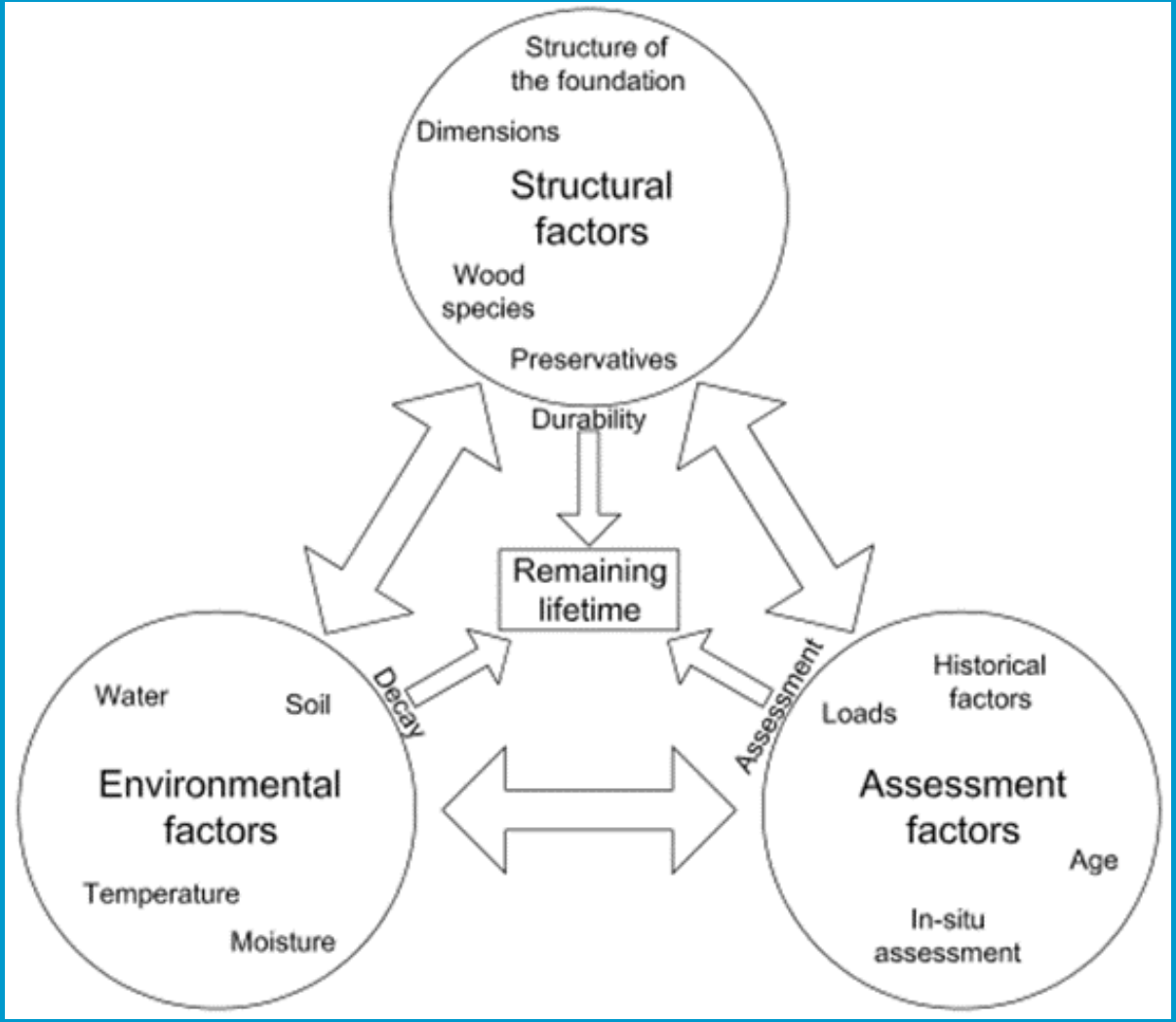
Many factors influence timber pile service life



Some factors influencing timber pile decay

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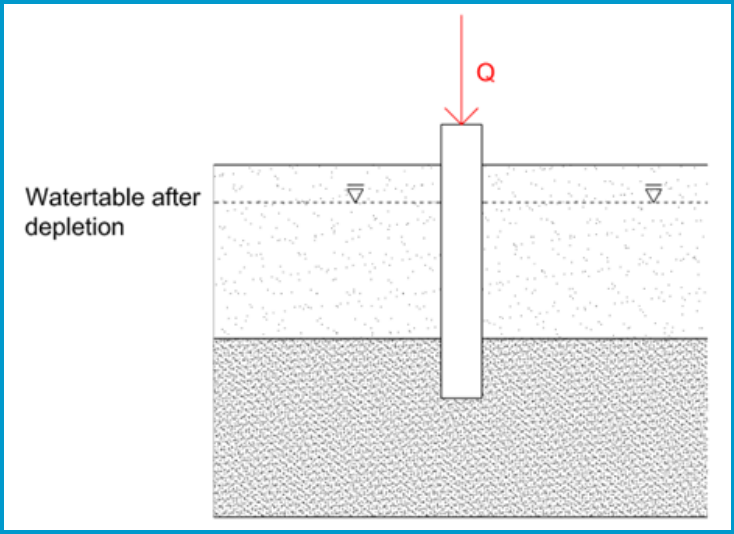
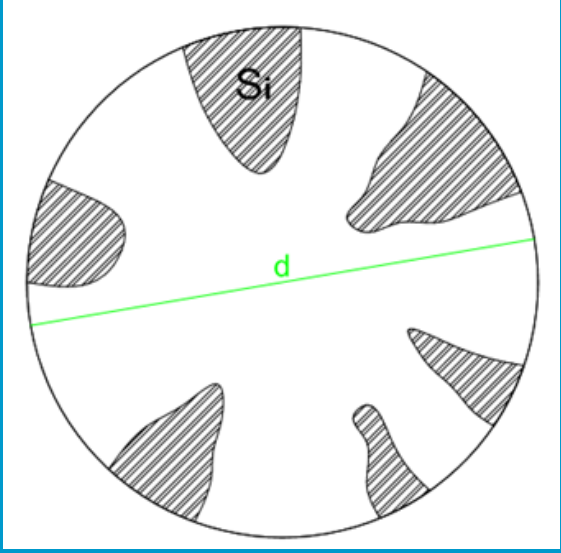
Representation of the problem

lifetime T: F(T) = Q(T)



situation of the pile to assess



partly decayed cross section

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Remaining area

Different shapes of decay can be observed:

starts from the outside
[BRISCHKE and ROLF-KIEL, 2009]

from the inside

from radial cracks

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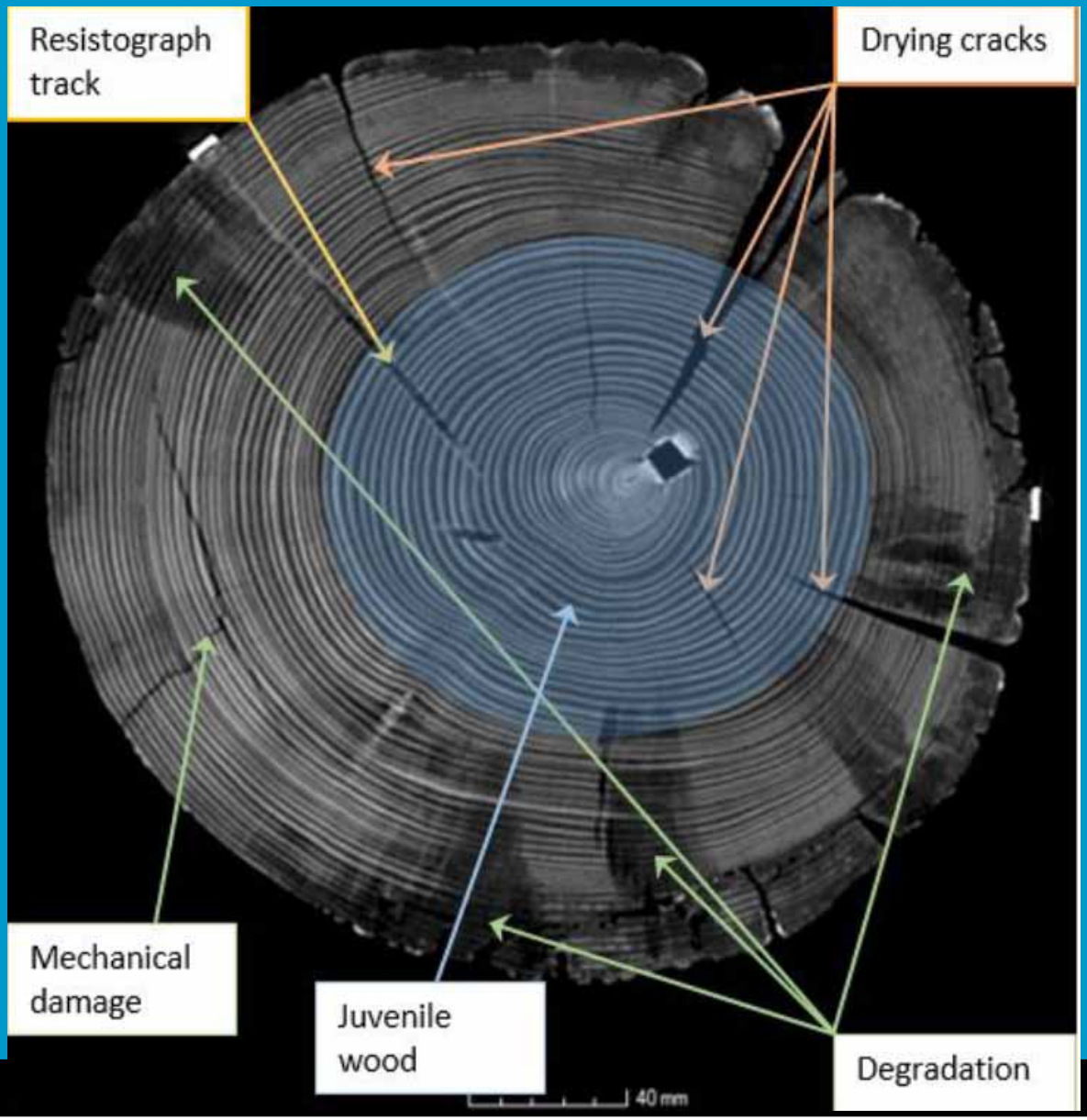

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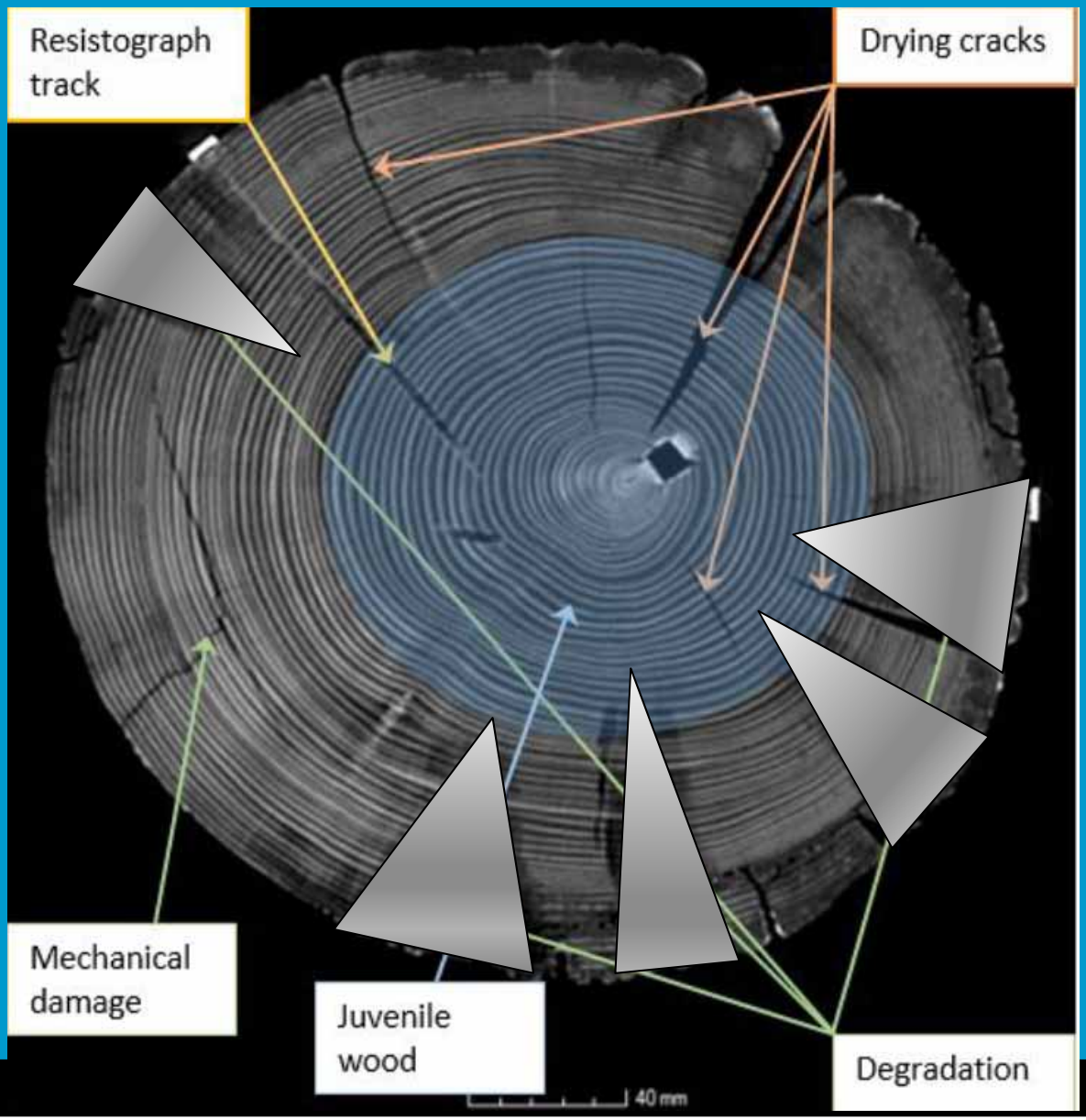

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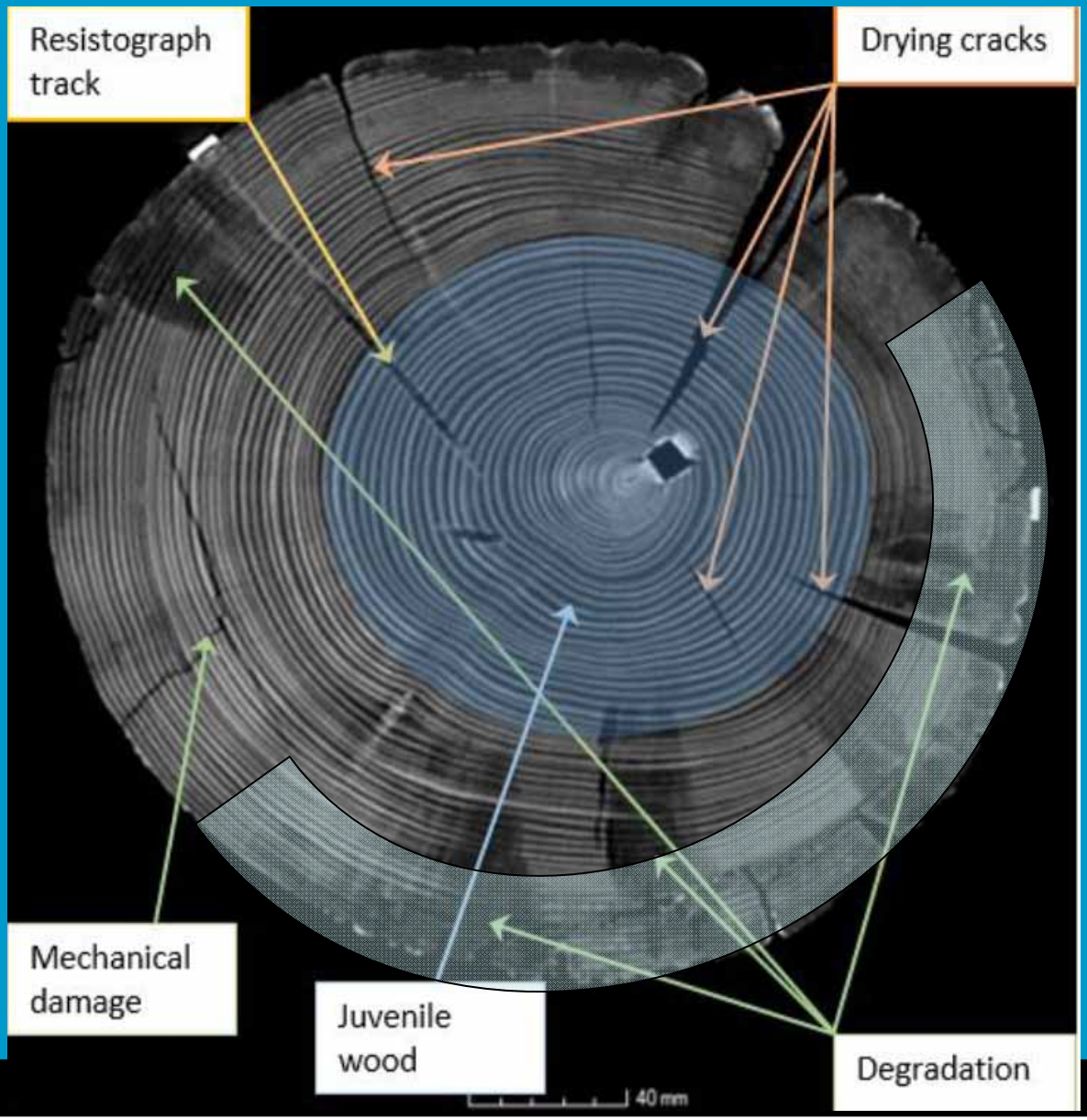

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Degradation of wood caused by bacteria

Tangential – Radial

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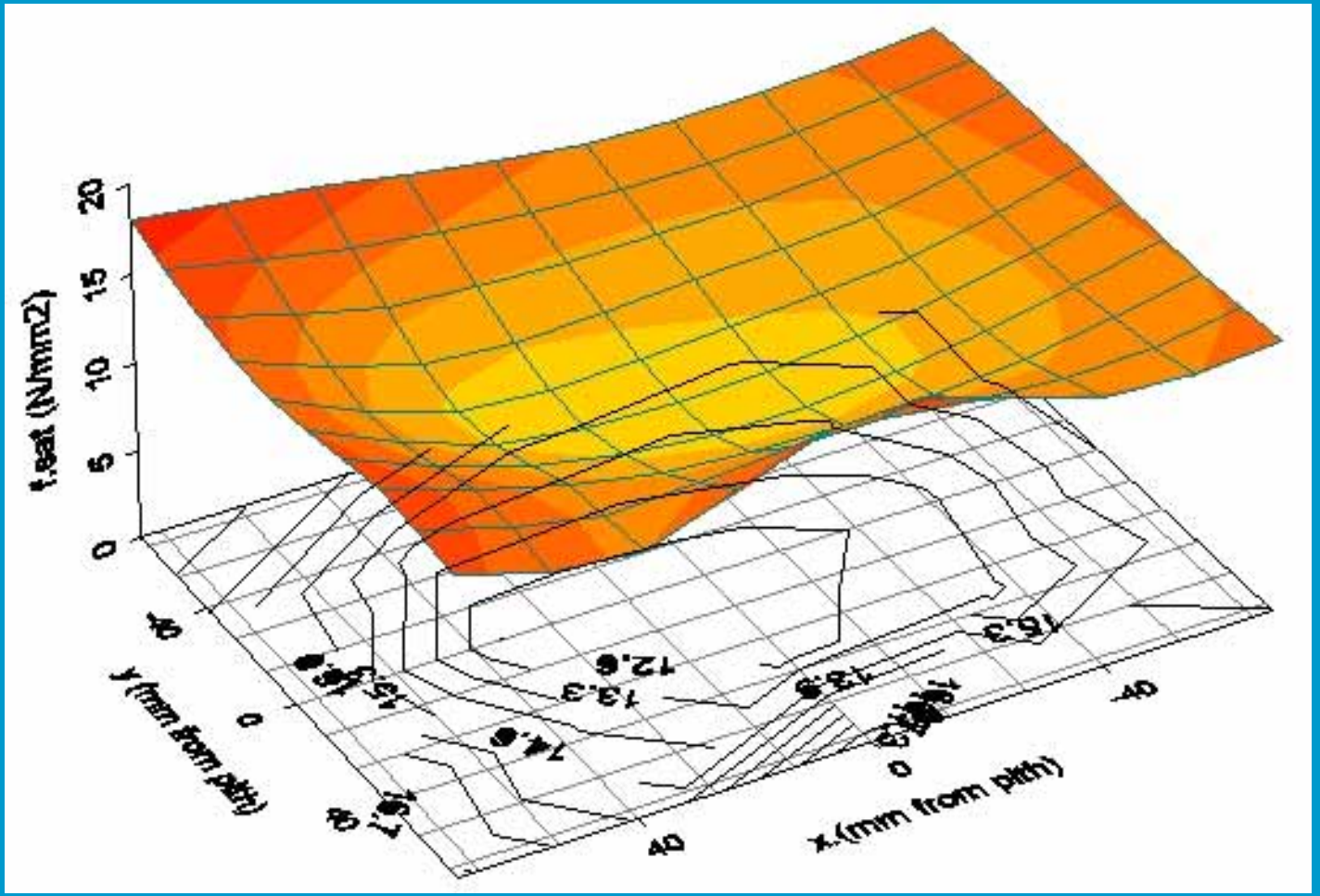
Cross sectional strength of healthy pile of 100 years



Van de Kuilen, 2007

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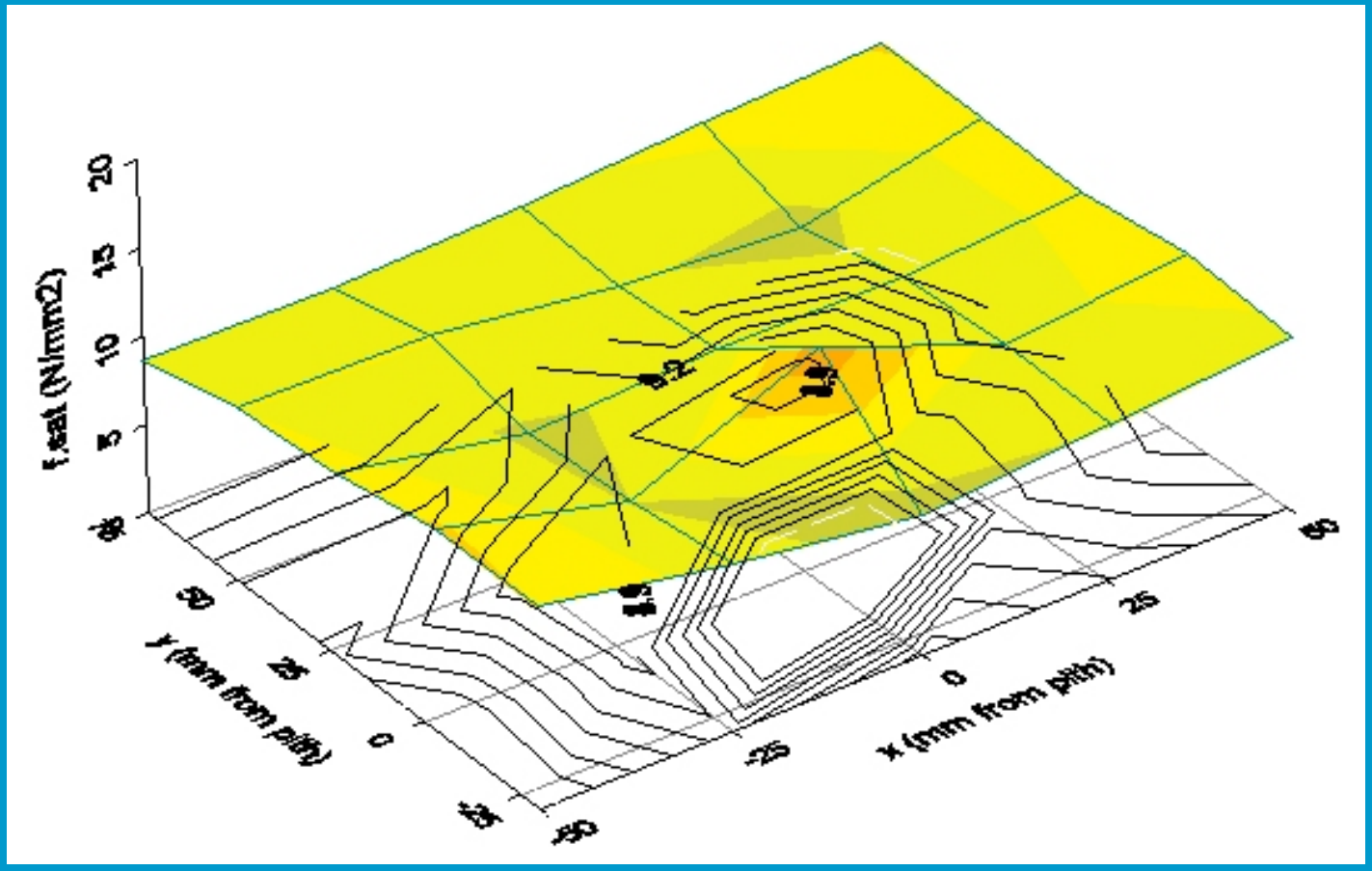
Cross sectional strength of healthy pile of 167 years



Van de Kuilen, 2007

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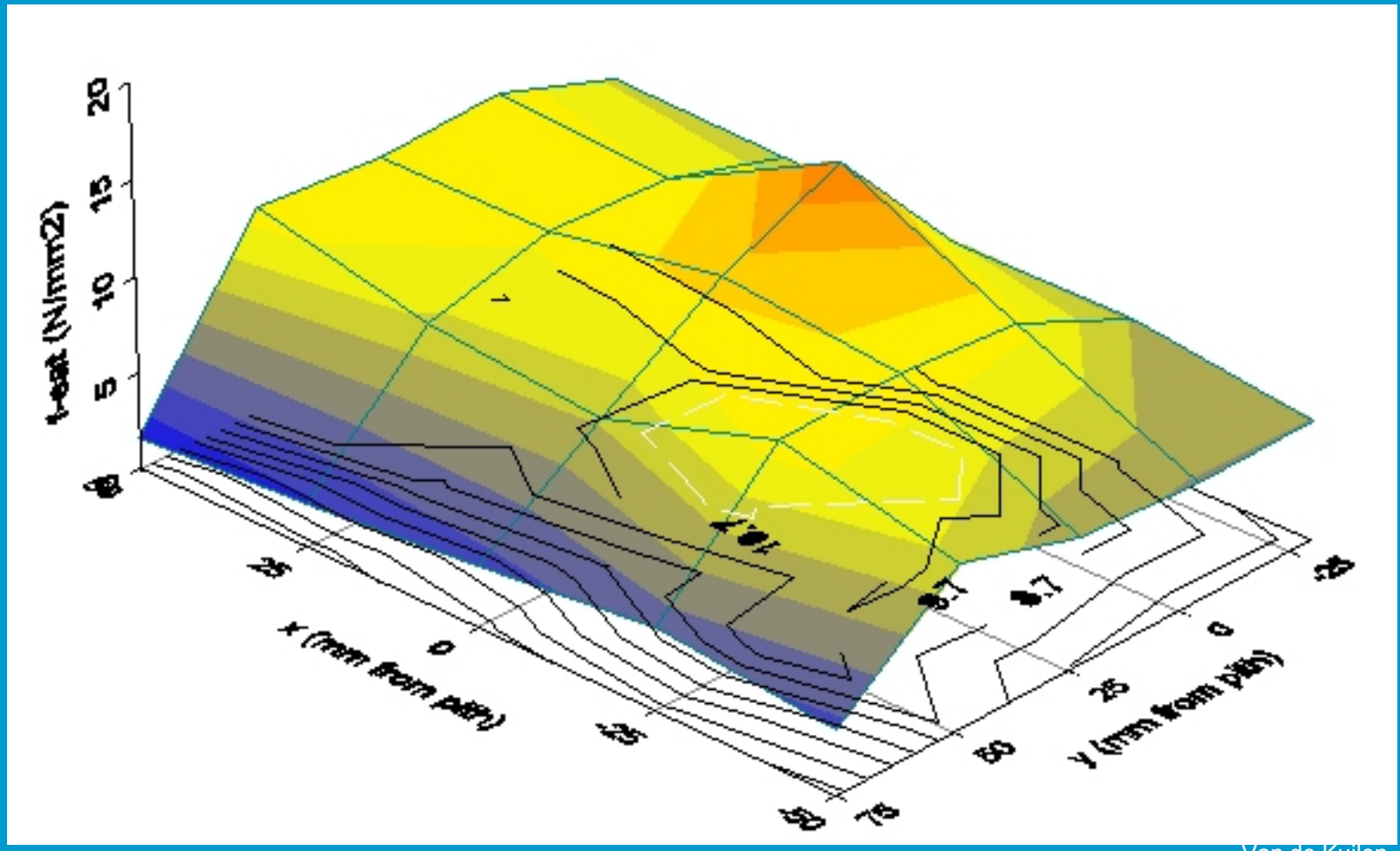
Cross sectional strength of deteriorated pile of 167 years



Van de Kuilen, 2007

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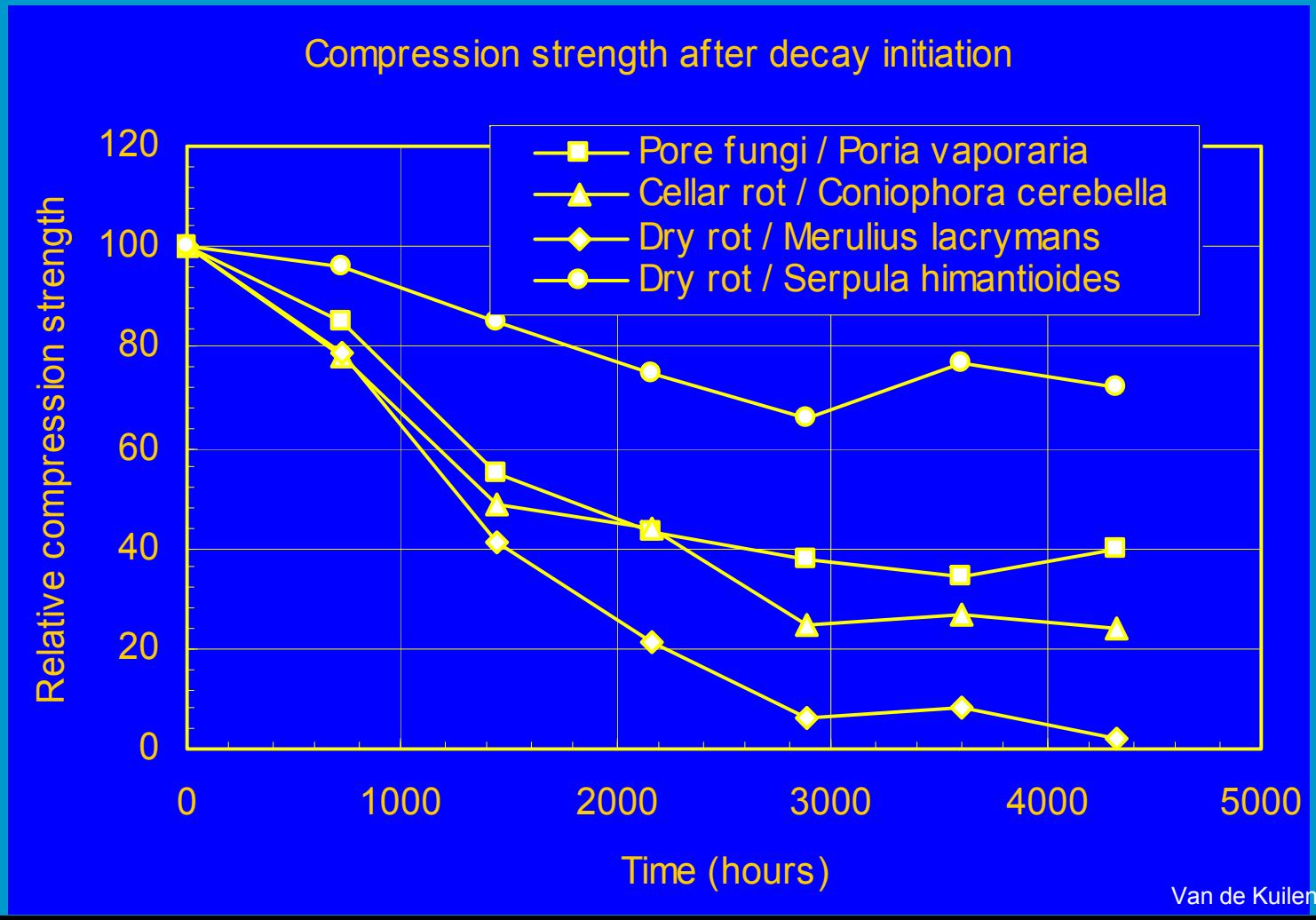
Influence of fungi on strength



Van de Kuilen, 2007

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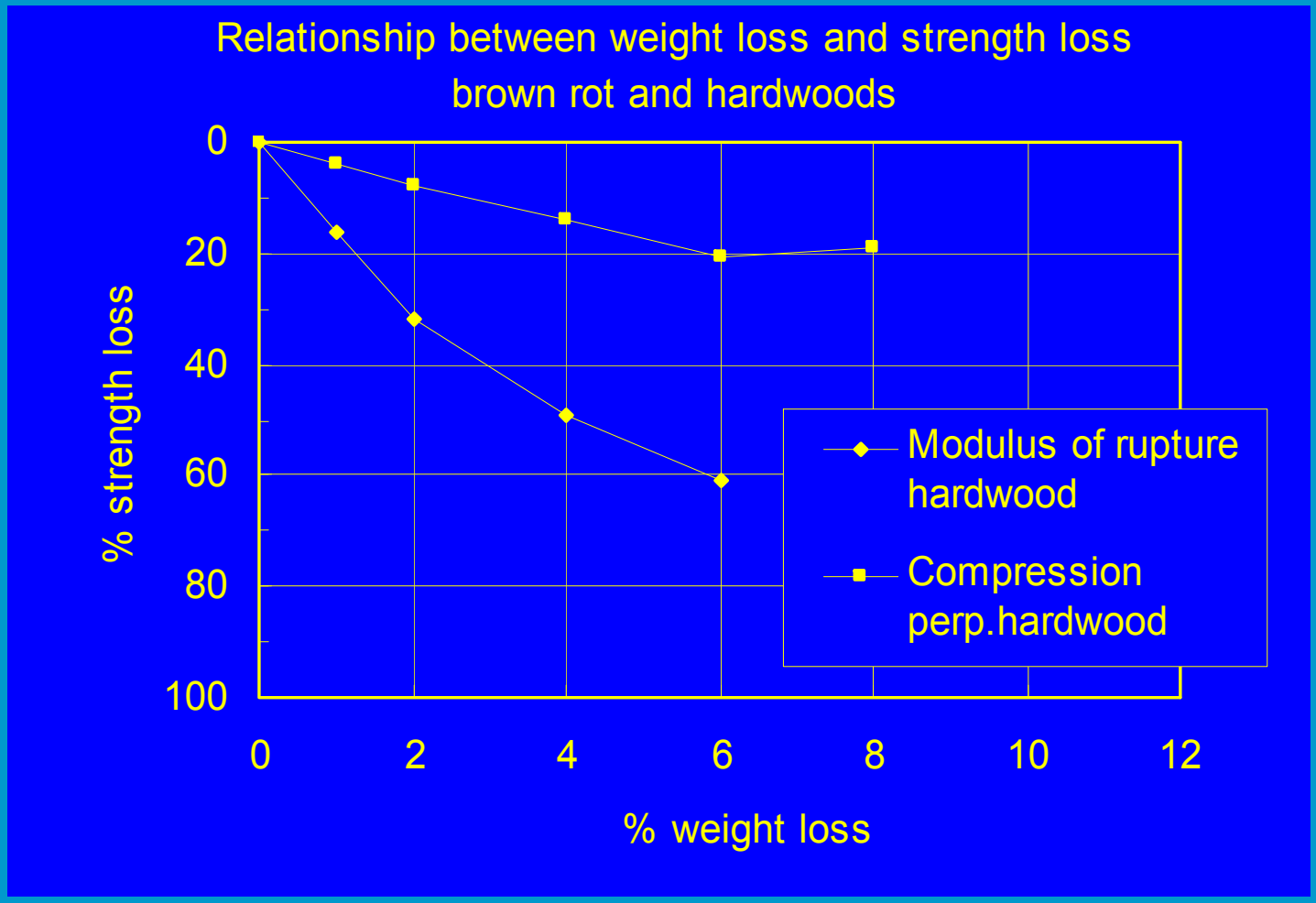

Van de Kuilen, 2007

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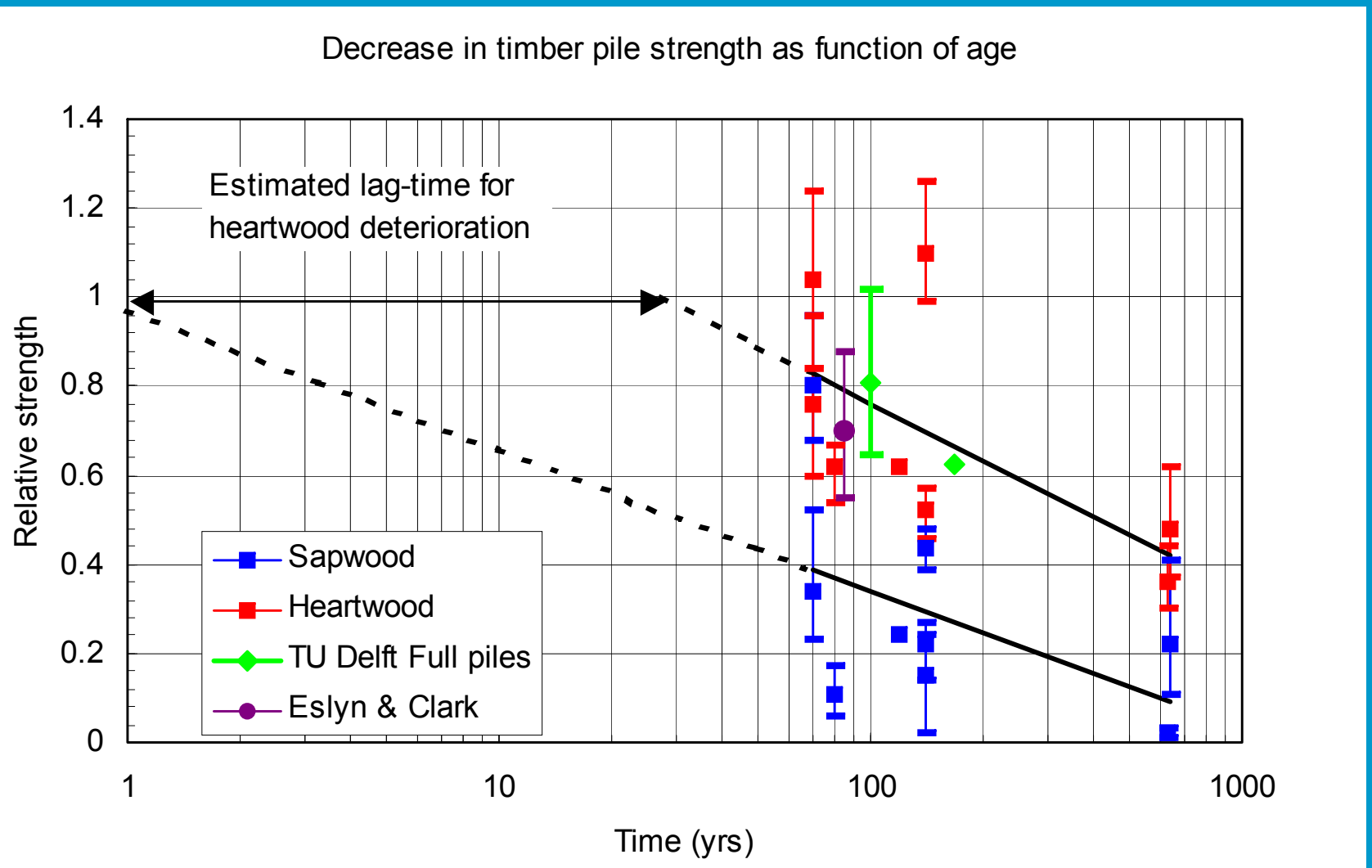

Van de Kuilen, 2007

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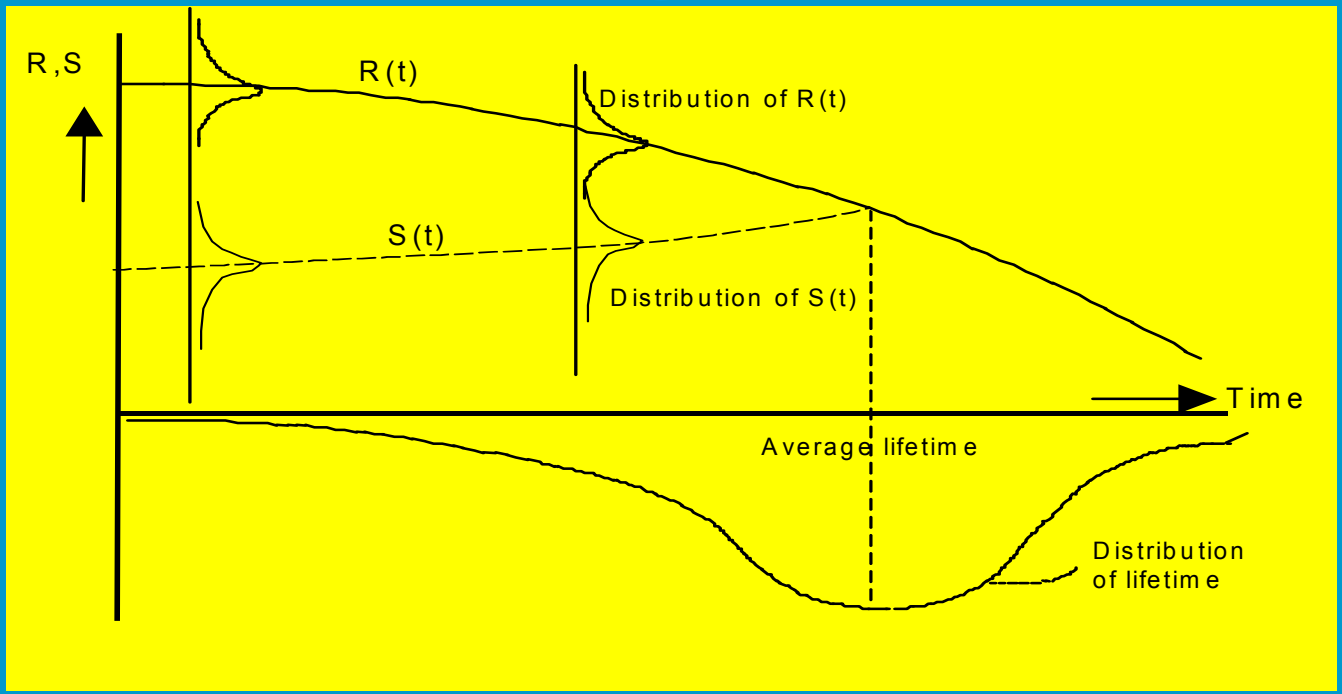
Assessment of time dependent reliability and performance



Goals of TERRE:

- Understand the development of R(t) and S(t)
- Influence this development by material choices and vegetation development
- Understand the interaction between wood, soil and vegetation

Van de Kuilen, 2007

Damage model for piles

Load carrying capacity:

$$F_u = f_{c,0} A_{rem} + f_{c,0,dec} A_{dec}$$

Ratio: healthy / degraded area
healthy / degraded strength

$$\alpha = \frac{A_{rem}}{A_{tot}} \qquad \beta = \frac{f_{c,0,dec}}{f_{c;0}}$$

Load carrying capacity:

$$F_u = f_{c,0} A_{tot} \left(\alpha(1\text{-}\beta) + \beta\right)$$

Exponential damage model

$$\frac{d\alpha}{dt} = \exp\left(-a + b\frac{F(t)}{F_s}\right)$$

Van de Kuilen, 2007

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Delft University of Technology

Damage accumulation modelling

$$\frac{d\alpha}{dt} = \exp\left(-a + b\frac{\sigma(t)}{f_s}\right) \rightarrow \frac{\sigma}{f_s} = 0.904 - 0.063\log t_f$$

$$\frac{d\alpha}{dt} = \exp\left(-a + b\frac{M(t,\omega,T)/W_0}{M_s(t,\omega,T)/W_t(\alpha_r,\beta_r,\omega,T)}\right)$$

- *Time dependent load and load carrying capacity*
- *Perform time integration to calculate damage state*

Van de Kuilen, 2007

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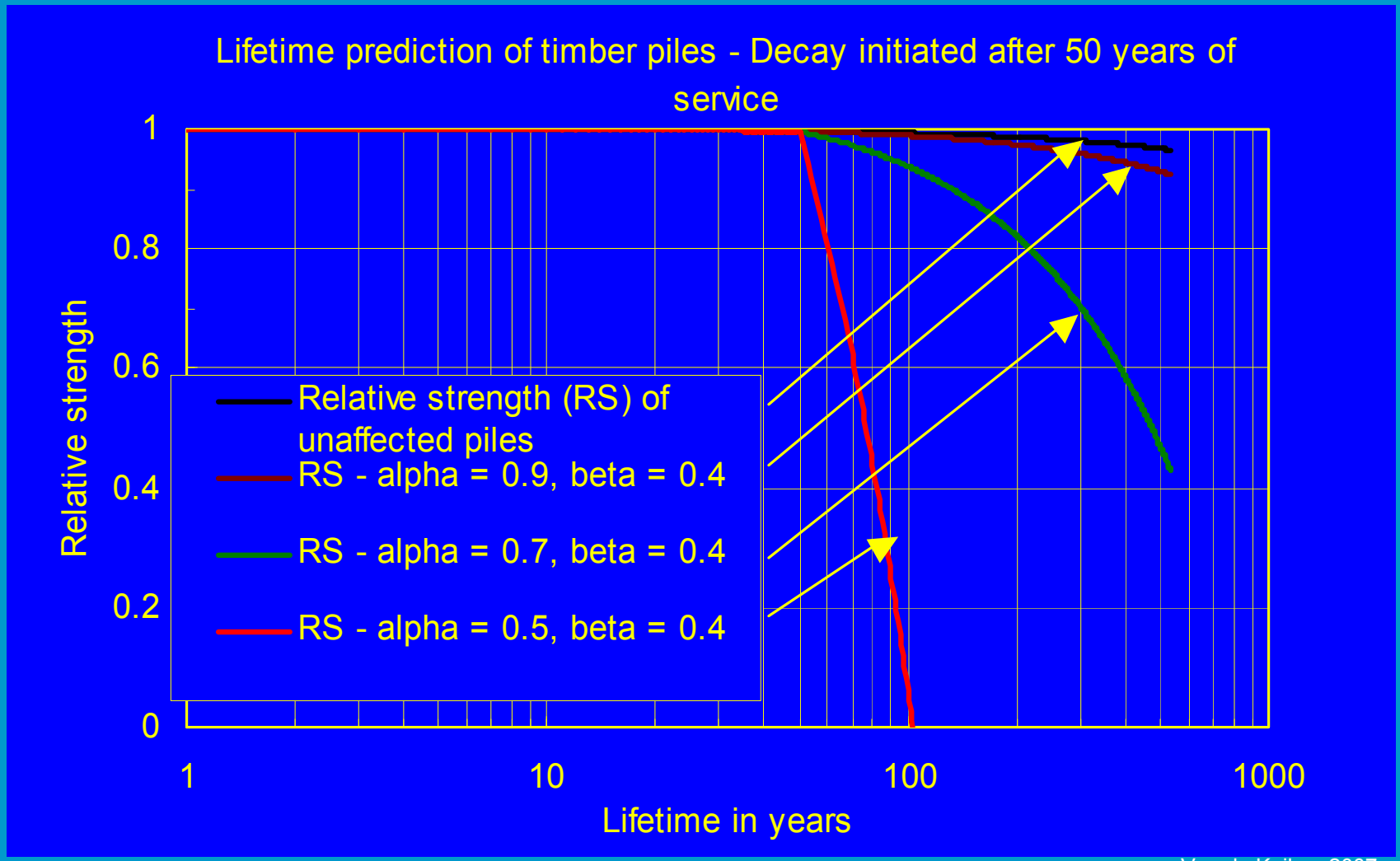
Remaining service life scenarios



Van de Kuilen, 2007

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Conclusion of the research?
The Queen is safe!

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Timber piles:

Sinking soil causes high ´repair´ costs

Lightweight – easy to apply

Foundation of:
sewer systems, greenhouses, stables etc.

Foundation of a city park

10 TECHNIEK DONDERDAG 8 SEPTEMBER 2005

Heipalen onder bomen Vondelpark

Amsterdam wil af van voortdurend ophogen grond

Ad Tiddink

Amsterdam - Bijna honderd nieuwe bomen voor het Amsterdamse Vondelpark krijgen de komende twee jaar een fundering van elk negen houten heipalen.

Dat is nodig om te voorkomen dat ze wegzakken in de drassige veenbodem. De funderingsconstructies komen alleen onder bomen met een lange levensduur, als eiken, kastanjes of platanen. Tot nu toe werden dergelijke bomen in het Vondelpark niet oud, doordat ze wegzakten in de bodem van het park, dat zich op een van de laagstgelegen punten van de hoofdstad bevindt, met een sterk wisselende grondwaterstand.

Onder elke boom komen negen houten funderingspalen tot de eerste zandlaag, zo'n 10 meter beneden maaiveld. Daarovenheen werden kisten gelegd die een houten vloer dragen van 4 bij 4 meter. De tafel die zo ontstaat moet het gewicht van de volgroeide bomen opvangen, zonder dat de bodem in-

De bijna honderd bomen in het Vondelpark krijgen elk negen funderingspalen.

zinkt. De constructie zelf wordt beneden het grondwater aangelegd, veilig voor houtrot. De ruimte boven het vlonder wordt aangevuld met ophoogzand; daarboven komt een laag humeuze grond waarin de bomen goed kunnen wortelen.

Manoeuvreren

Bijna veertig funderingsconstructies zijn de afgelopen tijd door Krinkels gerealiseerd; het bedrijf draaide de 10 meter lange palen met een licht trilblokje naar beneden, al manoeuvrerend met een kleine kraan door het bestaande groen. Alleen bij de laatste meters hoefde de heiinstallatie wat kracht te zetten. Later in het najaar, plant het groen- en infrabedrijf bomen met een diameter van 8 centimeter bovenop de funderingen.

Volgens verkeersverbreider en ontwerper Arno Heemskerk van stadsdeel Oud-Zuid zullen die bomen gewoon op eigen kracht groeien en niet direct gaan steunen op de funderingsconstructie. Alleen zakt de volwassen boom niet, zoals vroeger, door zijn eigen gewicht weg.

De 70 centimeter doorwortelbare ruimte boven het grondwaterpeil is volgens Heemskerk meer dan genoeg. Bomen wortelen over het algemeen nooit dieper dan een meter. Zelfs bomen van 30 meter hoogte niet. Wel zullen de wortels zich in de breedte uitbreiden en na een aantal jaar royaal buiten de randen van de funderingsconstructie uitsteken. Maar dat is geen probleem. Ze kunnen daar de bewegingen van de bodem volgen.

Renovatie

De opmerkelijk fundering maakt deel uit van de renovatie van het Vondelpark die al sinds 1999 gaande is.

Het intensief gebruikte park wordt ingericht op een manier waarop het park haar 10 miljoen bezoekers per jaar aan kan. Door de drainage en infiltratie te verbeteren zal het grondwaterpeil nauwelijks nog schommelen en daarmee het veen minder inklinken. Bovendien krijgen de bomen een meer permanente diepe doorwortelbare ruimte waarin ze zichzelf stevig kunnen verankeren.

Ook wil de gemeente af van het periodieke grootschalige ophogen van de grond die onder deze extra belasting alleen maar harder inklinkt. In 2001 al zijn experimenten gedaan met een aantal typen fundering of bodemverbetering en hogere en oudere bomen een kans te geven in het Vondelpark. Daarbij bleek de toegepaste funderingsconstructie als beste uit de bus.

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Timber piles

Straightness
Diameter
Taper

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Timber piles

- Light weight
- Low transport costs
- Store CO_2
- Low equipment costs

Timber piles are ideal for lightweight (agricultural) structures

Keep the wood saturated!

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Concrete + Wood

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Delft University of Technology

Concrete extension pile
Ground water level > 0.5 meter above wood pile

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That´s why Dutch tomatoes are so cheap!

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New timber structures

- Why use timber?

- Timber rots
- Timber burns
- Cutting trees is bad

But….

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New timber structures

- Why use timber?

- Cheap
- Widely available
- Easy to work with
- High strength – weight ratio
- Fire safe
- Earthquake resistant

- But…

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A comparative analysis of building materials at structure level

Centrum Hout, VVNH

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´Cradle to cradle´ : full structure cycle

Total environmental costs

Centrum Hout, VVNH

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CO_2 balance for 1 ton of product:

- 1 m3 of wood has a net storage of 1.7 tons of CO_2
- Concrete has released 160 kilos of CO_2
- Steel has released 1.24 tons of CO_2
- Aluminium has released 9.3 tons of CO_2

→ Use timber, the most abundant natural renewable material available!

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Structural timber products

- **Glued Laminated Timber (Glulam GLT, EN 14080)**
  - **1D Product**
- **Microlam (Laminated Veneer Lumber – LVL, EN 14374)**
  - **1D – 2D Product**
- **Crosslam – XLAM – CLT**
  - **2D Product**

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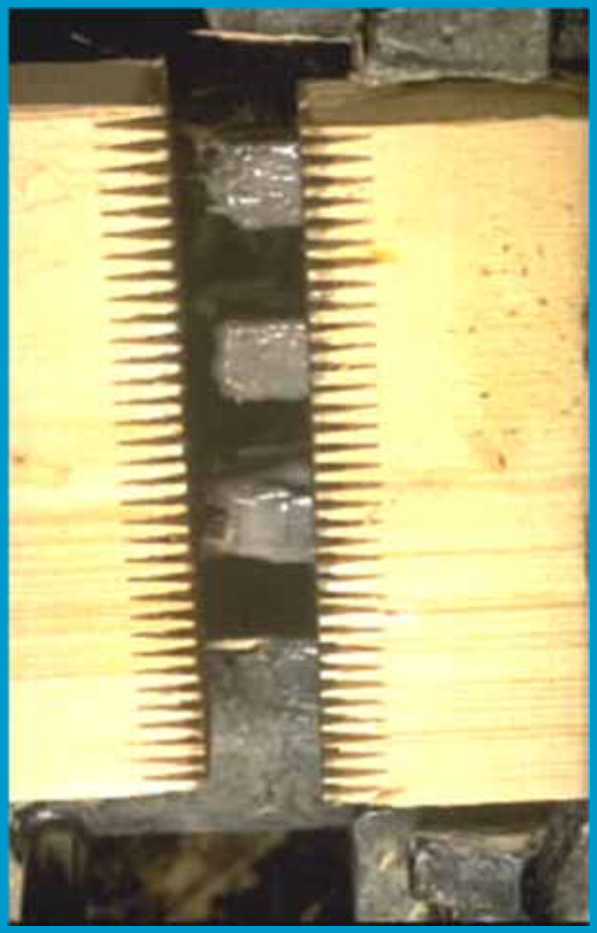
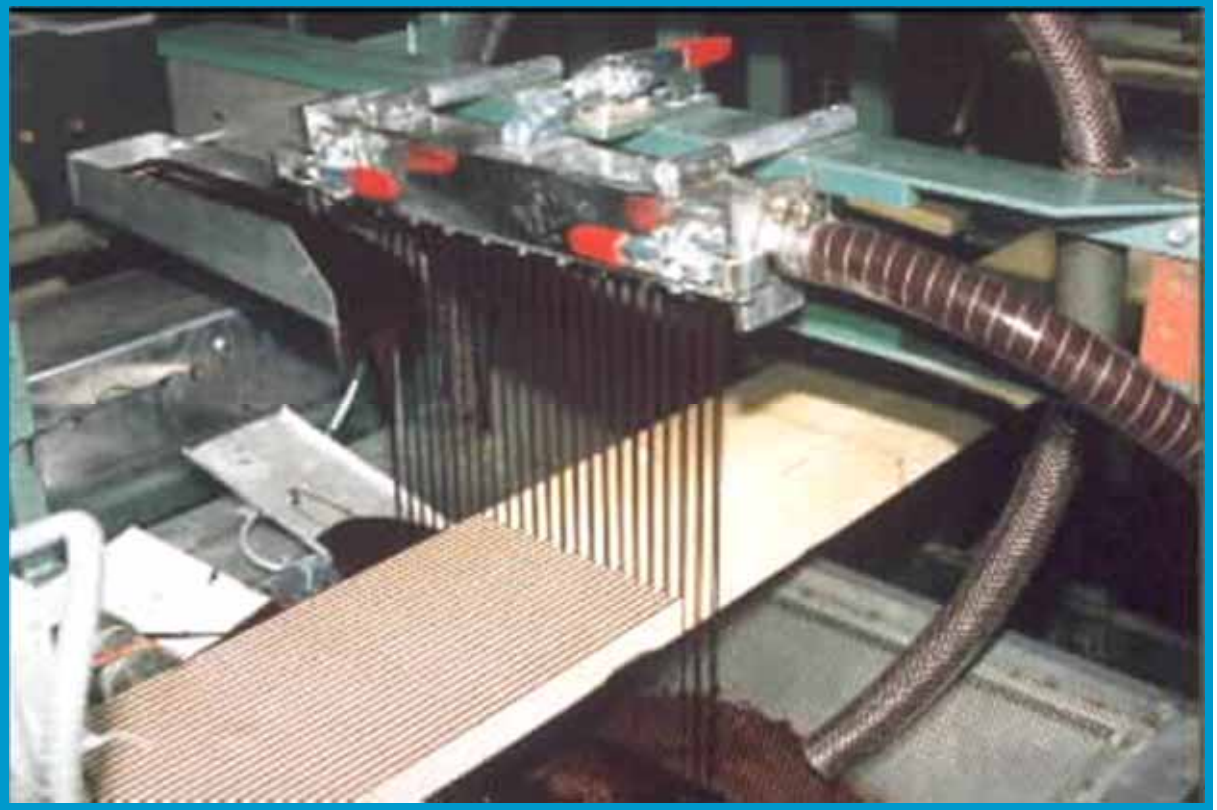


Finger joint in a lamella
Finger joints are characterised by length, width, tip width



Adhesive:
Phenol-Resorcinolformaldehyde (PRF)
Melamine-Ureaformaldehyde (MUF)
Polyurethane (PU)
Emulsion Polymer isocyanate adhesive (EPI)

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Curved glulam, 2 beams in the press
For curved glulam specialrequirements exist with regard to the Curvature and the thickness of the lamellas. Normally, these are: 11 – 22 – 33 – 40 – 45 mm.
Standard thickness for straight beams = 40 mm

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Resistenca:

- **Glulam: 24 – 48 MPa**
- **LVL: 40 – 70 MPa**
- **CLT: 24 MPa**

Spruce / Pine / Larice
Beech / Oak / Ash

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Roller Coaster
Amusement Park, Heide-Park Soltau
Germany
Height 52 m, length ca. 1300 m, 120 km/h

Pyramidenkogel, Austria

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Long span structures

SAP Arena Mannheim; 15.000 seats

Free span 87 m

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Aeroporto di CORK Airport in Irlanda (64.50 X 178.00 m)

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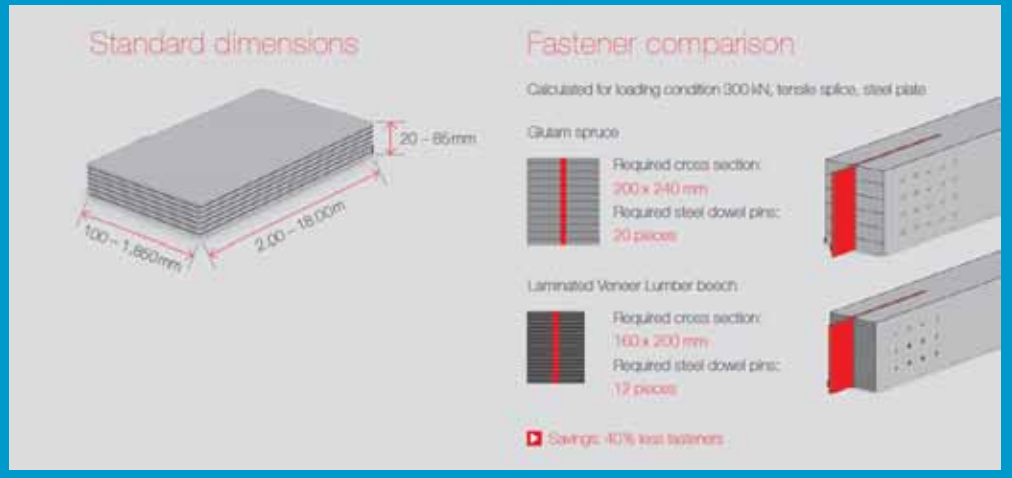
Laminated Veneer Lumber



Baubuche = Beech laminated veneer lumber

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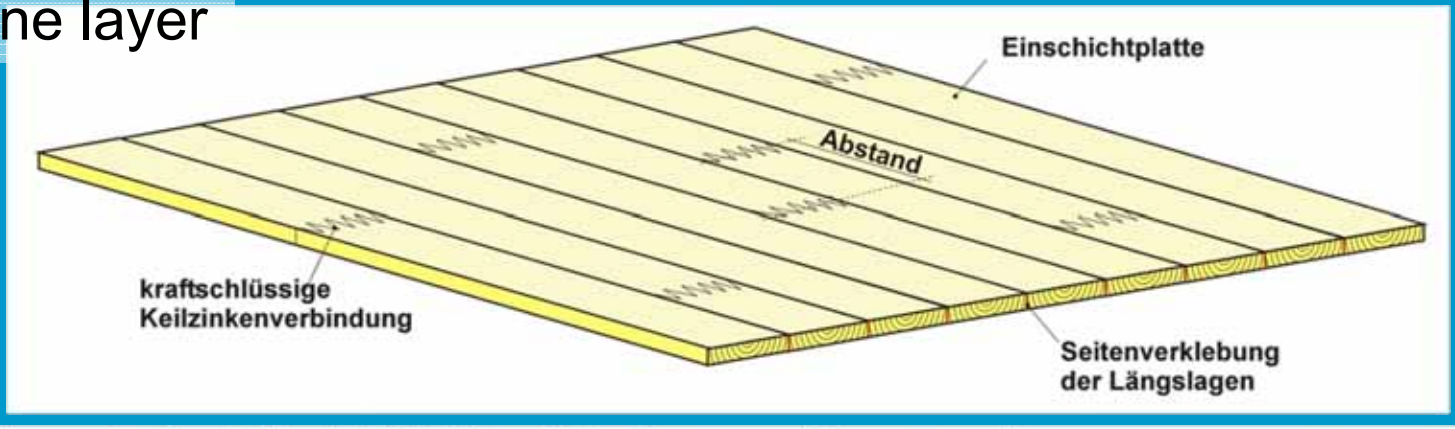
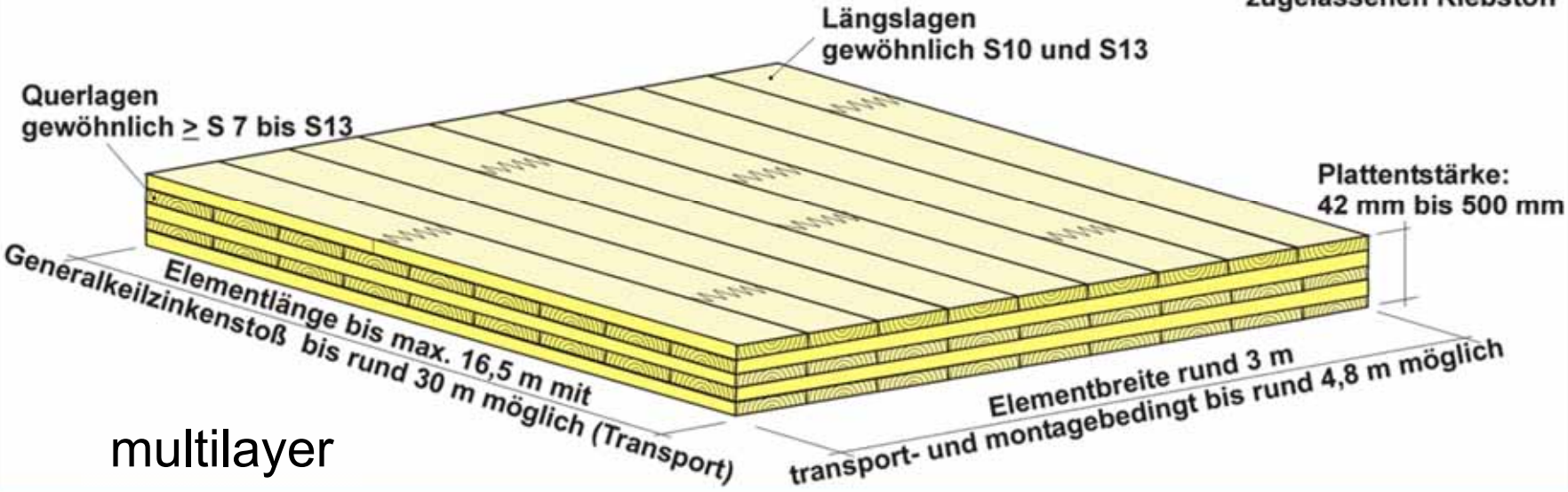
Cross Laminated Timber

one layer



Brettsperrholzplatte (BSP): Kombination von längs- und querorientierten Einschichtplatten

flächige Verklebung der Einschichtplatten mit einem zugelassenen Klebstoff



multilayer

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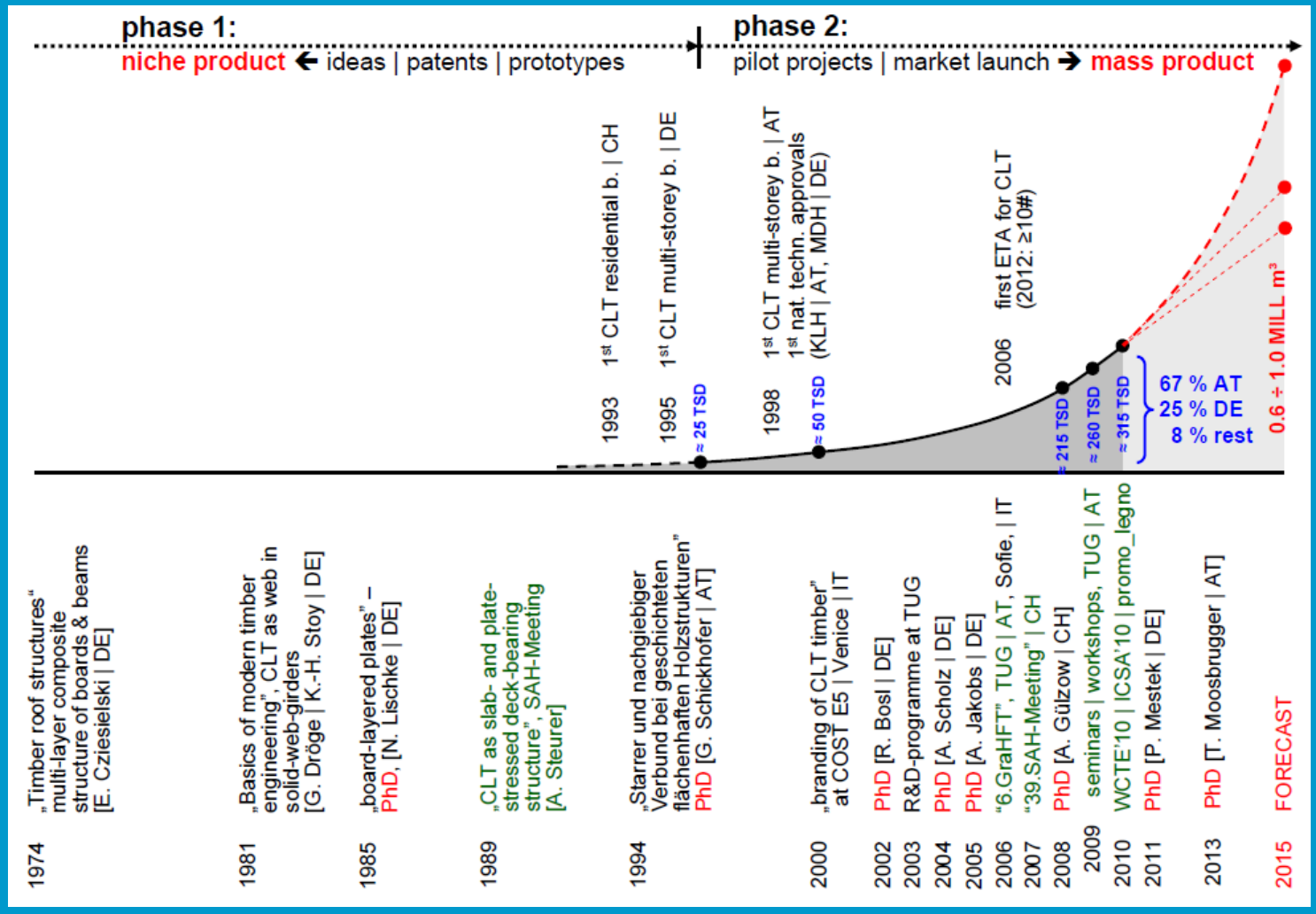
Cross Laminated Timber



Brandtner, 2013

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Cross Laminated Timber

Strength, stiffness, and flexibility
≈25 manufacturers in Europe +
US, Canada, New Zealand

France: www.clt-france.fr

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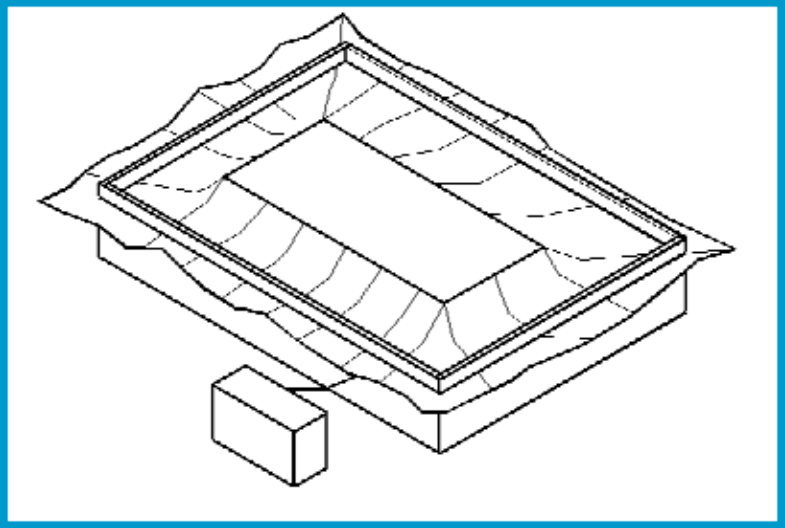

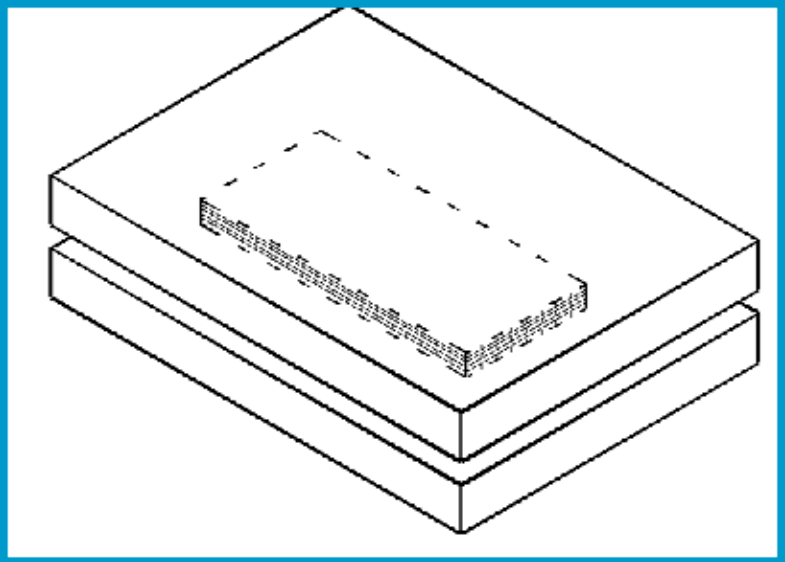

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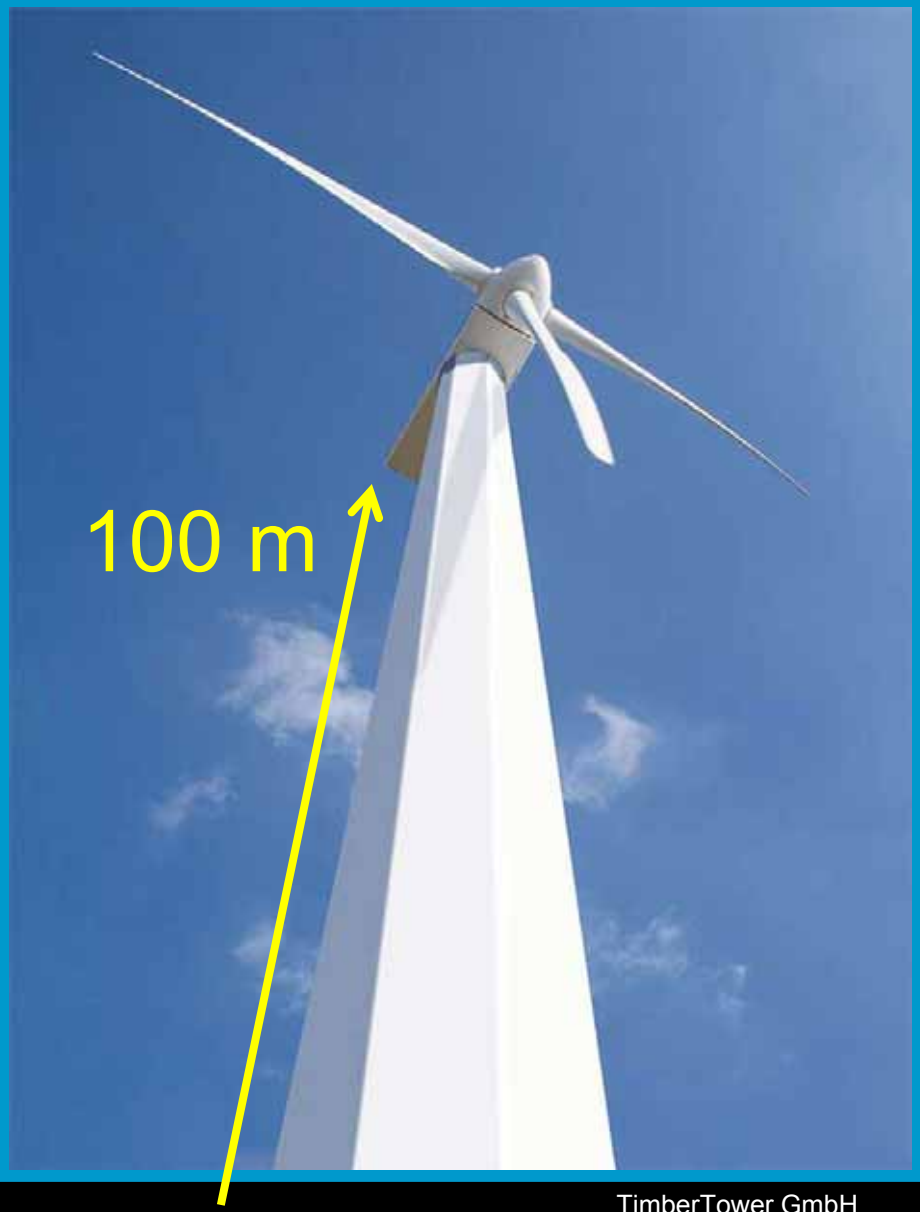
Tall structures

Wind turbine:
Height is 100 m
140 m is designed
Material:
Cross Laminated Timber
PU Coating



Timber Wind Turbine Tower
Hannover Marienwerder/Germany
2012
100m height, 100t weight, 1.5 MW, supplies 1000 households with electricity

TimberTower GmbH

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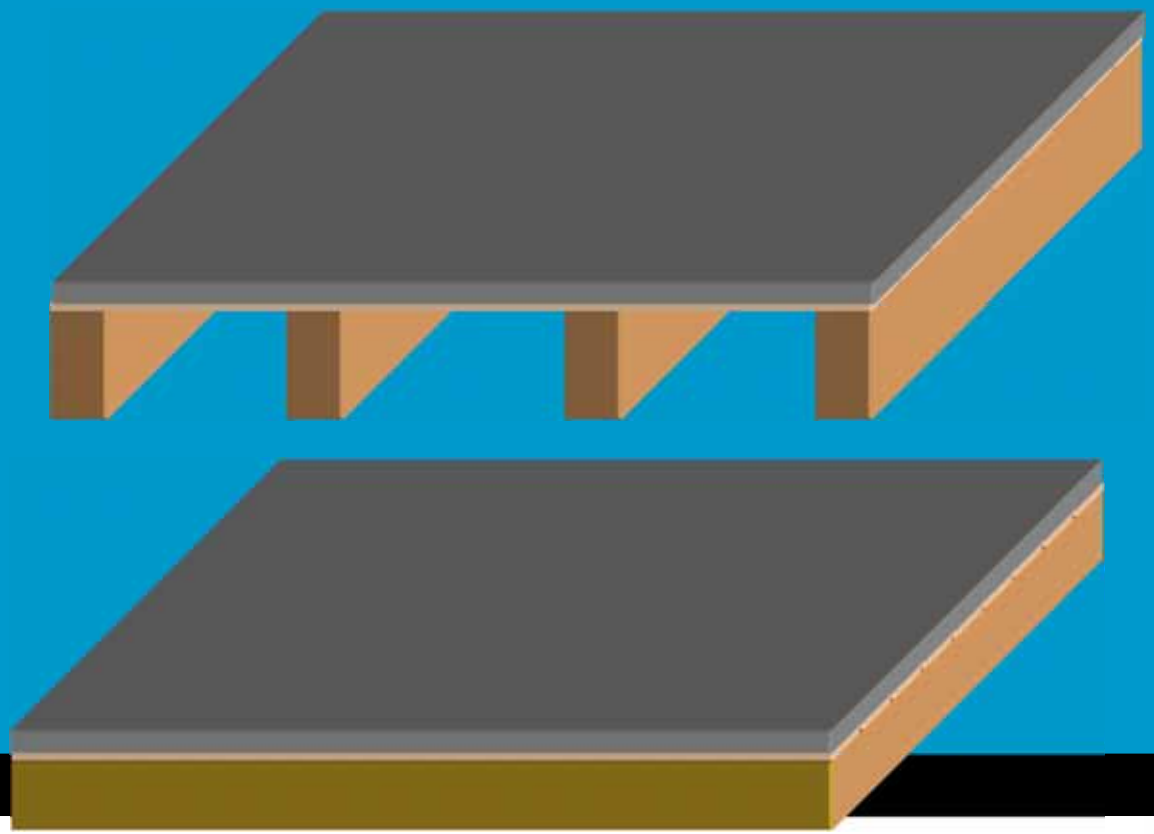
TU Delft TUM

Timber-concrete composite floors



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Delft University of Technology

Timber-concrete floors

Raadschelders Bouwadvies, NL

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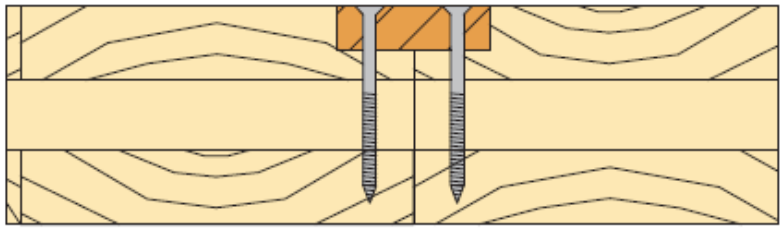
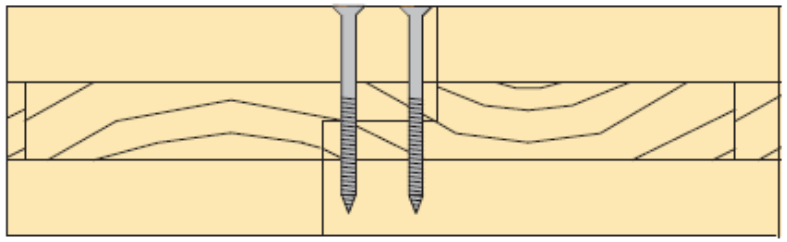
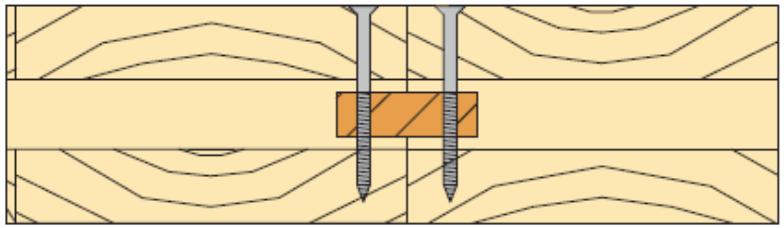
CLT-Panel connections



Leaf joint



Half lapped joint



Tenon joint

Binderholz

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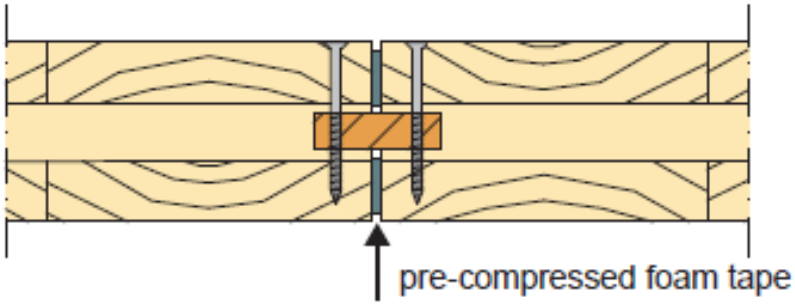

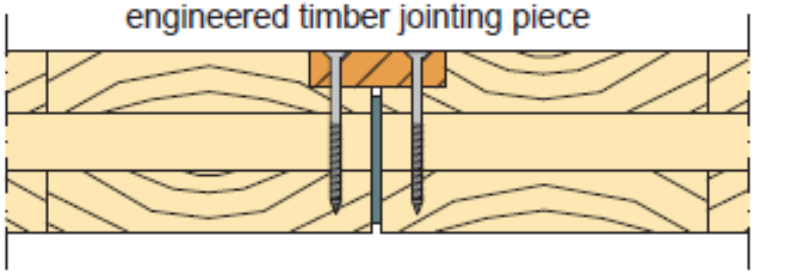

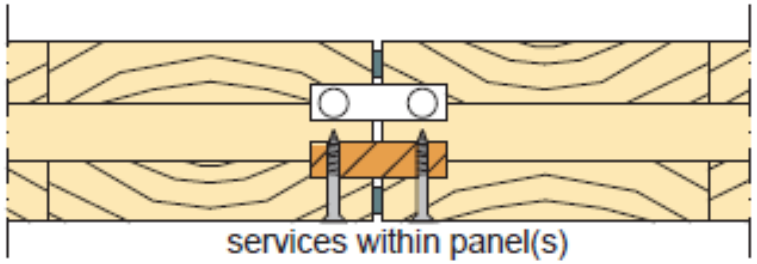

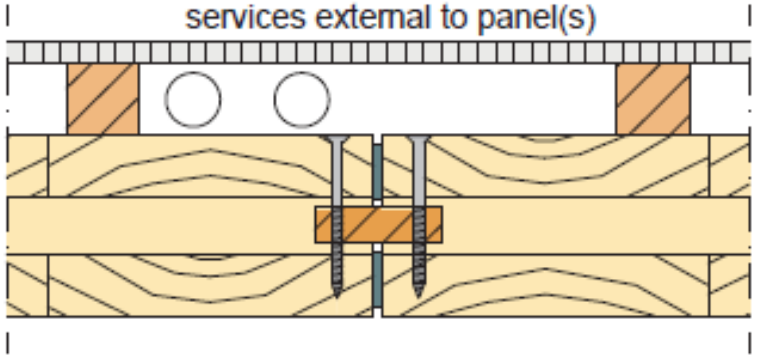

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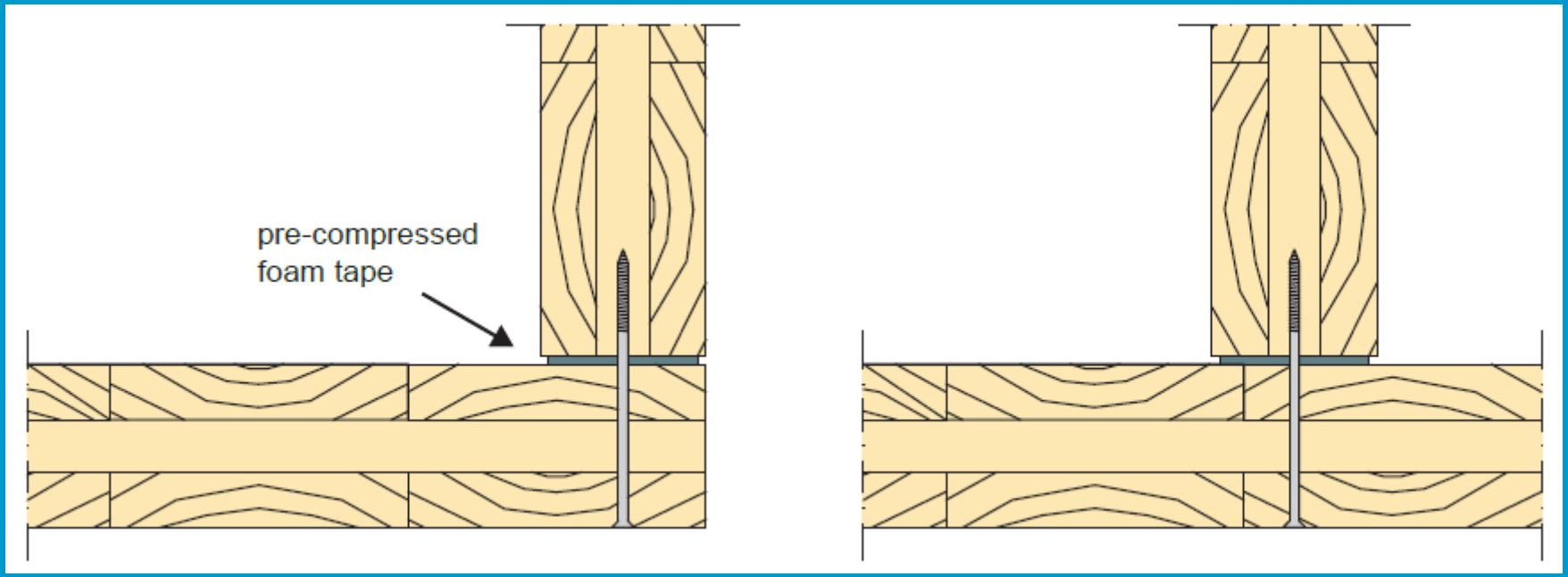

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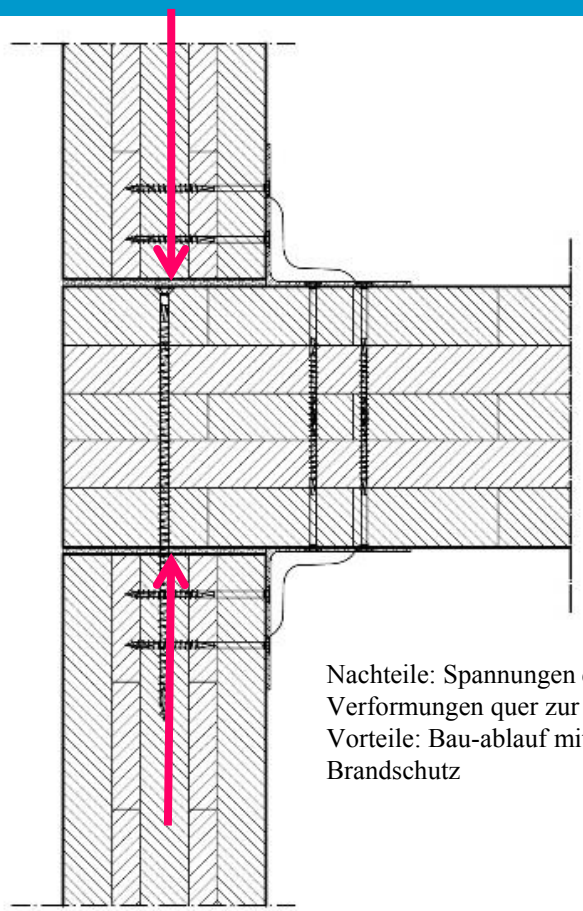
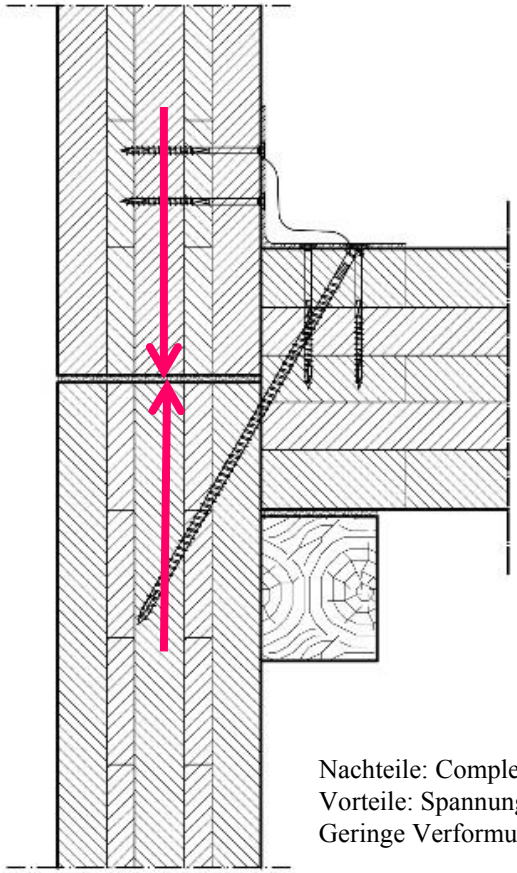


Nachteile: Spannungen quer zur Faser,
Verformungen quer zur Faser
Vorteile: Bau-ablauf mit Plattform
Brandschutz



Nachteile: Complex, Brandschutzl
Vorteile: Spannungen // zur faser
Geringe Verformungen pro Stockwerk

Platform

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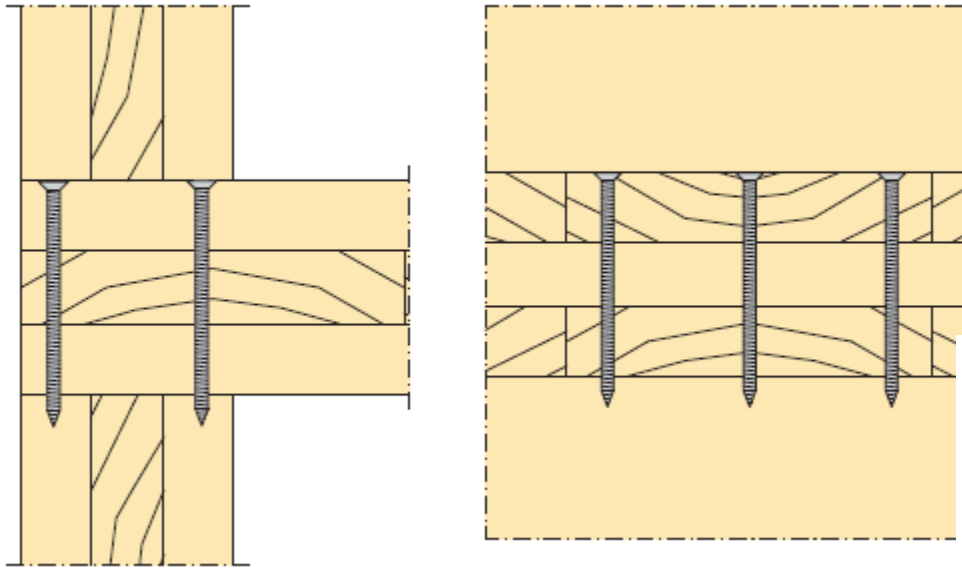
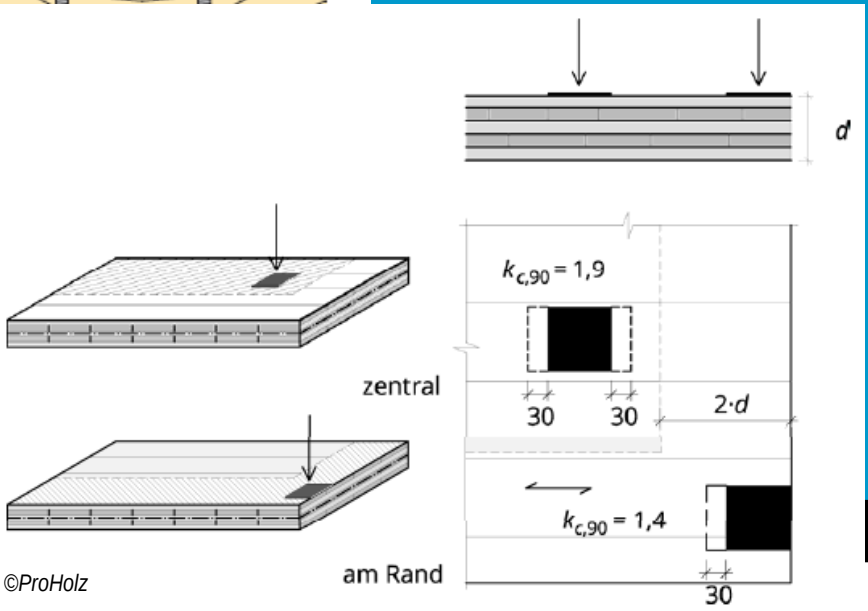
Platform frame: reinforcement against perp. to grain stresses



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



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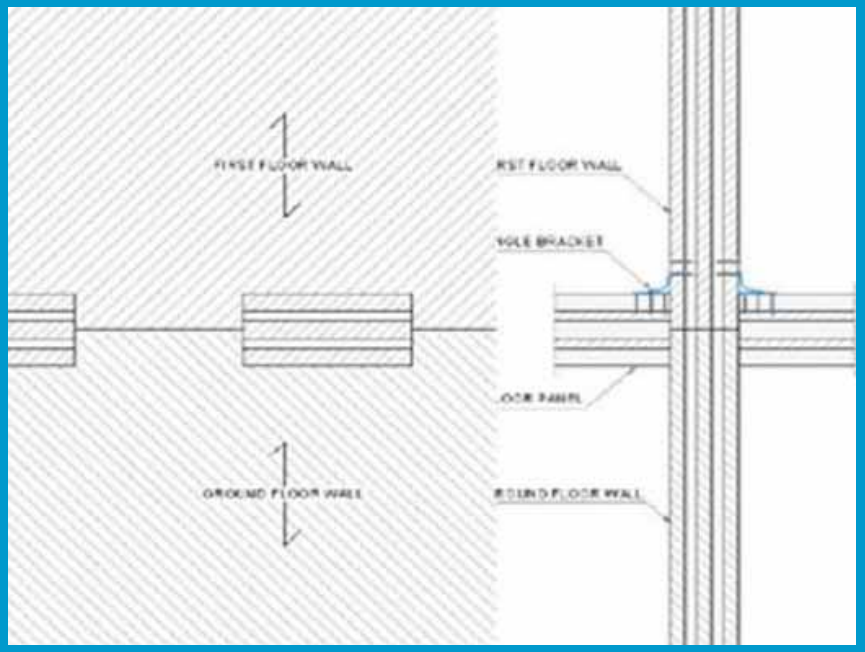
Pieces of a puzzle...



Detail for floor-floor / wall-wall connection
Source: P. Zumbrunnen

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Life Cycle Tower, Dornbirn, Austria

Source: H. Kaufmann, Architekt

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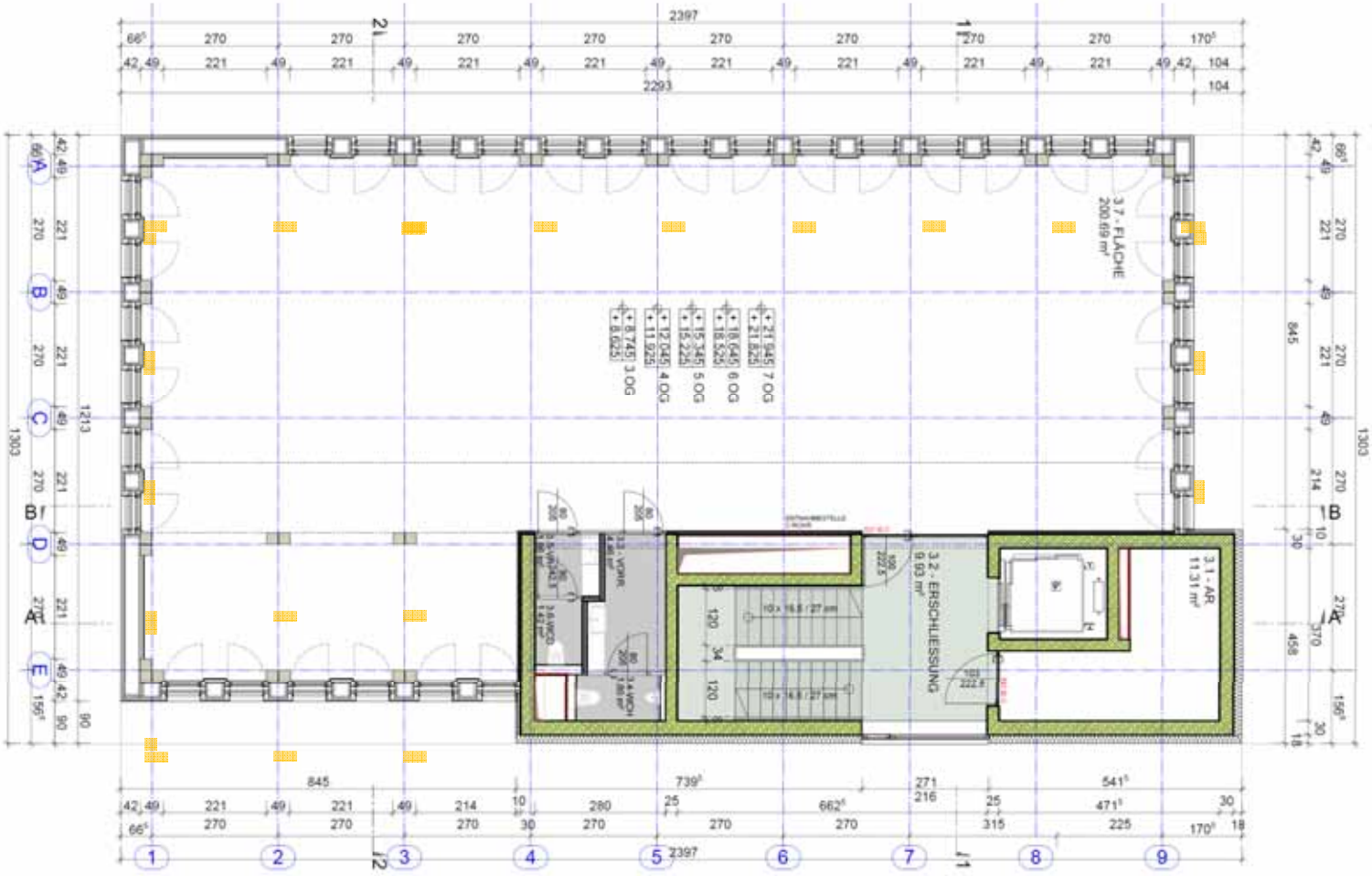

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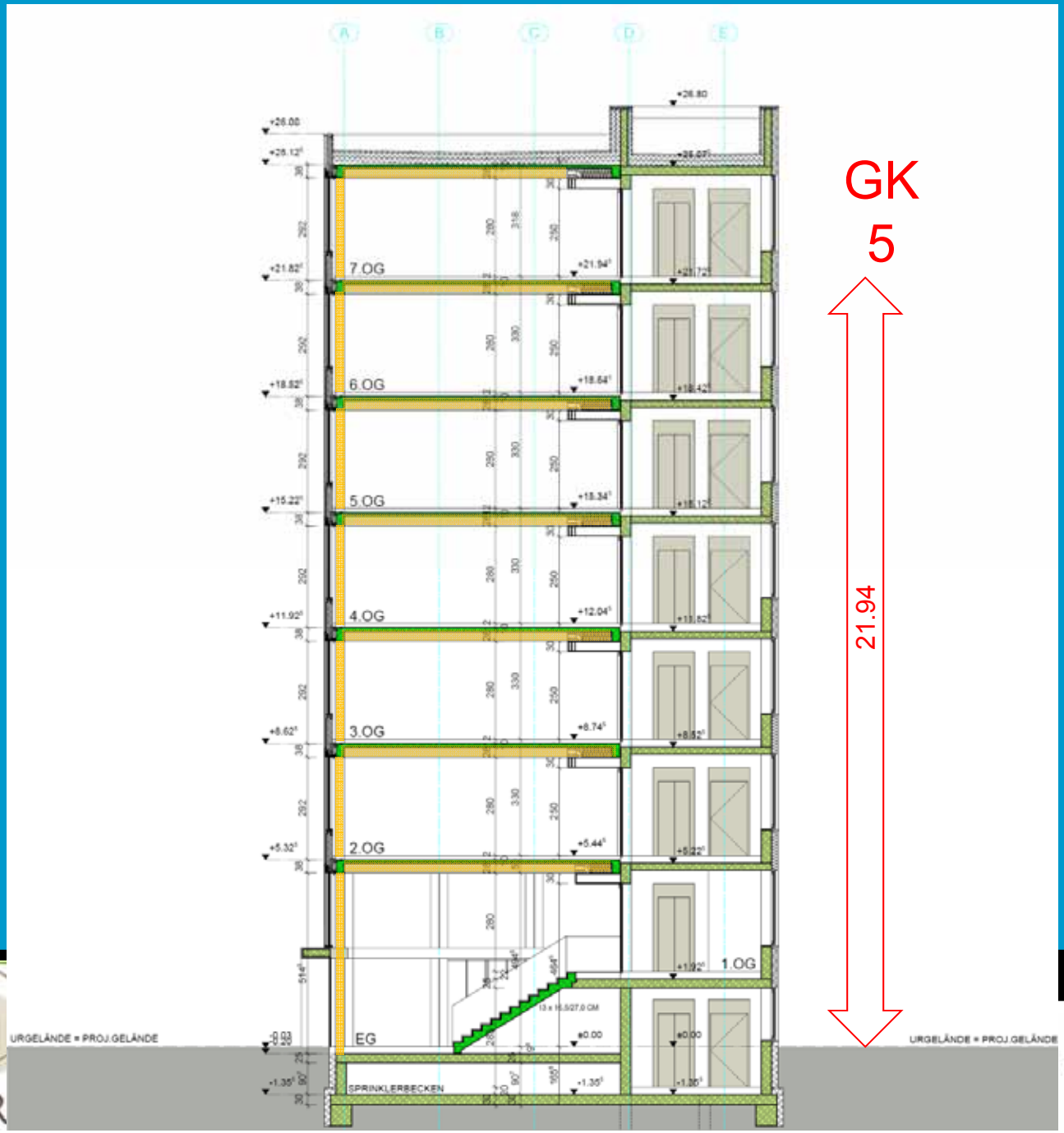

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Source: H. Kaufmann, Architekt

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Source: H. Kaufmann, Architekt

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Source: H. Kaufmann, Architekt

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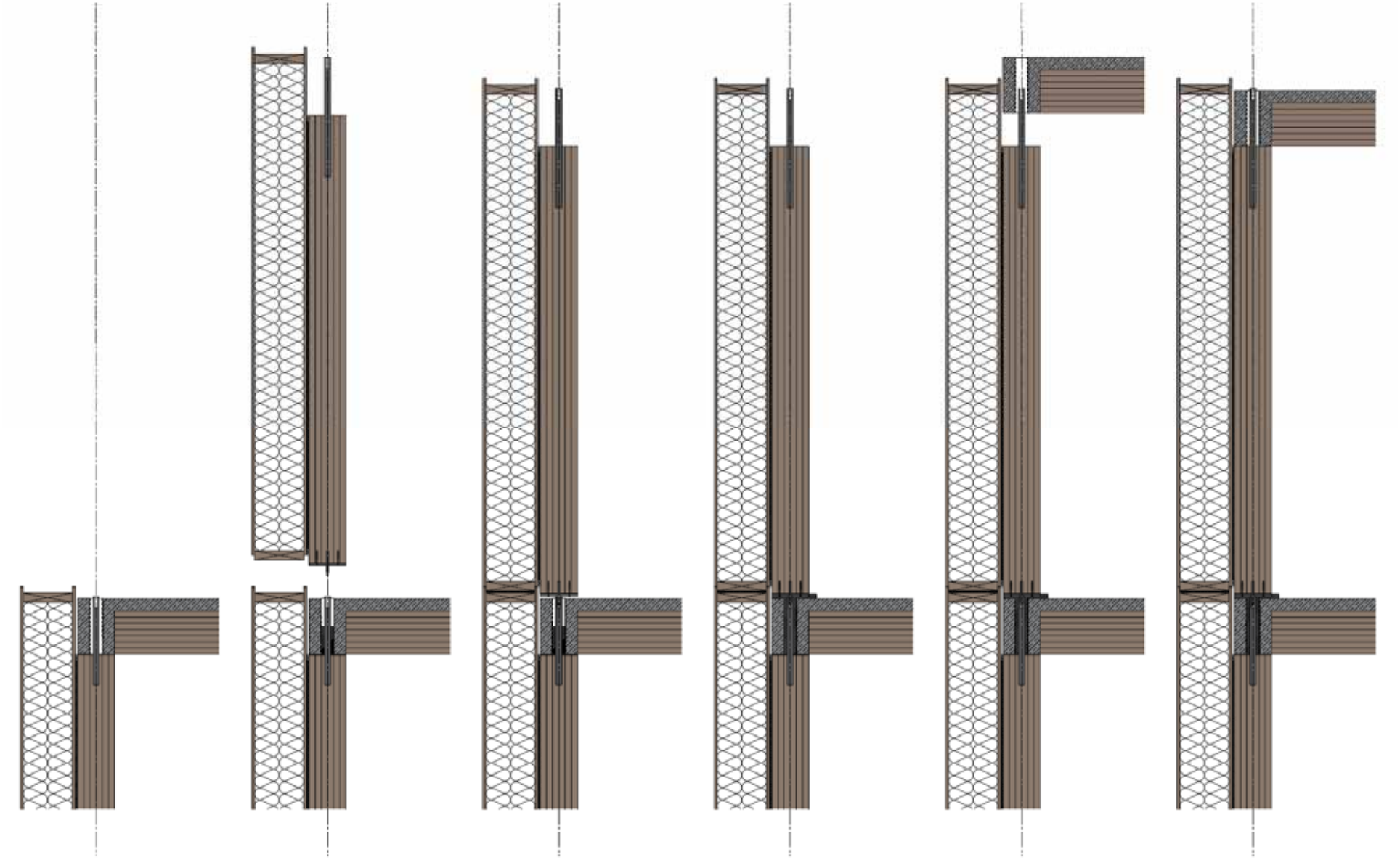

Source: H. Kaufmann, Architekt

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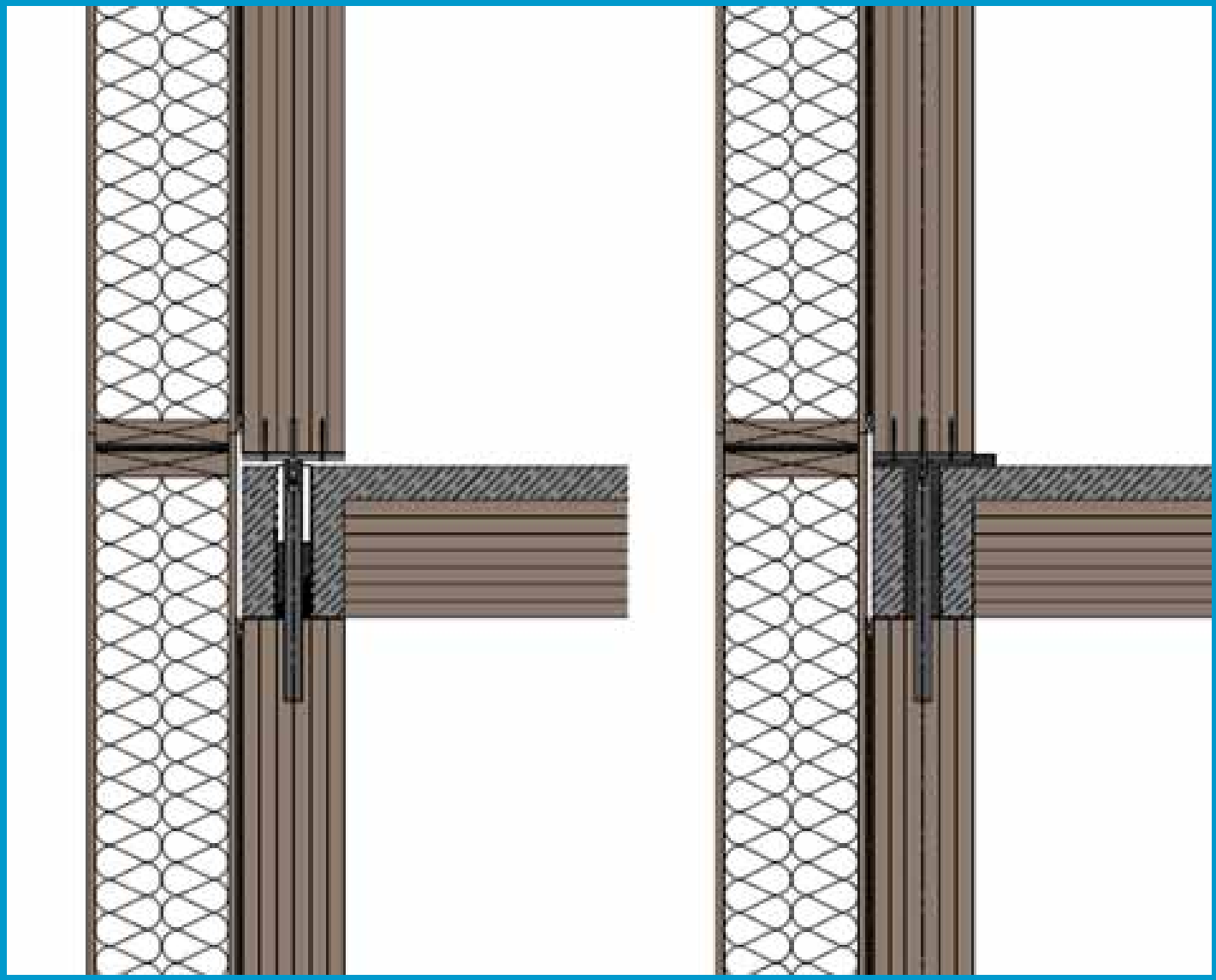

Source: H. Kaufmann, Architekt

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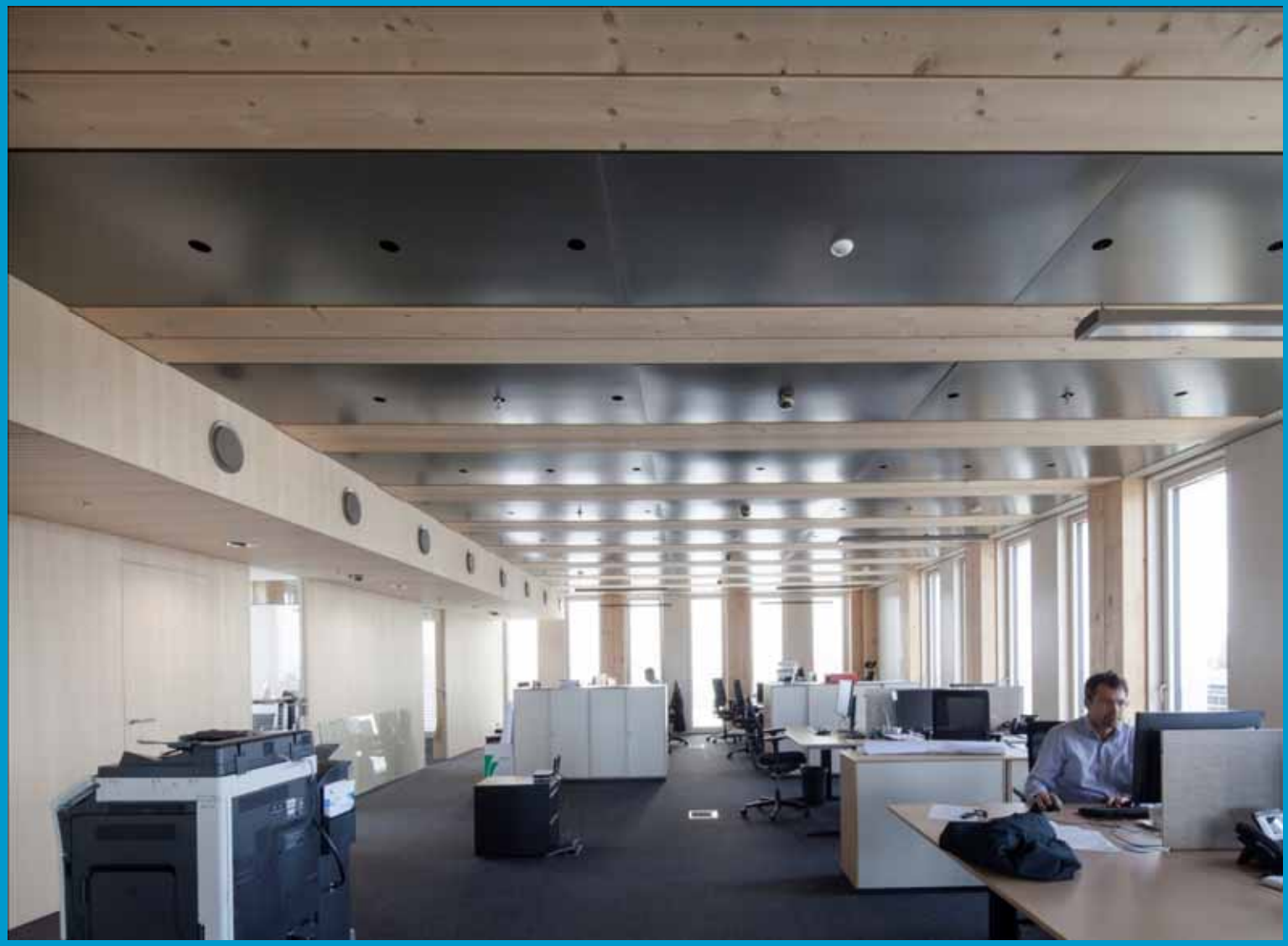

Source: H. Kaufmann, Architekt

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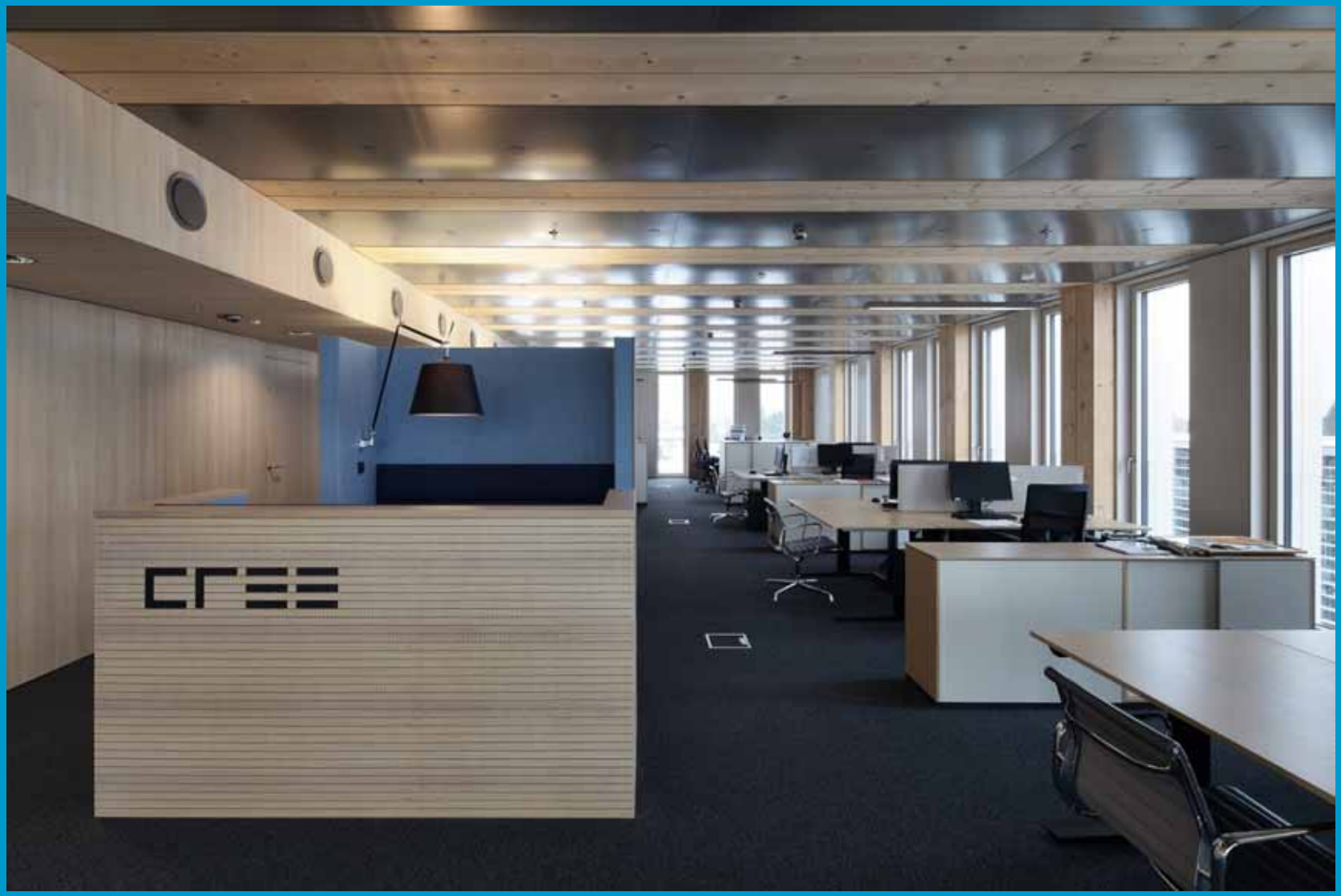

Source: H. Kaufmann, Architekt

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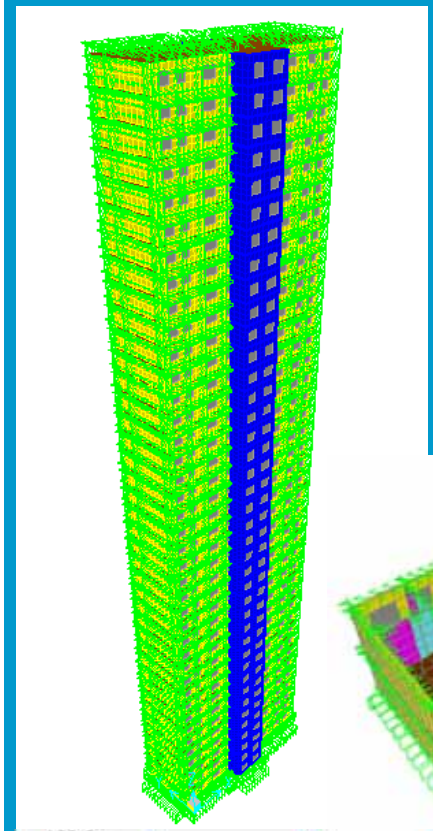
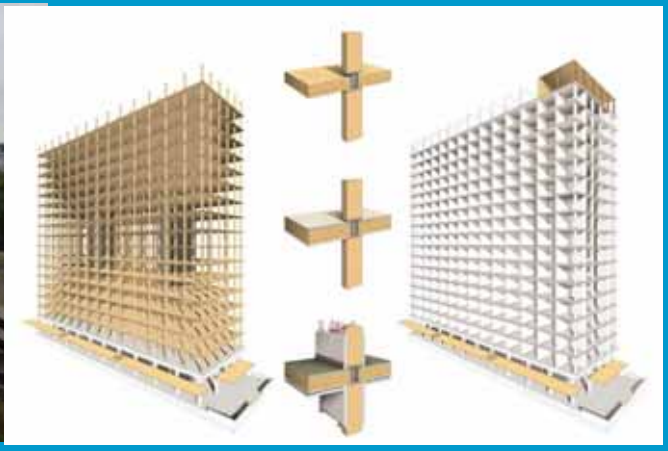
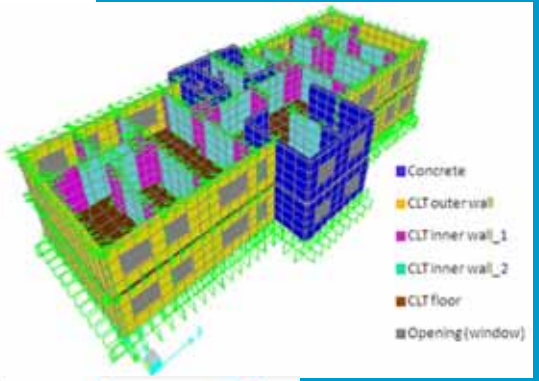
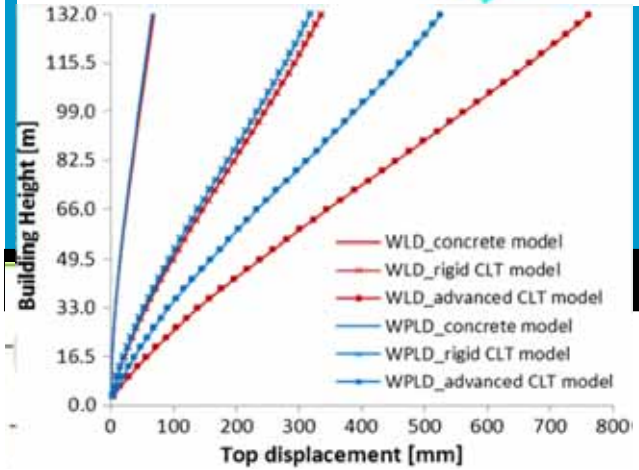
Multi-storey timber buildings: Hotel Jakarta Amsterdam





Source: H. Kaufmann, Architekt





Xia et al. 2014

UBC Vancouver – Student Housing

2 concrete storeys, 16 storeys of CLT

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- https://www.youtube.com/watch?v=GHtdnY_gnmE

Source: H. Kaufmann, Architekt

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- Example of a 3D Module

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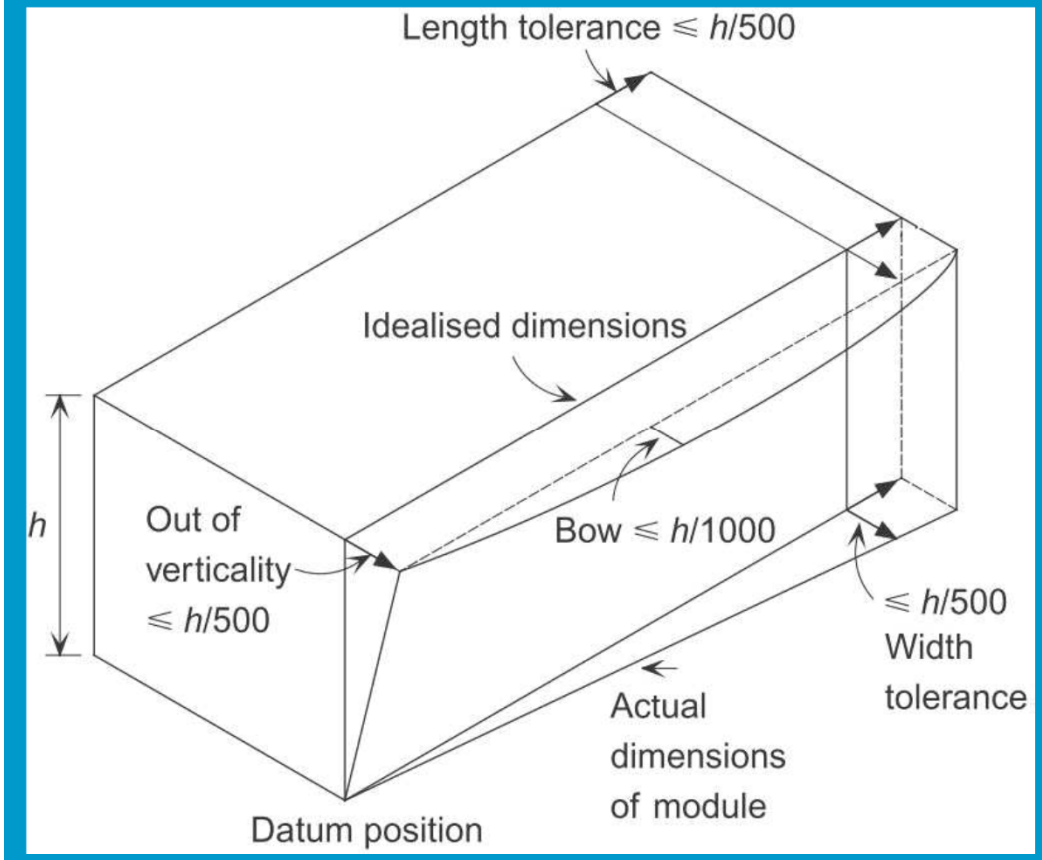

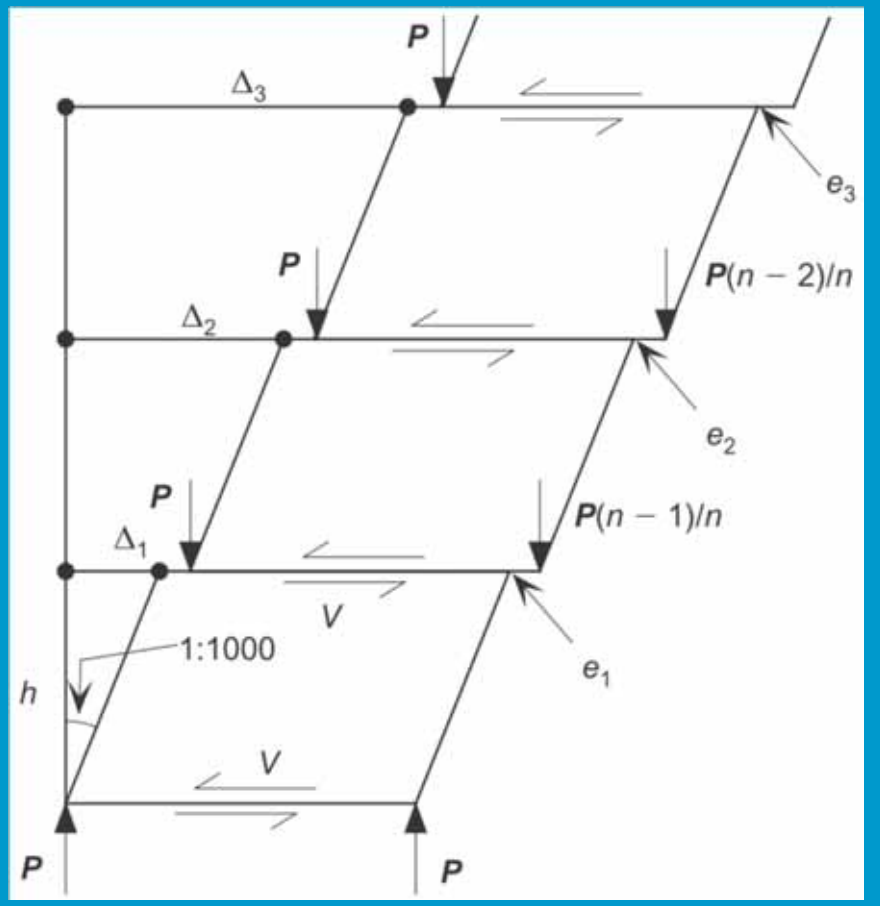

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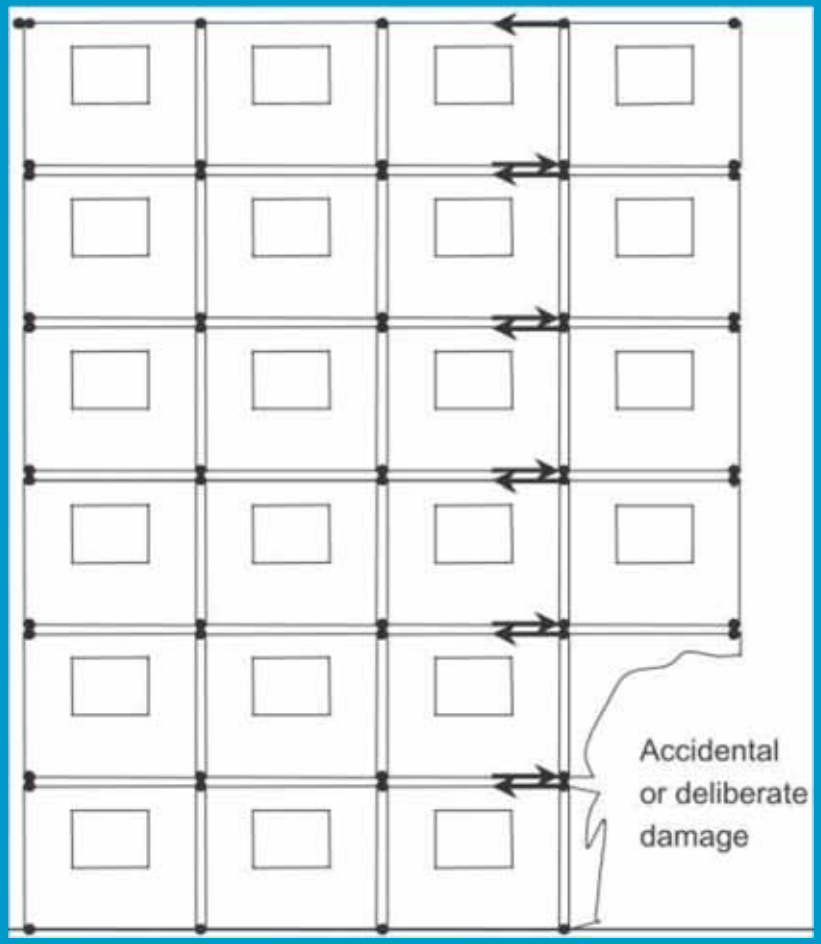

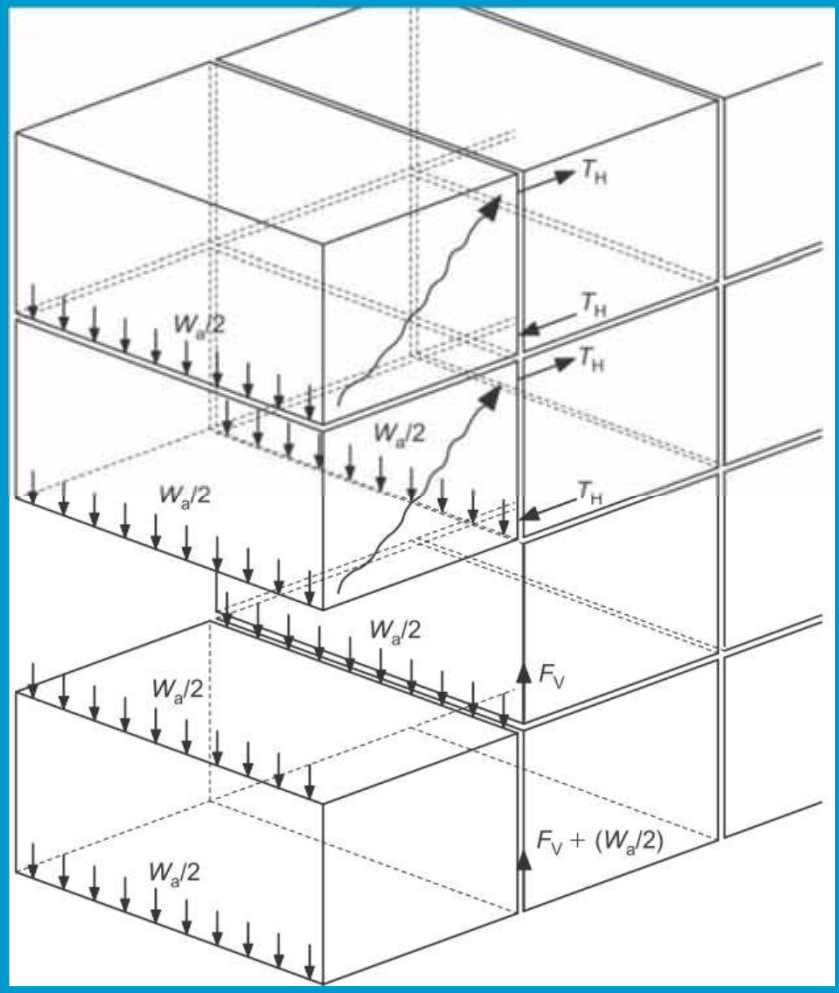

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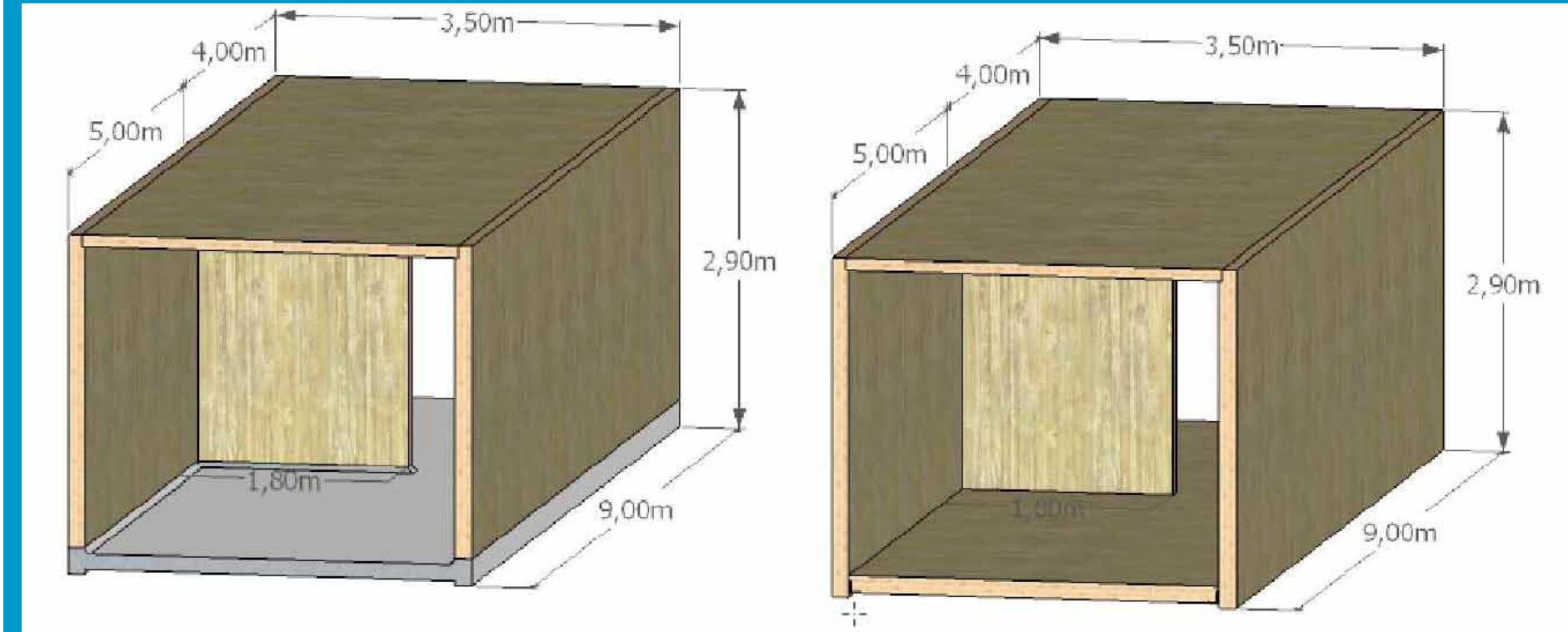

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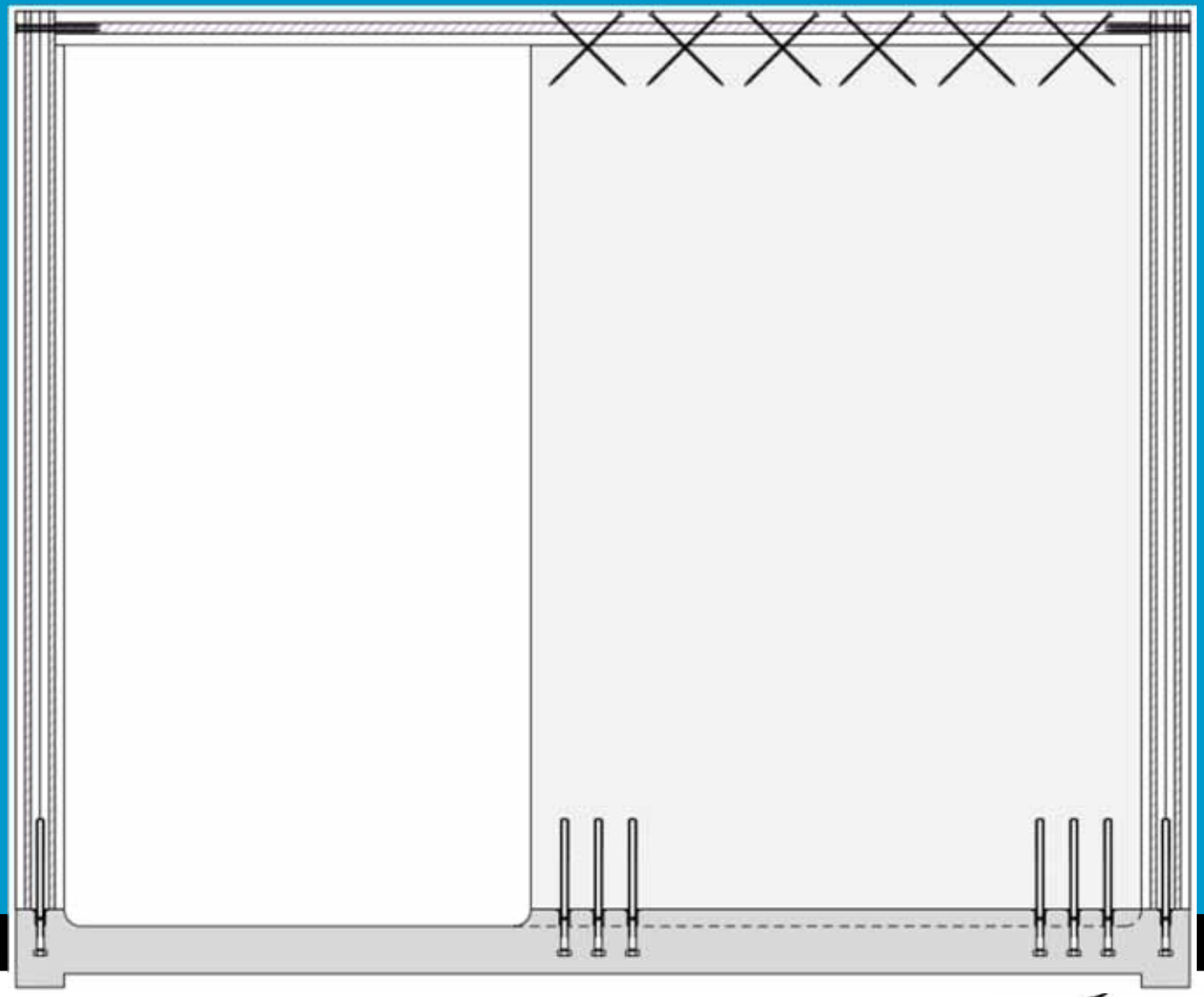

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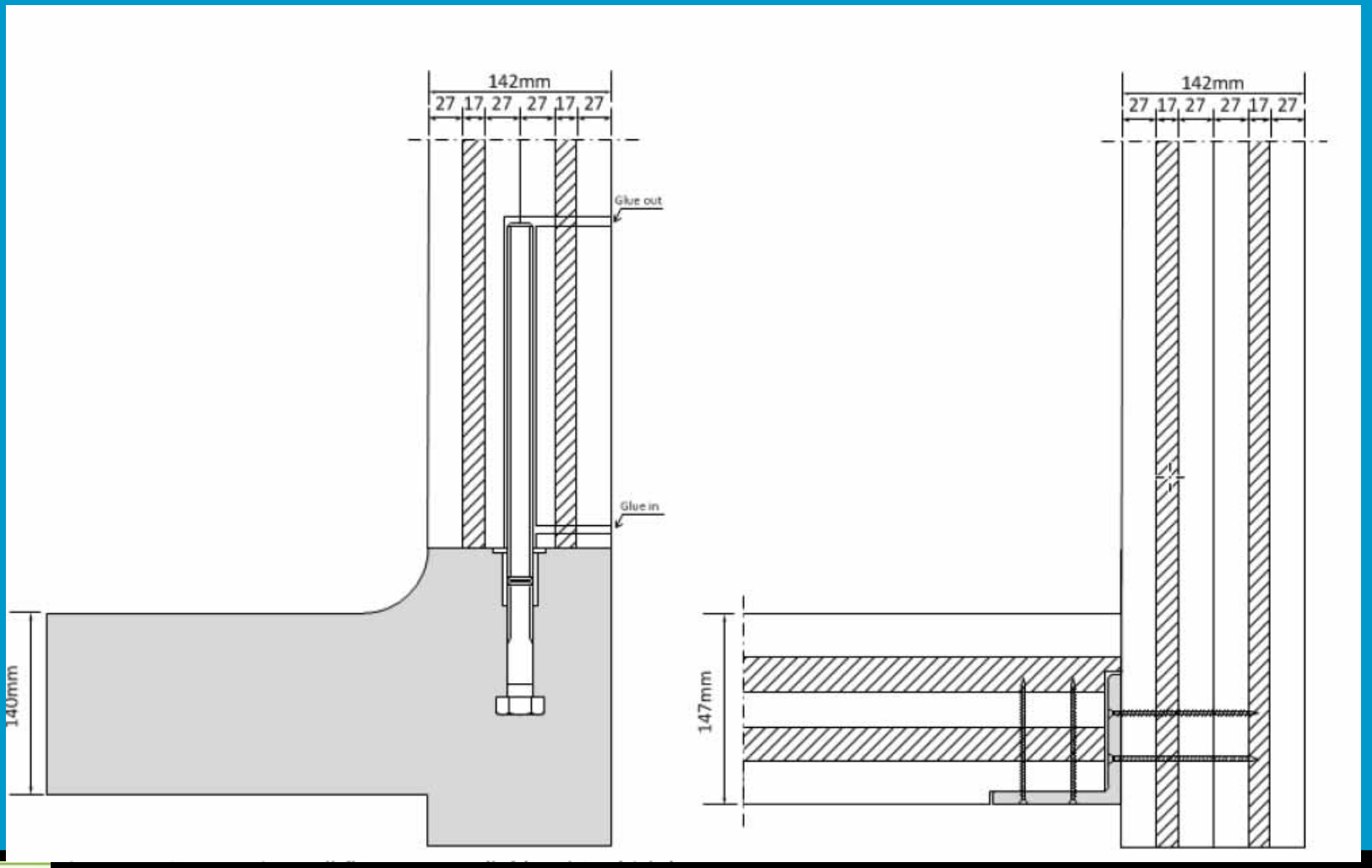

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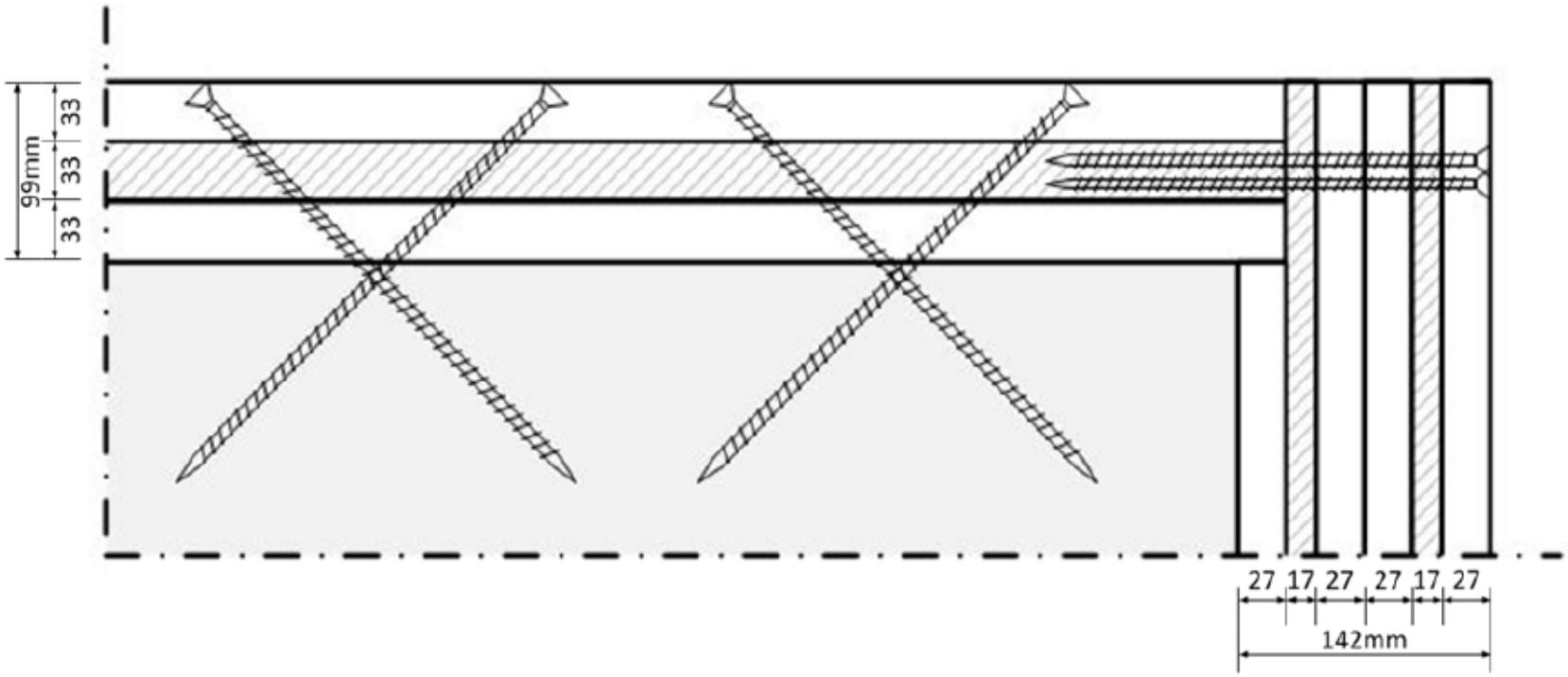

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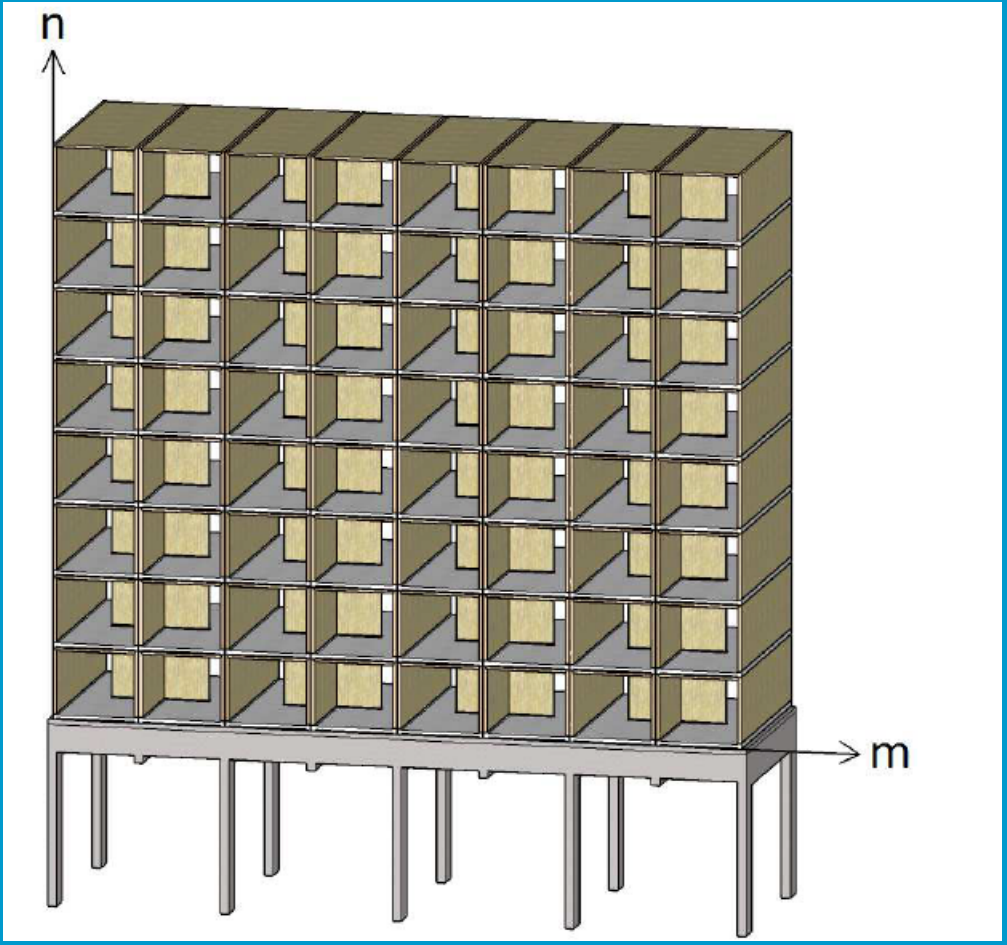

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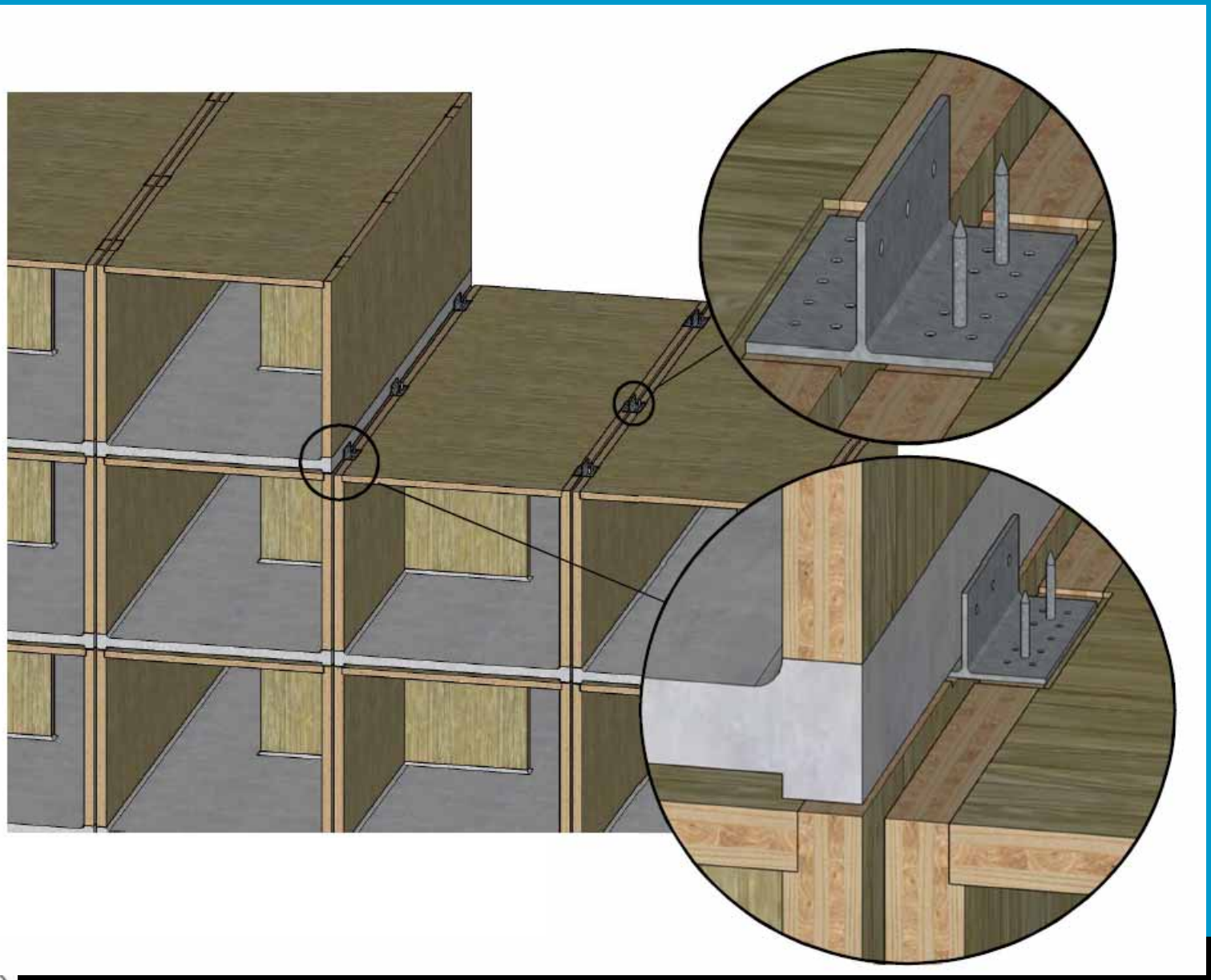

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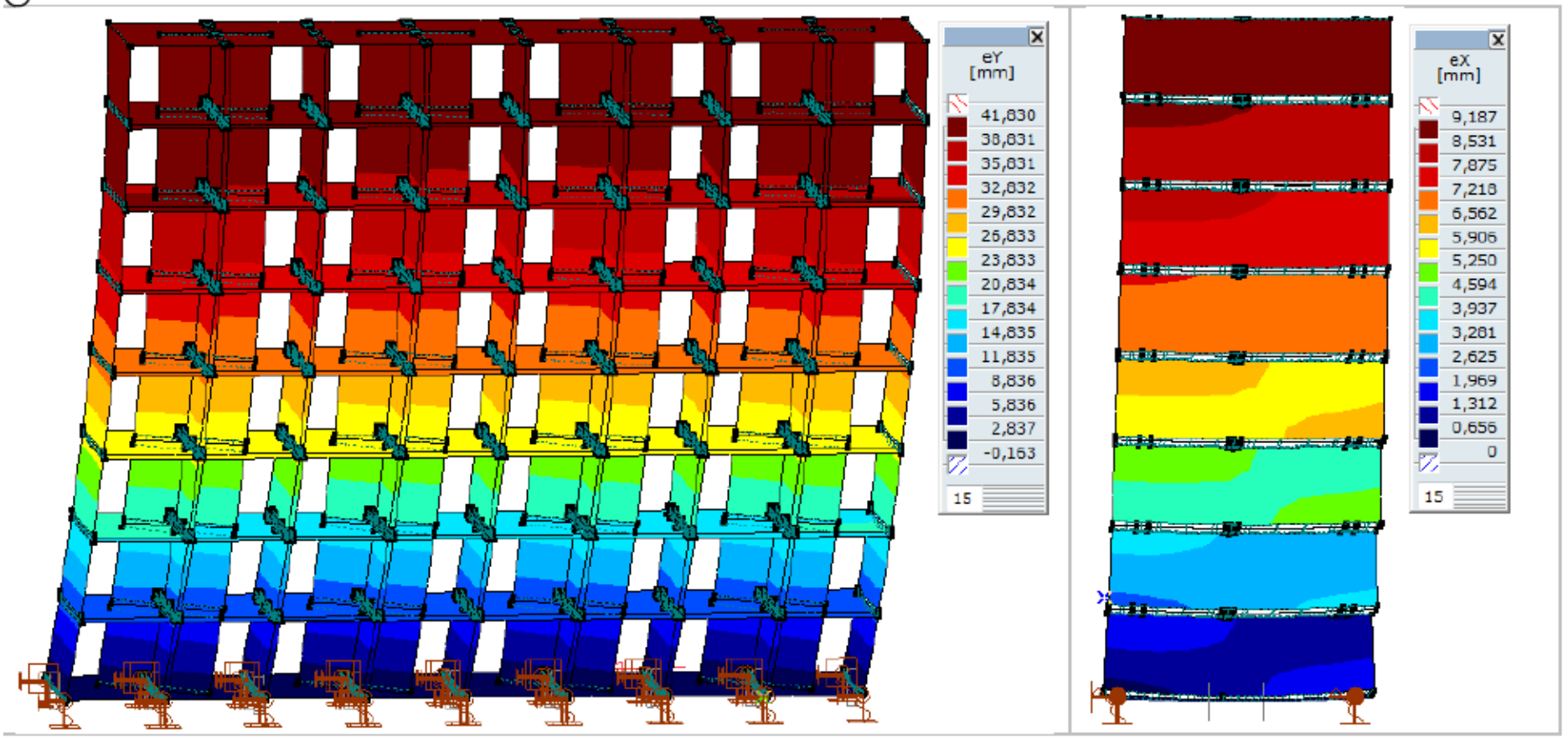

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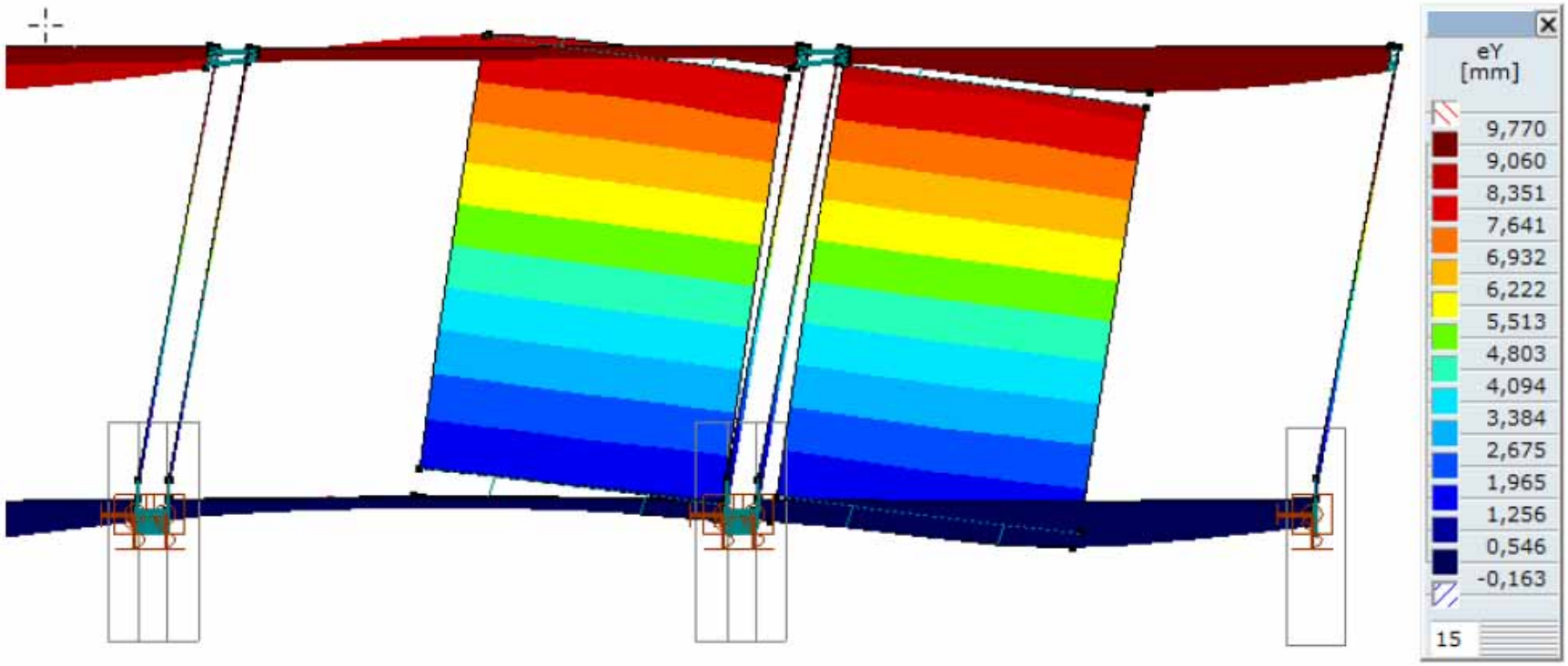

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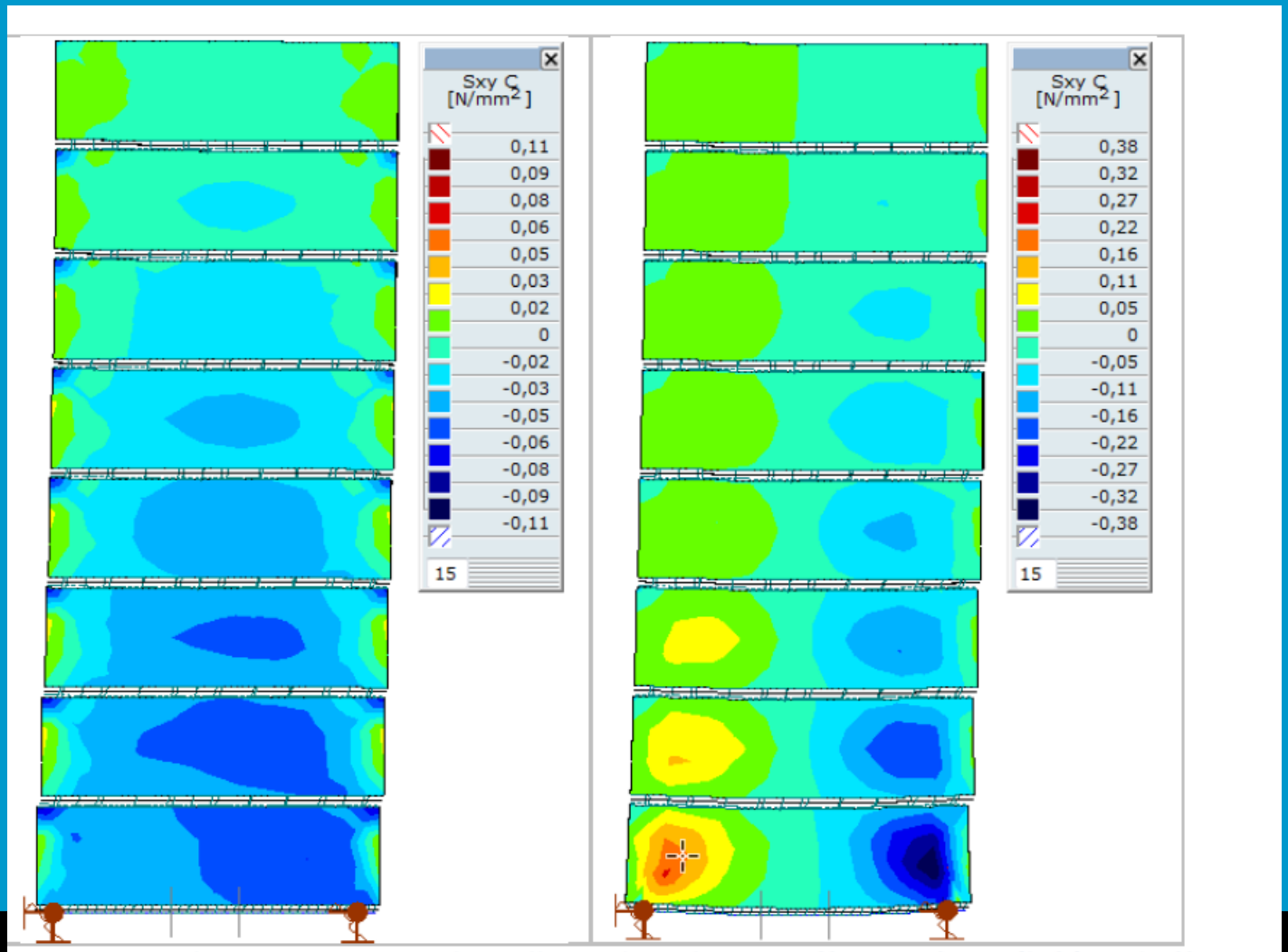

Figure 71 - Shear stresses in side walls, podium beam stiffness infinite (left) and effective

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Prefabricated unit

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Ready for transport

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15 May 2017
Highest point reached!

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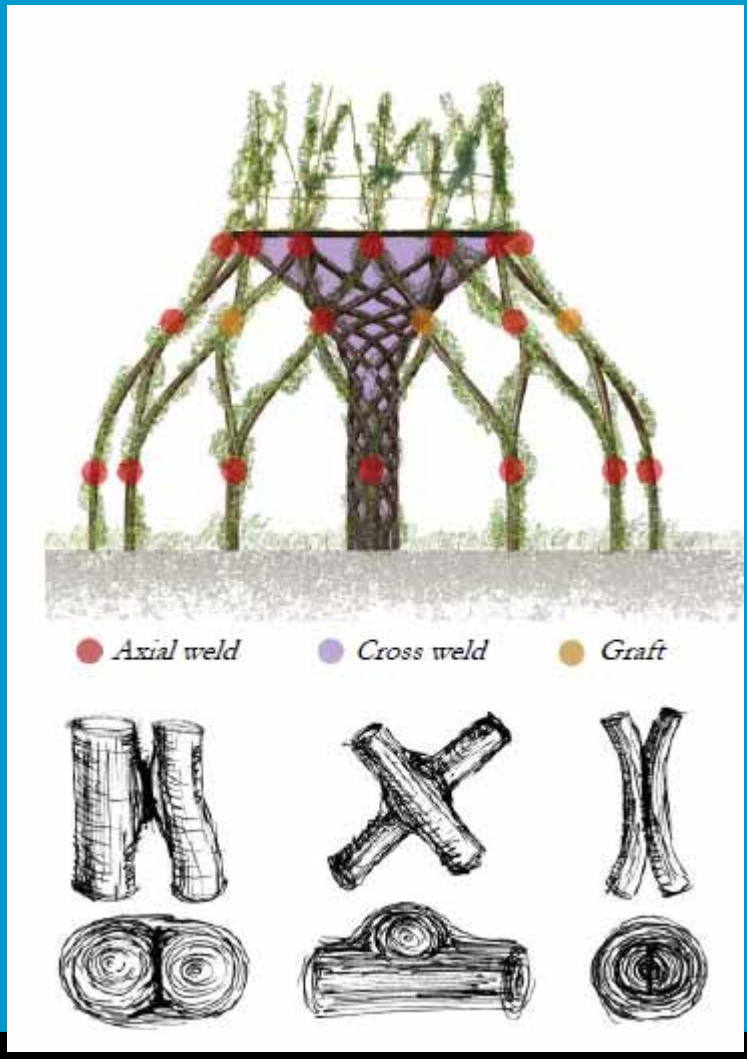
Biostructures: a living tree pavillion



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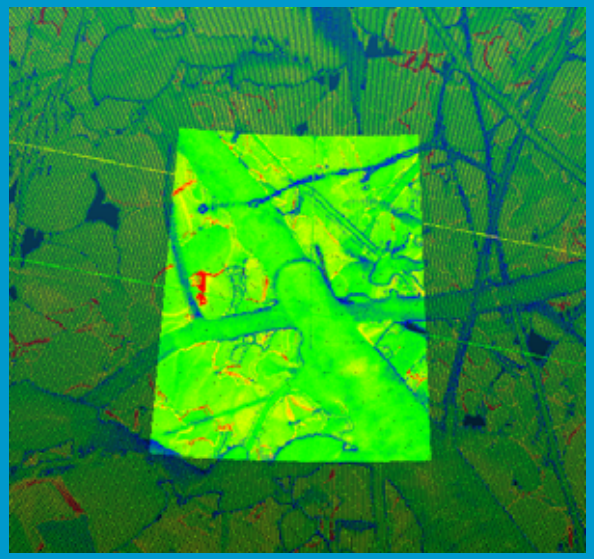
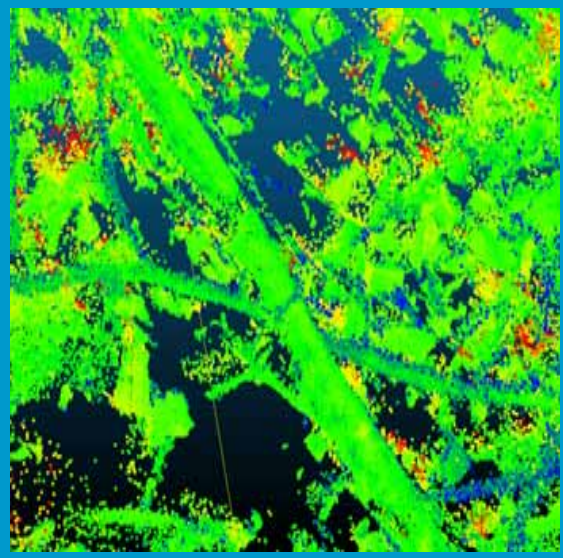
Biostructures: a living tree pavillion





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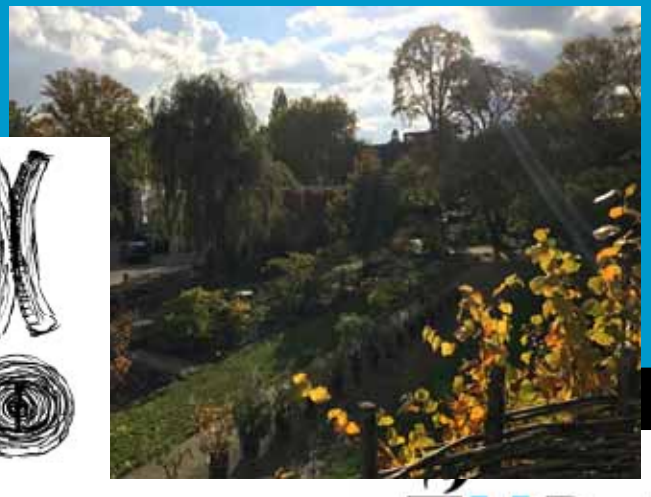
Biostructures: a living tree pavilion



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Biostructures: a living tree pavilion

- Proof loading...

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To be continued....

Delft, 2018!

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