Μάθημα CLT και οι εφαρμογές του

Multi-storeys Timber Building and Social Housing

Contemporary Timber Buildings





Dr. George Ntalos
Dr Dimitrios Koutsianitis

Nature has always produced structures subjected to light loads. Wood can be considered as the structural material for excellence in biology..

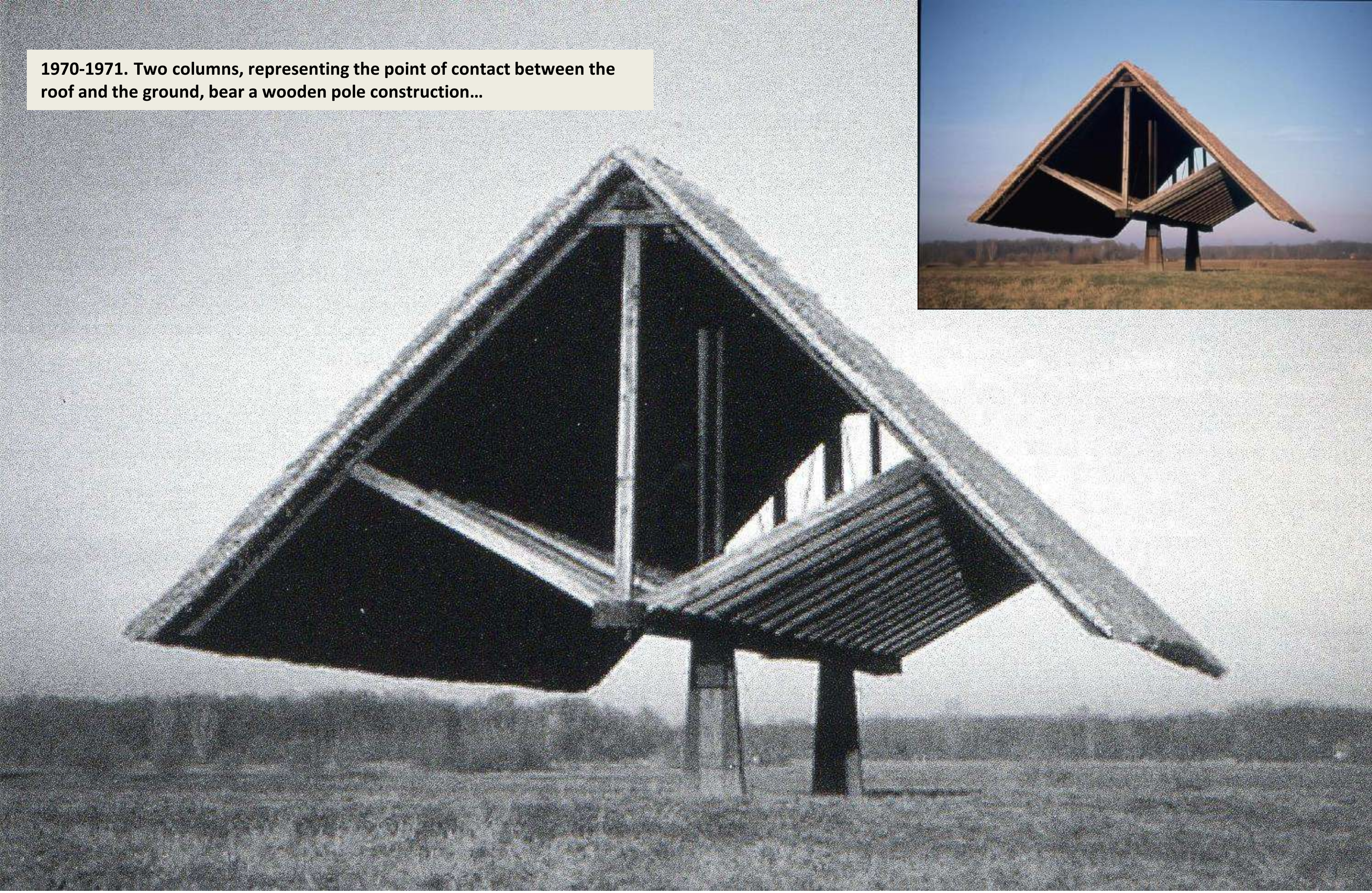
[…] in the advanced technologies, wood has proved to be an excellent material for construction under dynamic strain.

[…] the problem of wood is to be an excellent material too easily usable

James E. Gordon, The Science of Structures and Materials, 1988 (Translation: A. Alessi)

In “One Week” film (United states, 1920), Buster and his new bride have seven days to build a house from an assemble-it-yourself prefab kit. But even the best-laid plans have to be read right side up.

1970-1971. Two columns, representing the point of contact between the roof and the ground, bear a wooden pole construction…



Oton Jugovec, roof for the protection of archeological excavations, Otok pri Dovravi, Slovenia

Technologies

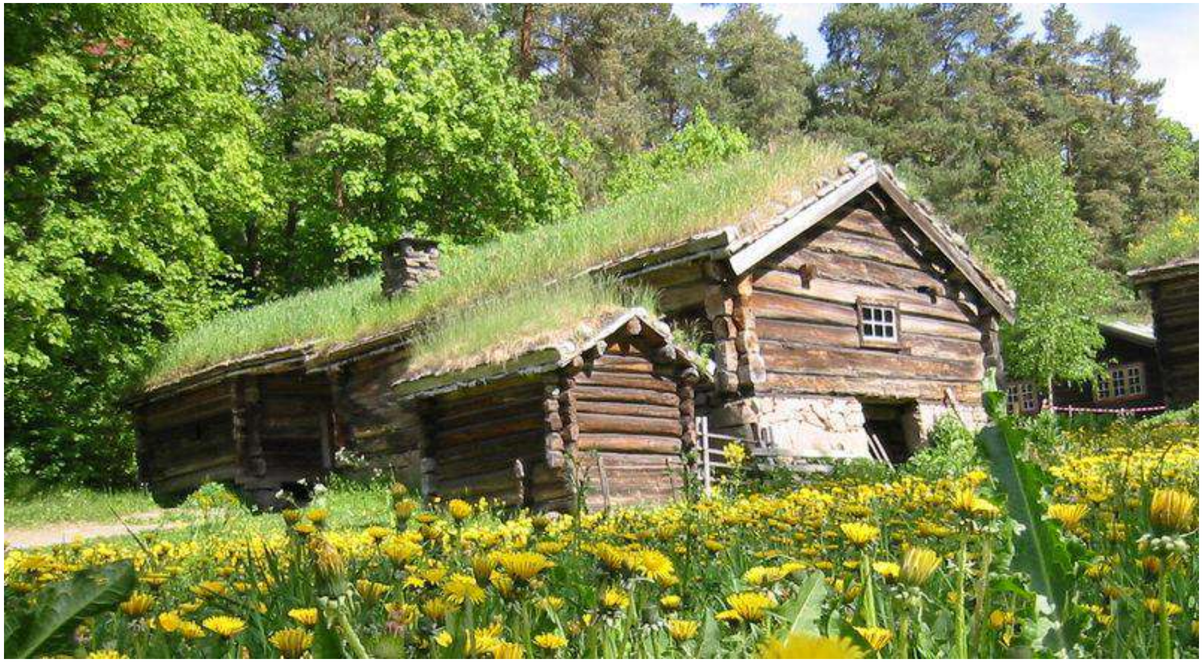
1. Timber should be felled between early Autumn and the time when Favonius begins to blow. For in Spring all trees become pregnant, and they are all employing their natural vigour in the production of leaves and of the fruits that return every year.

5. Trees vary and are unlike one another in their qualities. Thus it is with the oak, elm, poplar, cypress, fir, and the others which are most suitable to use in buildings.

Vitruvio, De Architettura, 20 a. C.

Blockhaus

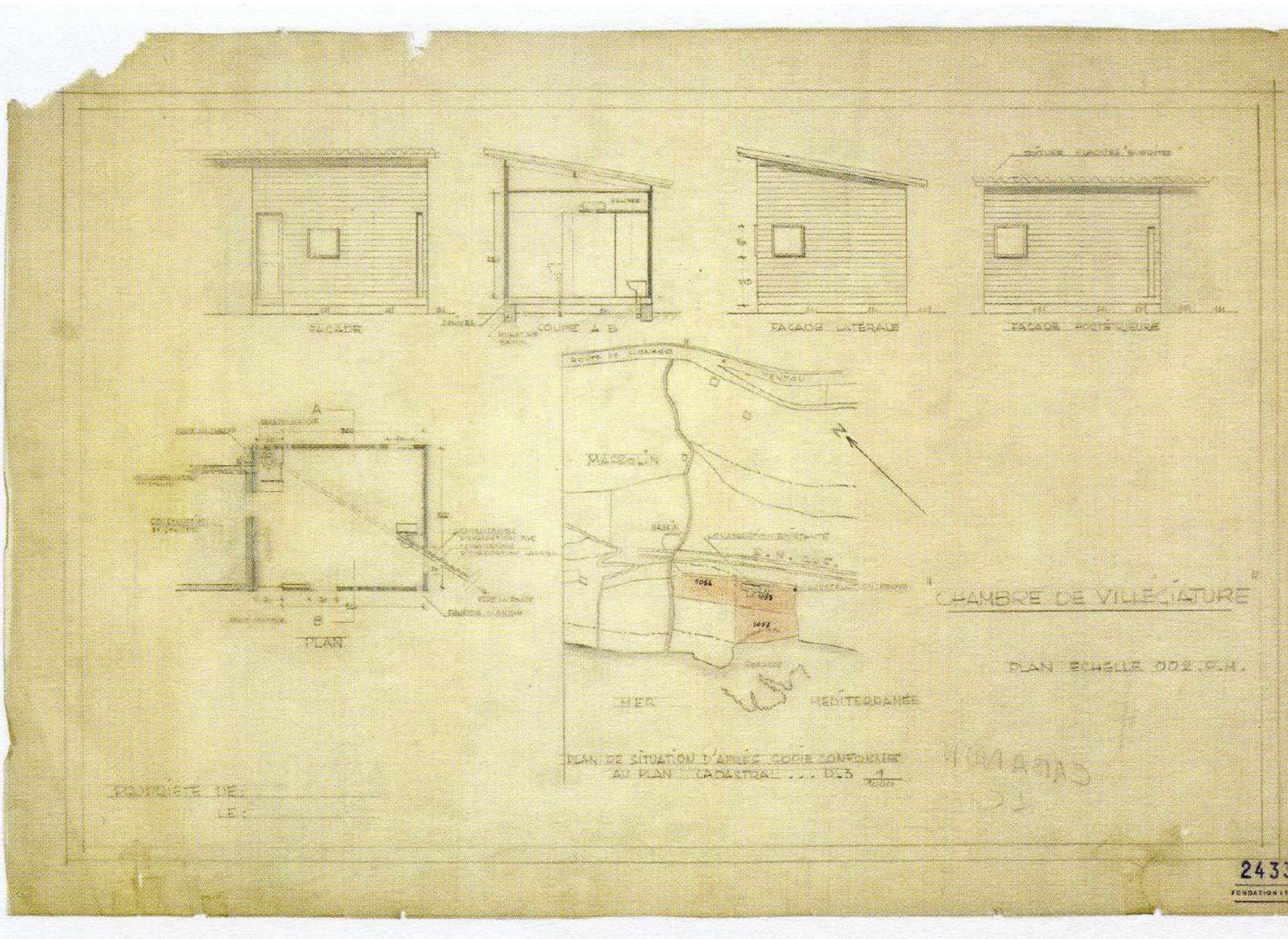
Log Cabin



Log cabins at the Norwegian Museum of Cultural History in Bygdøy, Norway

Le Corbusier, Petit Cabanon, Cap Martin, France, 1954

The Cabanon represents the culmination of research into the notion of the minimal cell that is at the heart of the concerns of modern architects of the 20th century and reconnects with the myth of the primitive hut.



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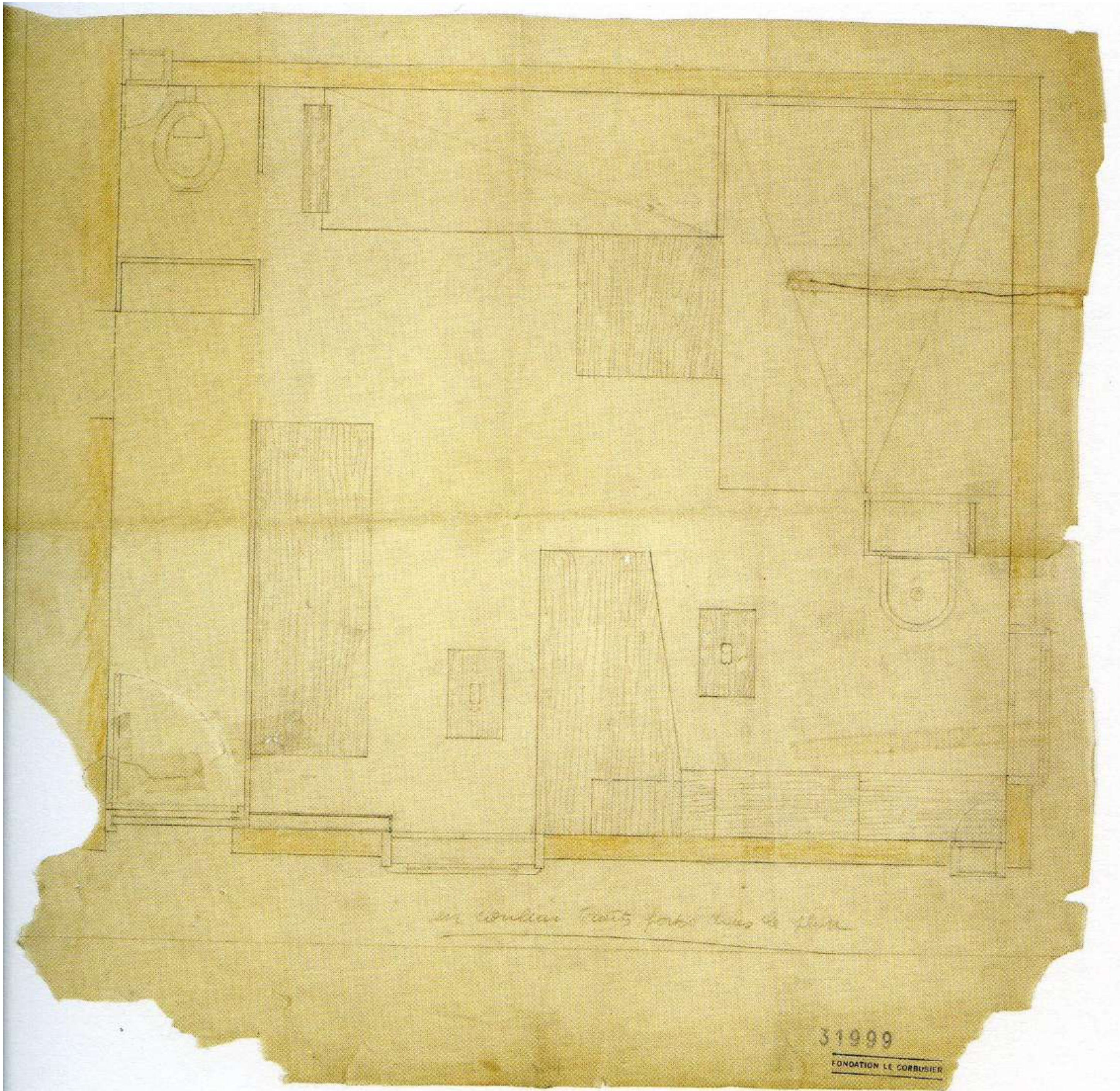
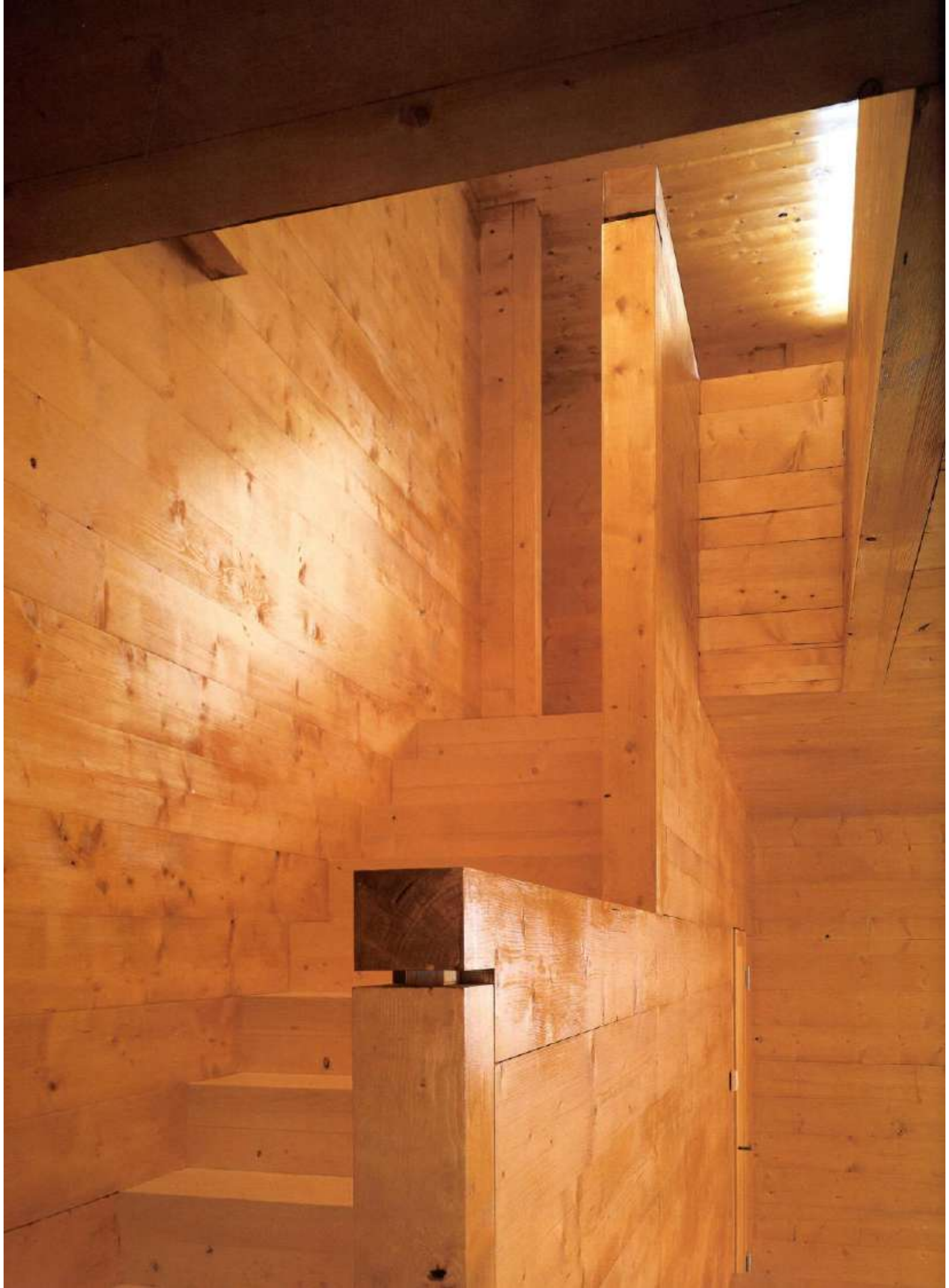

en couleur traits forts
31999
FONDATION LE CORBUSIER

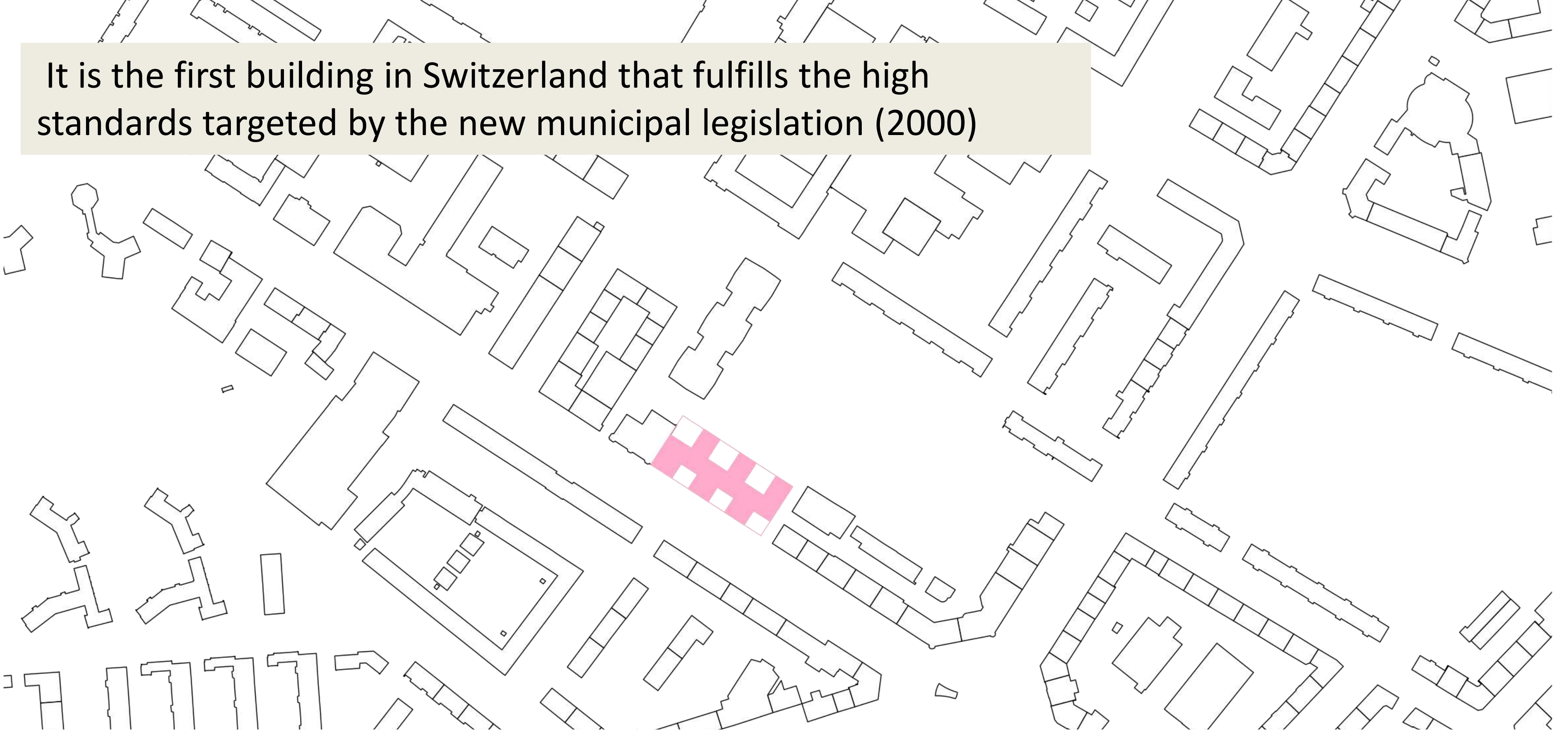
Gion Caminada, Projects for a village, Vrin, since 1990

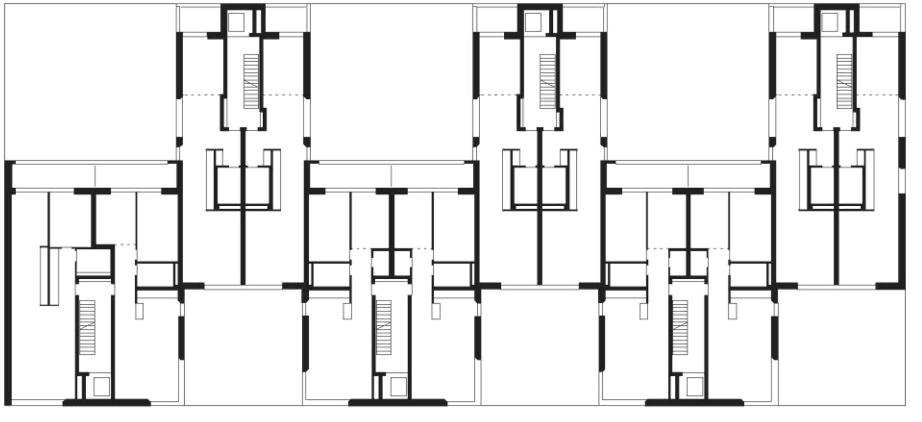


Pool Architekten, Housing Badenerstrasse 380, Zurich, 2009

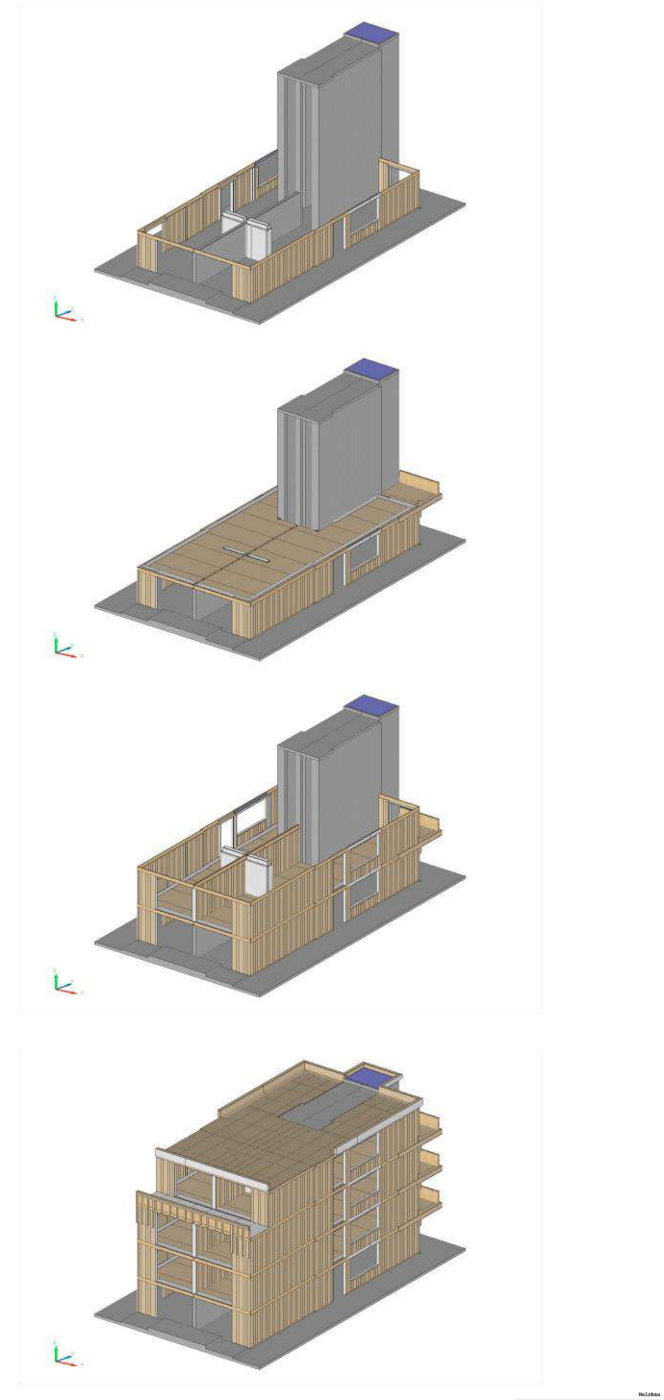

MIGROS
MIGROS

It is the first building in Switzerland that fulfills the high standards targeted by the new municipal legislation (2000)

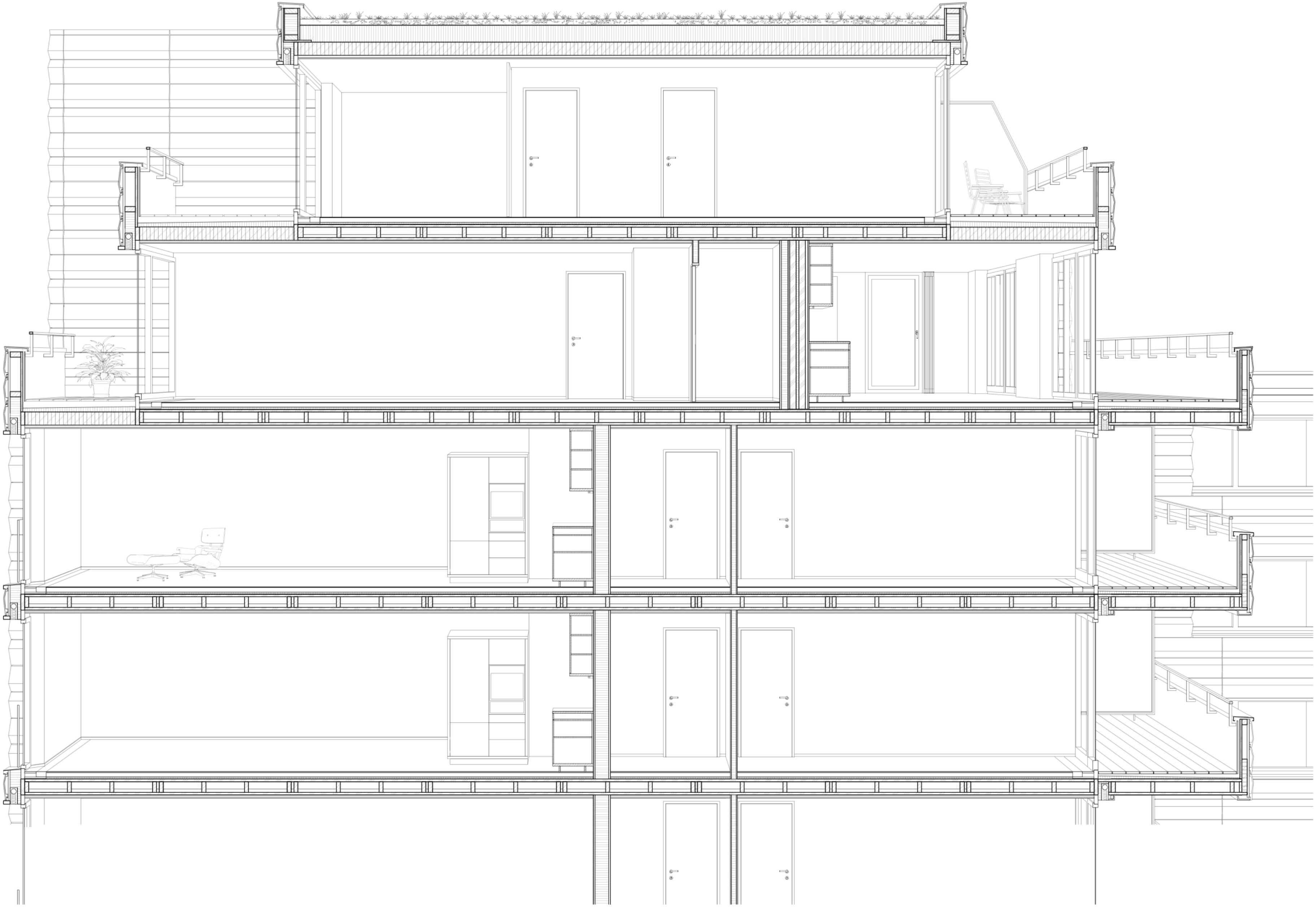


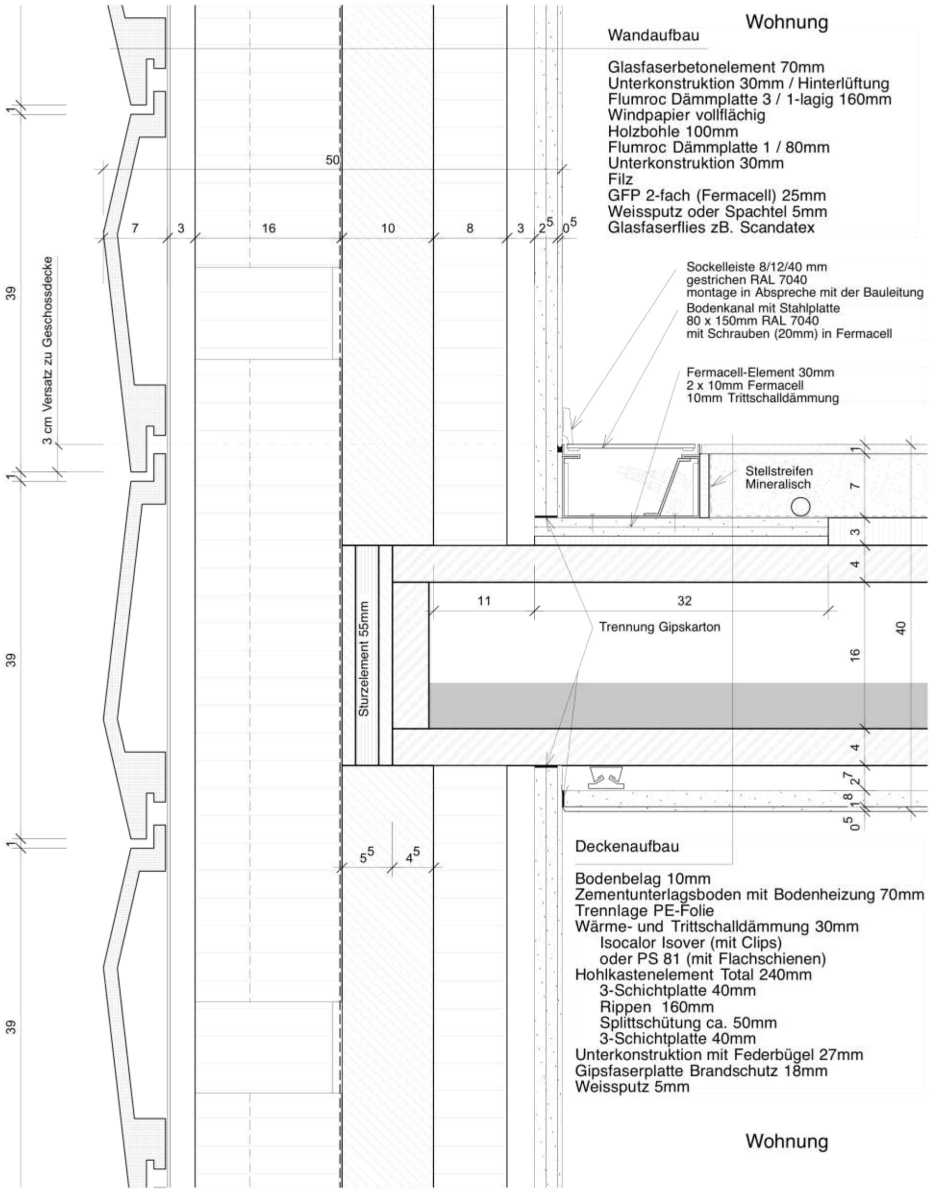


The ground floor level is executed as a retaining basin in site-mixed concrete in order to offer the supermarket a maximally column-free sales area. Constructed on top of this in a prefabricated timber element construction is the six-story residential section



Since the large solid wood transverse sections can be dismantled and be used as raw material for other high-quality products, it is not only a contribution to sustainable building methods, but also a response to the question of a long-term reusability of buildings.





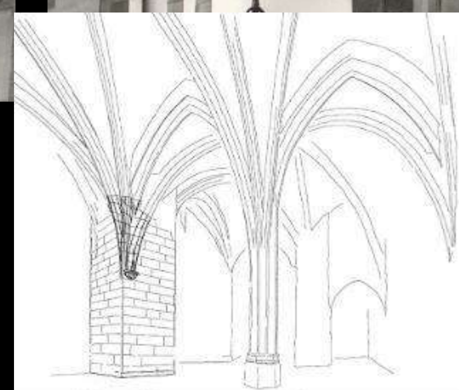
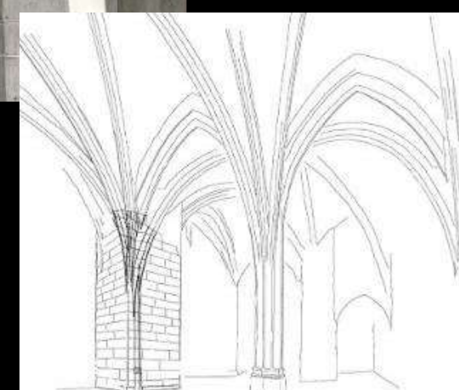
Detail 176.4801

0176 Wohn- und Geschäftshaus Badenerstrasse 380 — Deckenanschluss — 1:5

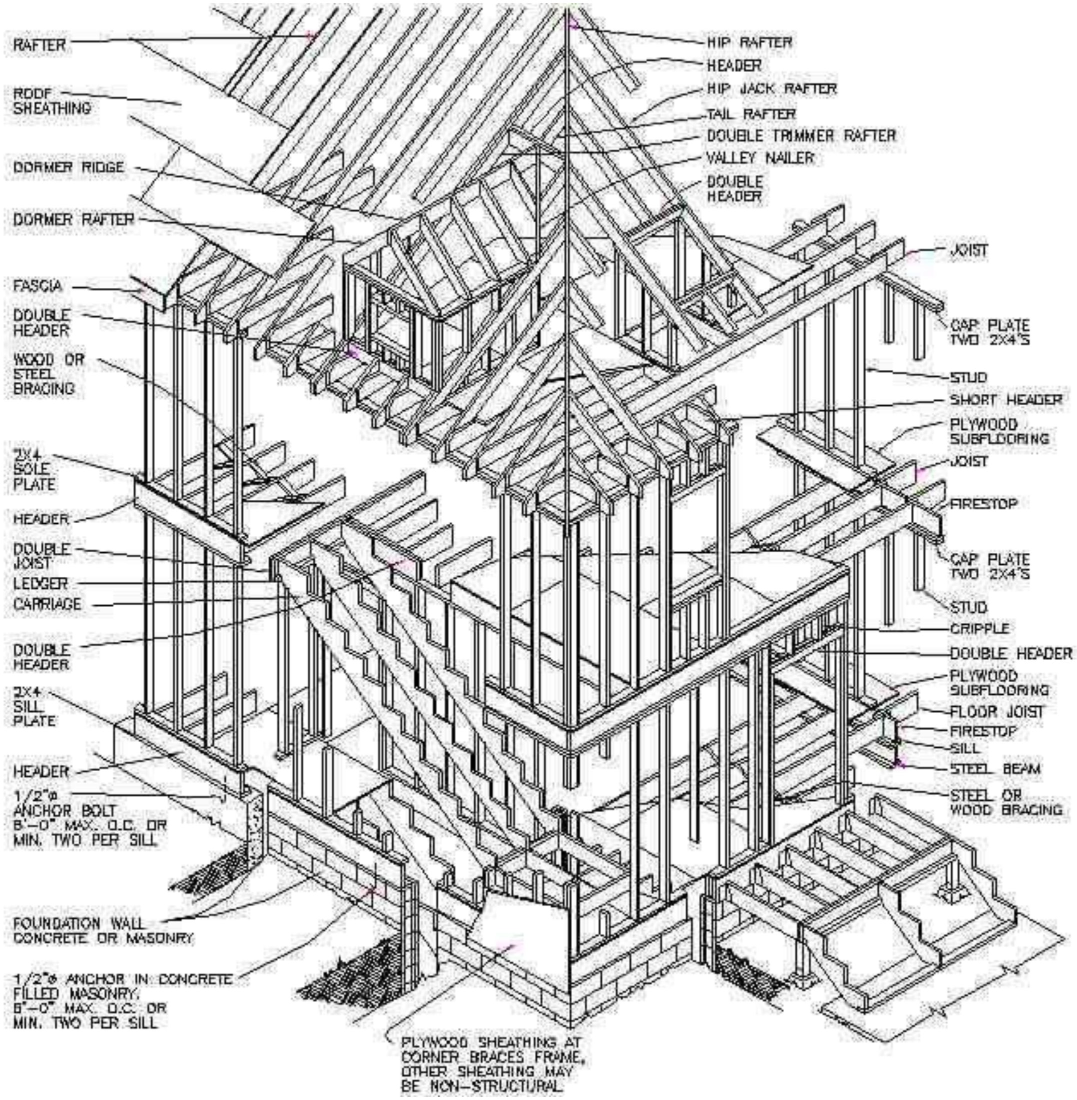
pool Architekten • Bremgartnerstrasse 7 • 8003 Zürich — gez. jla — Format A4 — Datum 10.08.2009

Frame-Work

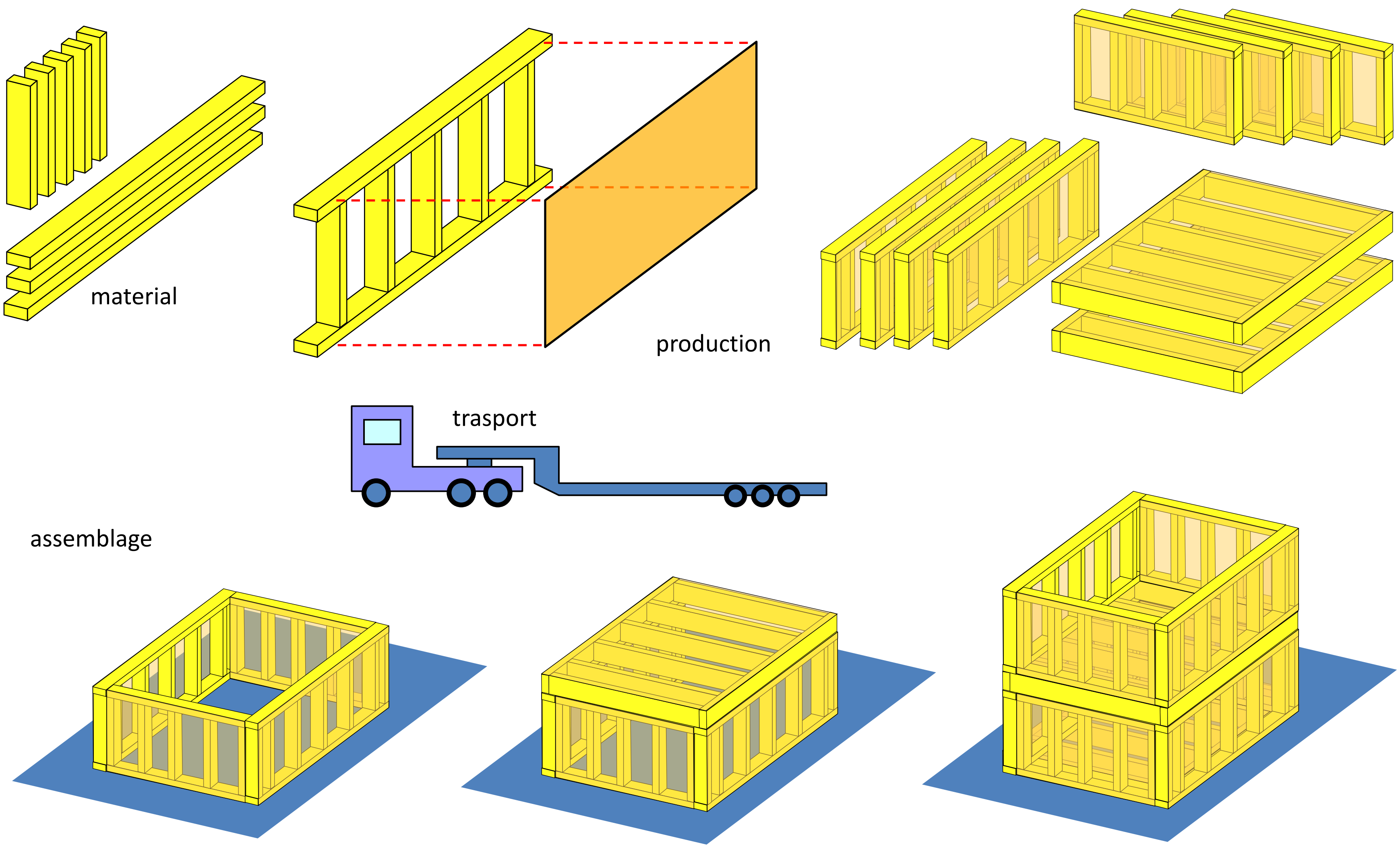


Fraumünster, Zurich, ca. 1400

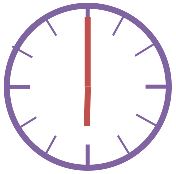

RAFTER
ROOF SHEATHING
DORMER RIDGE
DORMER RAFTER
FASCIA
DOUBLE HEADER
WOOD OR STEEL BRACING
2X4 SOLE PLATE
HEADER
DOUBLE JOIST
LEDGER
CARRIAGE
DOUBLE HEADER
2X4 SILL PLATE
HEADER
1/2"ϕ ANCHOR BOLT 6'-0" MAX. O.C. OR MIN. TWO PER SILL
FOUNDATION WALL CONCRETE OR MASONRY
1/2"ϕ ANCHOR IN CONCRETE FILLED MASONRY. 6'-0" MAX. O.C. OR MIN. TWO PER SILL
PLYWOOD SHEATHING AT CORNER BRACES FRAME, OTHER SHEATHING MAY BE NON-STRUCTURAL
HIP RAFTER
HEADER
HIP JACK RAFTER
TAIL RAFTER
DOUBLE TRIMMER RAFTER
VALLEY NAILER
DOUBLE HEADER
JOIST
CAP PLATE TWO 2X4'S
STUD
SHORT HEADER
PLYWOOD SUBFLOORING
JOIST
FIRESTOP
CAP PLATE TWO 2X4'S
STUD
CRIPPLE
DOUBLE HEADER
PLYWOOD SUBFLOORING
FLOOR JOIST
FIRESTOP
SILL
STEEL BEAM
STEEL OR WOOD BRACING

Production and assemblage of Wooden Buidings

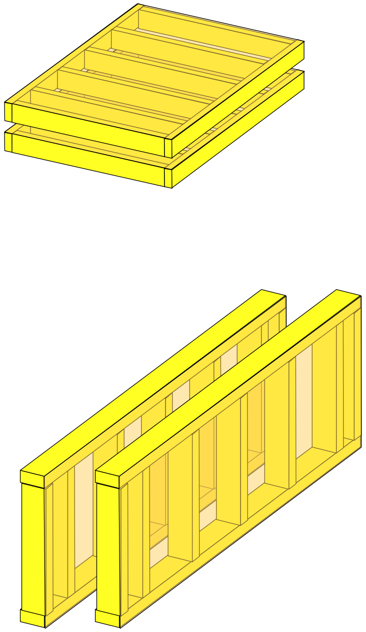


Dr. Ing. Andrea Bernasconi

07.00



18.00



Special dimensions
- transport
- assemblage

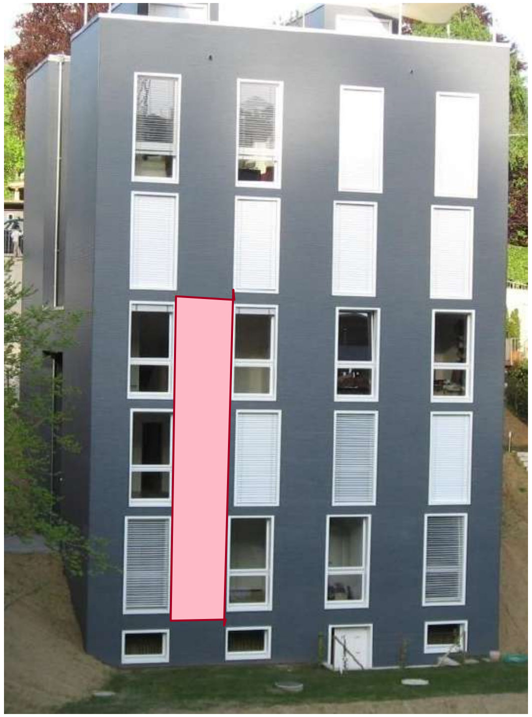
Frame and uprights elements
- GLT

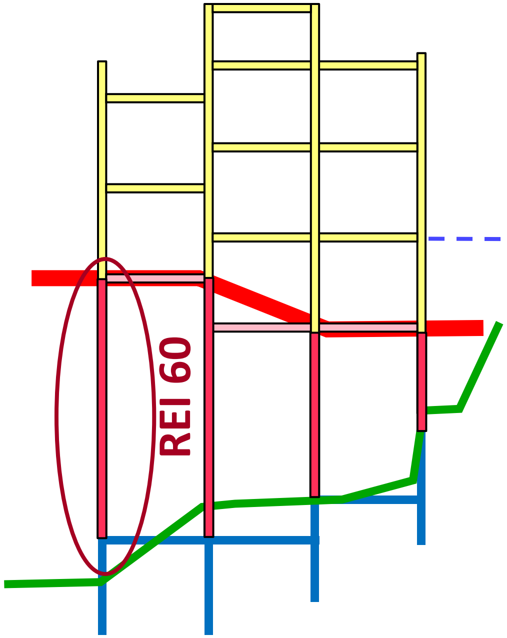
Panels
- OSB

An example of multi-storey building

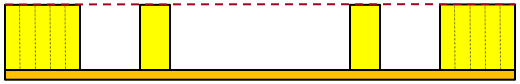
Solution for Fire-Protection
- Requirements REI 60 at the middle of the building
- Fire in the lower apartments: structural stability guaranteed for 60’ min.

Term in building codes	Corresponds to fire resistance class...
Fire retardant	R30
High fire retardant	R60
Fire resistant	R90
Highly fire resistant	R120
Very highly fire resistant	R180

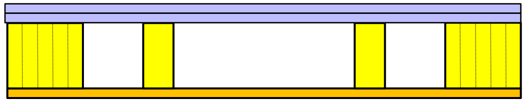




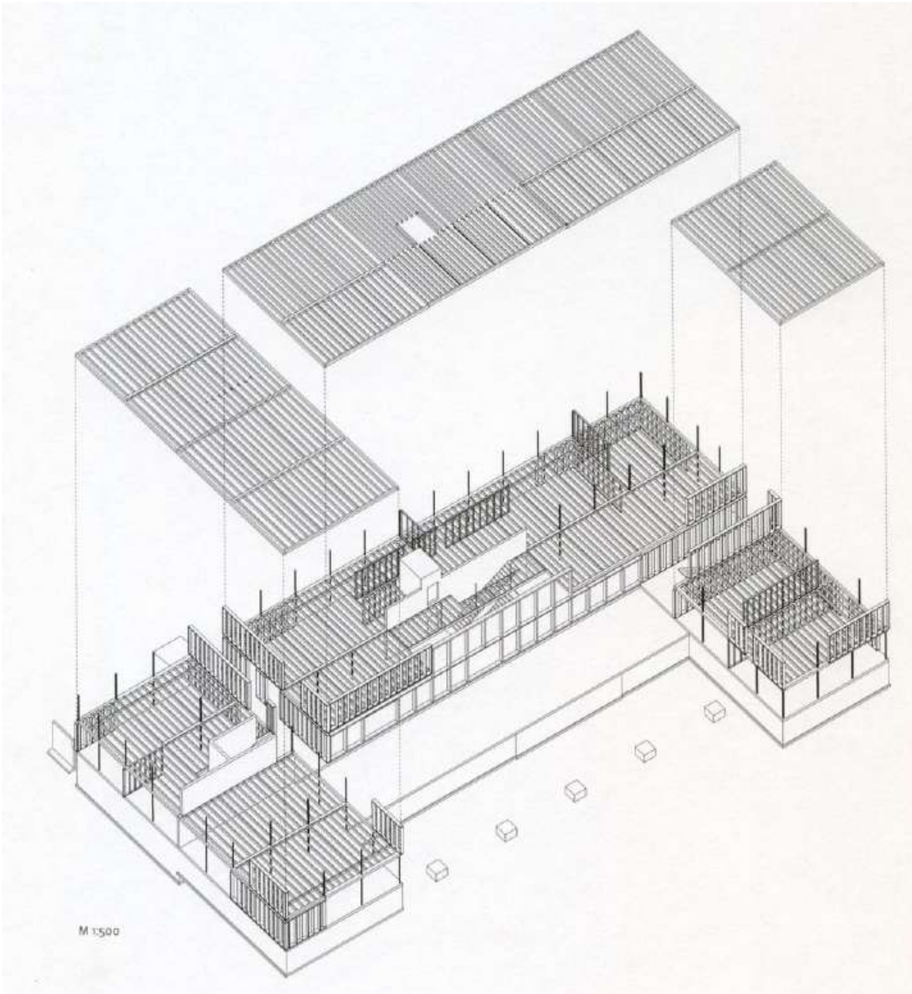
Parete "a freddo": h = ca. 3.0 m



Parete REI 60: h = ca. 9 m
- rivestimento gesso-fibra
- carichi accidentali



Hermann Kaufmann, Gemeindehaus, Ludesch, Austria, 2005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Blauraum, Vertical Extension Treehouses Babelallee, Hamburg, 2010

concept

Energiebedarf

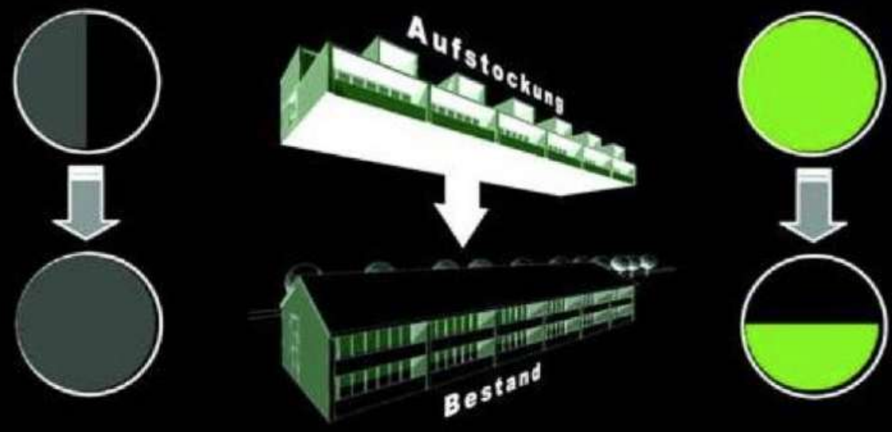
Bewertung des Gebäudes anhand des jährlichen Primärenergiebedarfs.

Nach Sanierung	Einsparung	Ist-Zustand
75.060 kWh 79 kWh/m²	63 %	203.800 kWh 215 kWh/m²

Maßnahmen

Sanierungs-Empfehlungen zur Senkung des Energiebedarfs.

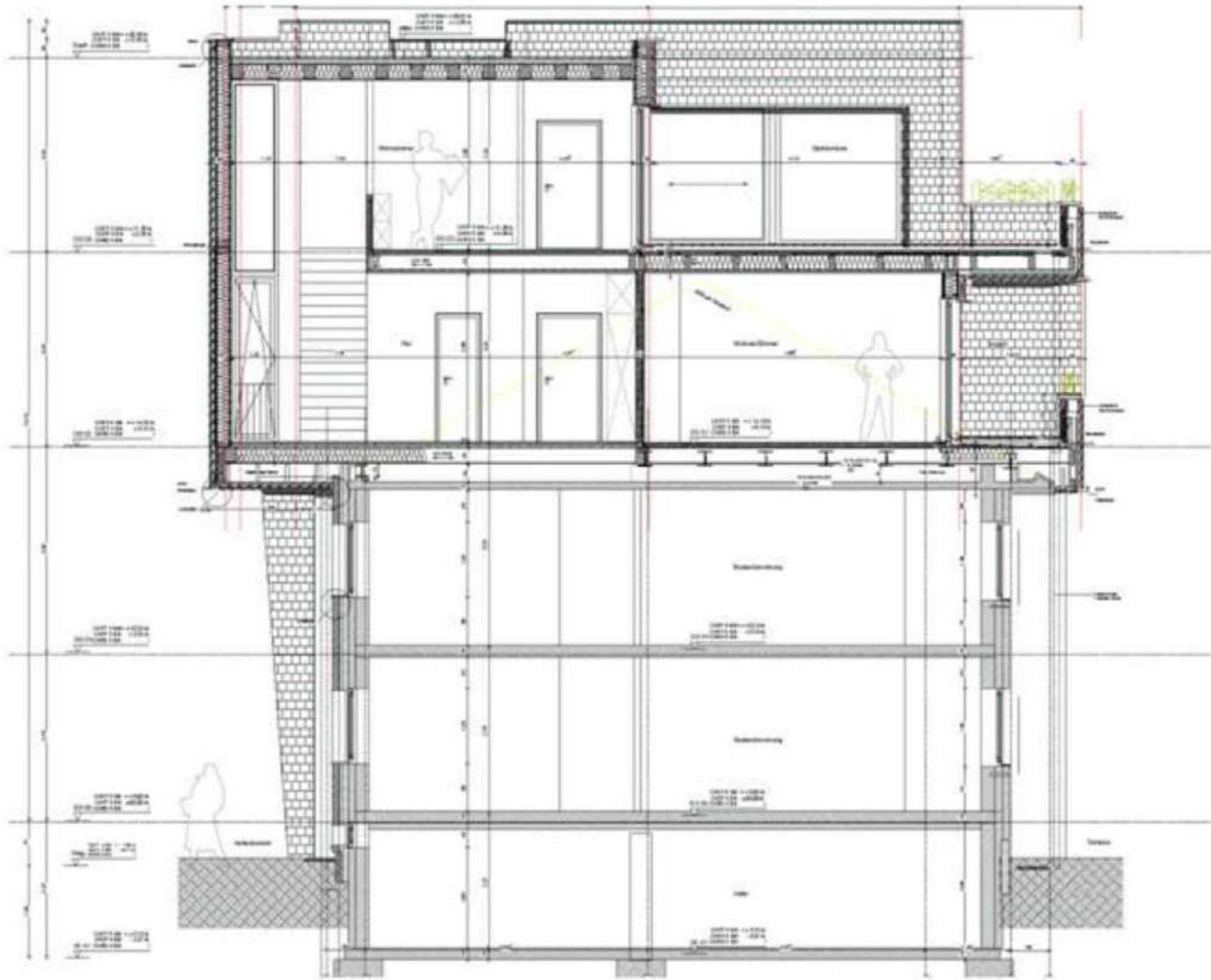
Allgemeines:	Die Konstruktionen einiger Bauteile mussten angenommen werden, da nur wenige Bestandsunterlagen zur Verfügung stehen und kein Zugang möglich war.
Dach:	16cm Poly 035 auf oGD zwischen Unterkonstr. ohne Abdeckung
Außenwände:	12cm MiWo 035 incl. neuer Vormauerschale 12cm WDVS: MiWo 035, mineralischer Putz, auf Putzbau Austausch gegen wärmeschutzverglaste Tür, vorh. isolierverglast
Grund:	6cm PS/PUR-Hartschaum 035 unterseitig, Verspachtelung + Malerarbeiten
Fenster:	Austausch gegen wärmeschutzverglaste Fenster, vorh. isolierverglast



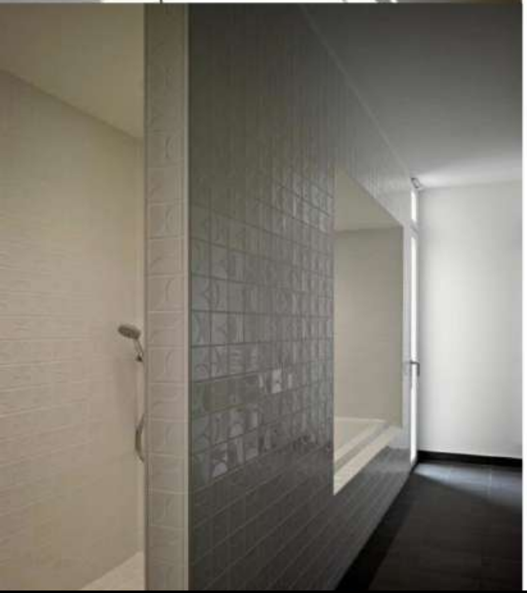
double living space

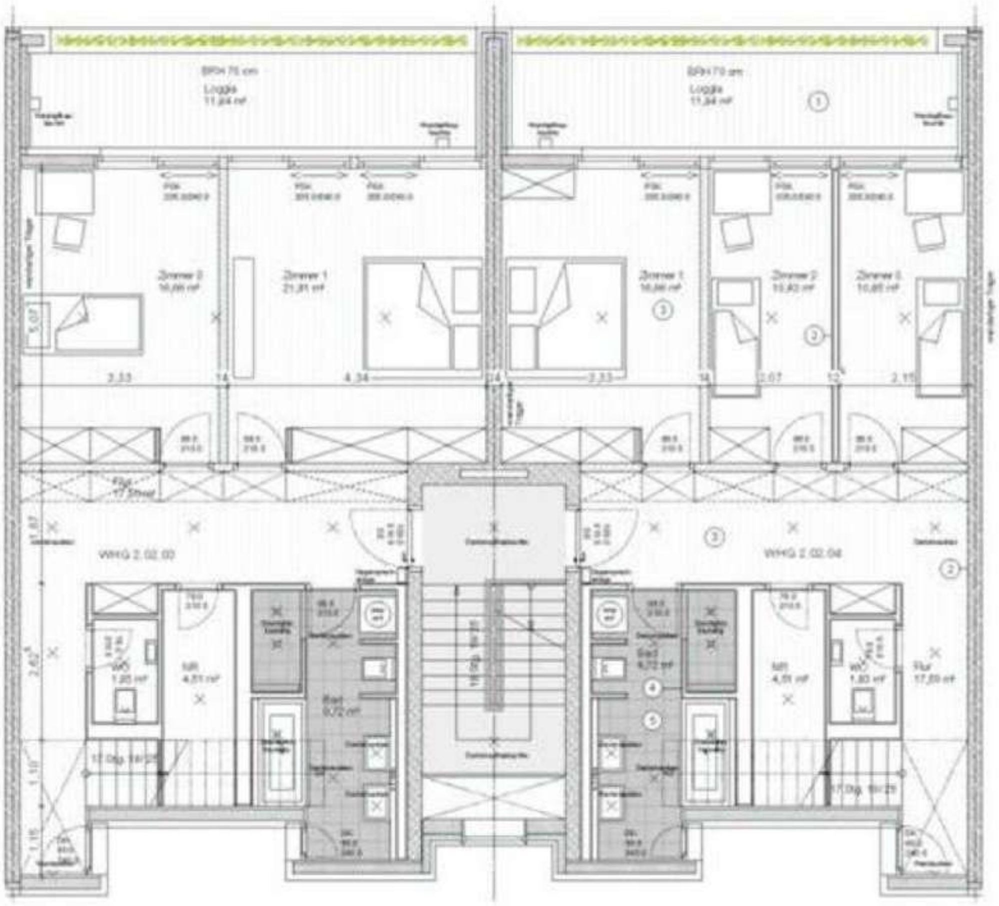
half CO2 emission



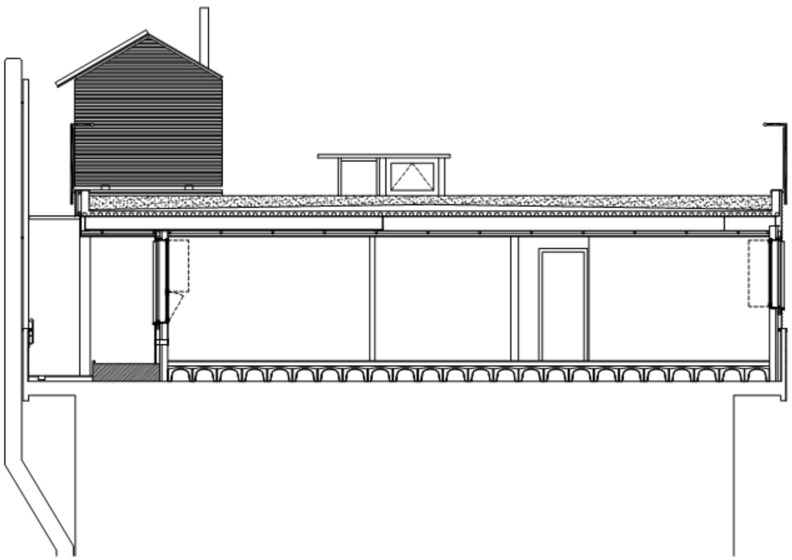
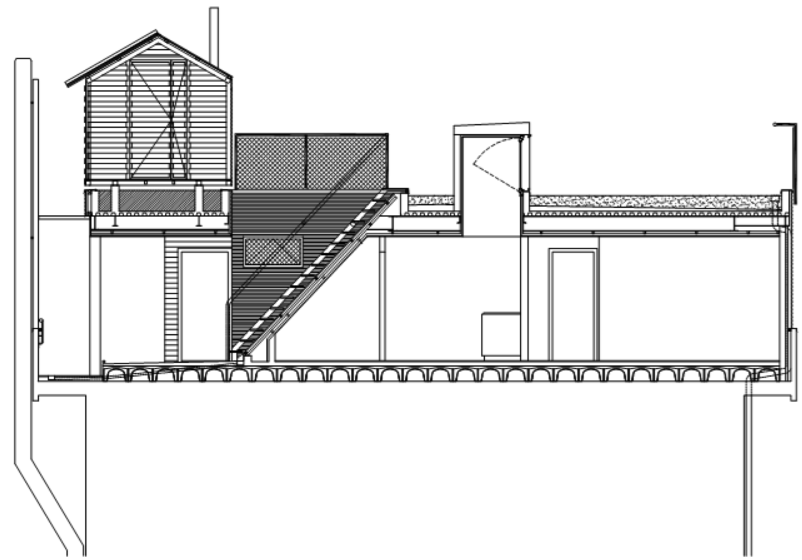
06 Ausschnitt Ausbau Block 2
2. Obergeschoss





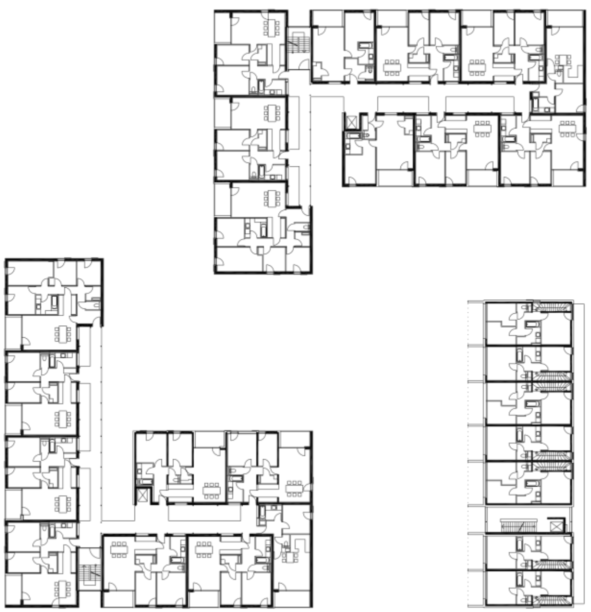
06 Ausschnitt Ausbau Block 2
3. Obergeschoss

studio Albori, Extension of 2 Social Housing Buildings, Cinisello Balsamo, 2007

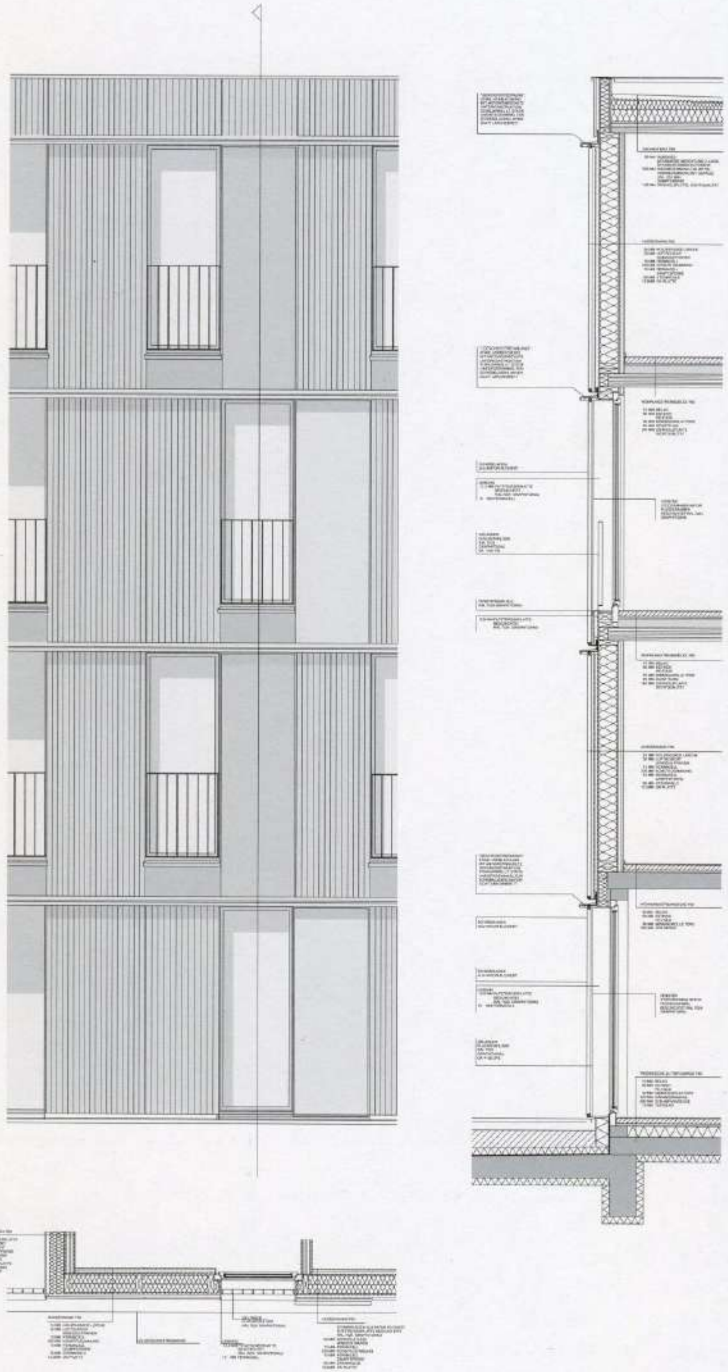



Hermann Kaufmann, Residential Settlement, Müllweg, Vienna, 2006

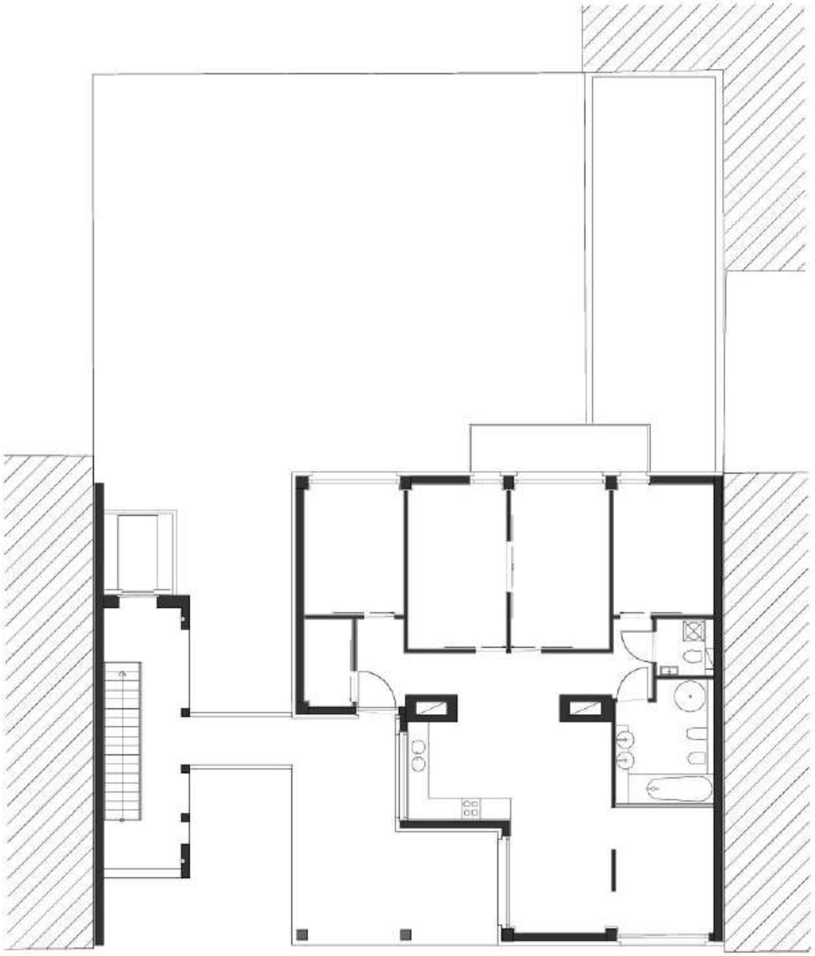
Erdgeschoss



Obergeschoss

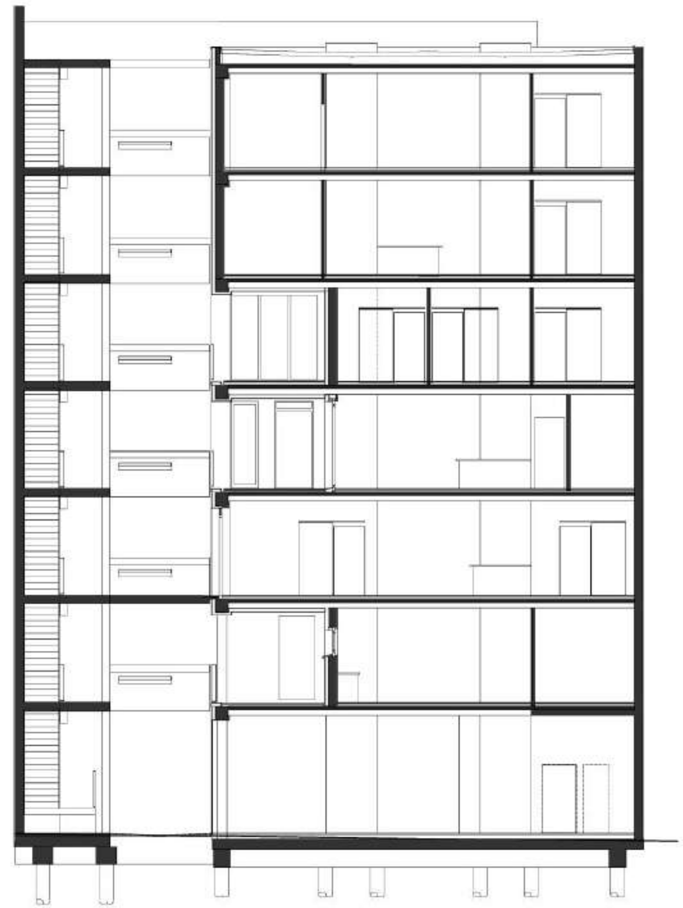


Kaden Klingbeil, Residential 7-Storey Building, Berlin, 2008



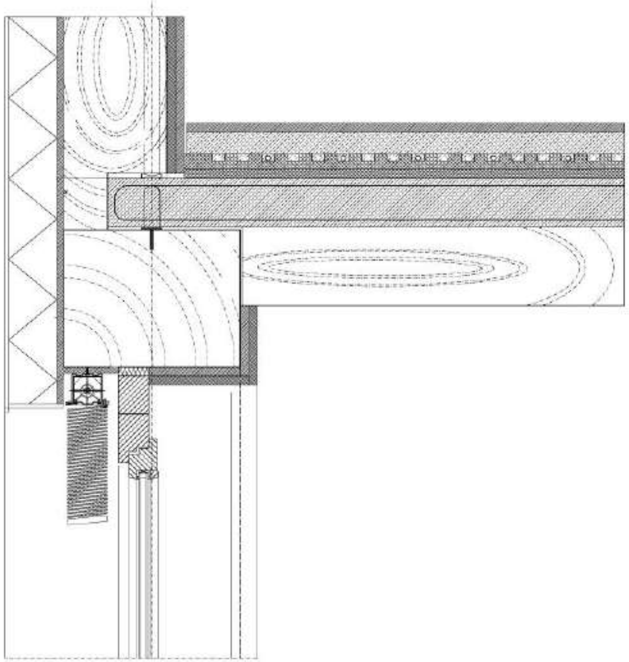
upper-story

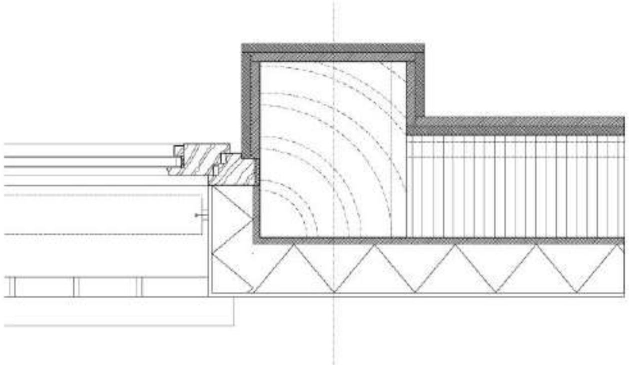
1



section

11





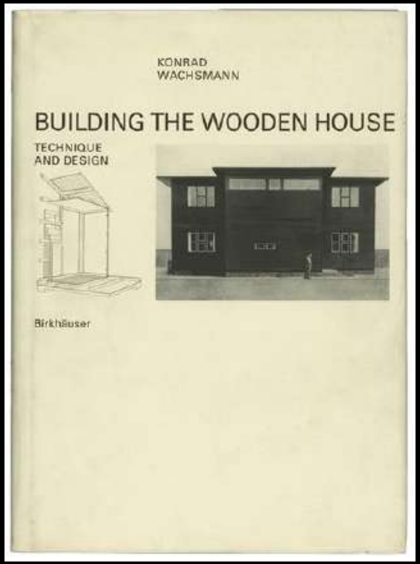
detail

d1


PERI
PEP 20-350

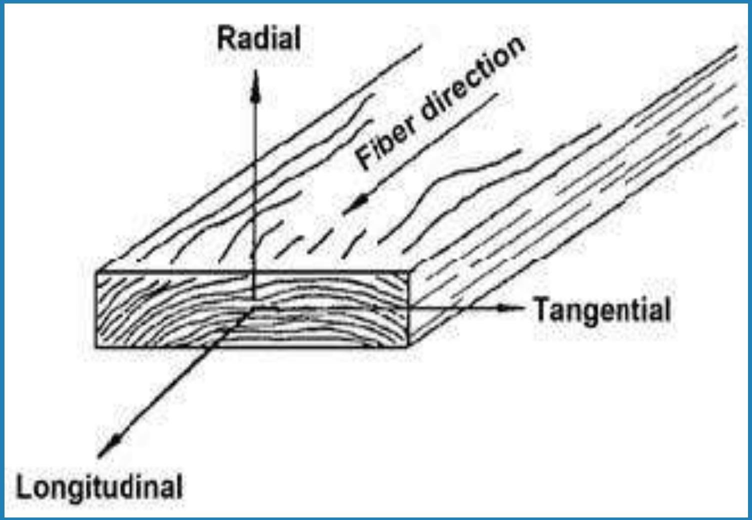
Today the wooden house is produced by **machines in factories**, not by the craftsman in his shop. A traditional, highly developed craft has evolved into a modern machine technology; new applications and new forms are being developed. Here wood finds new opportunities, new forms. Wood as a constructive element in the manner of carpenters no longer responds to the needs of production and structural stability.
On the contrary, as a **material produced in a factory**, worked by machinery, it becomes important as any other building material in terms of technical and economic. Each building that is technically correct has its own characteristic shape. So the new method of wood processing also changes the appearance of the finished structure. This agrees not so much with the common idea of a "wooden building", but it is in fact the organic development of the art of building in wood.

Konrad Wachsmann, Building the wooden House, 1930



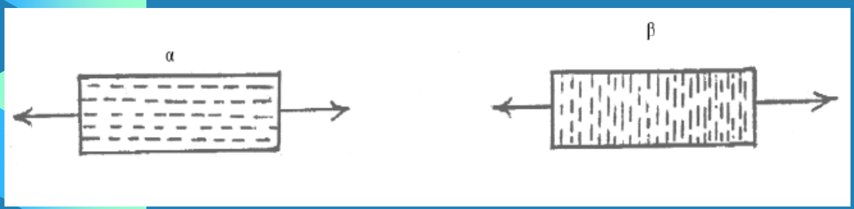
Μηχανικές Ιδιότητες

- Εφελκυσμός
- Θλίψη
- Διάτμηση
- Κάμψη



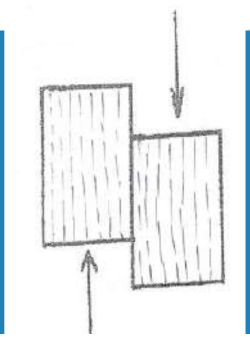
ΜΗΧΑΝΙΚΕΣ ΙΔΙΟΤΗΤΕΣ

Μηχανικές ιδιότητες = είναι το μέτρο της μηχανικής αντοχής του ξύλου, δηλ. της αντίστασής του σε εξωτερικές δυνάμεις, που τείνουν να το παραμορφώσουν.

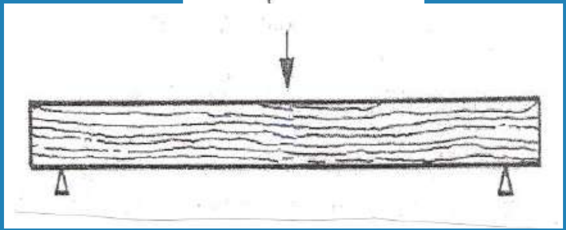


→ **ΕΦΕΛΚΥΣΜΟΣ**

→ **ΘΛΙΨΗ**



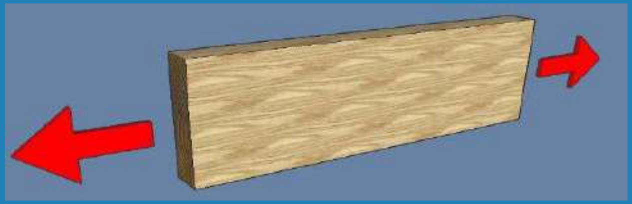
→ **ΔΙΑΤΜΗΣΗ**



→ **ΚΑΜΨΗ**

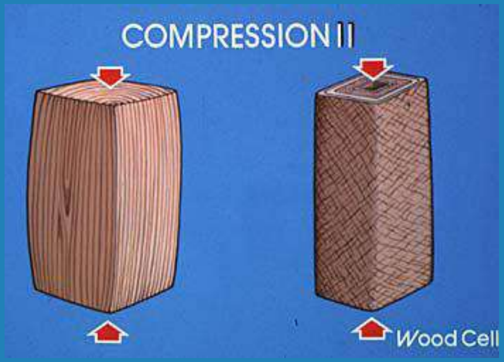
Αντοχή σε εφελκυσμό

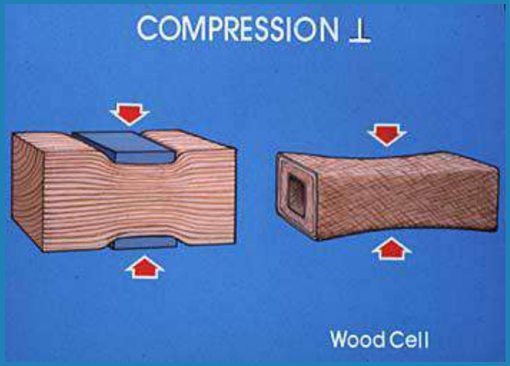
- Αξονικός εφελκυσμός μέχρι 50 φορές περισσότερο από ακτινική και εφαπτομενική φόρτιση.
- Κυμαίνονται από 500 – 1600 Kp/cm^3 αξονικά ενώ εγκάρσια από 10 έως 70 Kp/cm^3 σε τροπικά είδη μπορεί να φτάσει μέχρι 3000 Kp/cm^3



Αντοχή σε θλίψη

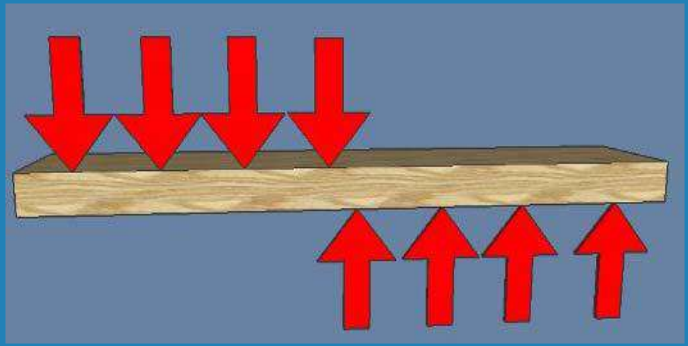
- Αντοχή σε θλίψη αξονικά μέχρι 15 φορές από την εφαπτομενική
- Κυμαίνεται από 250 - 950 Kp/cm^3 ενώ εγκάρσια 10 –200 Kp/cm^3





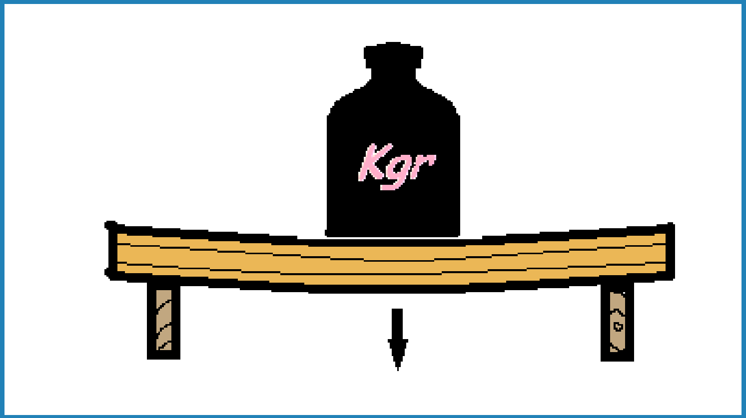
Αντοχή σε διάτμηση

- Αξονική
- Εγκάρσια
- Λοξή
- Κυλιόμενη



Αντοχή σε κάμψη

- Σπουδαιότερος τρόπος φόρτισης



ΠΑΡΑΓΟΝΤΕΣ ΠΟΥ ΕΠΗΡΕΑΖΟΥΝ ΤΙΣ ΜΗΧΑΝΙΚΕΣ ΑΝΤΟΧΕΣ ΤΟΥ ΞΥΛΟΥ

- **Υγρασία ξύλου:**

  Μείωση της υγρασίας του ξύλου, αυξάνει τη μηχανική αντοχή του. Είναι γνωστό ότι όσο πιο ξερό είναι ένα ξύλο, τόσο πιο γερό είναι.

- **Πυκνότητα ξύλου:**

  Η πυκνότητα αποτελεί τον καλύτερο δείκτη ποιότητας και μηχανικής αντοχής του ξύλου. Ξύλο με μεγάλη πυκνότητα πάντοτε έχει και μεγάλη μηχανική αντοχή.

- **Θερμοκρασία:**

  Η μηχανική αντοχή ελαττώνεται με την αύξηση της θερμοκρασίας.

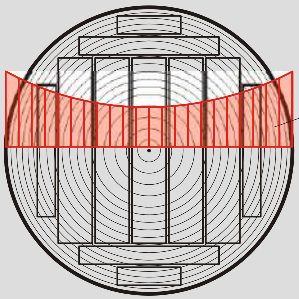
- **Σφάλματα δομής:**

  Η παρουσία σφαλμάτων στο ξύλο (π.χ. ρόζοι, ραγάδες) προκαλεί μείωση της μηχανικής του αντοχής.

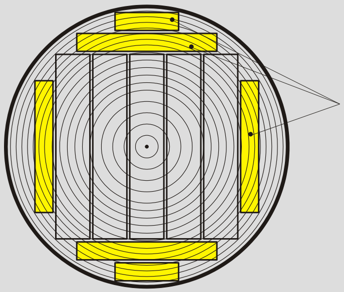
- **Διάρκεια φόρτισης:**

  Αρνητική επίδραση (επιστήμη Ρεολογίας - παραμόρφωσης και ροής των υλικών)

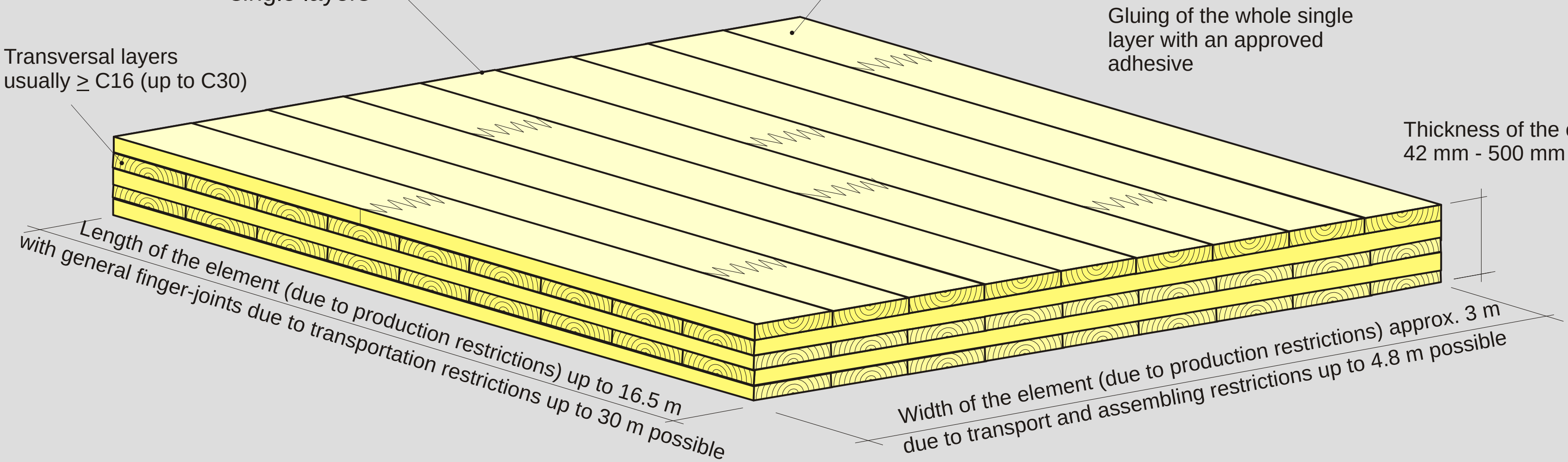
Distribution of mechanical properties in the log



Utilisation of side-boards



5-layered CLT-element



Unternehmen/Zentrale	Produktion 2007 in m³	Kapazität-in m³	Besonderheiten
Binder Holzbausysteme, Unternberg	20.000[1]	50.000	5-Holzarten mit 3-Oberflächen-Bearbeitungen
HMS Bausysteme, Schondra/DE	10.000	15.000	Individuelle und montagefertige Produkte
Finnforest Merk, Aichach/DE	15.000[1]	15.000[1]	–
Wigo/Ing. E. Roth, Feldkirchen	–	–	Prod.-Start Frühjahr 2008, primär Eigenversorgung
KLH Massivholz, Katsch/Mur	50.000	150.000	Technische Beratung
Lignotrend, Weilheim-Bannholz/DE	20.000	20.000	Astreine Oberfl. mit integrierter Schall-Absorption
Martinsons, Bygdsiljum/SE	6.000[1]	6.000[1]	–
Mayr-Melnhof Systemholz, Gaishorn	–	–	Neue Produktion 2008: 20.000 m3, Kap. 70.000 m3
Moelven, Moelv/NO	6.000[1]	6.000[1]	–
Moser, Taisten-Welsberg /IT	3.000	3.000	Spezialist für Detaillösungen
Pius Schuler, Rothenthurm/CH	k. A.	k. A.	–
Schilliger, Küssnacht/CH	k. A.	k. A.	–
Stephan, Gaildorf/DE	k. A.	k. A.	Produktion seit Oktober, FLEXcross
Stora Enso Timber, Bad St.Leonhard	–	–	Kapazität 2008 61.000 m3, Fugen verleimt

Alle in der Tabelle enthaltenen Angaben wurden von den jeweiligen Unternehmen gemacht. Die Tabelle erhebt keinen Anspruch auf Vollständigkeit.
1) Holzkurier-Schätzung
© timber-online 2007

Autor: DI Antonio Fuljetic
06.11.2007, 08:03 MEZ

Arguments PRO CLT:

→ **Massive construction, less layers in the construction, buffer for heat and moisture**

→ **High degree of prefabrication possible**

→ **Easy assembling and short duration for erection**

→ **Flexibility of utilisation**

Arguments CONTRA CLT:

→ **High price**

Production volume:

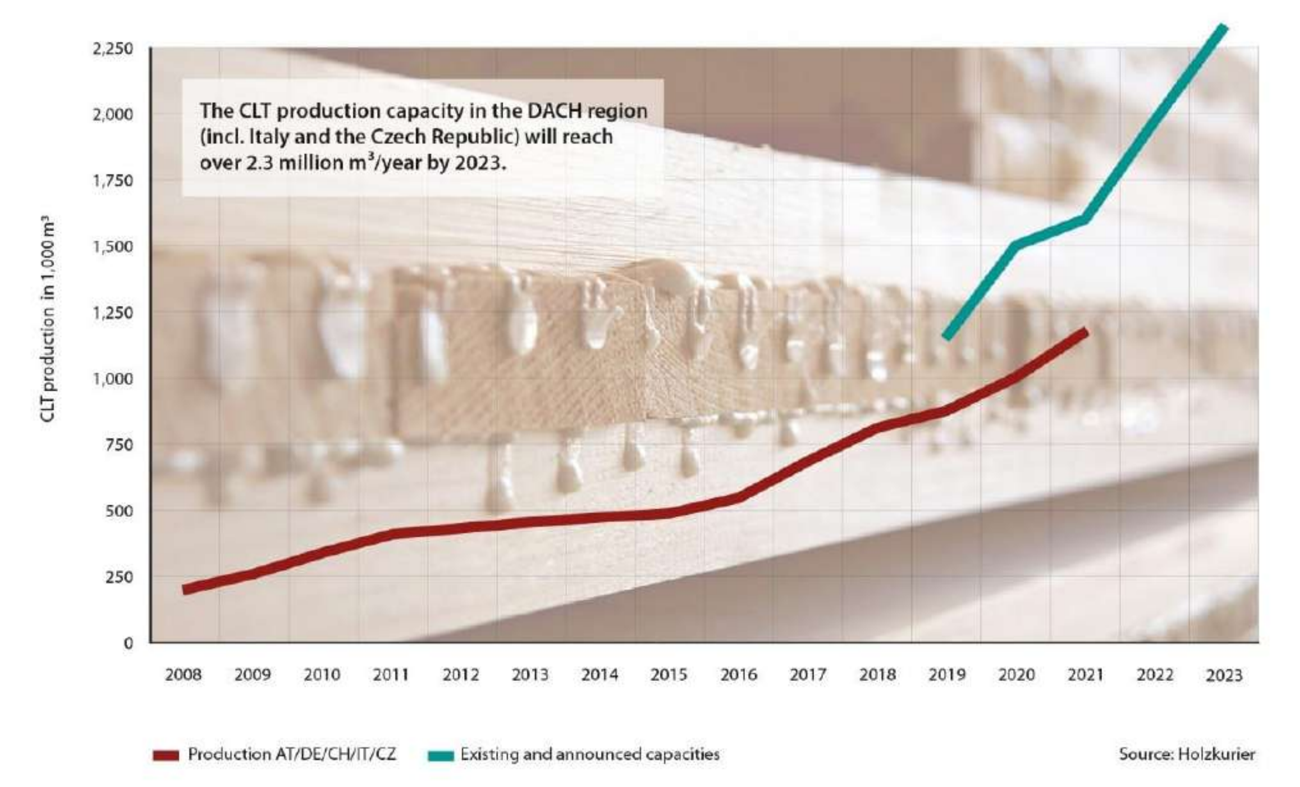
2008 About 400.000 m³ (+52 %)

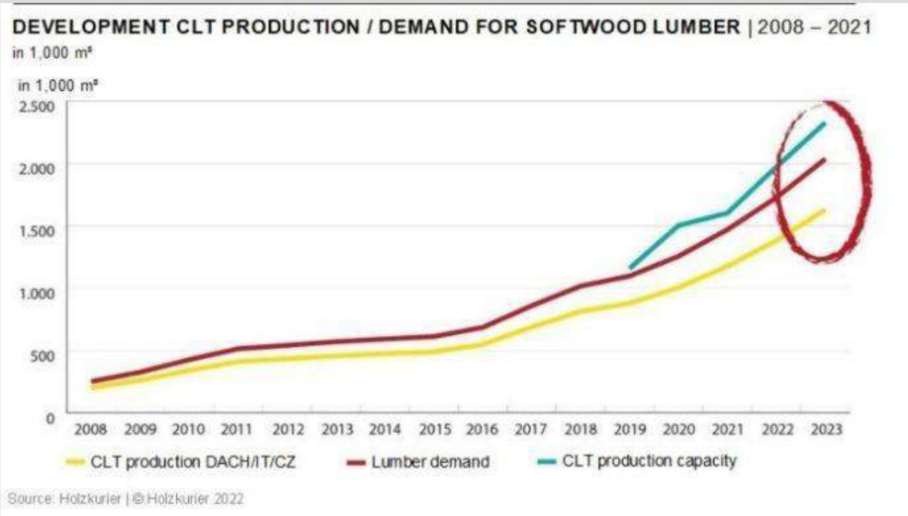
→ **To high amount for the market**

→ **Price will decrease (about 20 % in the next three years)**

Source: Timber Online / 2007

CLT – Production volume



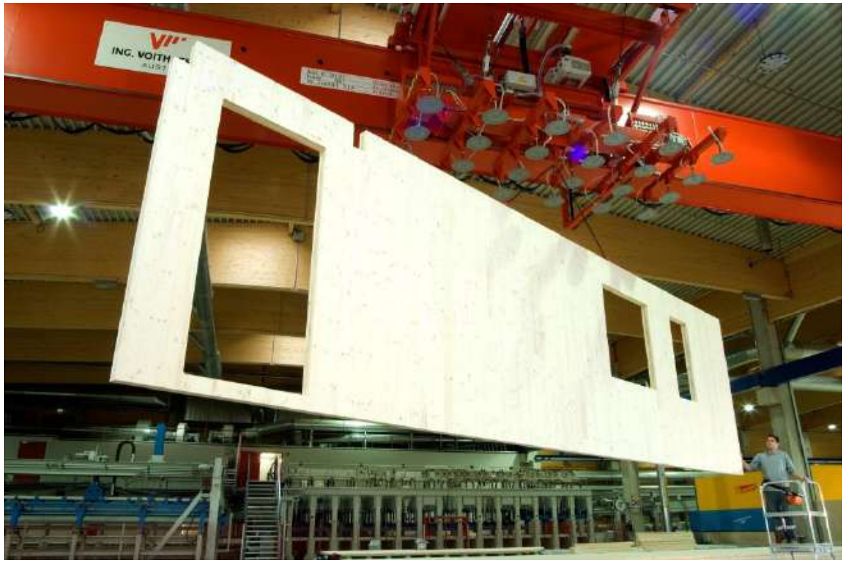


CLT production, CLT capacity and demand for softwood lumber from 2008 to 2023 © holzkurier.com

Cross-Laminated Timber

- Laminations of selected dimensional lumber.
- Each adjacent layer is oriented with grain perpendicular.
- Analagous to plywood made from solid wood rather than veneer.

Cross-Laminated Timber



Cross-Laminated Timber

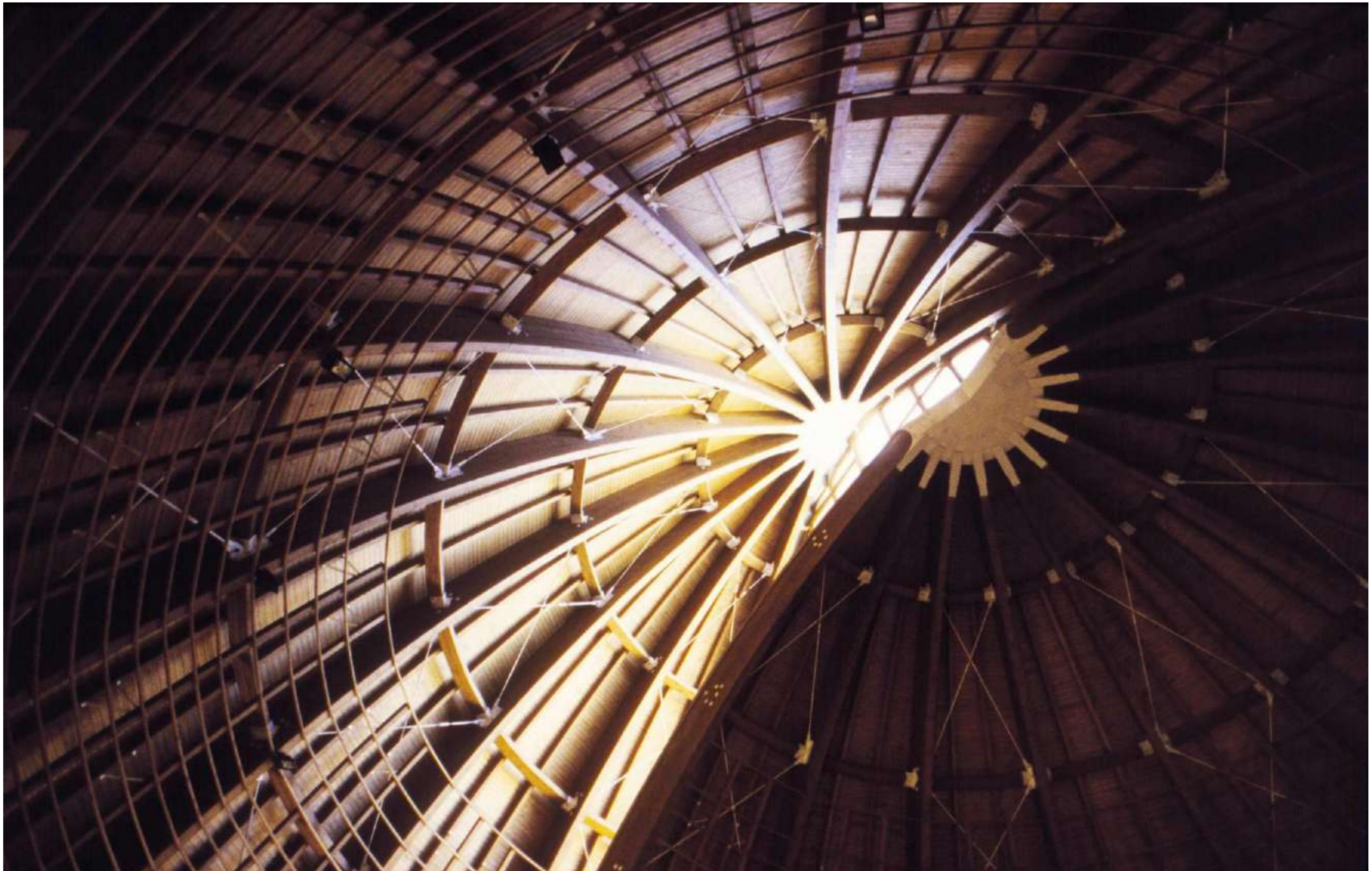
Nine-storey residential building (wooden construction)

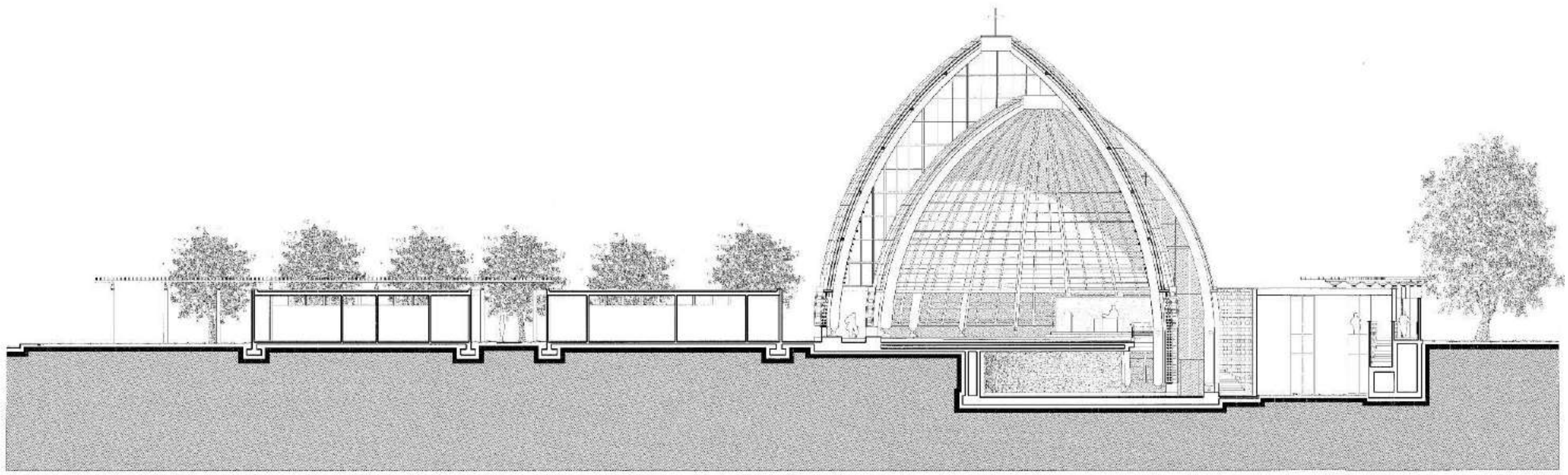
(Waugh Thistleton Architects)

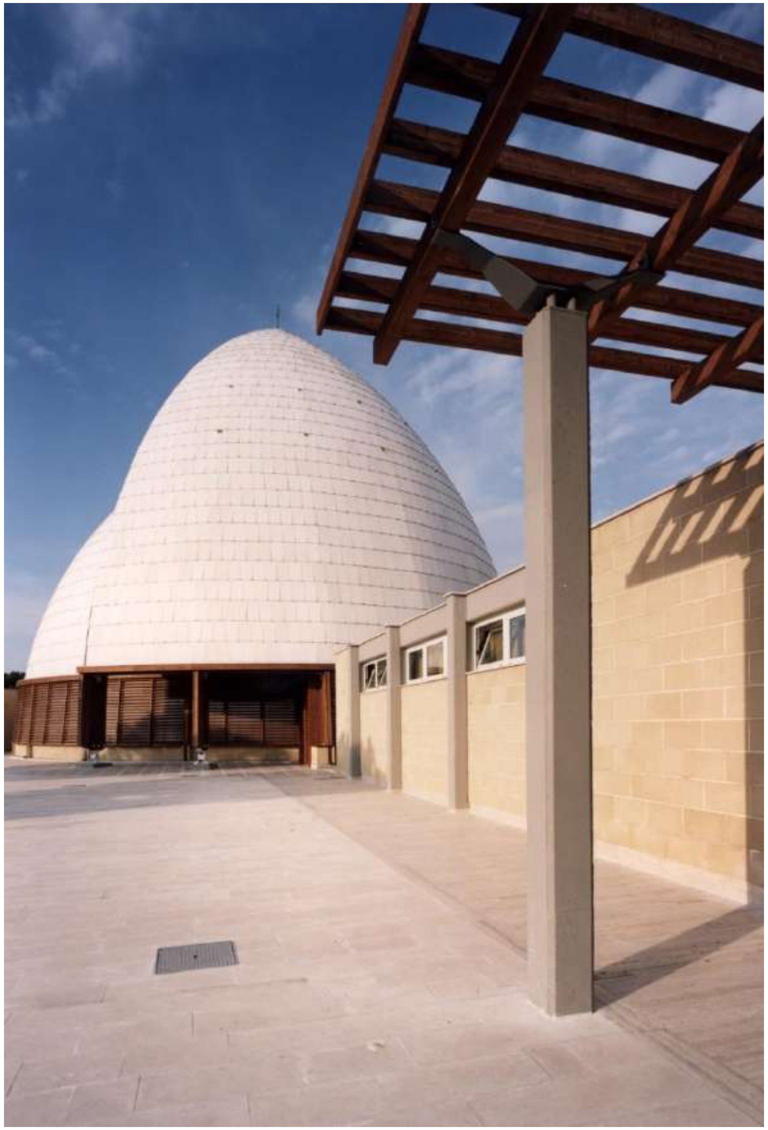
GLT

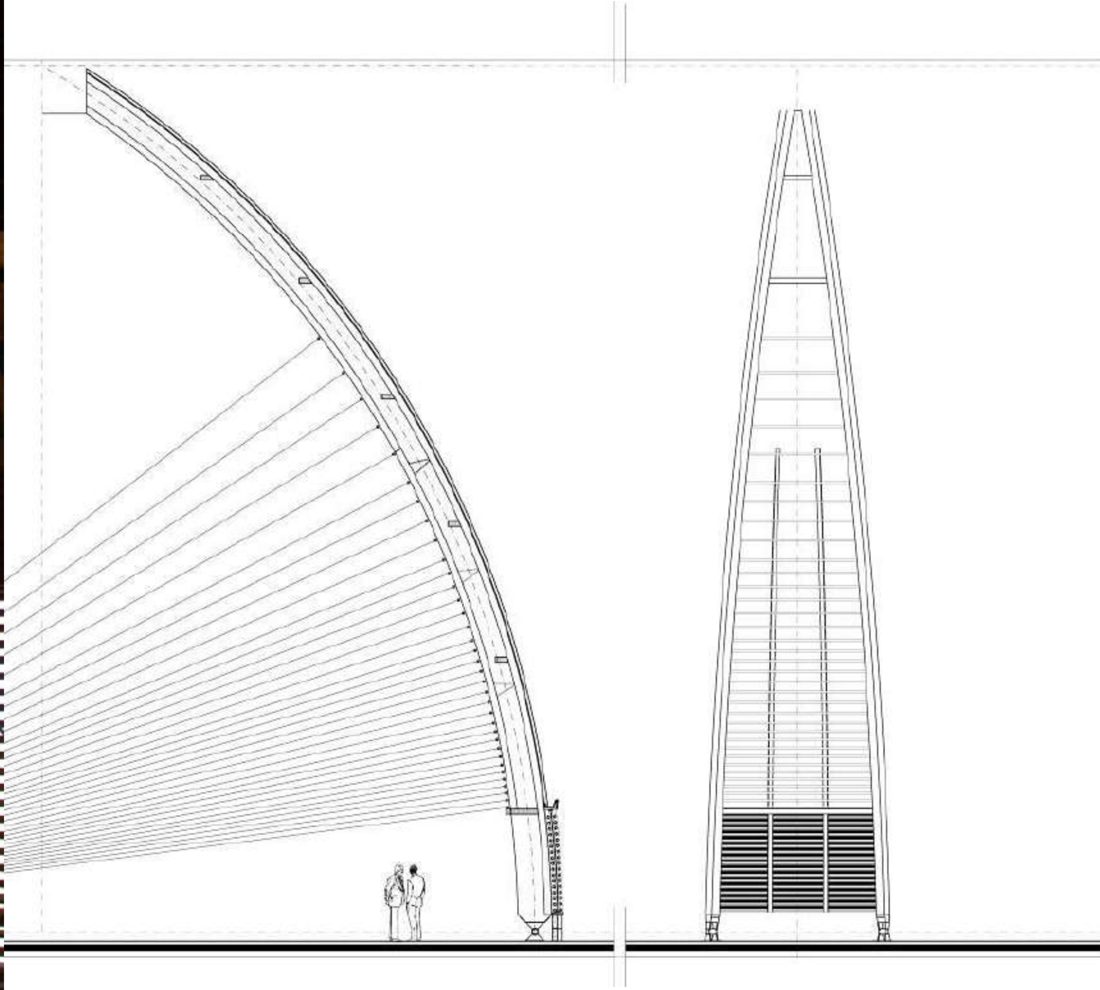
Glued Laminated Wood

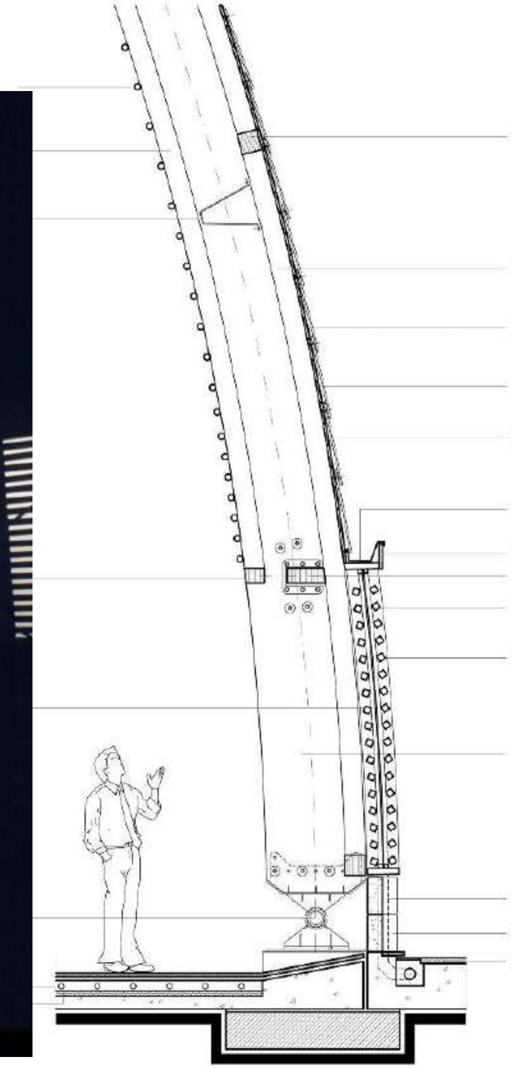
Ottavio Di Blasi, Church of St. Maria del Soccorso, Bari, 2005







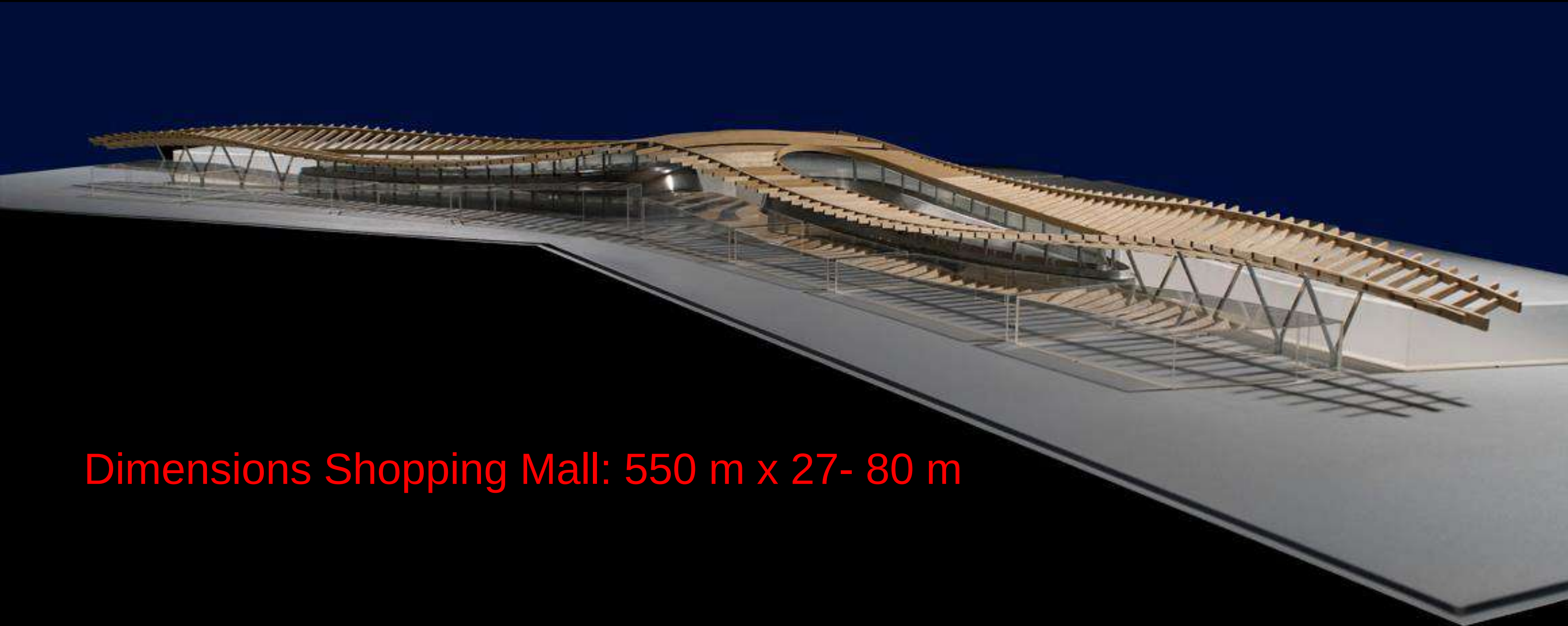



9
5


ATP, G3 Shopping Resort, Gerasdorf (A), 2012


HORNBACH
EKZ
FMZ

Roofing Shopping Mall

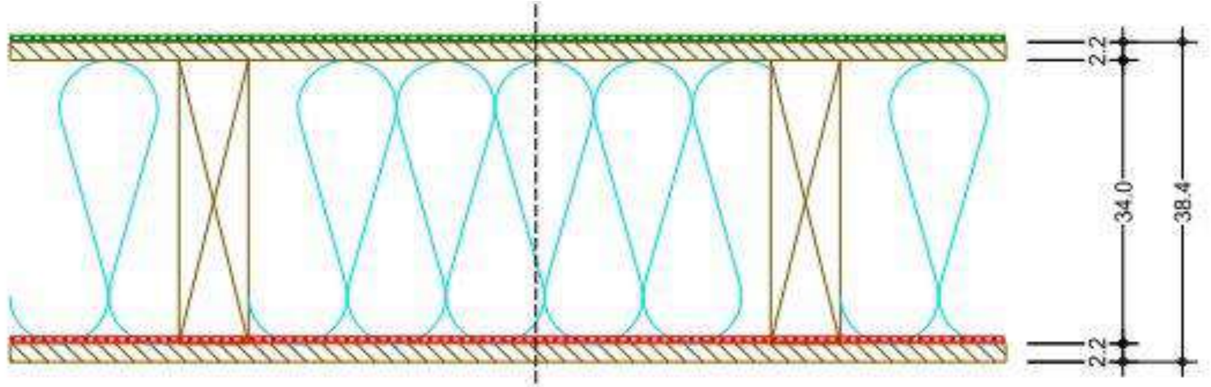


Dimensions Shopping Mall: 550 m x 27- 80 m

Roof Construction in Frame Work

Stratigrafia degli elementi pacchetto copertura

0,18 cm	guaina FPO
0,20 cm	feltro di separazione (διαχωριστικό)
2,20 cm	pannello OSB 3 (πάνελ OSB)
34,00 cm	telaio portante 34 cm (φέρον πλαίσιο)
	coibentazione 34 cm
	freno antivapore
2,20 cm	pannello OSB 3 (πάνελ OSB)

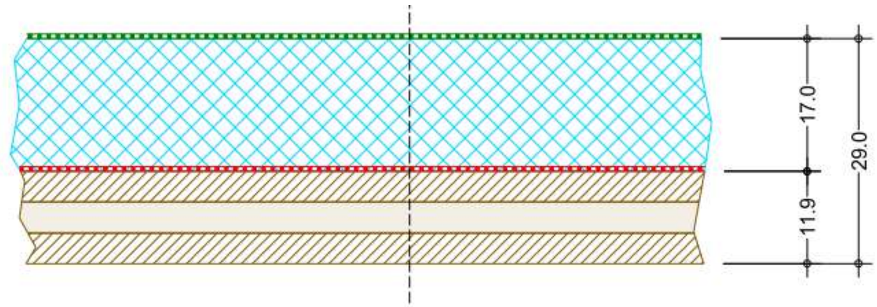


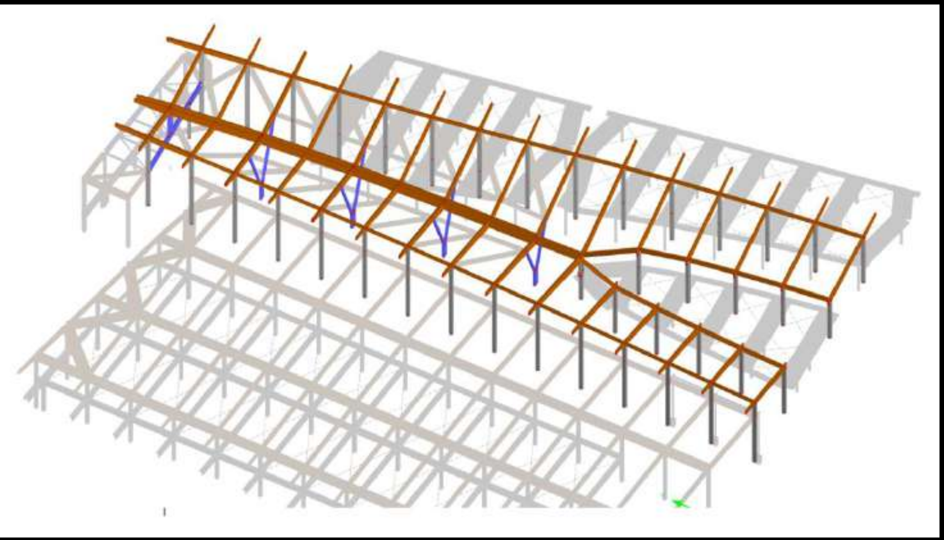
Στοιχεία στέγης

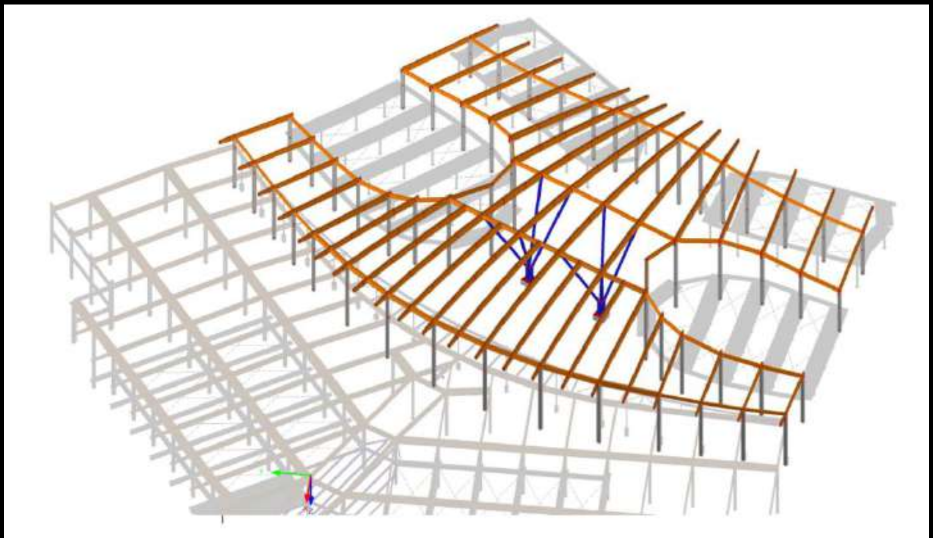
Roof Construction in XLAM

Stratigrafia degli elementi in XLAM

0,18 cm guaina FPO (Thermoplan T18)
17,00 cm coibentazione (polistirolo estruso) 0,037 W/mK
freno antivapore sd=1.800 m (μόνωση)
11,90 cm pannello XLAM (πάνελ)







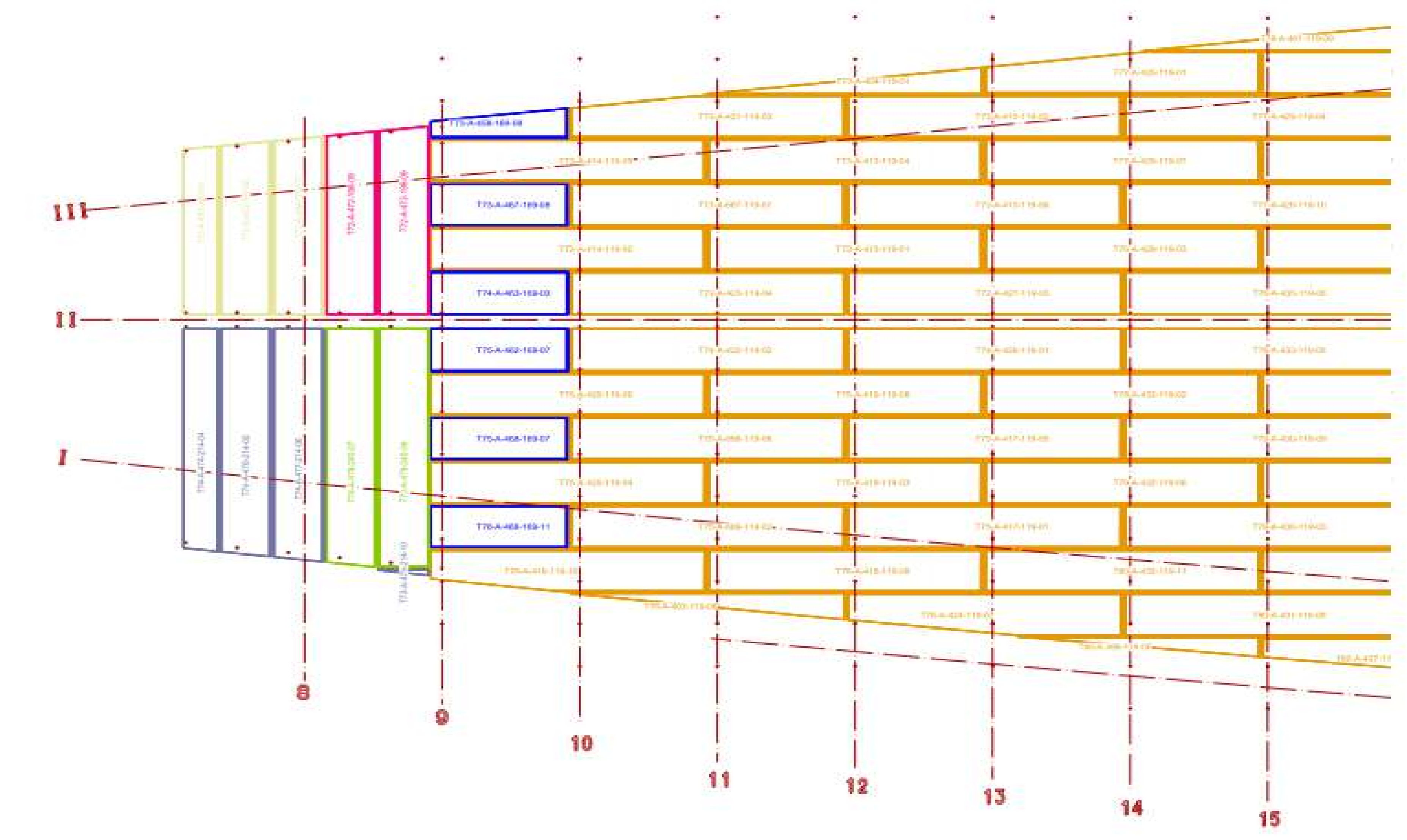
Each connection has a different geometry and inclination

Cantilevered Roof up to 8 m

Length of the Beams up to 80 m

XLAM Panels

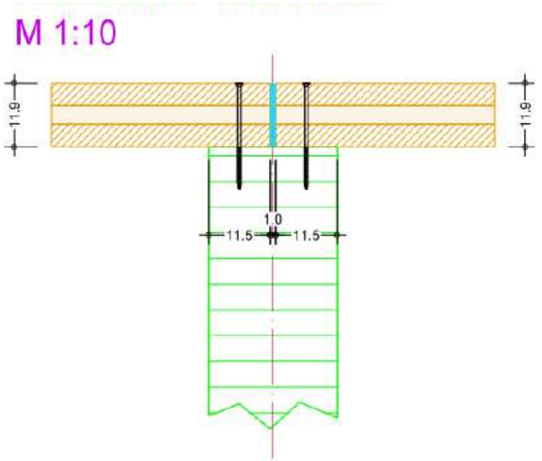
Dimensions : up to 16 m x 3 m
Thickness: fino a 40 cm
Glue: PU, melaminic resin
Time for gluing: ca. 20 min.
Press: up to 1,2 N/mm²


III
II
I
8
9
10
11
12
13
14
15

Tickness XLAM Panels

- Platte 94
- Platte 106
- Platte 112
- Platte 119
- Platte 134
- Platte 146
- Platte 160
- Platte 169
- Platte 173
- Platte 184
- Platte 198
- Platte 214
- Platte 240

Montage of 2 XLAM panels on a GLT Beam



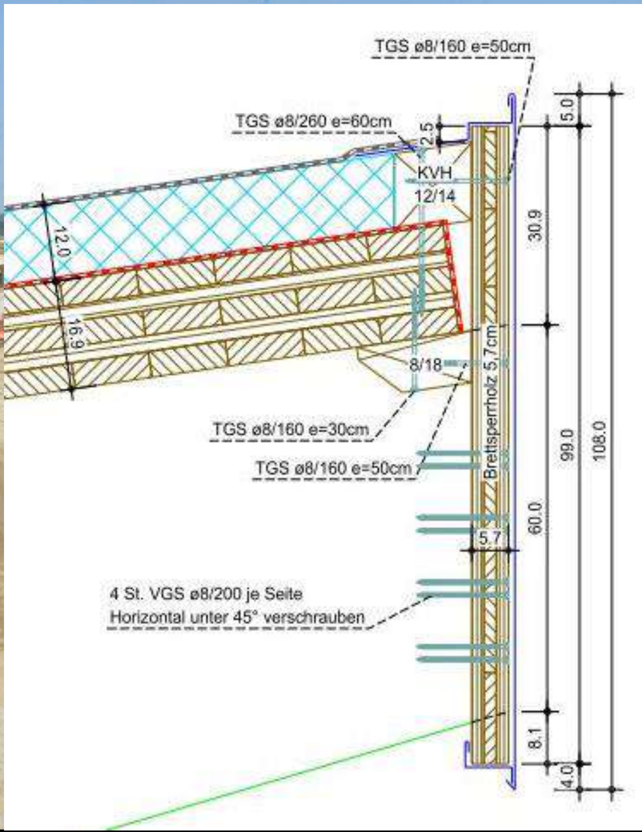
Collegamento dei pannelli

Viti con testa allargata

119	2x7 Tellerkopfschrauben 8/100
126	2x9 Tellerkopfschrauben 8/100
132	2x7 Tellerkopfschrauben 8/100
150	2x14 Tellerkopfschrauben 8/100
165	2x14 Tellerkopfschrauben 8/100
182	2x9 Tellerkopfschrauben 8/100
196	2x9 Tellerkopfschrauben 8/100
209	2x9 Tellerkopfschrauben 8/100
249	2x14 Tellerkopfschrauben 8/100


Detail Mall 06a
M 1:10
Innenrinne
Achse II, 7-21, 64-73
BSH
17/20
EPS
EPS
24.0
70.0
24.0

Realizzazione dei bordi della copertura:
Lastra verticale pannello XLAM 57 mm, collegamento con viti



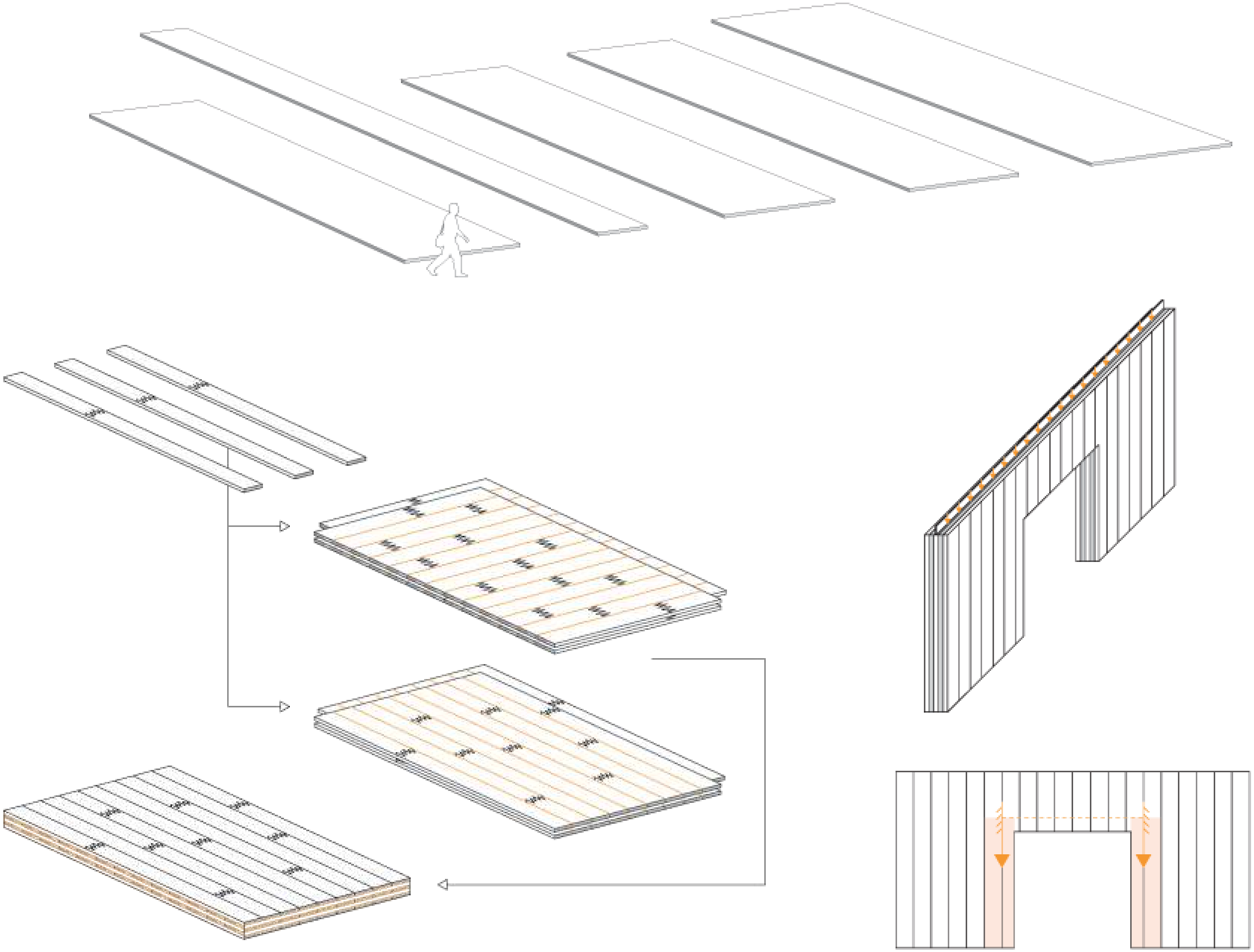

G3

New Wood

CLT Cross Laminated Wood

BSP Brettsperrholz

XLAM Pannello a Strati Incrociati

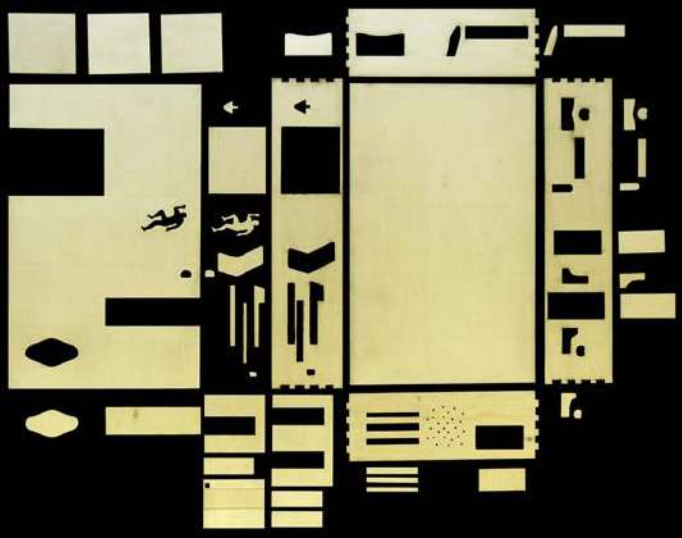



UNITEAM
CNC MACHINING CENTERS
extra

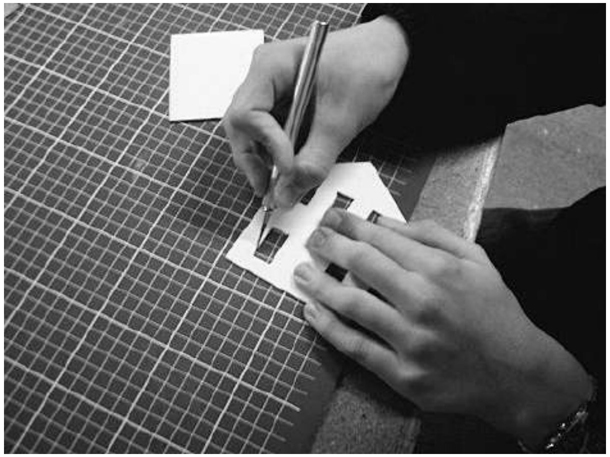
Thanks to the transfer of the main working processes in the factory it's possible, even during the bad seasons (too hot, too cold) to prepare parts of the building and set them aside. The construction time is much smaller than in a traditional brick building, so there are lower costs of construction and at the same time the investment pays for itself quickly. The construction process itself offers great advantages.

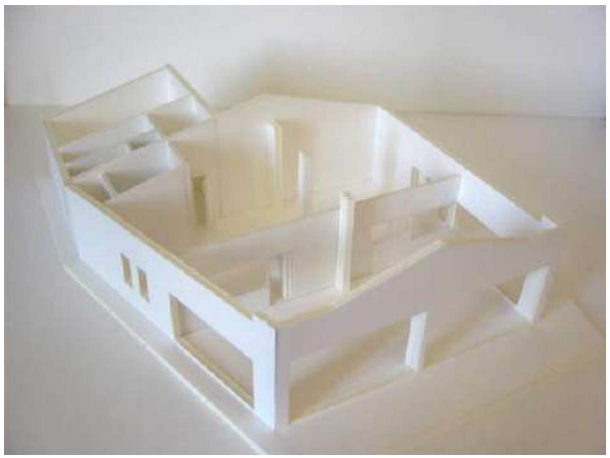
- First of all, it is accomplished in the form of a montage completely dry, only the foundations are made of masonry. So, in general, there is no moisture.
- While parts of the building are predisposed in the factory, the foundations are realized on site. This also means a considerable time saving, since the structure of the house is produced at the factory during the period when the foundation is built. On the construction site will then only be an assemblage of parts already delivered. The house can be built to the most extreme temperatures.
- Since the thickness of the wall of a wooden house, with the same insulation capacity, are significantly lower than those of a brick house, a wooden construction admits, for the same space, less cubic capacity, and is therefore more economic.

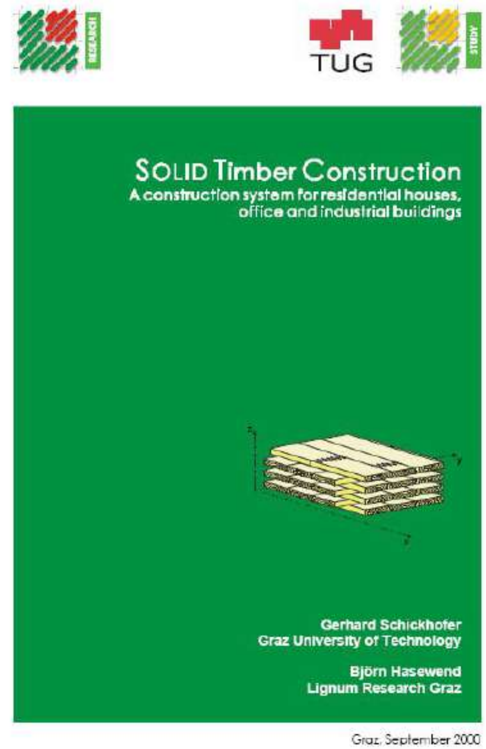
Konrad Wachsmann, Building the wooden House, 1930



CLT Cross Laminated Timber

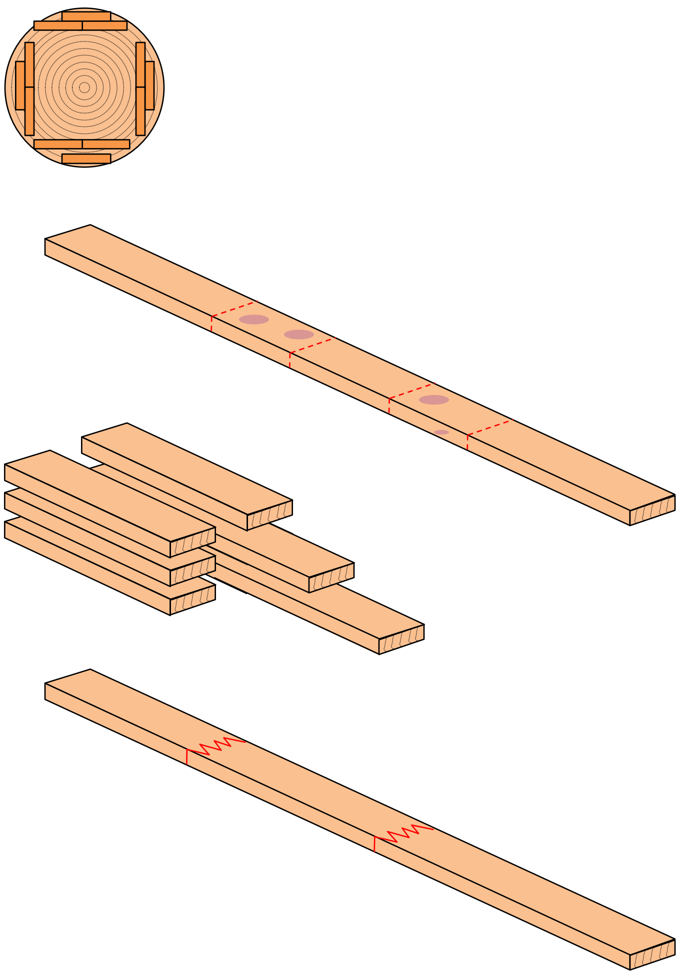


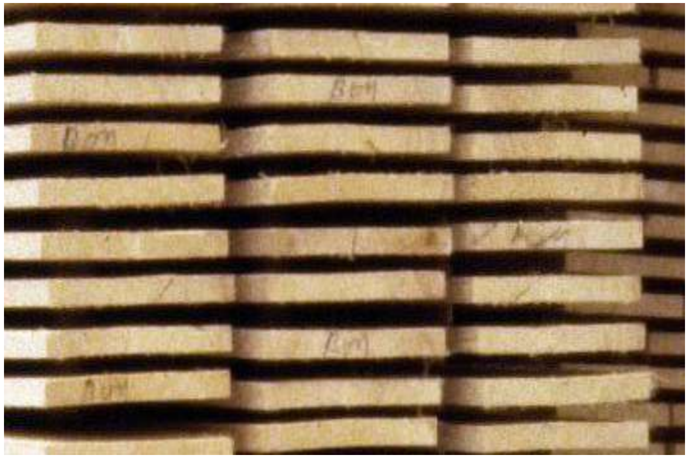


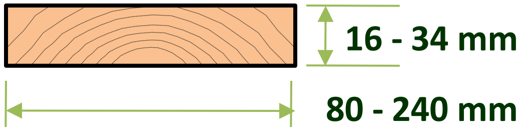


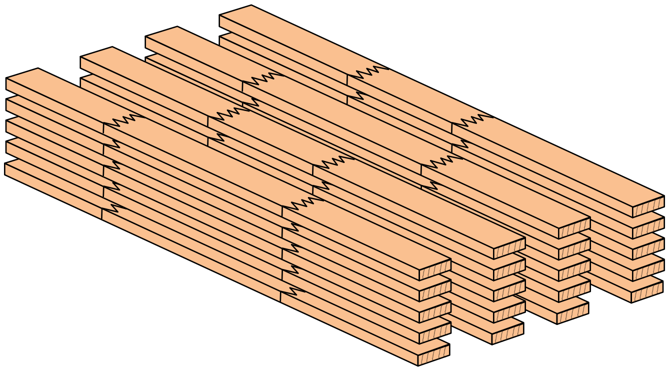
This new material appears in 1998

Raw material- the lamellae

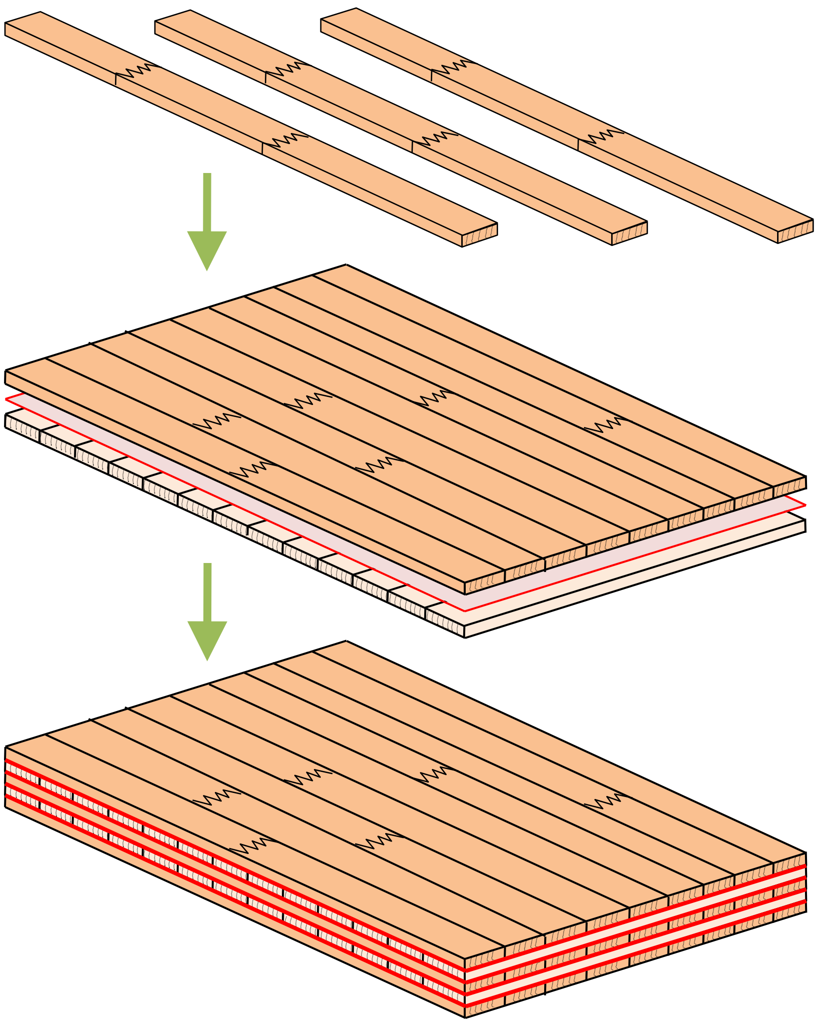








CLT Panels. The concept



unidirectional Layers
- Realized by several lamellae
- Glued on on the other

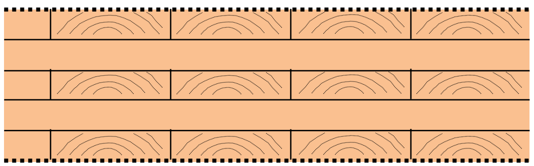
Fiber direction of the layers
-"glued"
- Adjacent Layer rotated by 90°

Structural gluing
- Same adhesive and technic of the e GLT
- Innovative processes

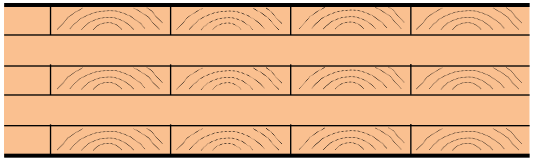
The product – CLT

The product – CLT

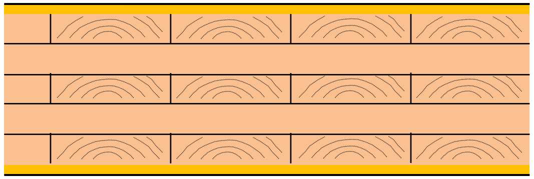
surface



- Not exposed
- ”raw"

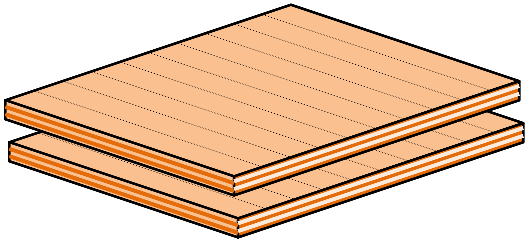


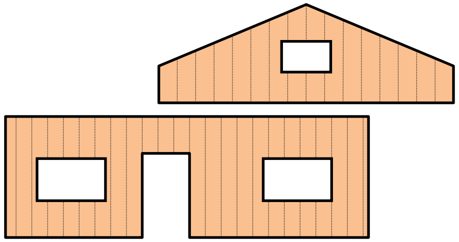
- facing
  - shaving
  - smooth
  - …

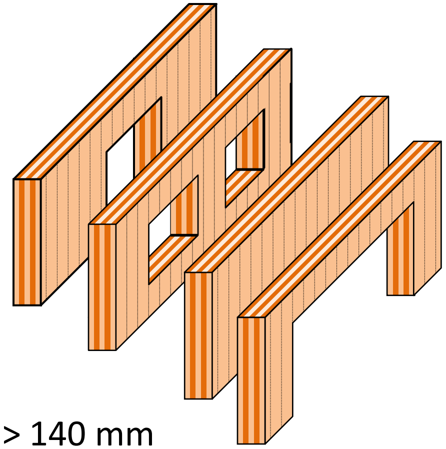


- Additional layer
- Facing slab
- other

Structural behavior- Resistence and stiffness

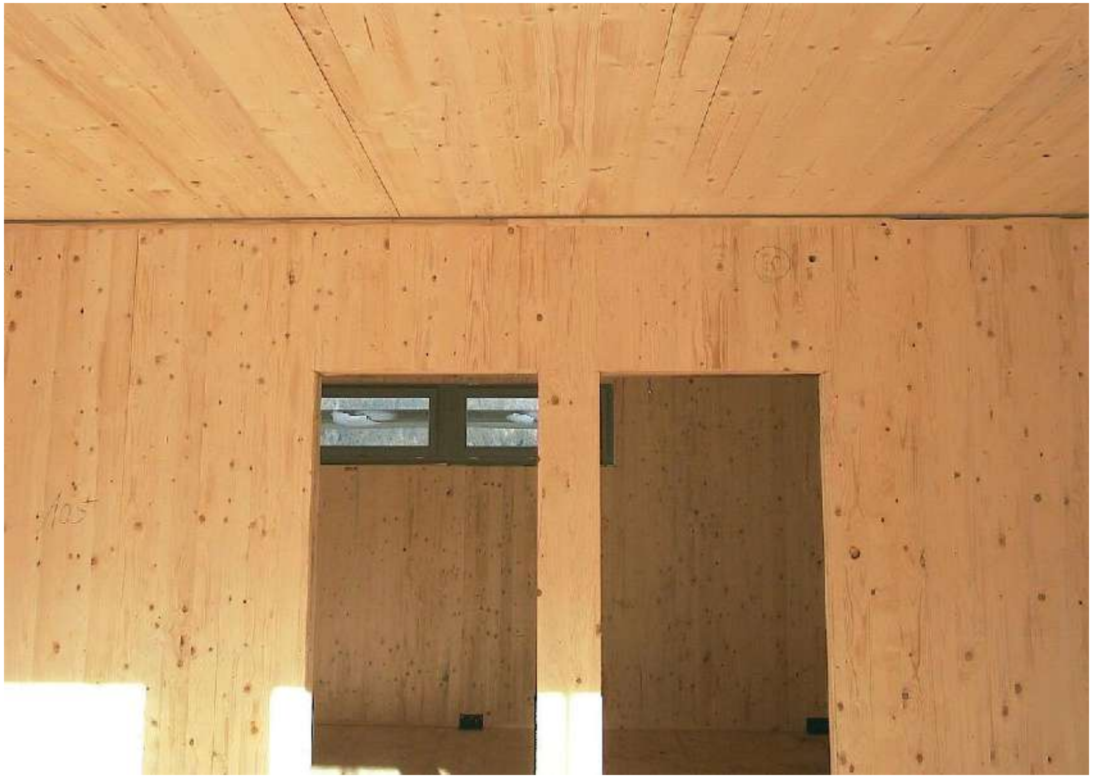






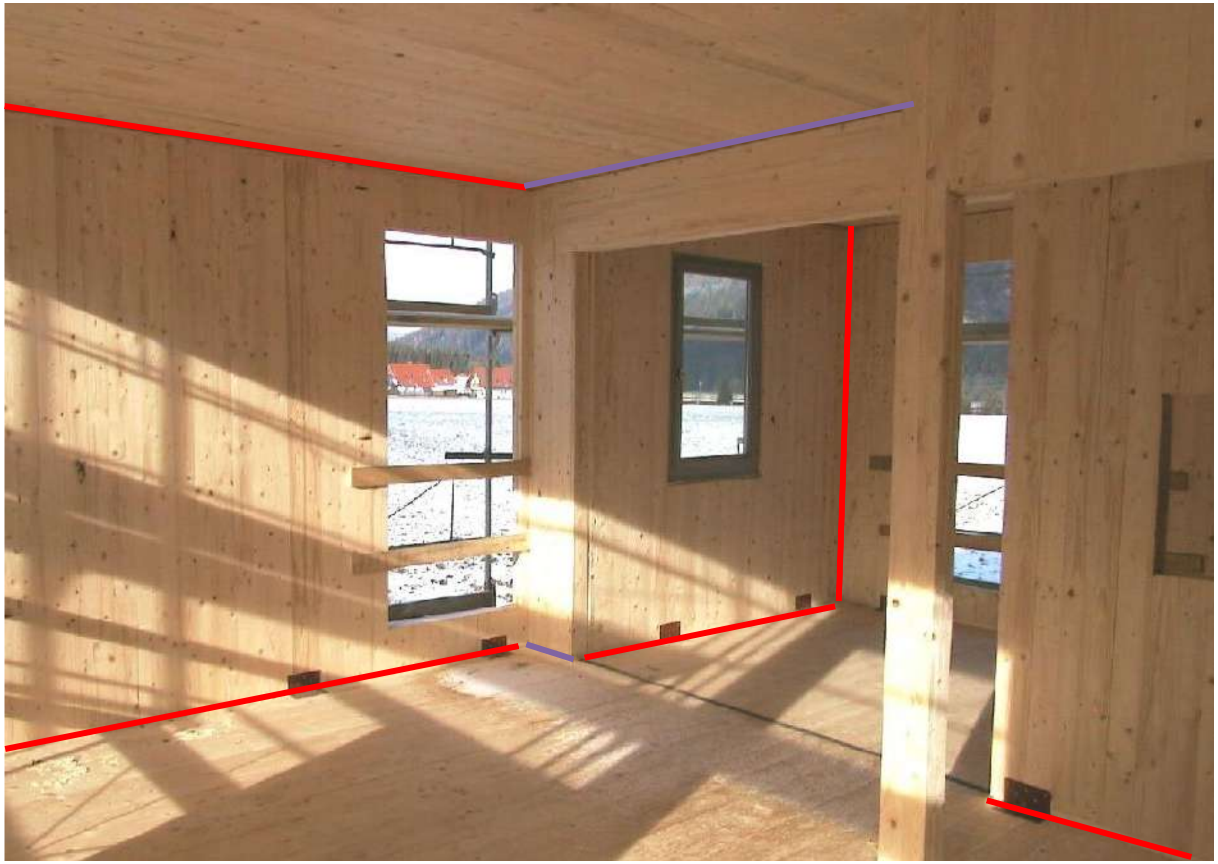
- Wall with openings
  - Wall with “incorporated” lintel
  - massive vertical slab

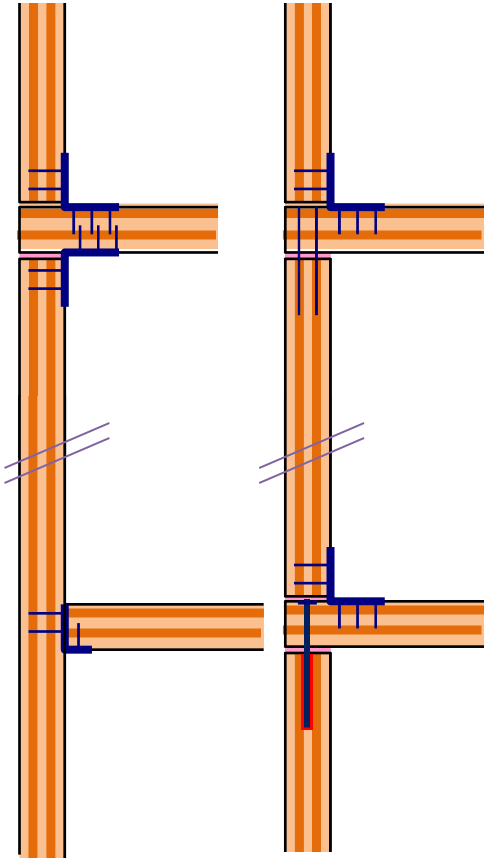
Thickness:
- Floor: > 140 mm
- Wall: > 100 mm



The wooden construction with CLT Panels

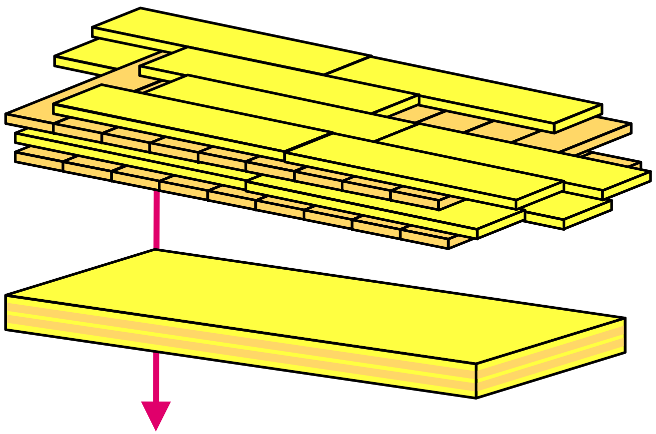
The connection between the panels
- Key elements
- Technically easy and effective

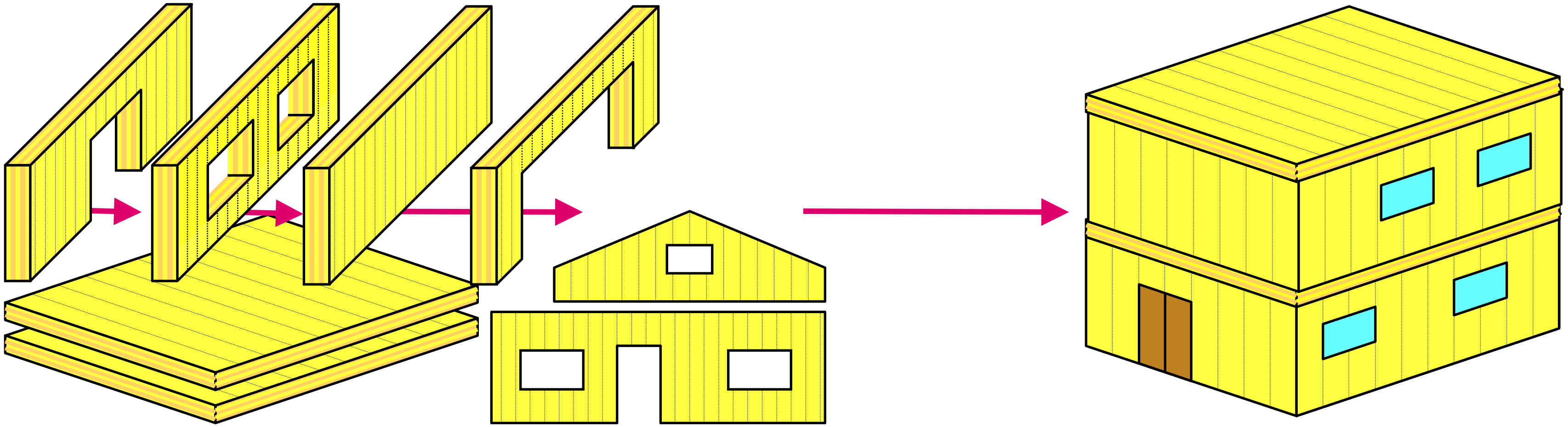




Structural panel in big dimensions

CLT Panels as structural typology

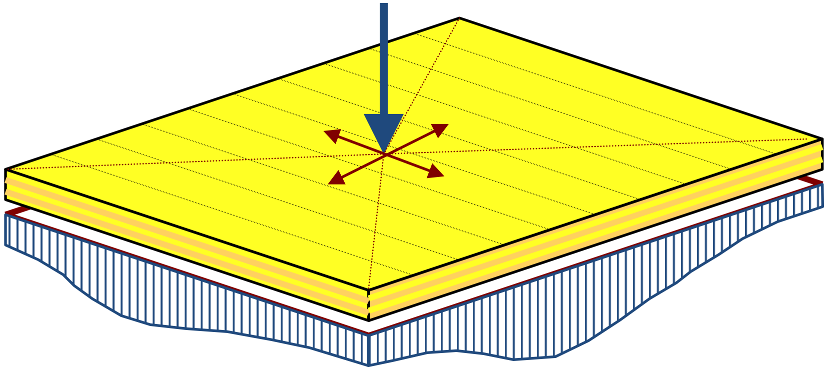




CLT Structural panel in big dimensions

Structural behavior of the CLT Panels

- Massive plane element
- Stiffness and resistence in both direction of the plane



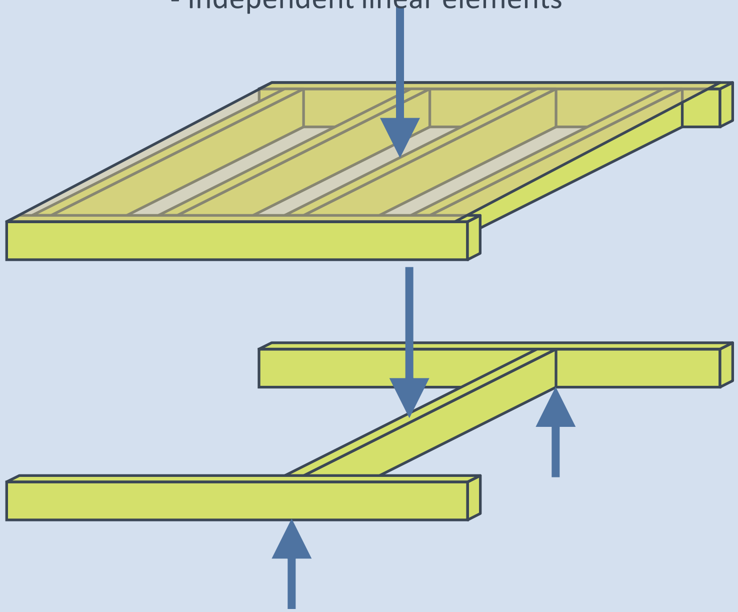
Loads transmission:
- Supported by the entire element
- Dsitribution on the whole su tutta la substructure
- Reduced stress for each element

CLT Structural panel in big dimensions

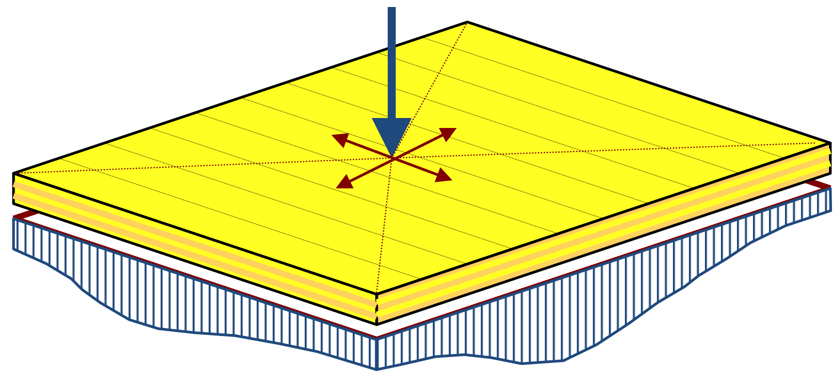
Structural behavior of the CLT Panels

- Massive plane element
- Stiffness and resistence in both direction of the plane

Classical wooden floor system
- parallel beams
- Independent linear elements



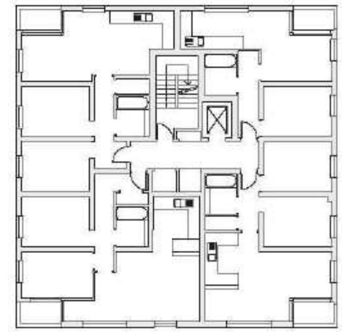
- Only one load-bearing direction
- Only one element ”involved"

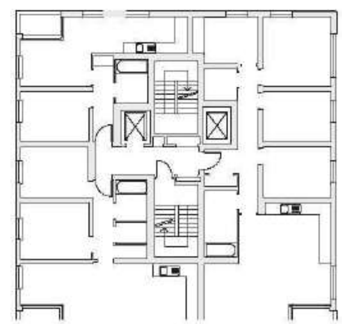


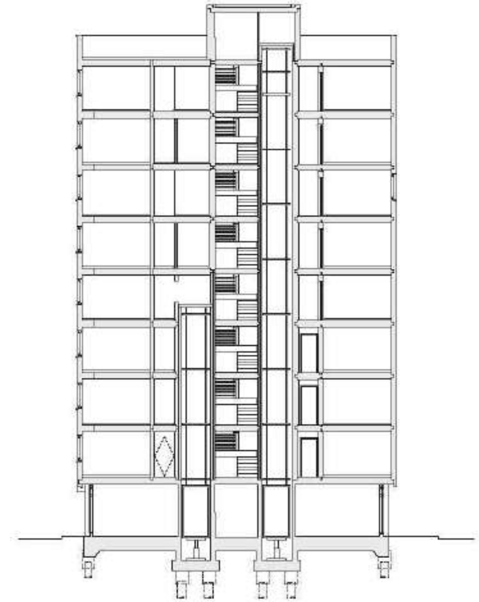
Loads transmission:
- Supported by the entire element
- Dsitribution on the whole su tutta la substructure
- Reduced stress for each element

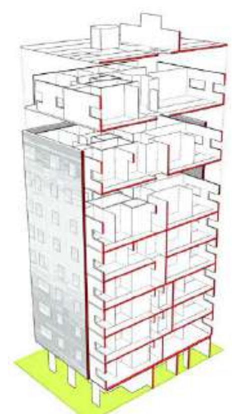
Waugh Thistleton, Residential Tower, London, 2008

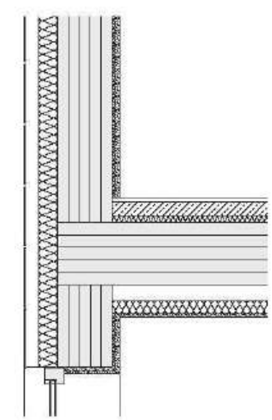

THE
MONARCH
FREE HOUSE



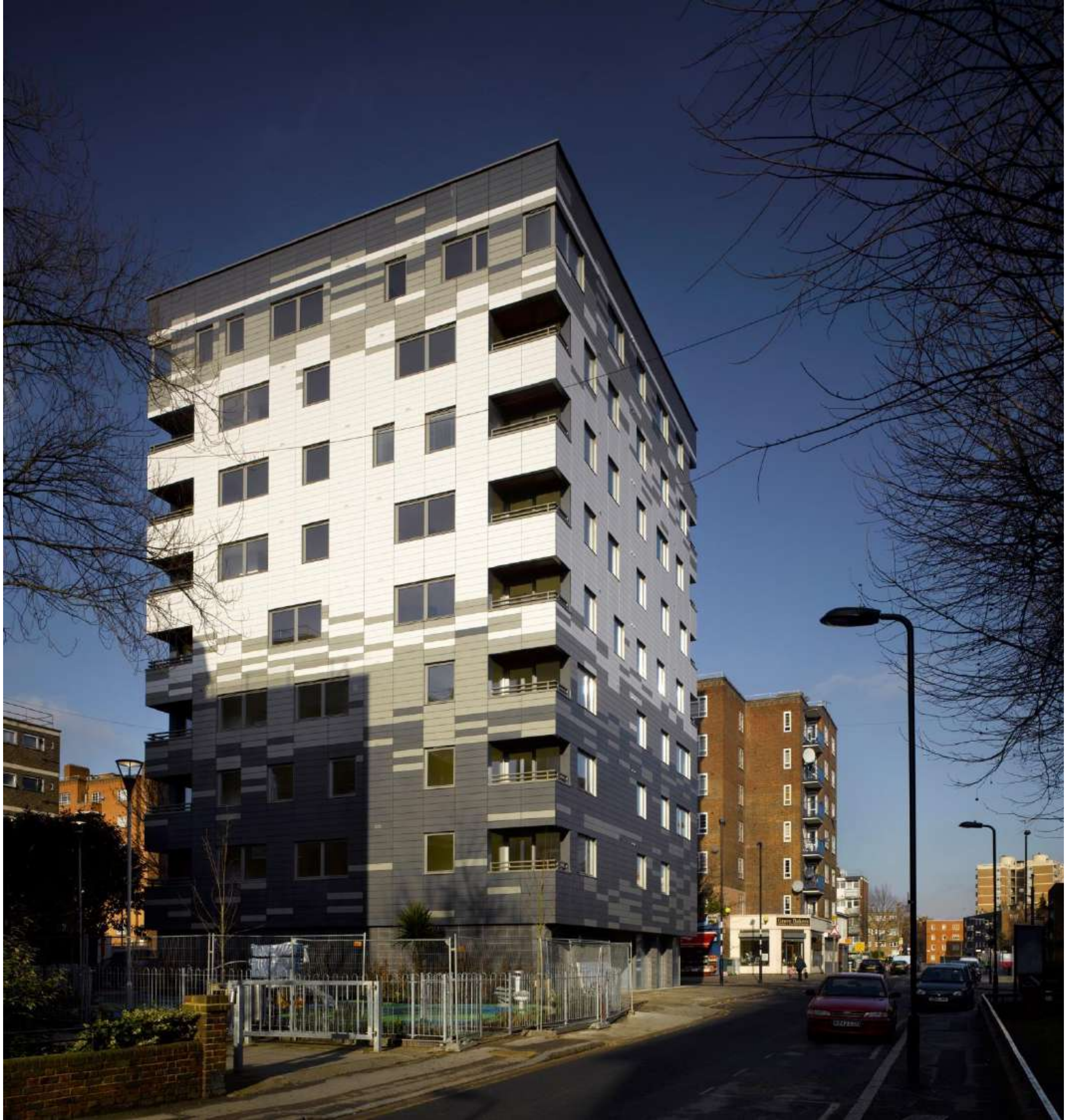






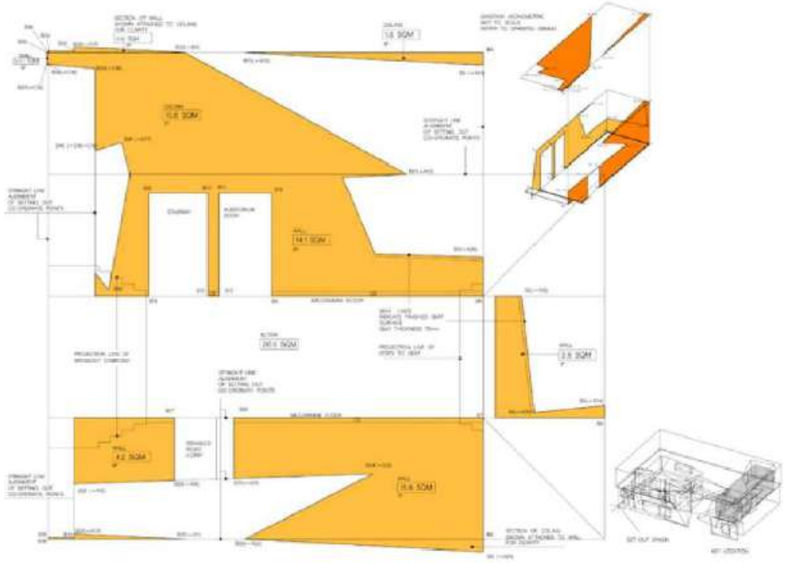


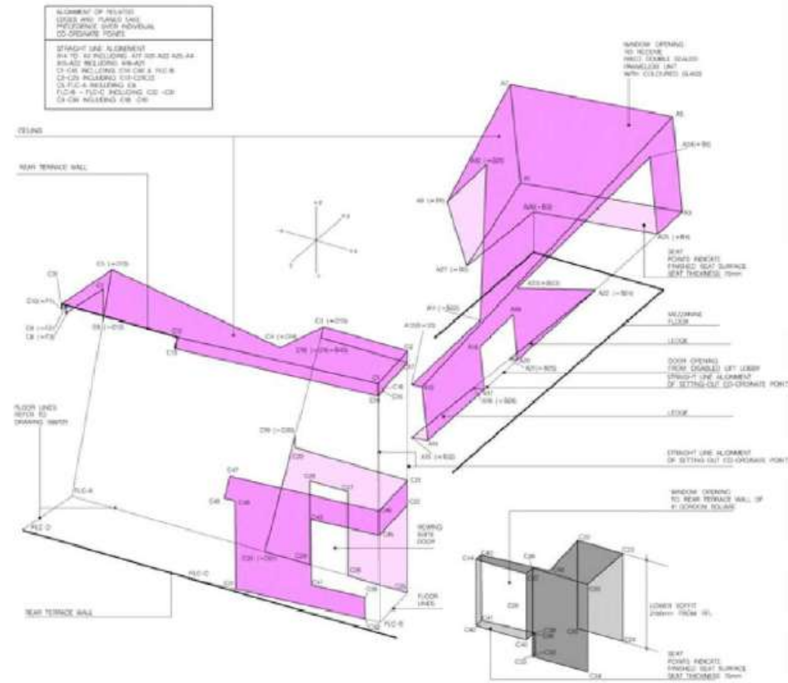


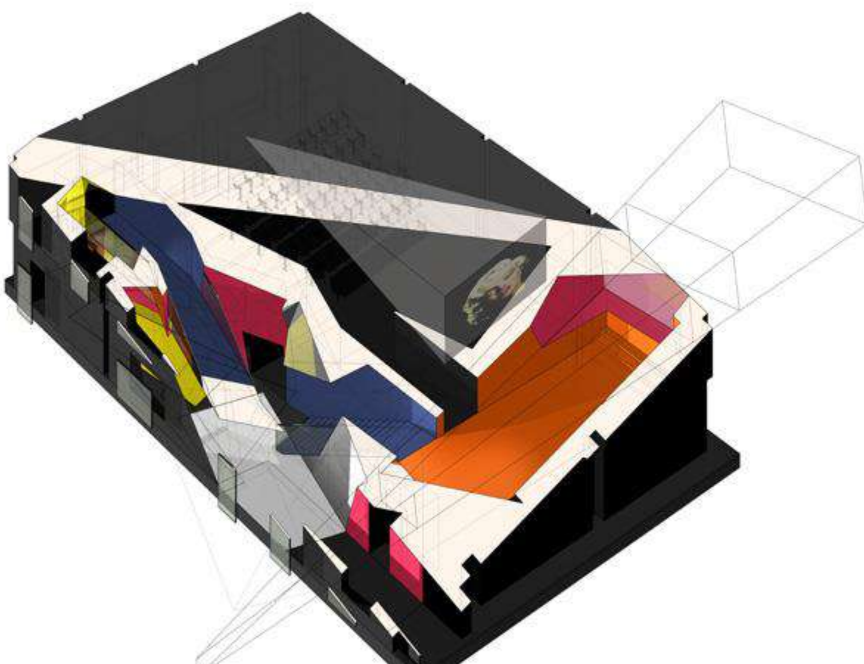


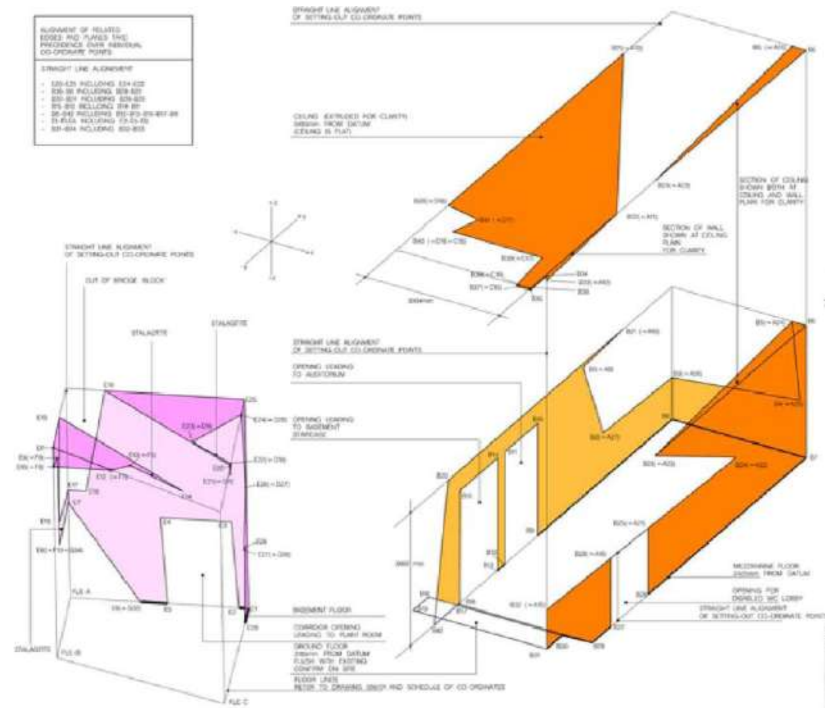
Surface Architects, Birkbeck College, London, 2007

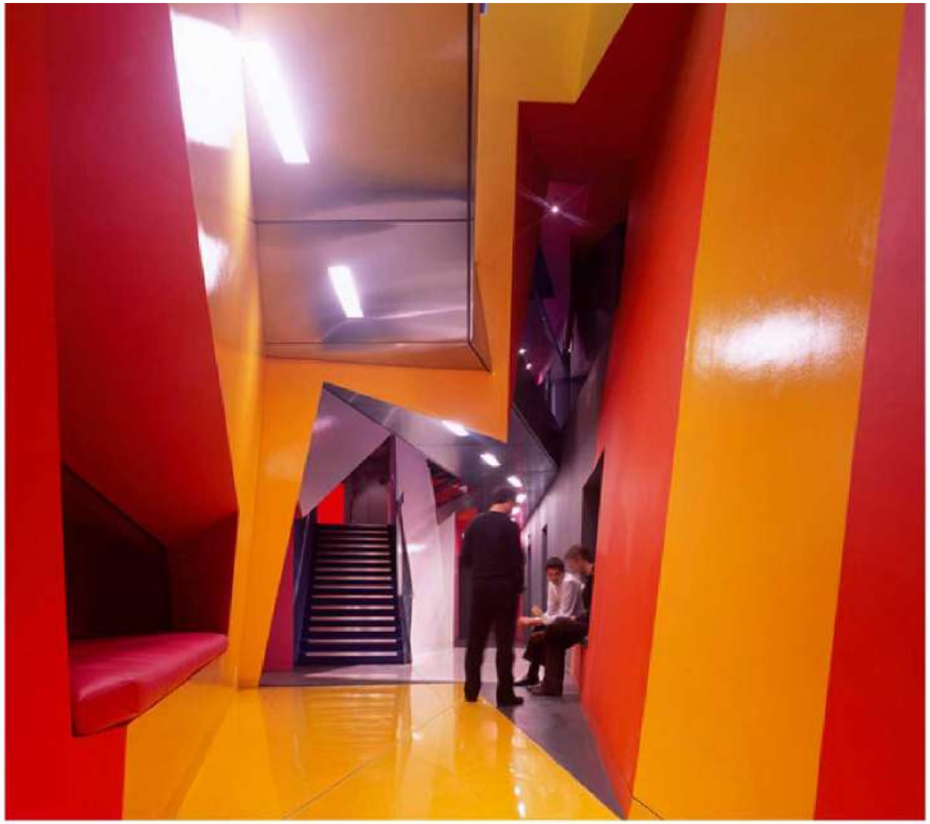

ENDSLEIGH
PLACE
36
36
GORDON
SQUARE




CEILING
REAR TERRACE WALL
REAR TERRACE WALL




STALAGTITE
STALAGTITE
BASEMENT FLOOR



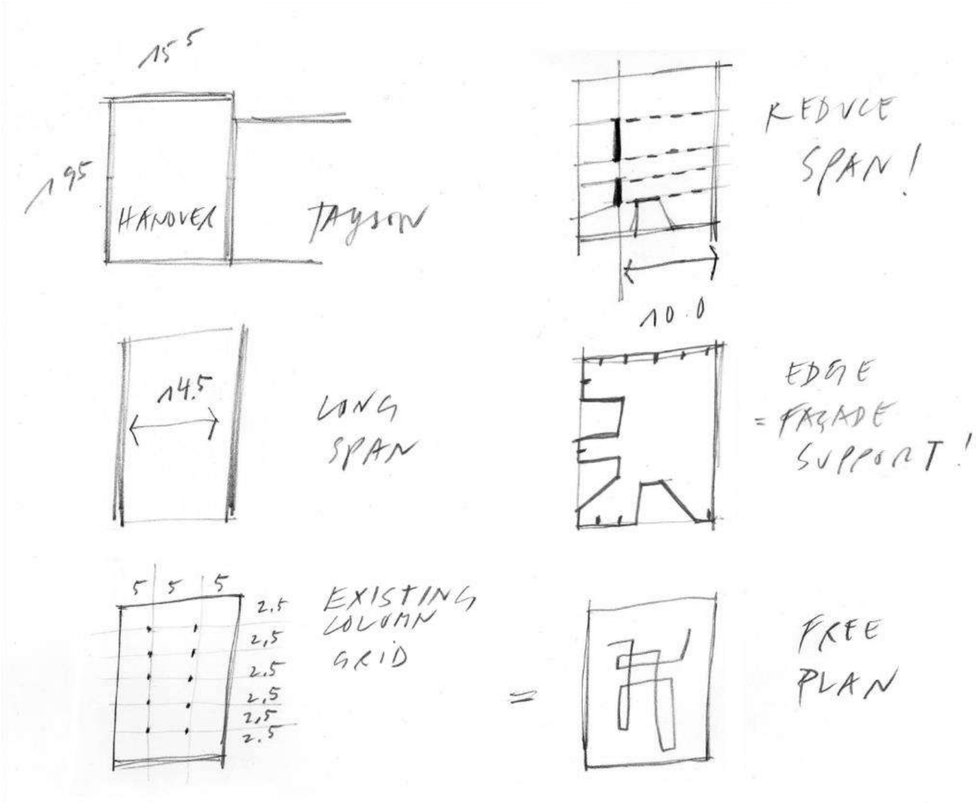


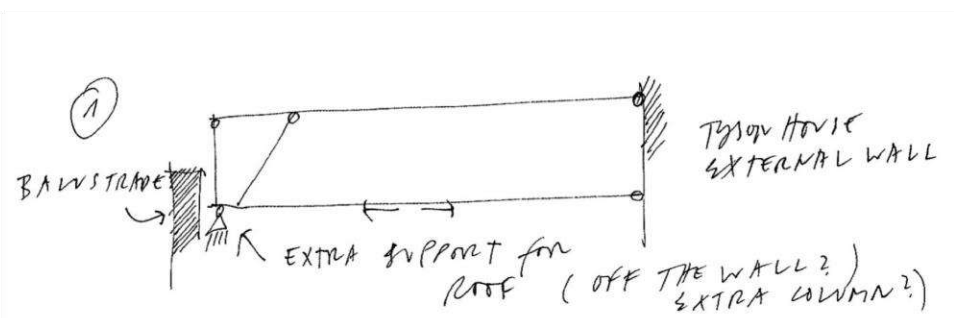

Daniel Fuegenschuh, Renovation of an attic floor, Innsbruck, 2007

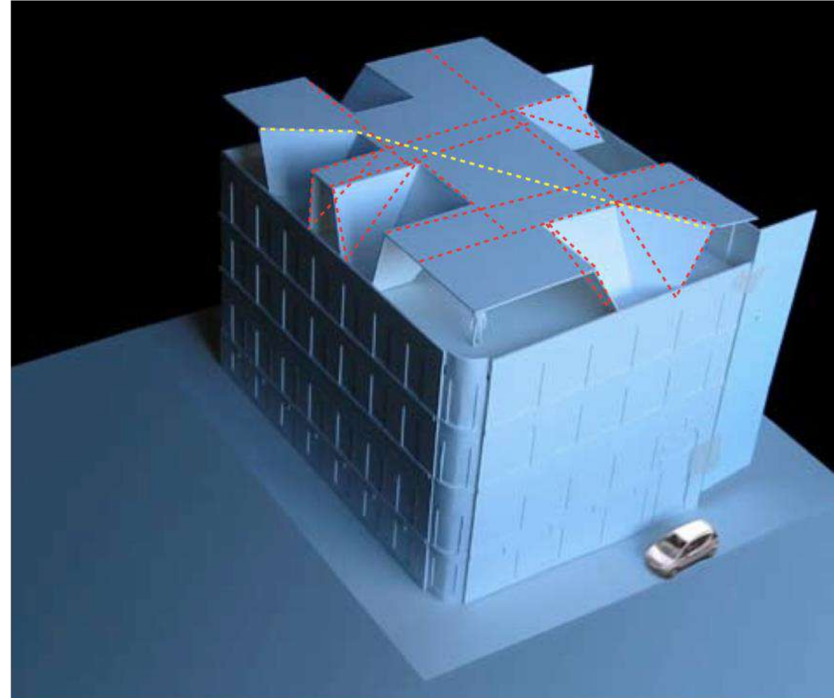


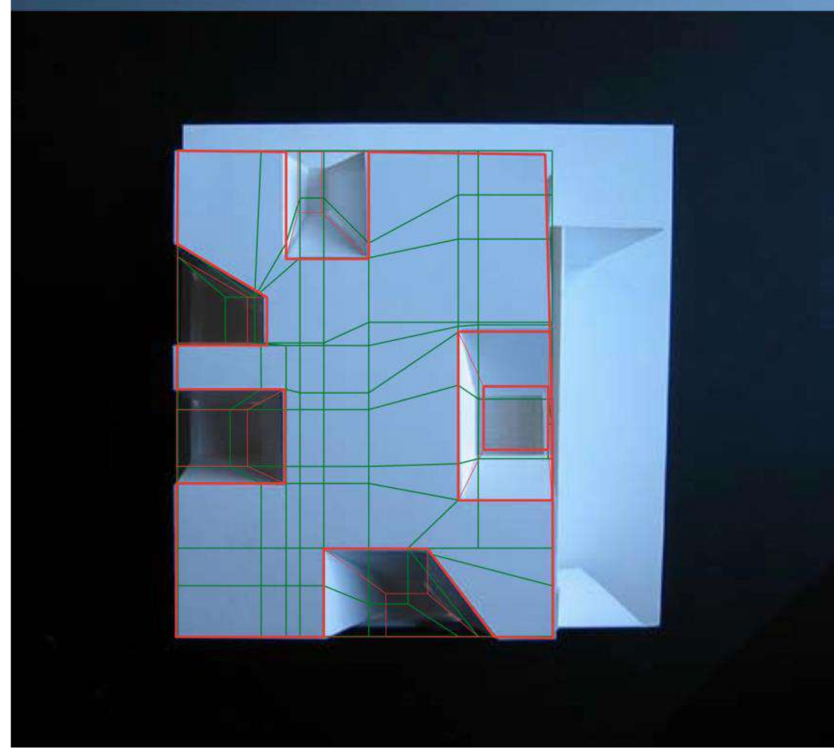


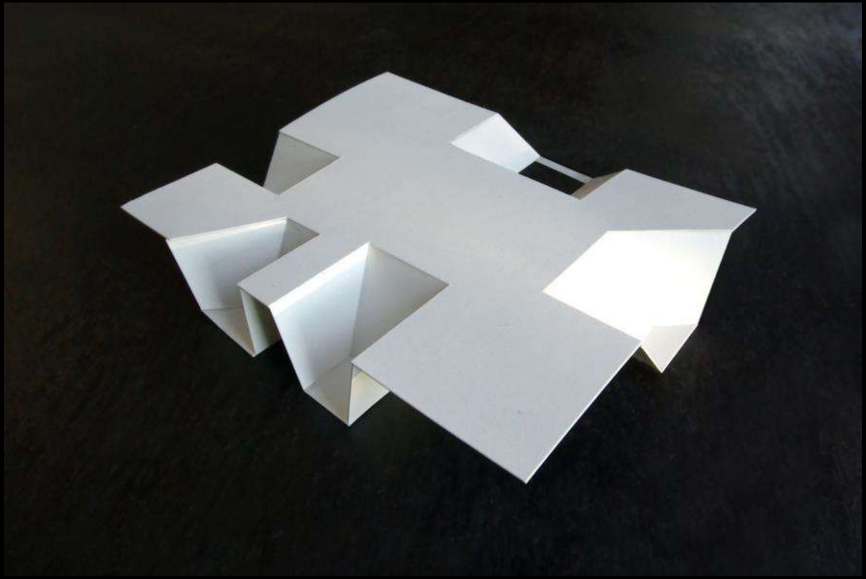
Kraus & Schönberg, Hanover House, Bradford, 2007


15.5
19.5
HANOVER
TAYSON
REDUCE
SPAN!
10.0
14.5
LONG
SPAN
EDGE
= FAÇADE
SUPPORT!
5 5 5
2.5
2,5
2.5
2.5
2,5
2.5
EXISTING
COLUMN
GRID
=
FREE
PLAN


1
TYSON HOUSE
EXTERNAL WALL
BALUSTRADE
EXTRA SUPPORT FOR
ROOF (OFF THE WALL?)
EXTRA COLUMN?)








INDUSTRIAL
COOLING
SERVICES
DG56 LFW

Fabrizio Rossi Prodi, 4 Towers 9 Storey-Housing, Milan, 2012-13

Prof. Arch. Fabrizio Rossi Prodi

Prof. Arch. Fabrizio Rossi Prodi

Residential units

- 124 residences
- 2 to 4 rooms (1 to 3 sleeping rooms - 100/75/50 m^2 area)

Surfaces

- 9300 m^2 gross floor area
- 17000 m^2 gross built floor area

Costs*

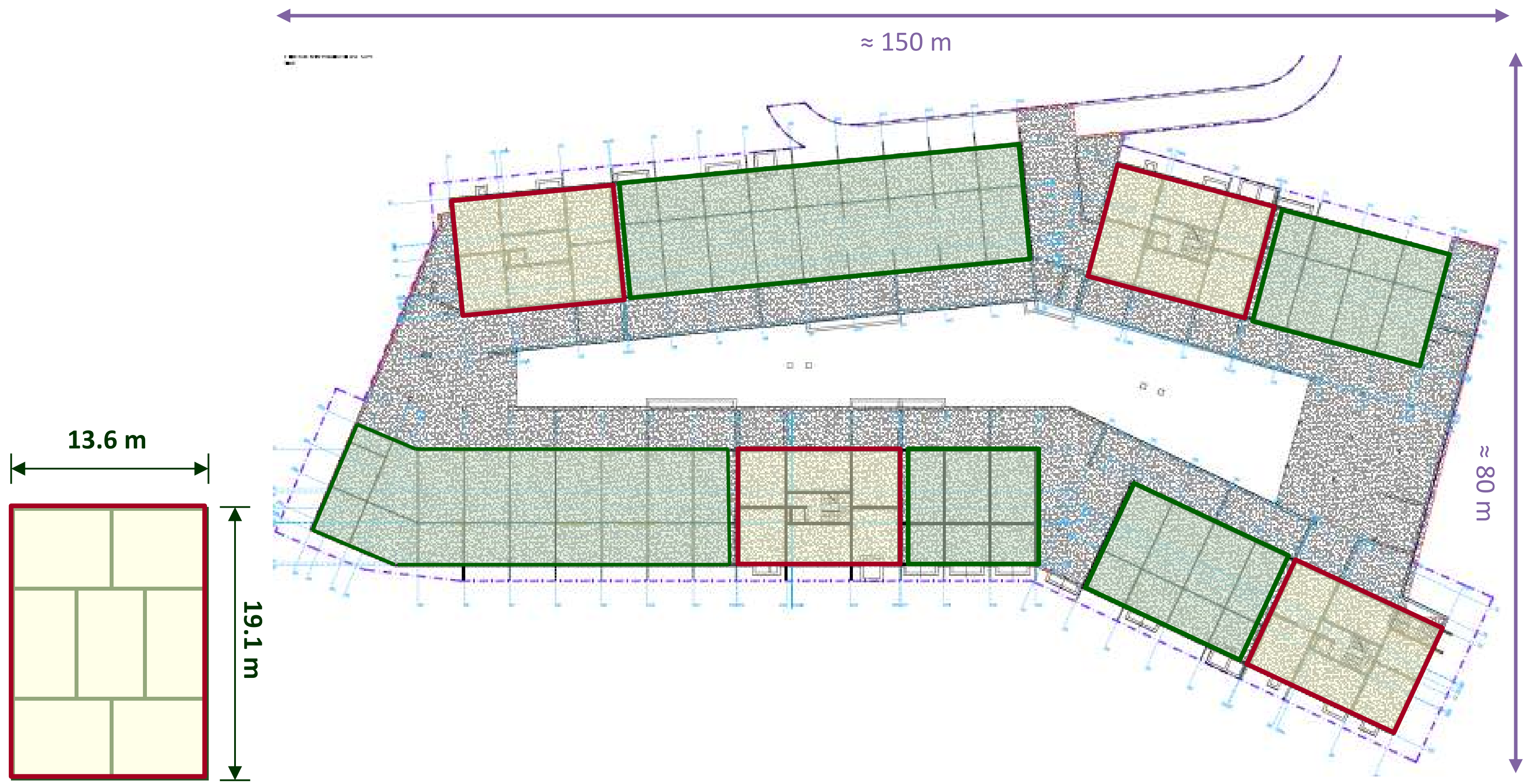
- 17 Mio. € all inclusive

- rent: 500 to 1000 €/month
- sales: 150'000 to 300'000 €

* approximately

Building timetable

- begin excavation: January 2012
- begin timber construction: June 2012
- building time all inclusive: 15 months
- completion expected without delay, according program

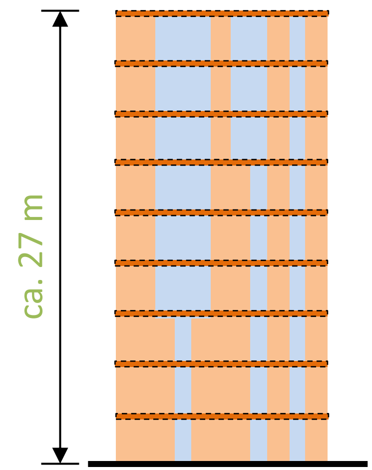


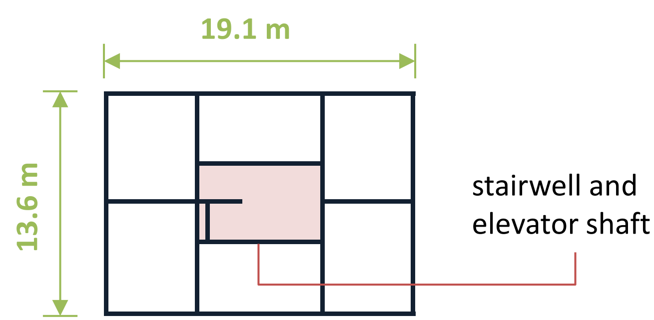
9-storey Towers
- 4 similar buildings
- "full" timber construction

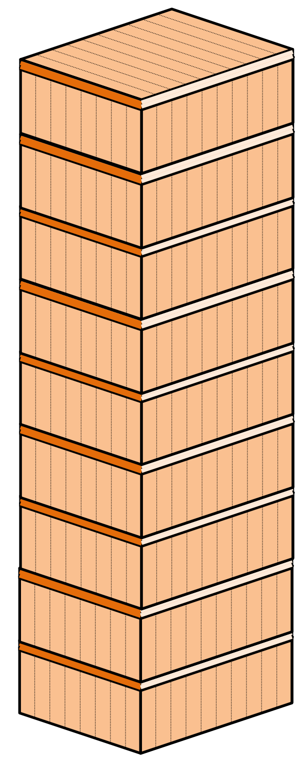
2-storey connection buildings
- 4 similar buildings
- timber construction with similar technology to the towers

The load bearing structure on CLT

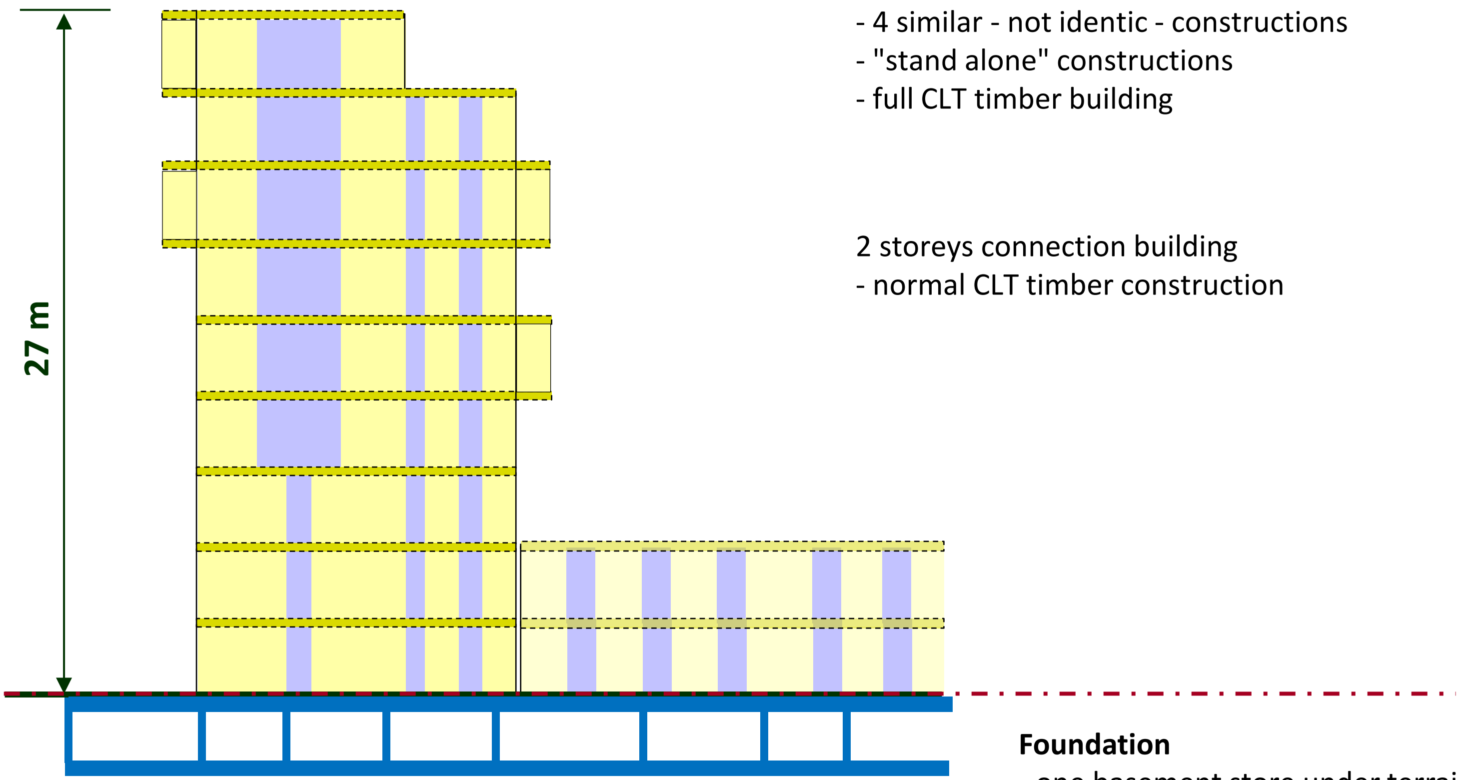
9 storey, spatial, 3-d CLT-structure
- composed of CLT decks and walls
- full timber construction
- included stairwell and elevator shaft







The bearing structure on CLT



9-storey Towers
- 4 similar - not identic - constructions
- "stand alone" constructions
- full CLT timber building

2 storeys connection building
- normal CLT timber construction

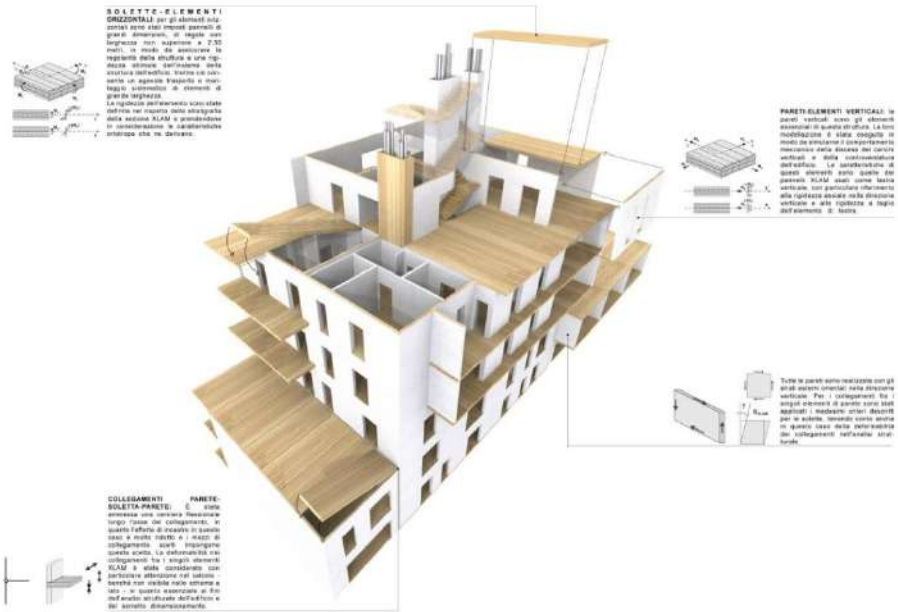
Foundation
- one basement store under terrain surface
- concrete
- parking
- technical equipment's

Conditions - Requirements - and Challenges - for project and design

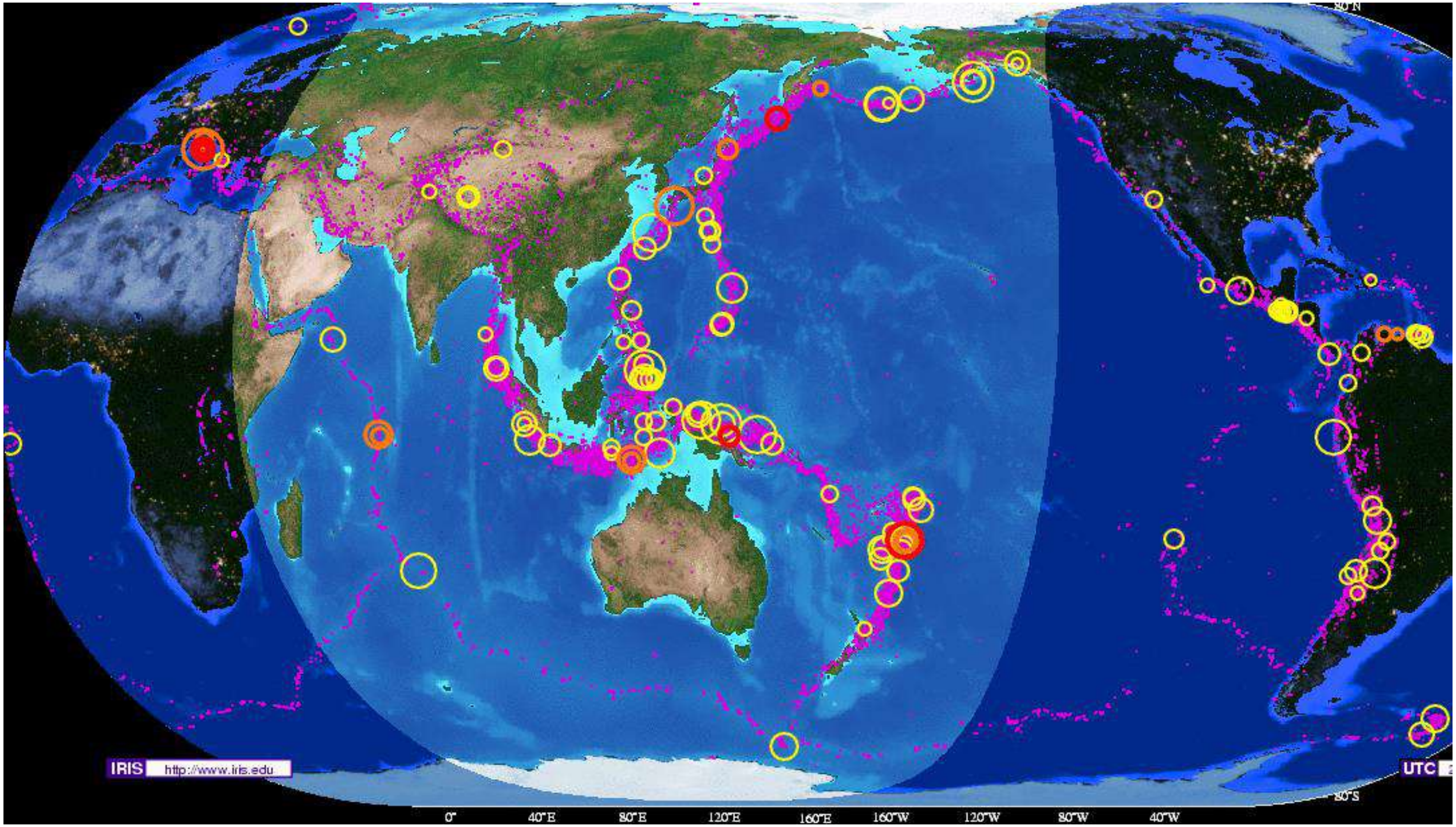
Earthquake risk
- not very high, but really existing
- important and with high significance by authority and population
- general earthquake engineering rules have to be strictly respected as principle of the structural project
- CLT-timber appropriate for the requirement

High number of storeys - height of the building
- relatively new with timber
- absolutely new on earthquake area

State of the Art
- some experience with similar buildings - but not by earthquake risk and by easier conditions of ratio height/large
- new and innovative, but under applications of actual technology and knowledge
- innovative application of the actual state of the art


SOLETTE-ELEMENTI ORIZZONTALI
PARETI-ELEMENTI VERTICALI
COLLEGAMENTI PARETE-SOLETTA-PARETE

Learning from Emergencies…


80°N
IRIS
http://www.iris.edu
UTC
80°S
0°
40°E
80°E
120°E
160°E
160°W
120°W
80°W
40°W

Timber and earthquake - an interesting an successful history

- many interesting remarks can be founded

Three undamaged modern Canadian-style wood-frame buildings in background, collapsed older building in foreground, after Japan’s 1995 Kobe earthquake.

Timber and earthquake - an interesting an successful history

The oldest timber buildings are - for example - in Japan

One of the oldest surviving timber structures in the world is the Horyuji temple, which was built at the start of the 8th century. These buildings have outlasted many earthquakes including the Kobe-earthquake in 1995.

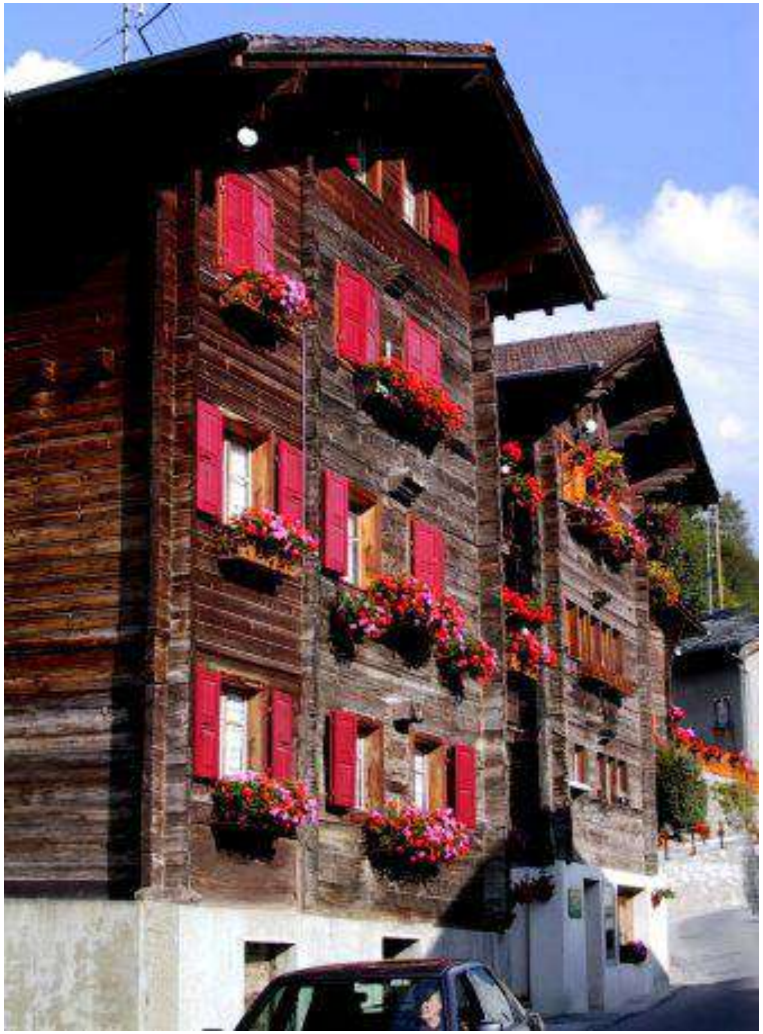
Timber and earthquake - an interesting an successful history

The oldest timber buildings are - for example - in Japan

- Sakyamuni Pagoda, Fogong Temple (NW Ying County, Prov. Shanxi)
- h_{tot} = 67.31 m
  - 9 storeys, 5 identifiable
  - corresponding to a 20-storeys building
  - containing 26 Buddha's statues
- build up under Qing Ning en1056
  - has at the time the +/- 950ème birthday...
- has survived many strong earthquakes
  - it's reported of a "7 day long earthquake"
  - Xingtai (Province Hebei)
  - Tangshan
  - Helinge'erm

Timber and earthquake - an interesting an successful history

Switzerland is a country of low seismicity - but the oldest timber constructions …



… are in the Switzerland part with the highest risk of earthquake

… and they have survived certainly to a lot of small earthquakes

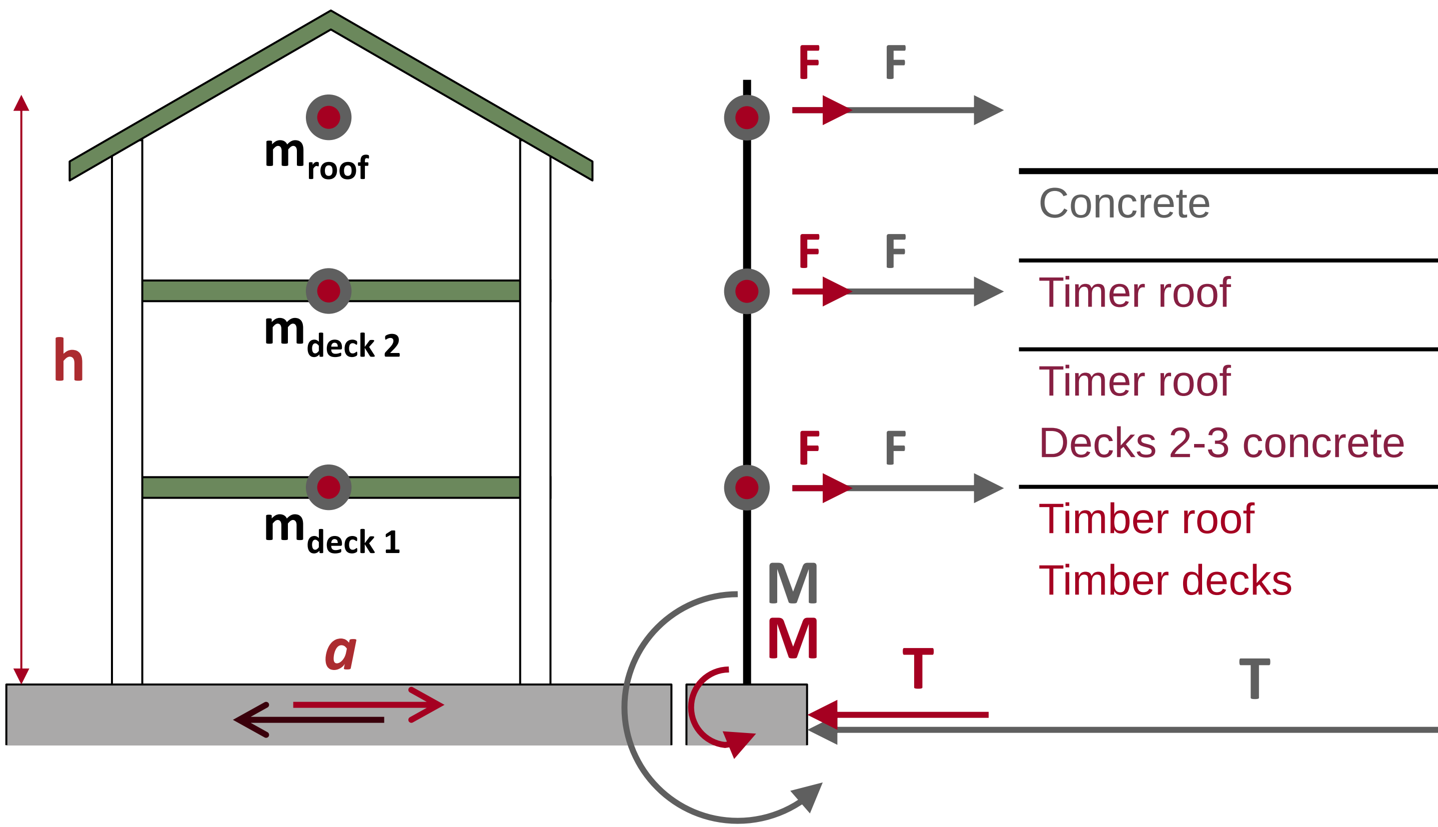
Timber and earthquake - today

The advantages of timber

- **the reduce weight: $\rho_{mean} \approx 500\ kg/m^3$ ...**

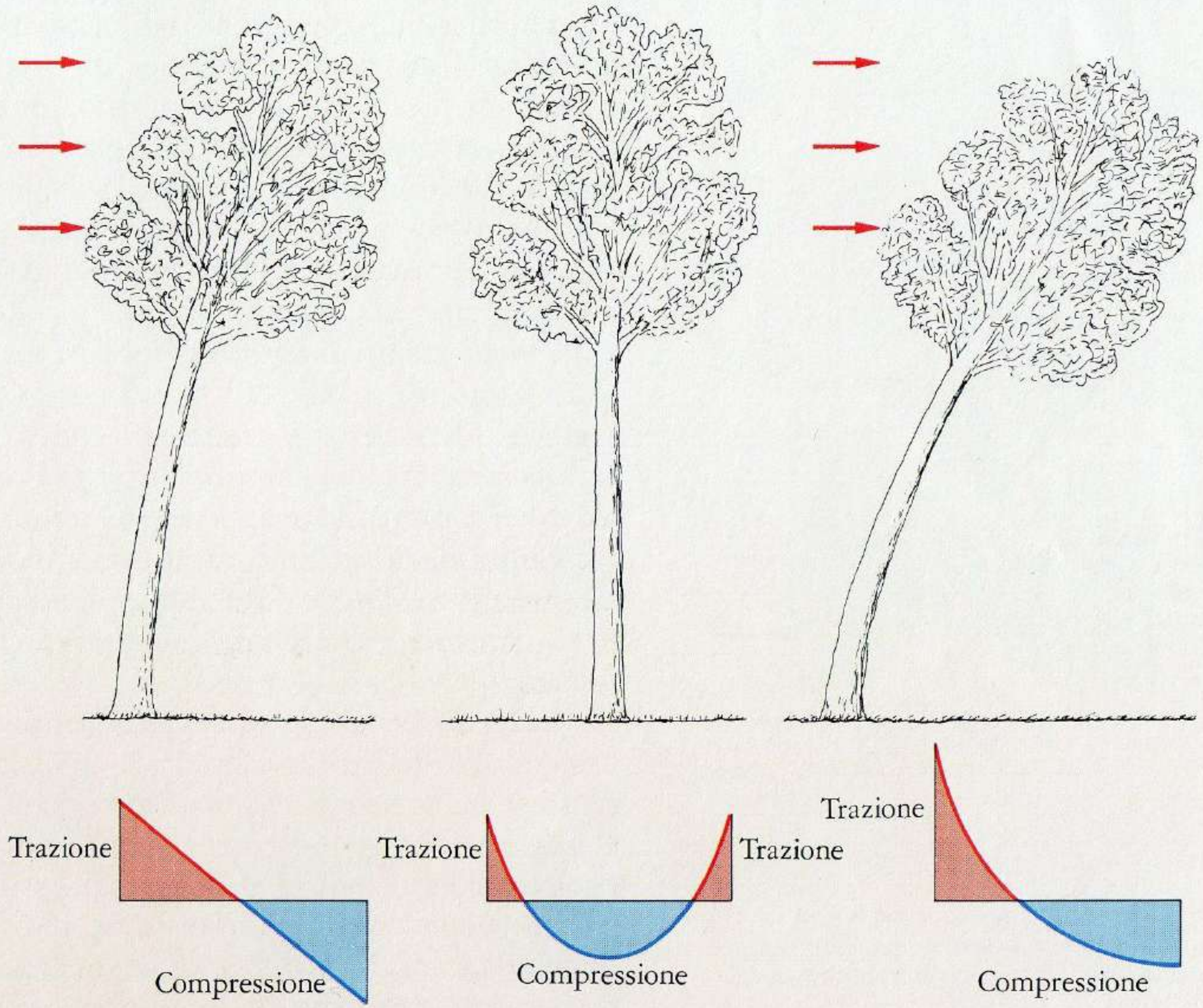
... reduce the forces in case of earthquake

- **ground seismic acceleration *a:* given by the earthquake**
- **mass relationship mineral to timber construction : $m_{cocnrete} : m_{timber} = 4:1$**

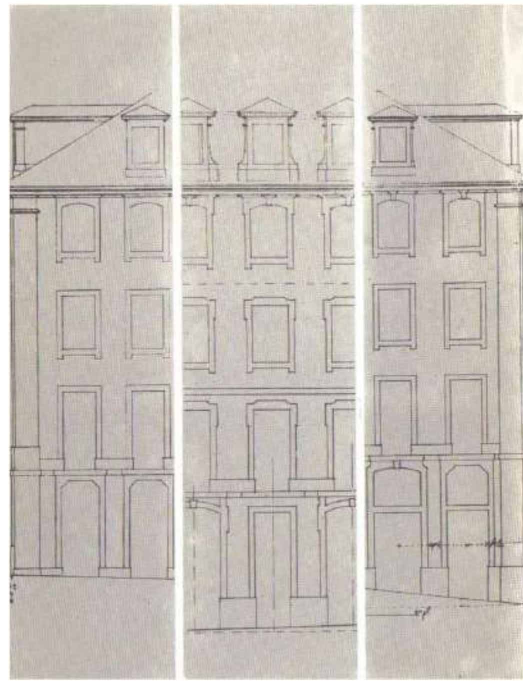


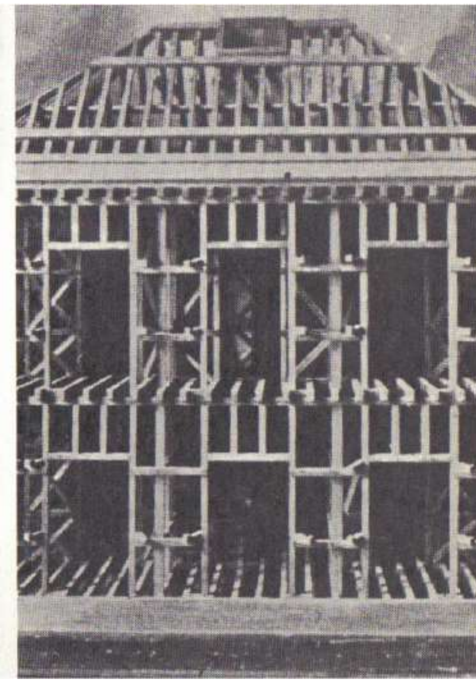
	T %	M %
Concrete	100	100
Timer roof	75	62.5
Timer roof Decks 2-3 concrete	50	37.5
Timber roof Timber decks	25	25

Presollecitazione nel tronco d'albero. Poiché il legno è molto più debole in compressione che in trazione, l'albero cresce con gli strati esterni del tronco presollecitati in trazione. I tronchi interi che venivano spesso usati nelle applicazioni tecnologiche più tradizionali (per esempio le alberature delle navi) erano perciò più resistenti alla flessione di strutture più complesse costruite con legname segato.



Traction / compression





Gaiola Bombalina, Lisbon, after the Earthquake of 1755


FIXING
KOBELCO

Seismic Test In Miki of a CLT System Building

before the Earthquake

after 7 destructive Earthquakes

Dr. Ing. Ario Ceccotti


LENOTEC
EG Wand 5.1
P.T. BASSO
LOC. SUD
LATO NORD
ANG. W


P.T. BASSO
LOC. SUD
LATO NORD
ANG. W
LENOTEC

Timber and earthquake - today

A lot of investigation on full scale specimen shows interesting results

Example: 3 storeys building with ground surface 7 x 7 m

Results:

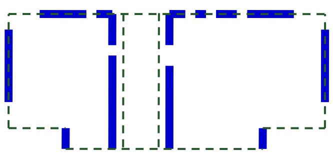
- **good behaviour in case of the Kyoto earthquake**
- **the "weakest point" is given by the connections: they have to be correctly designed**
- **by small building the effect of the friction between the elements is probably very favourable**

Timber and earthquake - today

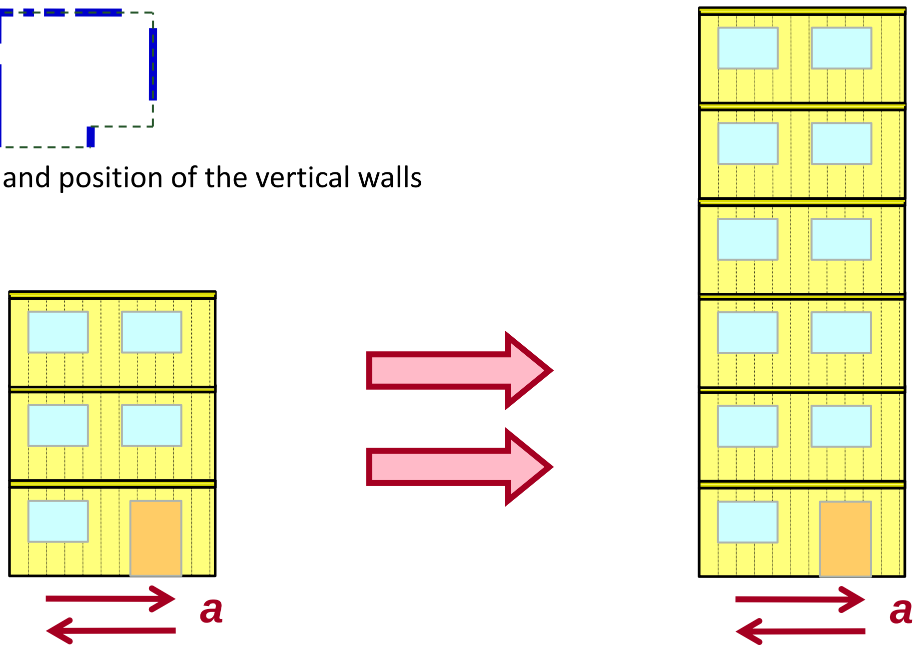
Seismic effect on timber buildings

Study M. Turri 2008
A. Bernasconi, heig-vd
M. Piazza, Uni TN

A case study based on a real example of a building



Ground schema and position of the vertical walls



Aim of the study: the behaviour of different timber construction systems (framework, CLT, with timber or concrete decks, …)

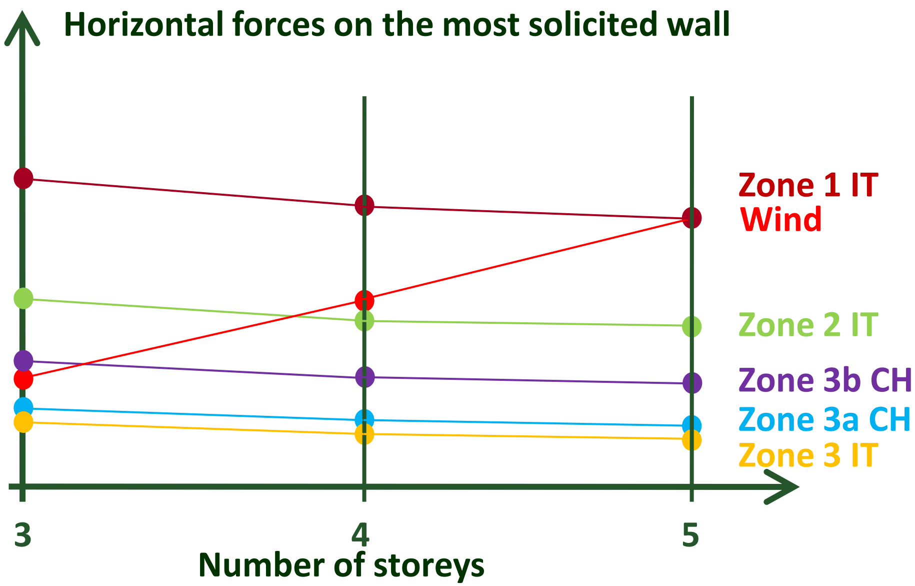
- **Design for static load (wind)**
- **Check for need of reinforcements in case of seismic risk at different levels**
- **Analysis for 3, 4 and 5 storeys for the same configuration**

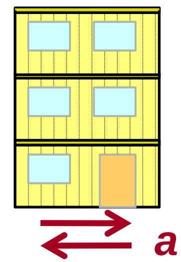
Timber and earthquake - today

Seismic effect on timber buildings

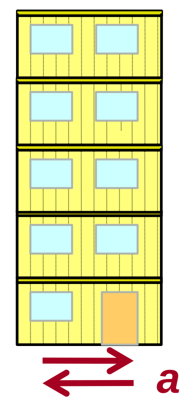
A case study based on a real example of a building

Study M. Turri 2008
A. Bernasconi, heig-vd
M. Piazza, Uni TN





3 storeys: reinforcement for risk zones 1 and 2



5 storeys: nowhere reinforcement required

Construction system:

CLT-walls

Concrete-Timber decks

- green zones: reinforcement for the earthquake risk is not necessary
- red zones: reinforcement for the earthquake risk is necessary


PALAZZO DEL GOVERNO




Particolare tavoletta di
giunzione




Applicazione
colla


Fissaggio
tavolette/pannelli
con viti ϕ 8/10


Fissaggio solaio con
viti ogni 15/20 cm




1


5


Il 29 luglio 2009
Sistem Costruzioni
è arrivata al tetto della
prima palazzina


15

78

An example of very modern timber building

An example of very modern timber building

An example of very modern timber building

After one working day on the timber constructor

An example of very modern timber building

After two working days on the timber constructor

An example of very modern timber building

After three working days on the timber constructor

An example of very modern timber building

After five working days on the timber constructor

An example of very modern timber building

After six working days on the timber constructor

An example of very modern timber building

Very large use of prefabrication

- need of accurate planning
- need of accurate timing

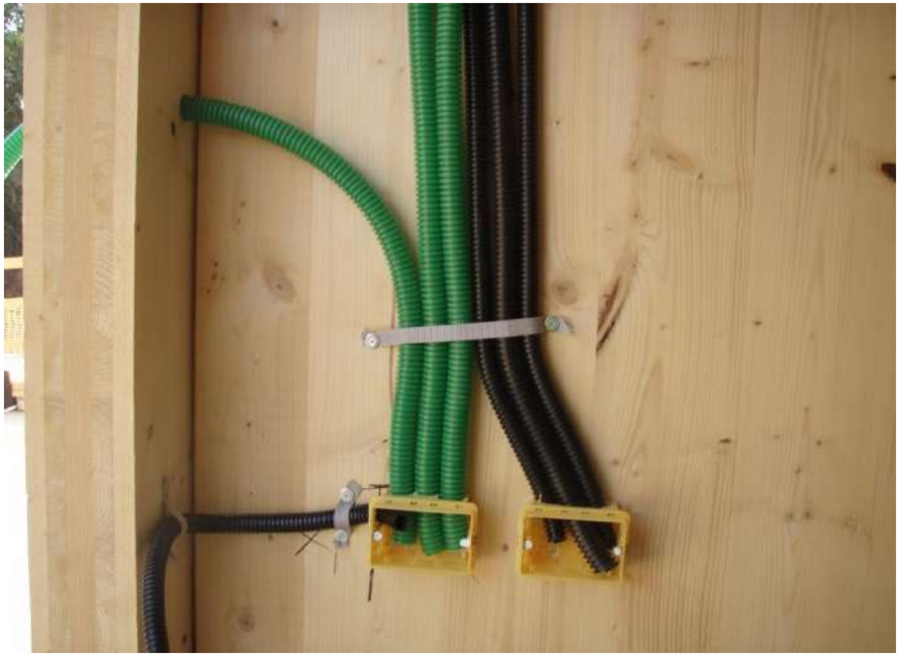
An example of very modern timber building

Stairs on CLT

An example of very modern timber building

Equipment and installation

- prefabricated
- cable bundles delivered the correct in length and form



An example of very modern timber building

Insulation of the stair shaft

- inside because stair shaft not heated
- clothing with gypsum boards

An example of very modern timber building

Floor construction

- dry construction
- insulation
- solution with mortar plates (dry by the installation)

Modernster Holzbau - Ein Beispiel

Thermic insulation over the upper deck

- principle of the cold roof
- roof surface to have an inclined surface

An example of very modern timber building

Outside construction of the walls

- cork panel for insulation
- air ventilation of the facade elements
- external part with cement fibres boards

An example of very modern timber building

An example of very modern timber building

Costs … and numbers

Requirements in the announcement
- about 30 apartments
- place for about 80 people

Reference price for the offers
- 2'200'000 €
- 11 millions € because offer for at least 5 building (identical)

This object
- 27 apartment
- about 80 people

Reference price for the offers 2'200'000 €
- 3,09 per cent reduction (criteria for adjudication): 2'132'020 €
- 2100 m^2 surface
- 1015,25 €/m^2

An example of very modern timber building

Some view of the apartment "ready for living"

A second example of very modern timber building

Fro this object

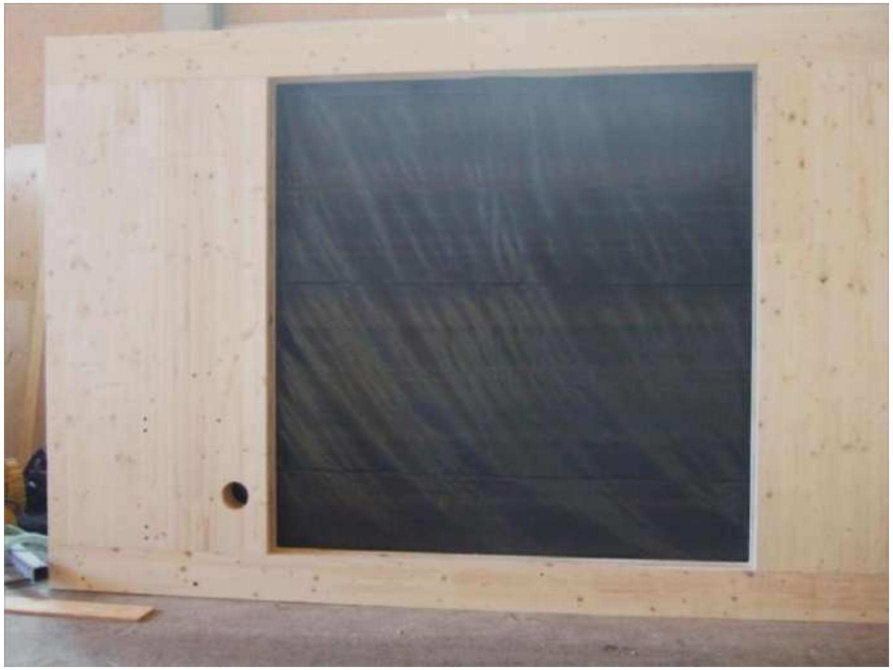
- 24 apartments
- place for 81 people

A second example of very modern timber building

Fro this object

- 24 apartments
- place for 81 people

A second example of very modern timber building

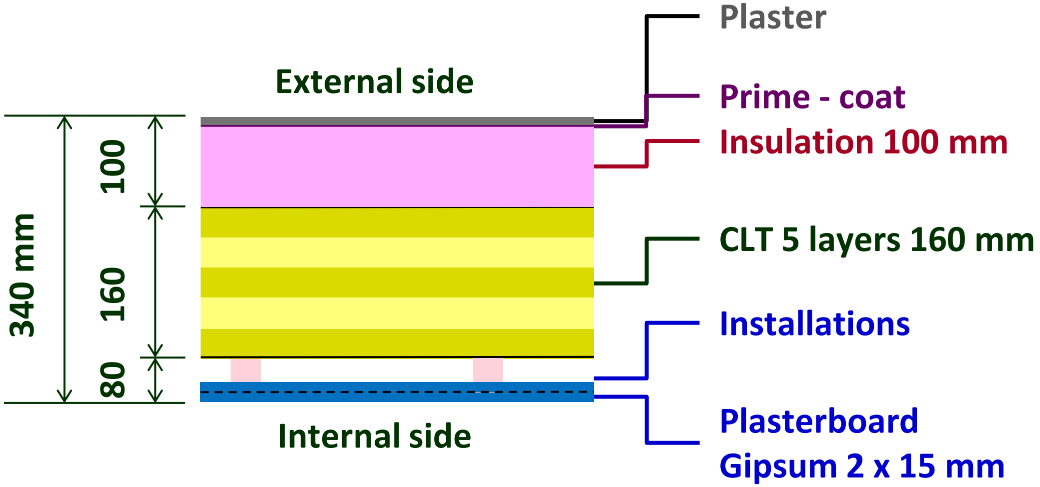


Walls on CLT

A second example of very modern timber building

Vertical external walls on CLT

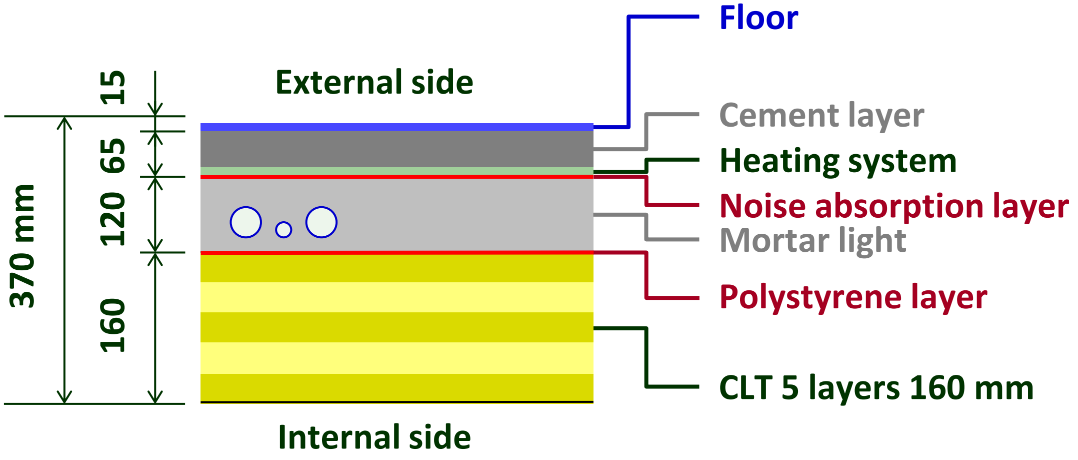
- composition of the construction layers



A second example of very modern timber building

Horizontal decks on CLT

- composition of the construction layers



A second example of very modern timber building

Erection of the timber construction within 73 day - in one case the effective building time was 55 days

Costs

- 2'051'400 €,
- 1801 m^2 surface
- 1140 €/m^2

A second example of very modern timber building

Some view of the apartment "ready for living"

Conclusions

Two cases of modern timber constructions

- two examples from a lot of realized timber projects

Construction on "safety platforms"

- design based on reduced horizontal forces
- condition of maximum weight of the construction
- project with timber structure relatively easy (reduced weight - high earthquake safety)

Timber building without platforms

- higher earthquake design forces
- stronger structural details, i.e. all kind of connections
- … but of course possible

The project of the Via Cenni, Milan

End of June 2013

The project of the Via Cenni, Milan

Interesting example of the State of the art

- CLT for ambitious engineering constructions
- a new way for urban and multi storey buildings
- timber engineering for modern architecture
- CLT engineering for urban architecture

The project of the Via Cenni, Milan

Via Cenni, Milano - Arch. Rossi Prodi - 04.10.2013

Two examples of timber building after earthquake

Building program CASE

- two examples from a lot of realized timber projects

Construction on "safety platforms"

- design based on reduced horizontal forces
- condition of maximum weight of the construction
- project with timber structure relatively easy (reduced weight - high earthquake safety)
- examples for "speedy building"
- examples for "modern timber building"

Facts

For instance
Italy 2010, new buildings

Total all buildings	40.000
Total wood buildings	7.500
(3.000 in Abruzzo)	

Total apartments	220.000
Total wooden ones	8.500
(3.500 in Abruzzo)	

Wood Buildings realized in Italy

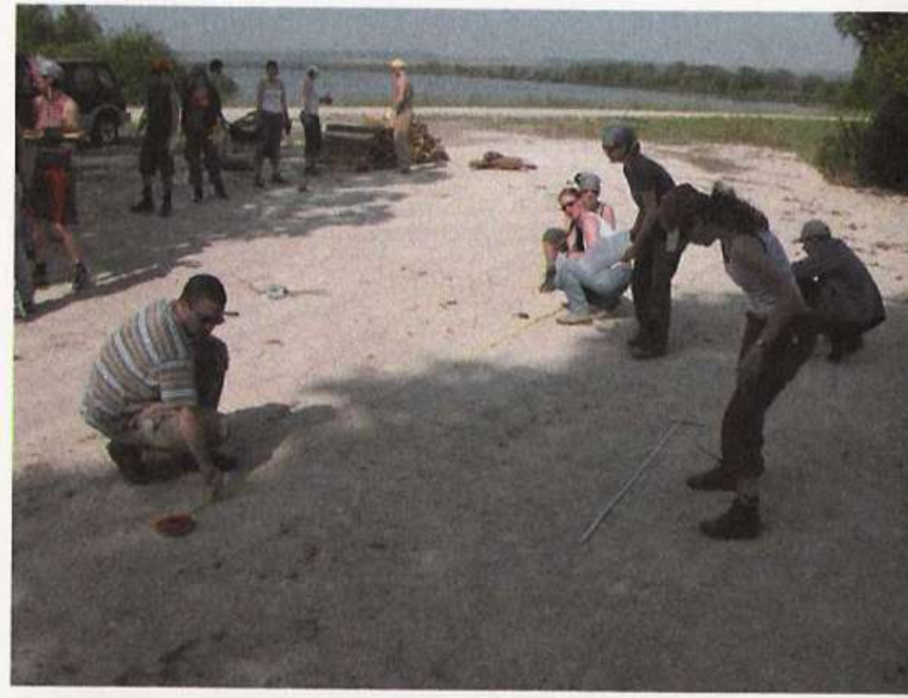
2006 100%
2010 500%
2015 900% (ca.)

The buildings realized with other materials and technlogies are actually decreesing and in recession

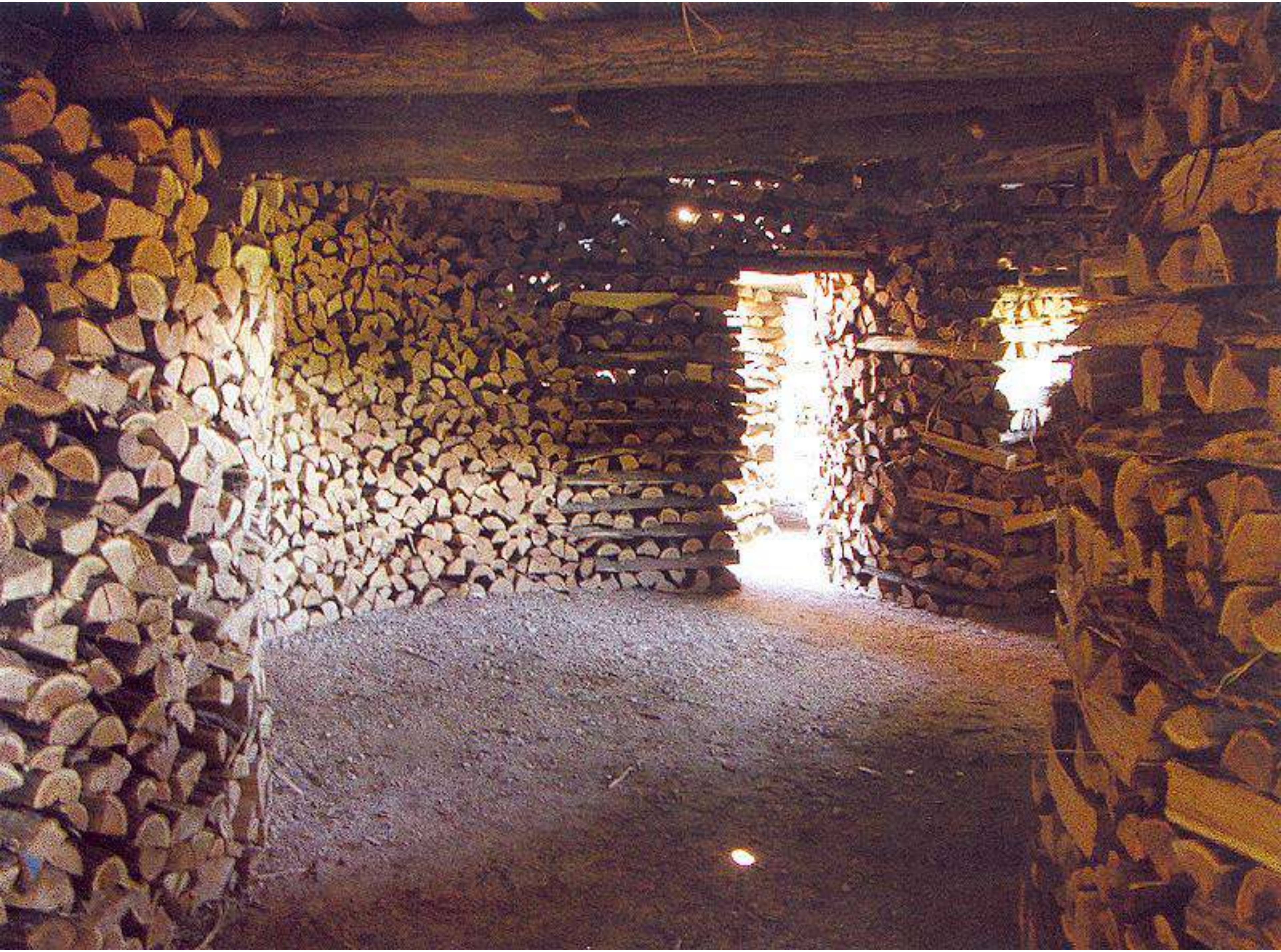
[…] the problem of wood is to be an excellent material too easily usable

James E. Gordon

Students of the ETH Zurich, Birdwatching Station, Lake Balaton, 2003

DAS PROJEKT VON A-Z



At the begin it was the timber home

Home building was in the past on timber …

… and the homes exist always and show

- a long live capacity
- a good conservation
- an economic interesting investment

… but they are today

- not very modern
- but interesting and fascinating

… then the timber becomes multi-storeys

Timber multi-storeys is an old history too …

… and the houses exist always and show

- a long live capacity
- a good conservation
- an economic interesting investment

… but they are today

- not very modern
- very interesting and fascinating

… then the timber becomes multi-storeys

Yesterday and today

- timber construction is visible from outside

… then the timber becomes multi-storeys

Yesterday and today

- timber construction is visible from outside

- timber construction behind a façade

… then the timber becomes multi-storeys

Yesterday the same situation as today? No, because a lot of reasons

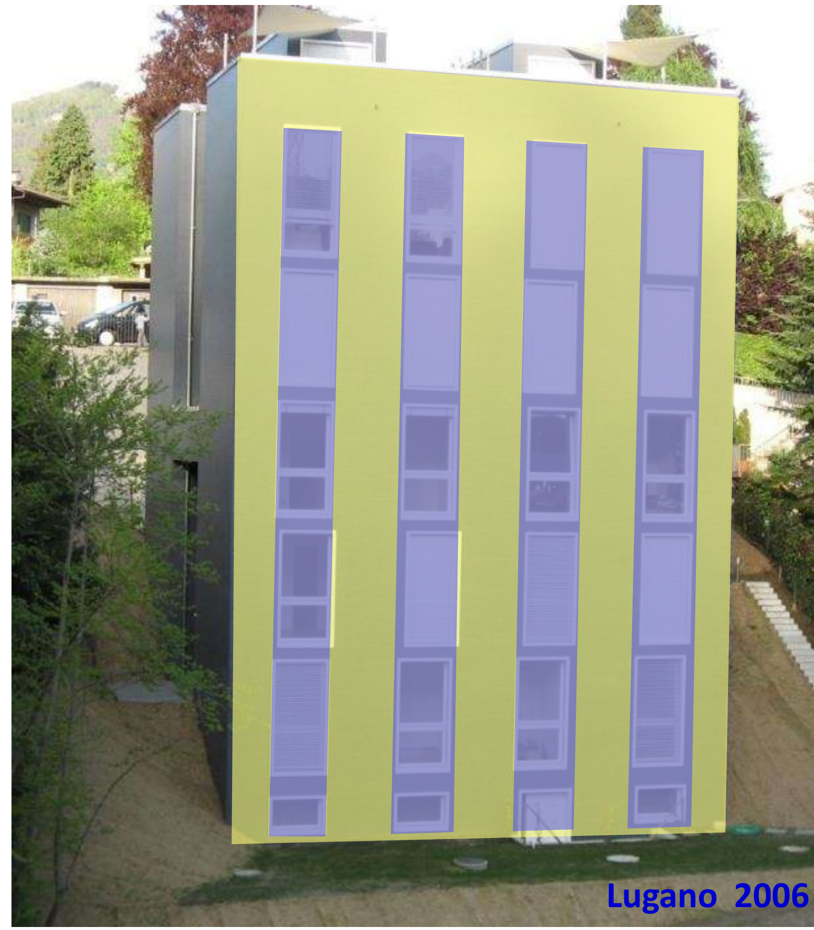
- technical requirement are stronger
- architectonic requirements are different
- requirement for ecology
- higher performances needed

… then the timber becomes multi-storeys

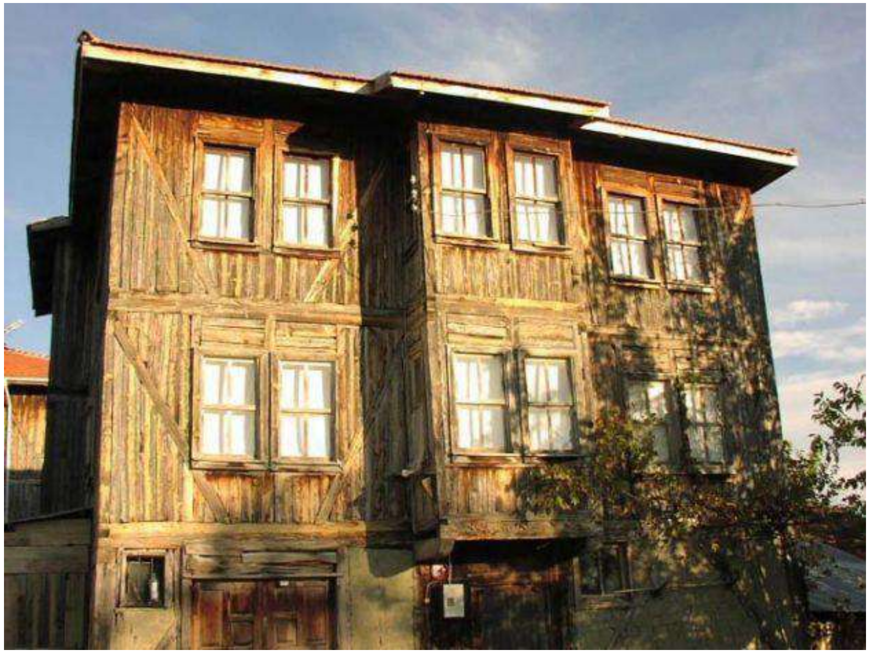
Yesterday the same situation as today? No, because a lot of reasons

- compact and "closed" structure
- walls with very small opening

- a lot of big openings
- slender, small walls elements



Timber and earthquake - an interesting an successful history



- many interesting remarks can be founded
- ...

Turkey earthquakes and damages of buildings

Earthquake

12.11.99 Duzce
17.08.99 Kocaeli

Behaviour of traditional wooden buildings

Wooden buildings have been discussed most after these earthquakes. Many traditional timber framed buildings were performed better than the other buildings with different material

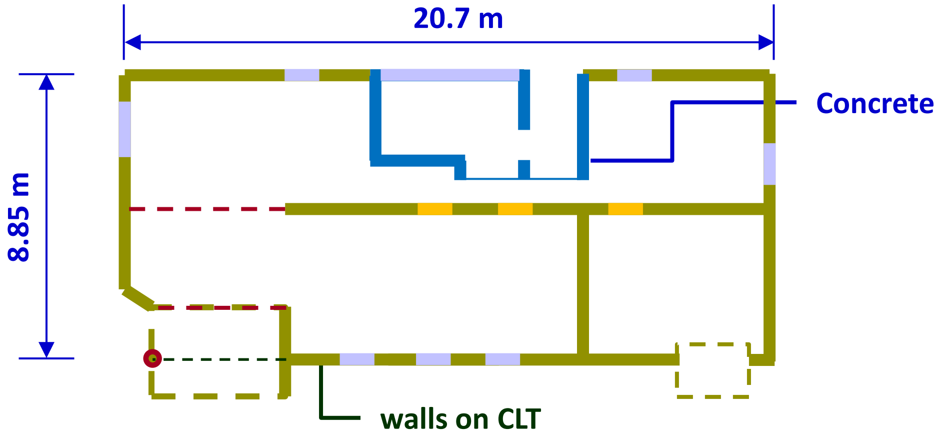
Appartements house Sirio - Lugano

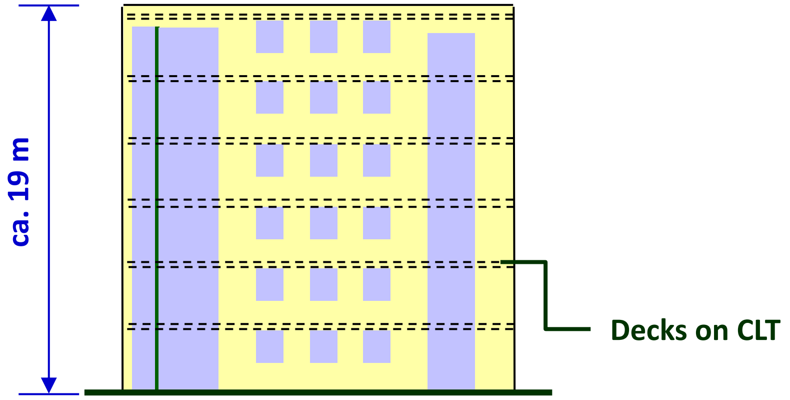
Modern timber building

Apartment building **Sirio - Lugano**

6 - storey building with CLT structure

- stairwell and elevator shaft partially on concrete
- 3D structure on CLT

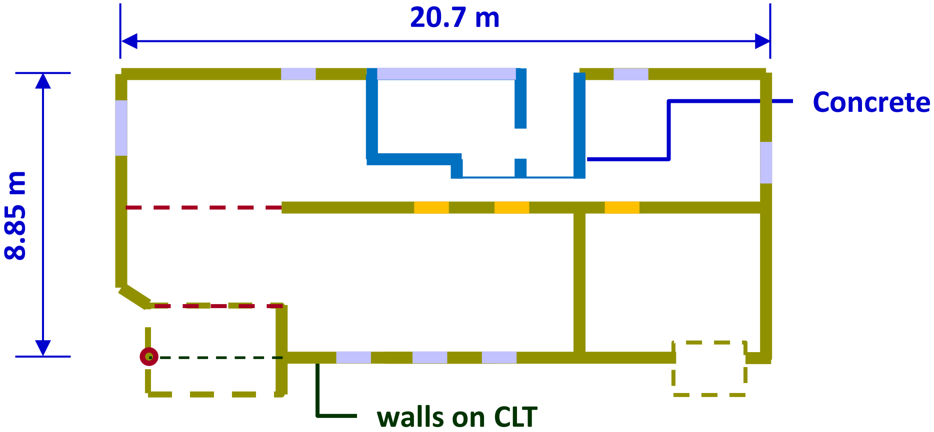


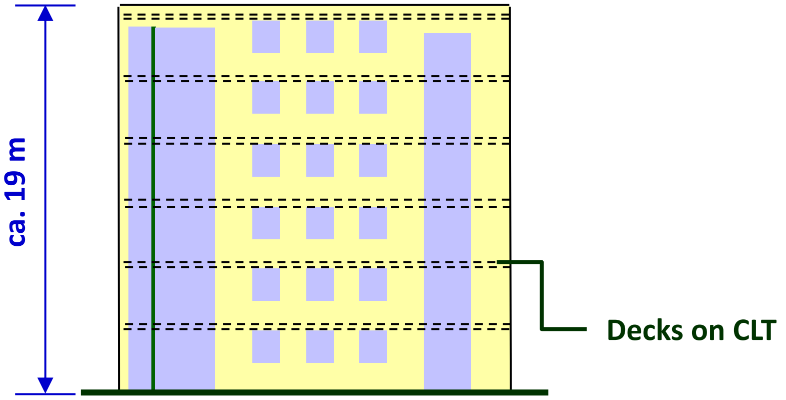


Modern timber building

6 - storey building with CLT structure

- stairwell and elevator shaft partially on concrete
- 3D structure on CLT





The project of the Via Cenni, Milan

Rendering Arch. Fabrizio Rossi Prodi - 2009

Image Arch. Riccardo Ronchi - 2013

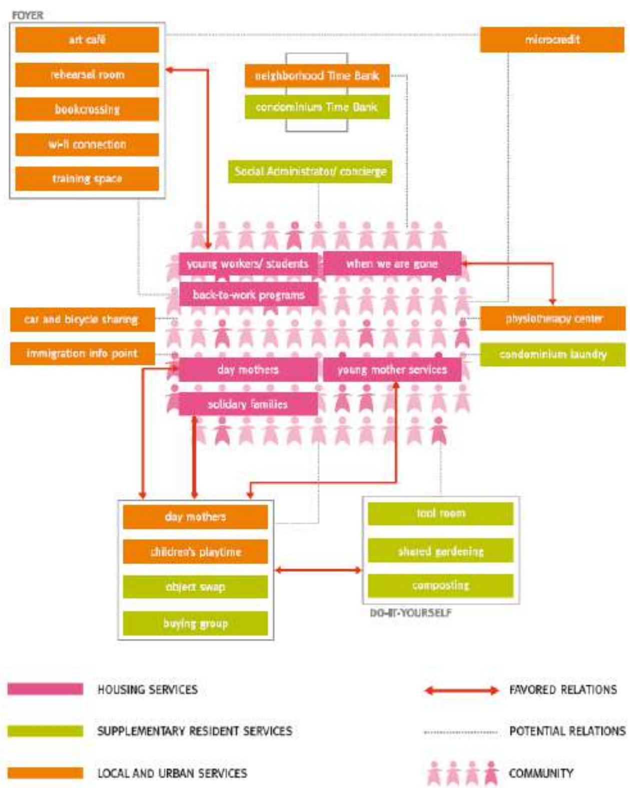
The project of the Via Cenni, Milan

4 towers with 9 storeys - 4 connection buildings with 2 storeys

The project of the Via Cenni, Milan

The begin of the project: a design competition in 2009

- promoted by Polaris Investments SRI
- with the goal of promoting ongoing experimentation in innovative approaches to social housing management
- calls for the preliminary design of a social housing project supplemented by resident, local and urban services



Winner Arch Fabrizio Rossi Prodi

- innovative technical solution: timber construction - CLT
- CLT construction:
- high safety of the structure
- high comfort of the residence
- high flexibility by the organization of the space

The project of the Via Cenni, Milan


Image Arch. Riccardo Ronchi - 2013

Residential units

- 123 residences
- 2 to 4 rooms (1 to 3 sleeping rooms - 100/75/50 m^2 area)

Others

- some space for urban services
- concierge and administration
- social spaces
- public area and garden

Surfaces

- 9300 m^2 gross floor area
- 17000 m^2 gross built floor area

Costs*

- 17 Mio. € all inclusive

- rent: 500 to 1000 €/month
- sales: 150'000 to 300'000 €

* approximately

The project of the Via Cenni, Milan

Foto Arch. Riccardo Ronchi - 2013

Construction

- 4 buildings with 9 storeys
- 4 connection buildings 2-storeys

Architectural project

Rossi Prodi e Associati S.r.l., Firenze

Timber structures project

Borlini & Zanini SA, Lugano

…

Project management

Tekne SpA, Milano

Timber construction

Servicelegno Srl, Treviso

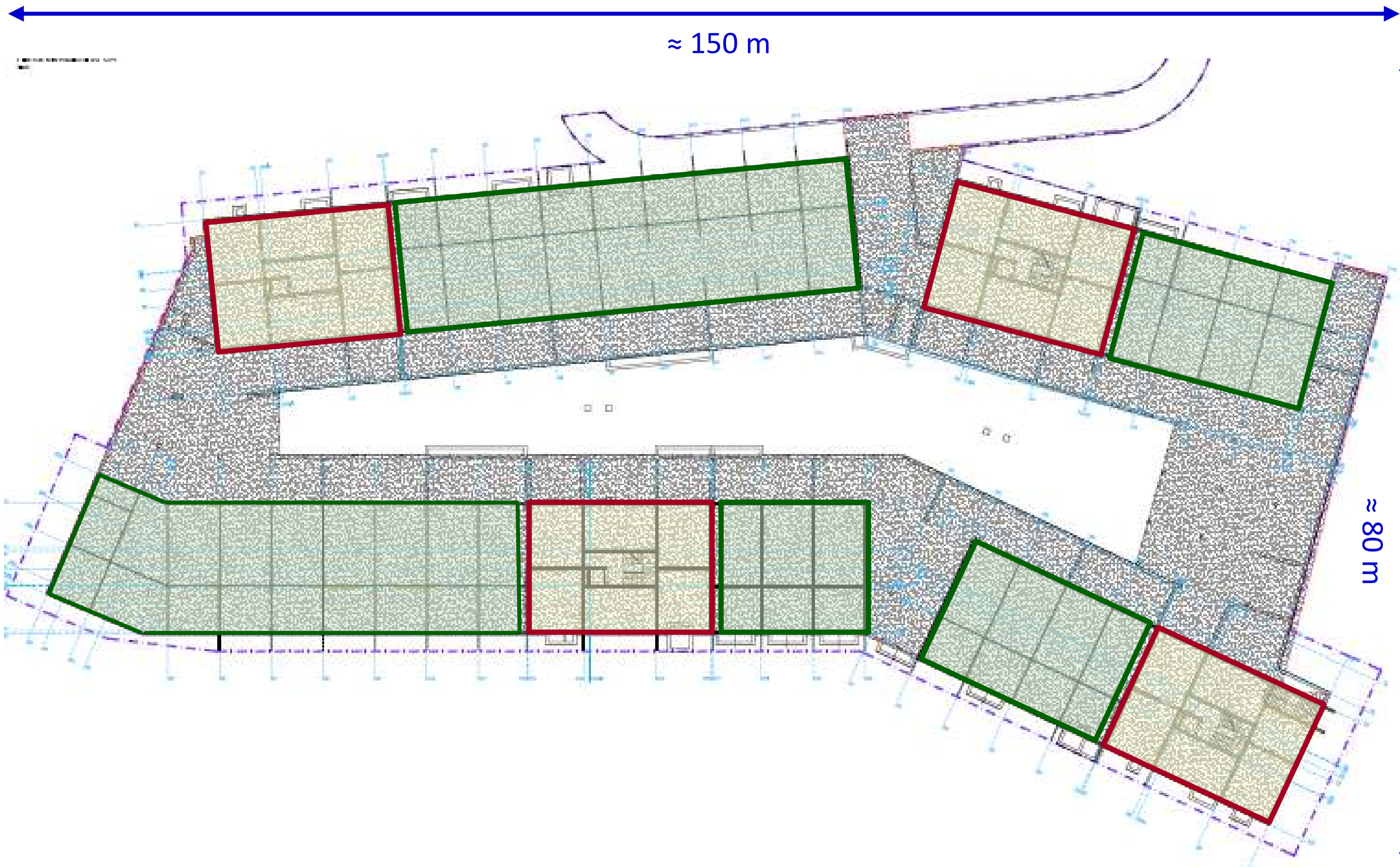
Owner - Promoter

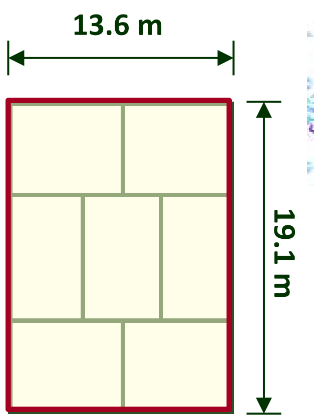
Polaris Investments Italia SGR Spa with

- Fondazione Housing Sociale
- Fondo Federale di Lombardia

The project of the Via Cenni, Milan

The project





9-storey Towers

- 4 similar buildings
- "full" timber construction

2-storey connection buildings

- 4 similar buildings
- timber construction with similar technology to the towers

CLT - solid timber decks and walls

Spatial structural timber construction for high engineer performance

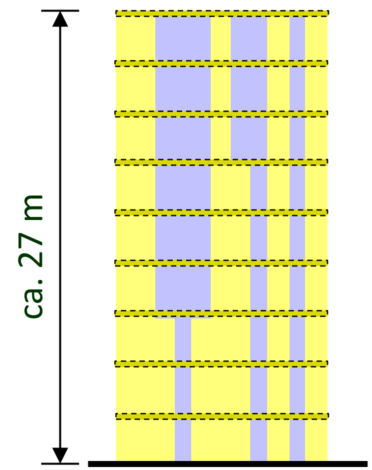
The "revolution" on the timber construction - may be on the construction

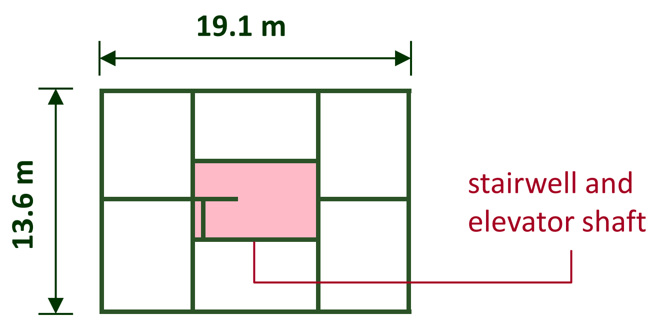
plane, solid timber surfaces for structural elements

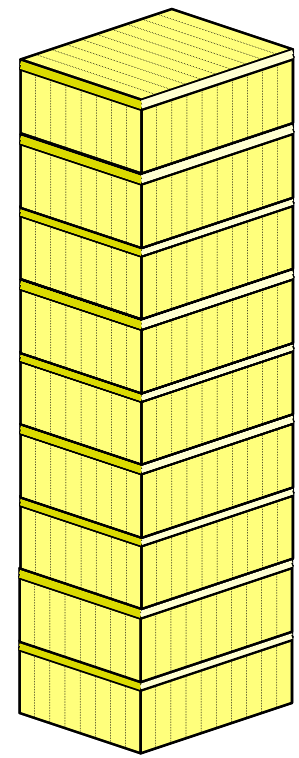
The project of the Via Cenni, Milan

The load bearing structure on CLT

9 storey, spatial, 3-d CLT-structure
- composed of CLT decks and walls
- full timber construction
- included stairwell and elevator shaft



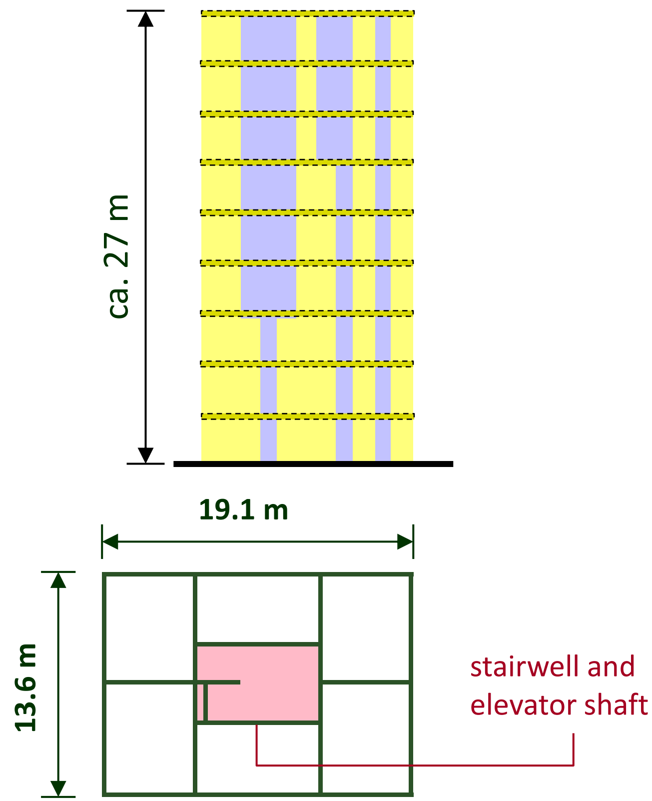


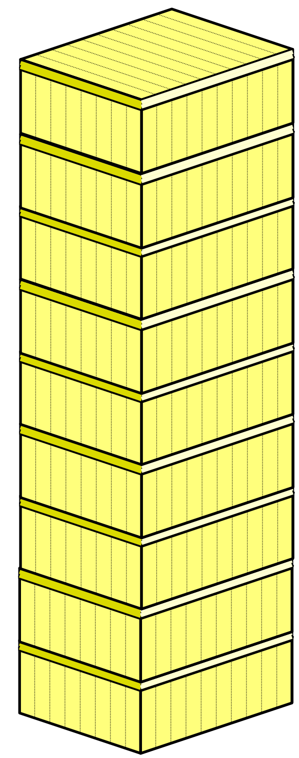


The project of the Via Cenni, Milan

The load bearing structure on CLT

9 storey, spatial, 3-d CLT-structure
- composed of CLT decks and walls
- full timber construction
- included stairwell and elevator shaft





The project of the Via Cenni, Milan

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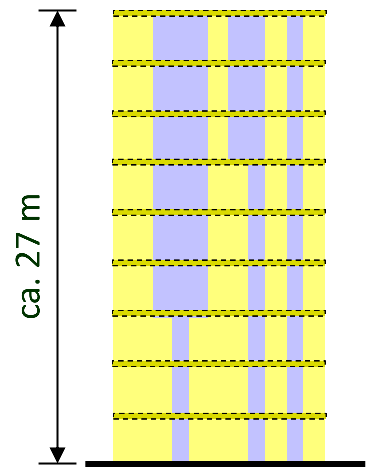

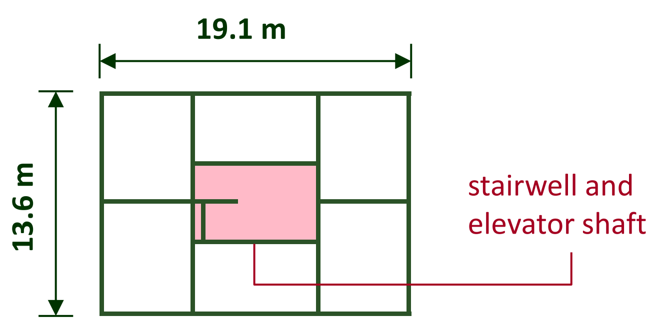

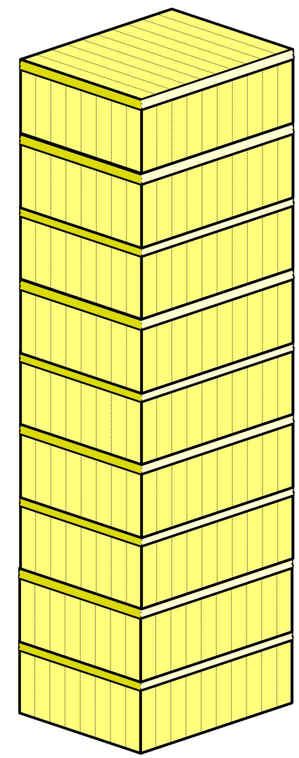

The project of the Via Cenni, Milan

Conditions - Requirements - and Challenges - for project and design

Form and dimensions

- high and slim building - tower
- fascinating und interesting

Earthquake risk

- not very high, but really existing
- important and with high significance by authority and population
- general earthquake engineering rules have to be strictly respected - principle of the structural project
- CLT-timber appropriate for the requirement

High number of storeys - height of the building

- relatively new with timber
- absolutely new on earthquake area

State of the Art

- some experience with similar buildings - but not by earthquake risk and by easier conditions of ratio height/large
- new and innovative, but under applications of actual technology and knowledge
- innovative application of the actual state of the art

The project of the Via Cenni, Milan

Formal requirements

Special authority validation

- examination and approval of the engineering project by a special investigation commission of the national authority
- to assure that timber technology are capable to assure a correct safety level, according the buildings codes and the requirements for building with other material
- the project was evaluated from specialists on building engineers, on earthquake constructions and on high buildings

Timber solutions for engineering constructions

- have "simply" to respect and fulfil the general requirements for similar buildings
- doesn't allow to use the same solutions and details as the "timber houses" with one or two storeys

The project of the Via Cenni, Milan

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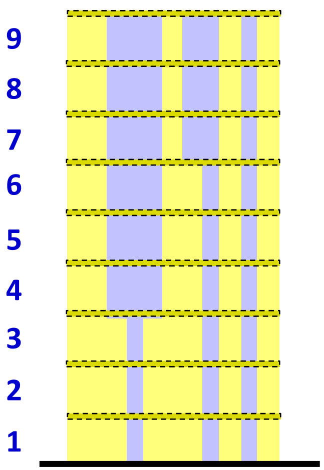
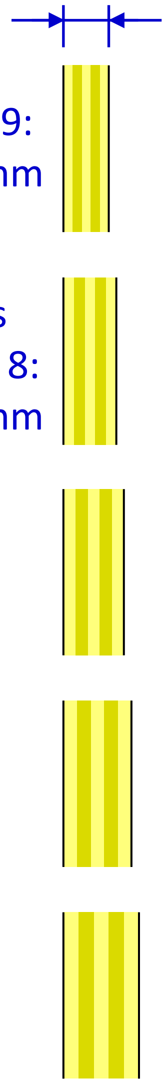
Since 2012
Special approuval not required

The project of the Via Cenni, Milan

CLT-wall elements





Level 9:
120 mm

Levels
7 and 8:
140 mm

Levels 5 and 6:
Thickness 160 mm

Levels 2, 3 and 4:
Thickness 180 mm

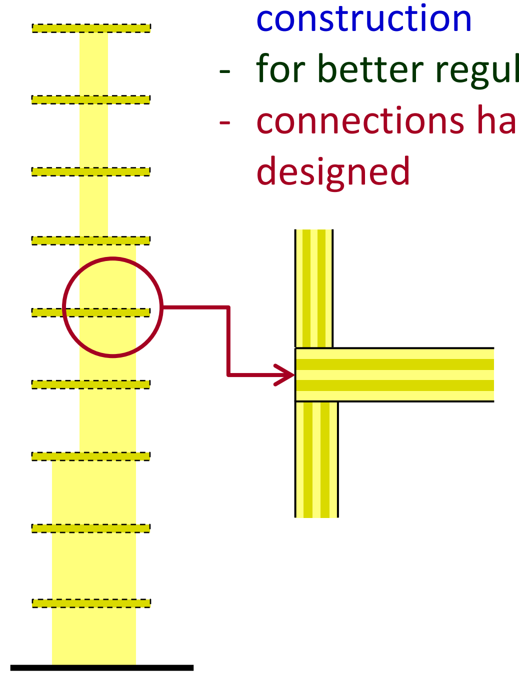
Level 1:
Thickness 200 mm

Characteristics

- more thickness in the lower storeys
- CLT with not less than 5 layers for better horizontal bracing

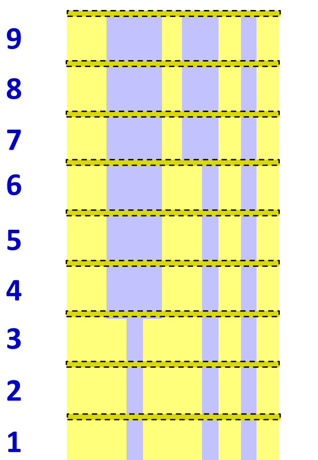
Wall panels interrupted at decks level

- because production, transportation and construction
- for better regularity of the structure
- connections have to be accurately designed



The project of the Via Cenni, Milan

CLT-wall elements



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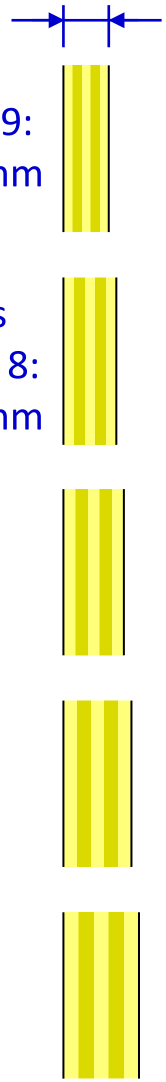
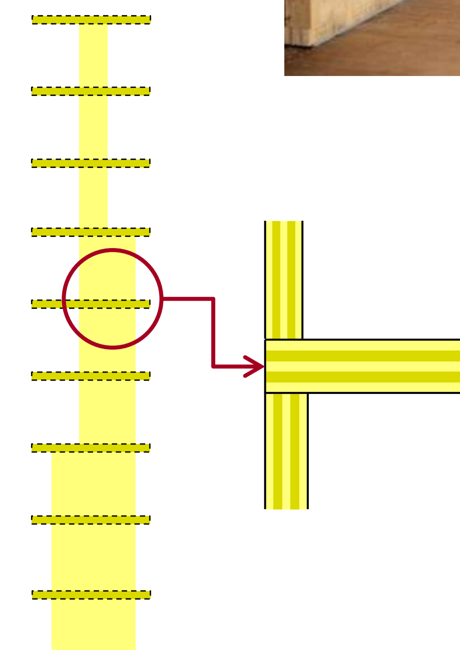


Levels 5 and 6:
Thickness 160 mm

Levels 2, 3 and 4:
Thickness 180 mm

Level 1:
Thickness 200 mm



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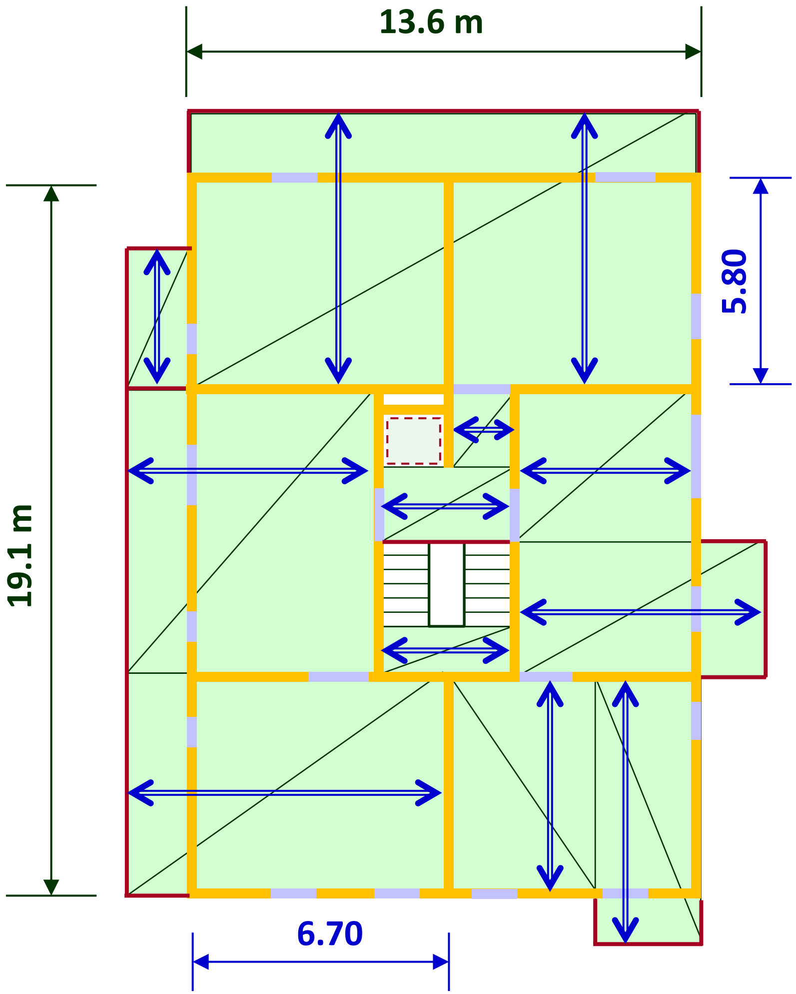
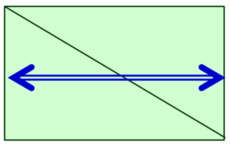
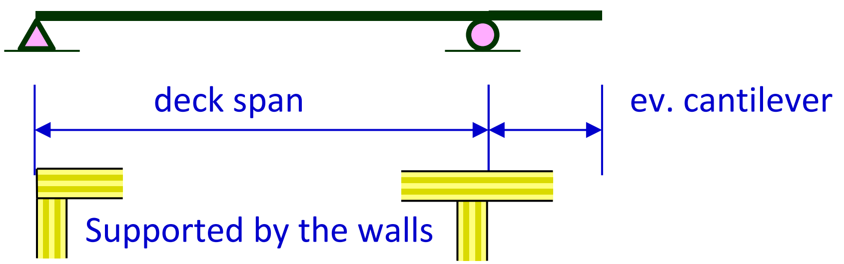
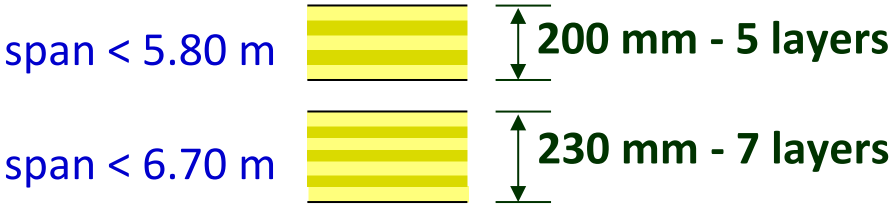
CLT-decks elements





Main direction (outside layers) of the deck





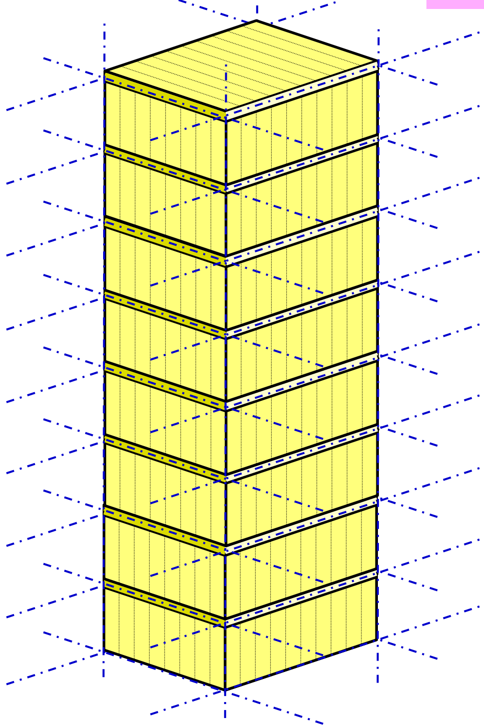
The project of the Via Cenni, Milan

3-d structure is given by CLT-panels and connections between the panels

The structure

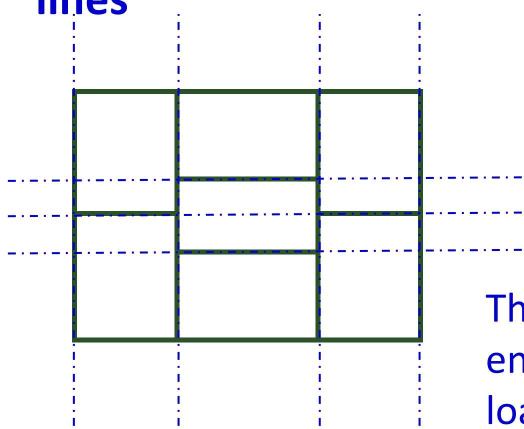
- three-dimensional (3D)
- structural surfaces on CLT (2D)
- connections - as "connection lines" (1D) - are essential

3D Structure **3 D**

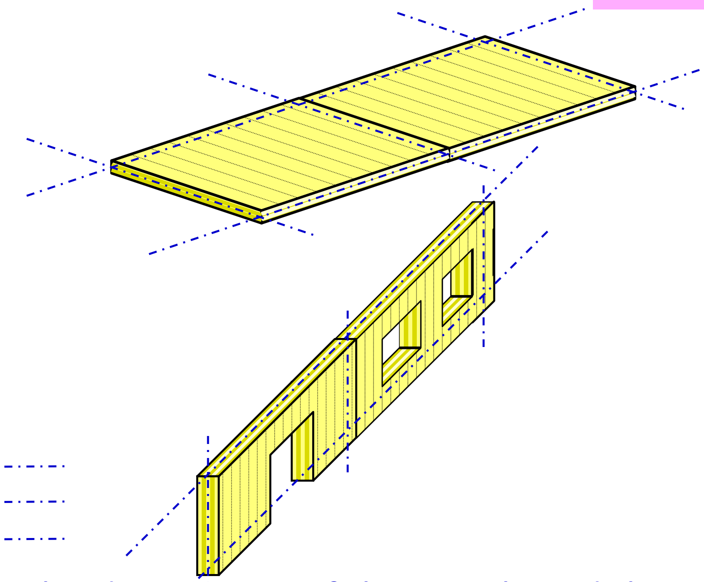


3D = 2D + 1D

Connection lines **1 D**



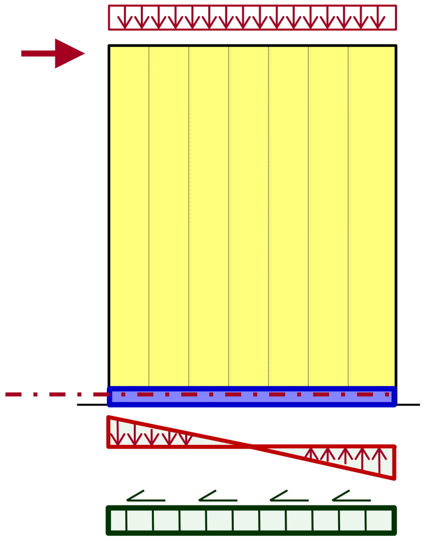
Structural surfaces **2 D**



The dimensions of the panels and the entire composition are relevant for the load bearing

The project of the Via Cenni, Milan

Connections are the essential structural component



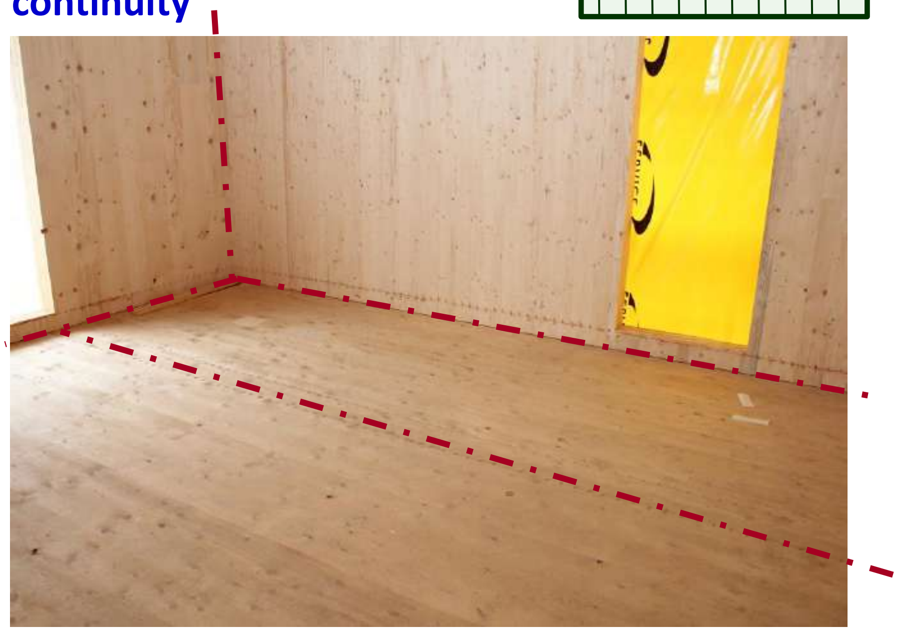
Design and construction of "connections lines":

- not just connection points - but a "continuous stitching" to assure high performance in the load transfer
- high performance of connections needed

  not "just" on resistance but

  on stiffness

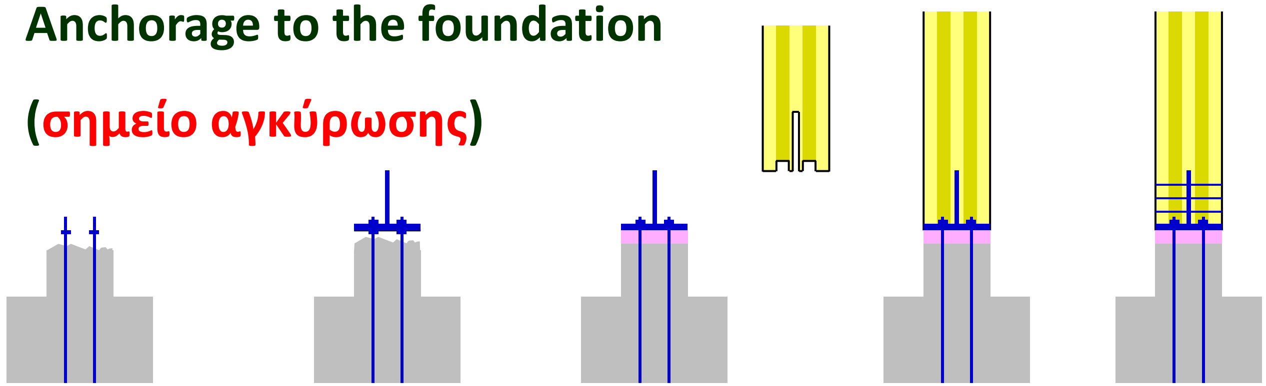
1 D **Continuity of the connection - structural continuity**



Connection systems for continuously CLT connections

Anchorage to the foundation

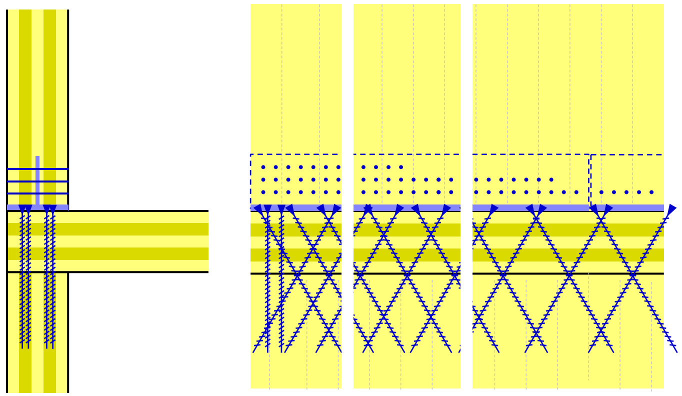
(σημείο αγκύρωσης)



Phase 1 Phase 2 Phase 3 Phase 4

Connection systems for continuously CLT connections

Connection systems for continuously CLT connections



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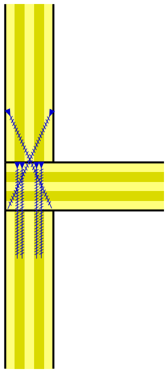

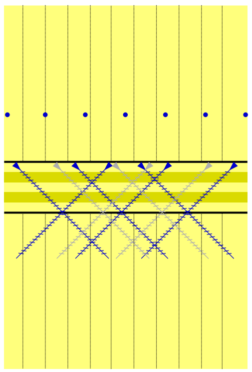

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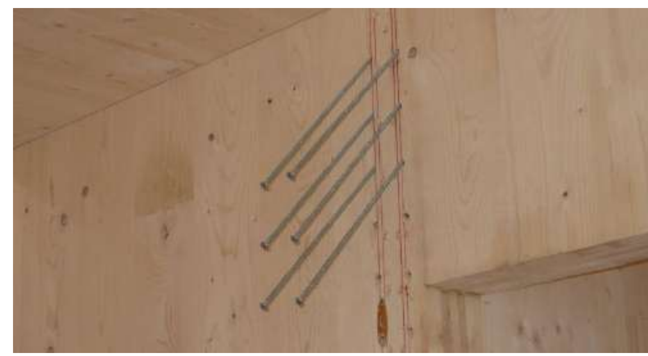
Connection systems for continuously CLT connections

Connection line for continuously connection with high performances



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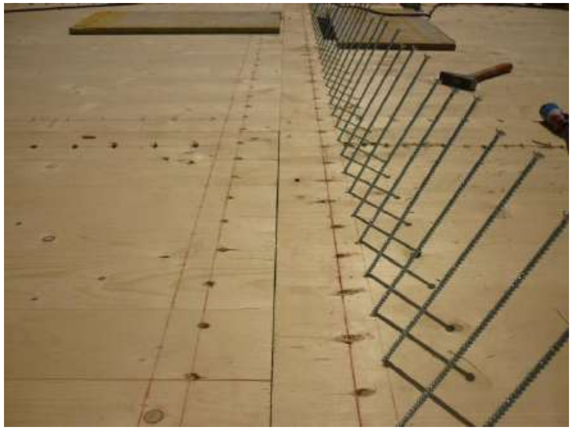
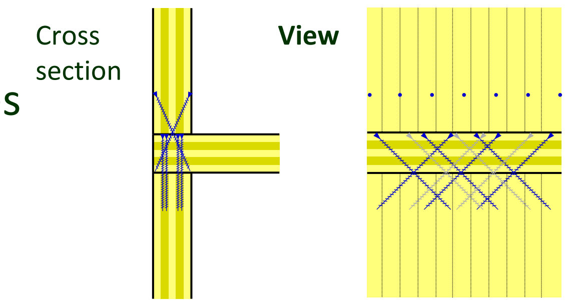


Connections for high performance CLT structures

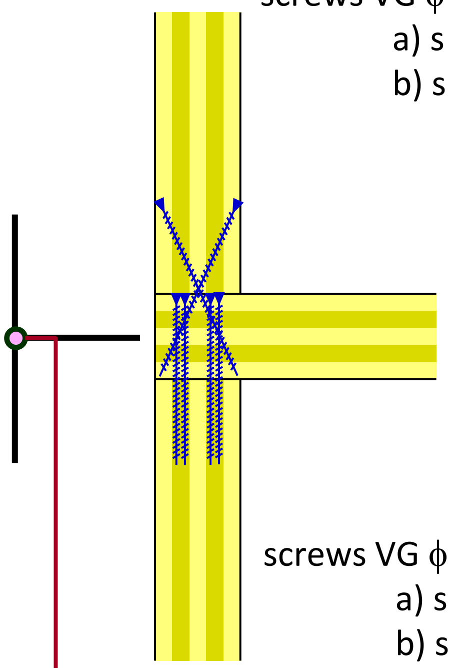
Example of the connection's mechanical values - long screws

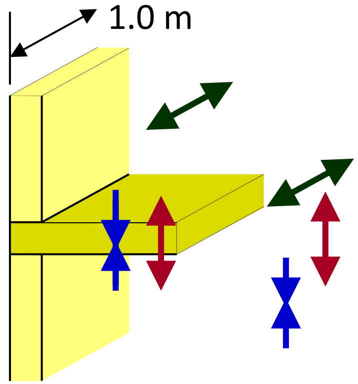
Typical connection's values

- tension-, compression, and shear resistance values
- tension-, compression, and shear stiffness values



screws VG ϕ 8; a = 30°; ℓ = about 300 mm
a) s = 100 mm = 2 x 10 /m'
b) s = 50 mm = 2 x 20 /m'





R_d [kN]			K_{ser} [kN/mm]		
a	b		a	b	
40	80		24.0	48.0	
112	224		47.0	93.0	
446			585		

screws VG ϕ 8; **a = 45°**; ℓ = ca. 450 mm
a) s = 100 mm = 2 x 10 /m'
b) s = 50 mm = 2 x 20 /m'

connection axis: articulation

compression: contact

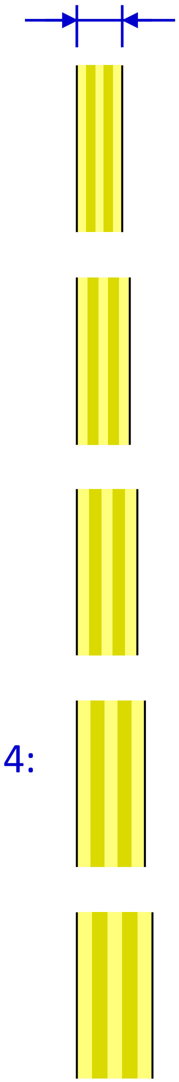
tension: mechanical connection

shear: mechanical connection

The project of the Via Cenni, Milan

Structural elements

Walls



Level 9:
120 mm

Levels 7 and 8:
140 mm

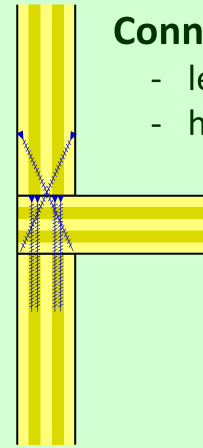
Levels 5 and 6:
160 mm

Levels 2, 3 and 4:
180 mm

Level 1:
200 mm

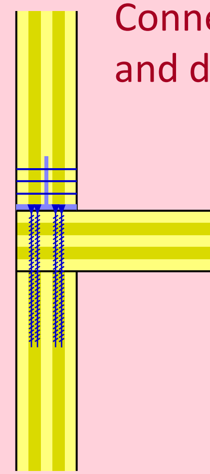
Decks

200 mm
230 mm



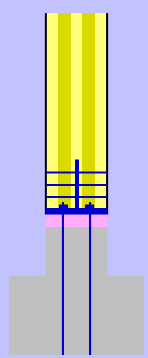
Connections with screws

- level 4 - 9 roof deck
- high stiffness



Connections steel plates, screw and dowels

- Level 1 - 3
- high stiffness
- high resistance



Anchorage with steel plates

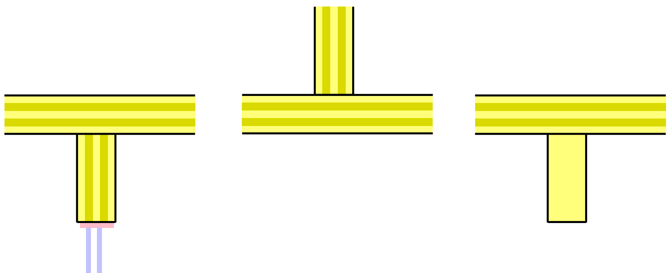
- high stiffness
- high resistance

The project of the Via Cenni, Milan

Timber structure - local reinforcements

Special solutions for singular points

- due to the requirement of the project
- global resistance and robustness to be assured



Opening of walls - interruption of decks support

- bending beam integrated in the upper or lower wall (CLT wall)
- in some local cases, bending beam (CLT, GL, LWL or steel) was added to the structure to local reinforcement

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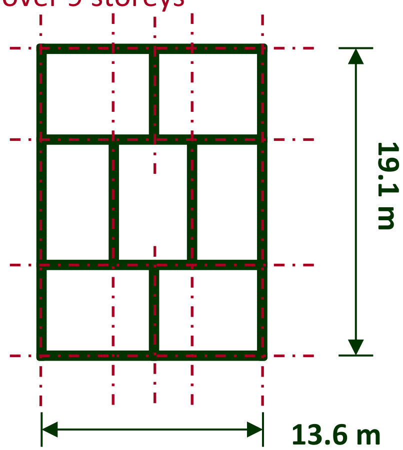
Structure composed of CLT-decks and walls

Position - axis - of the walls over 9 storeys

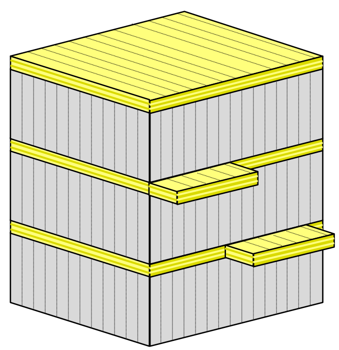


Balcony

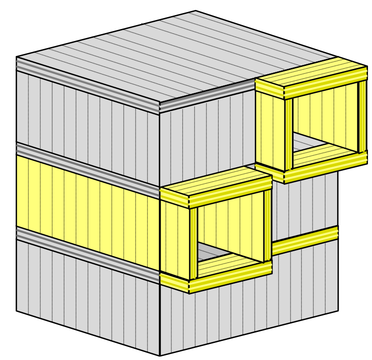
- fundamental architecture elements
- variability and flexibility needed

Balcony

- added elements on the spatial structure
- without influence on the regularity of the main structure
- allows to respect and fulfil the requirements of the architecture
- can be open or closed (lateral wall, deck, windows, …)



Cantilever decks



Cantilever walls

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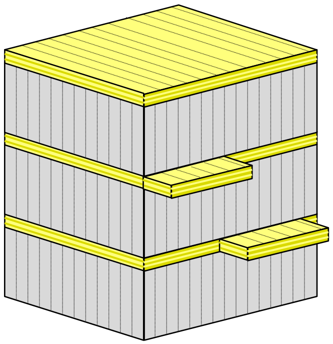
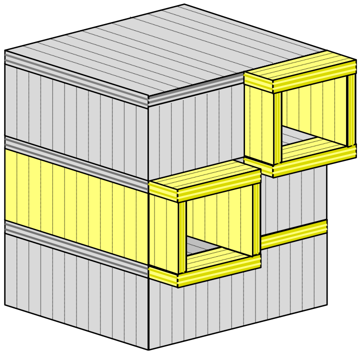
Timber structure for the balcony



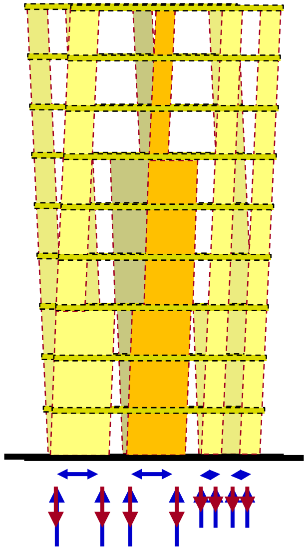
Cantilevered deck



Cantilevered walls

The project of the Via Cenni, Milan

Earthquake behaviour



Design principle

- generally: timber structure are adequate and interesting
- spatial wall and decks structure are adequate
- CLT-structure are very good qualified

Essential conditions

- right concept for the structure
- application of the basic of earthquake engineering
- correctly designed

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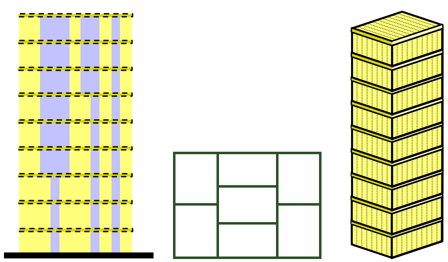
Fundamental requirements from the earthquake engineering



Basic requirements for design

- **Simplicity**
- **Regularity**
- **Redundancy**

Simplicity

- stairwell is central and not interrupted
- load bearing walls are not interrupted - from level 0 to 0
- balconies are just a prolongation of the structure

Regularity

- in the horizontal and in the vertical planes
- architecture consistent with engineering
- continuous load transfer form the upper to the lower level
- **spatial, three dimensional structure**

Redundancy

- spatial, three dimensional structure
- **continuity of the structure - and of the connections**

Requirements strong fulfilled

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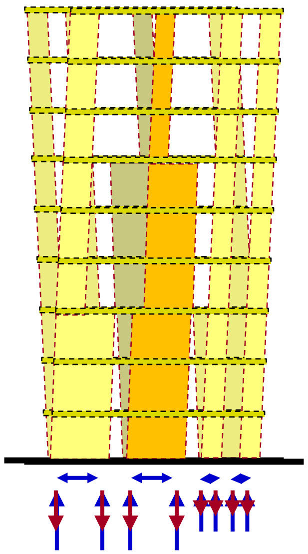
Earthquake behaviour



Design principle: elastic behaviour of the structure

- dissipation of energy and ductility not applied for design
- effective value of q not needed, because q = 1.0
- verification and demonstration of q > 1.0 not needed
- demonstration of the compatibility of the not elastic deformations of the structure components not needed
- over dimensions of some structural components

Design conditions

- elastic behaviour in case of earthquake
- value of q = 1.0
- "no damage" in case of design-eartquake

Practical. practicable, appropriate and convenient procedure

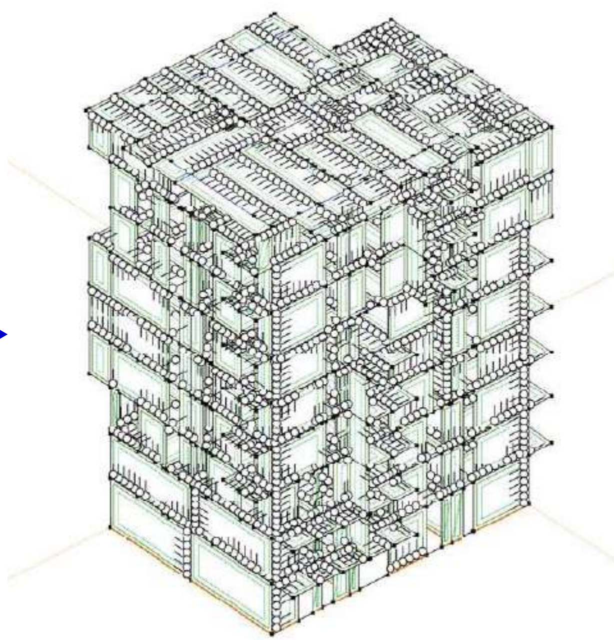
- for low to middle earthquake risk: consequences acceptable
- first experience with big building in earthquake area

In case of higher seismic risk

- the concept (design of structure and connection) can be applied for higher performance or for higher seismic risk - and seismic load conditions

The project of the Via Cenni, Milan

Numerical modelling and calculation



Static structural analysis
- confirmation internal forces M_x, M_y, V_x, V_y, N_x, N_y, N_{xy}
- forces on connections

Dynamic analysis
- resonance frequencies
- earthquake analysis

Parametric numerical analysis
- stiffness of connections K_{ser} have to be considered
- sensibility of the modelling

Modelling
- high performance software required
- user interfaces not optimized for this kind of systems

The project of the Via Cenni, Milan

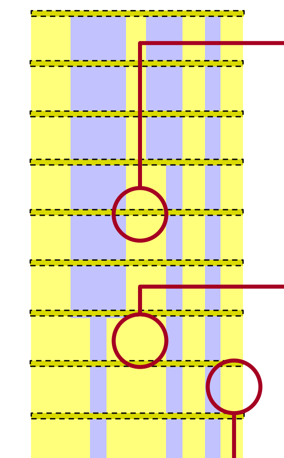
Principle of the fire protection

Requirement

- **Fire compartments: REI60**
- **Other structural elements: R60**

Realisation: full protection of the timber by fire resistant sheeting

- sheeting EI60 of all structural timber elements
- some other singular prescription

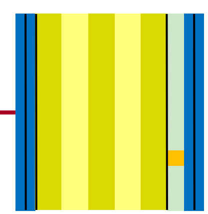


Decks:

- upper surface: sheeting EI60
- lower surface:
  floor construction EI60
- fire safety REI 60 given also by branding time of CLT

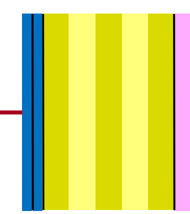
Internal walls:

- sheeting on both sides EI60



External walls:

- internal sheeting EI60



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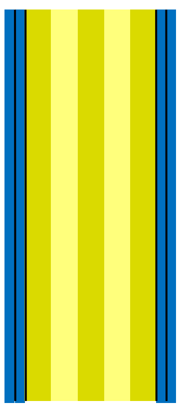
Remarks about fire protection - possible discussion points

Principle of fire protection: fire resistant sheeting to obtain EI60

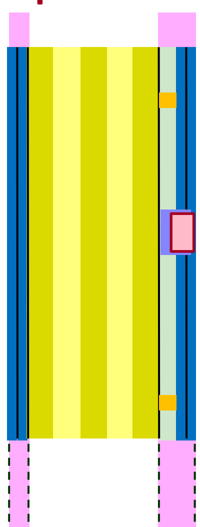
- sheeting should be so near as possible to the protected element (CLT wall)
- space between protected element and protection = risks and problems ...

Principle



60' 60'

Installations inside of fire-protected space



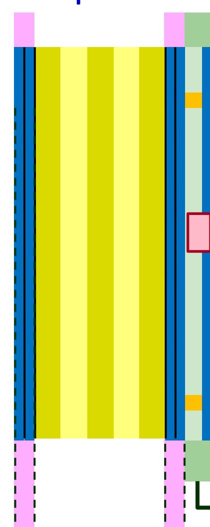
protected area

60' 60'

Special solution required

- protection of sheeting perforations
- later interventions by residents not under control

Installations outside of fire-protected space



Safer solution

- timber directly protected
- installations not relevant for fire protection

"free" area

protected area

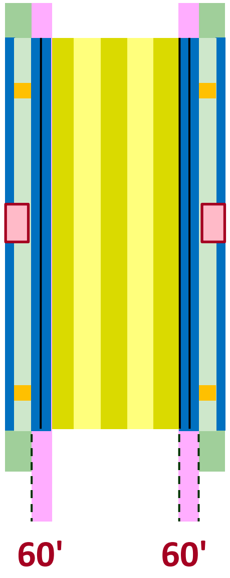
60' 60'

The project of the Via Cenni, Milan

Remarks about fire protection - possible discussion points

Principle of fire protection: fire resistant sheeting to obtain EI60

- sheeting should be so near as possible to the protected element (CLT wall)
- space between protected element and protection = risks and problems ...

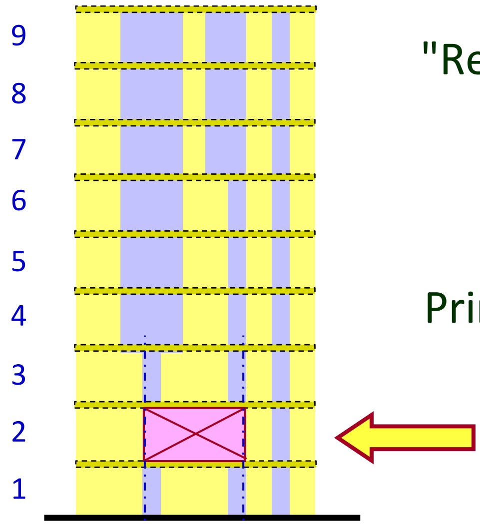


The robustness of the 9 storey towers - via Cenni, Milan

A progressive collapse have to be avoided in case of local accidental event

Alternative load transfer possibilities have to be assured

- assumption of "local" accidental event: failure or remove of one wall
- requirement: the structure have to remain stable

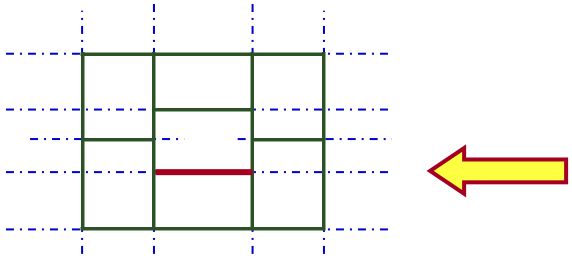


"Removable wall"

- load bearing wall between two perpendicular walls
- failure of any wall is possible
- failure due to unexpected event, for example local explosion

Principle of the alternative way for the forces

- in case of the event, the construction remain stable
- consideration of reduced safety coefficient

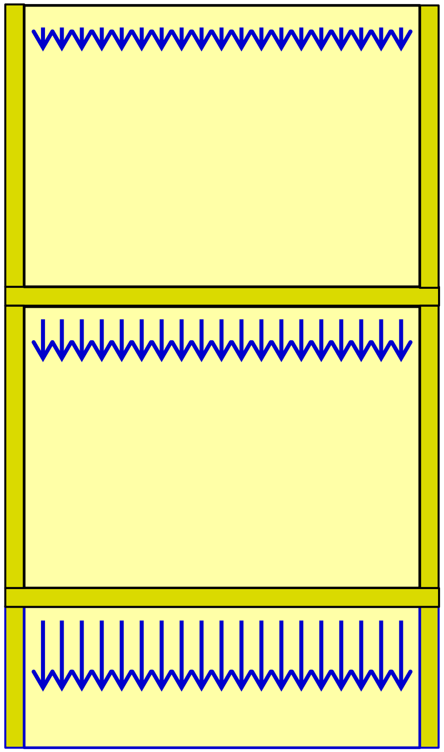


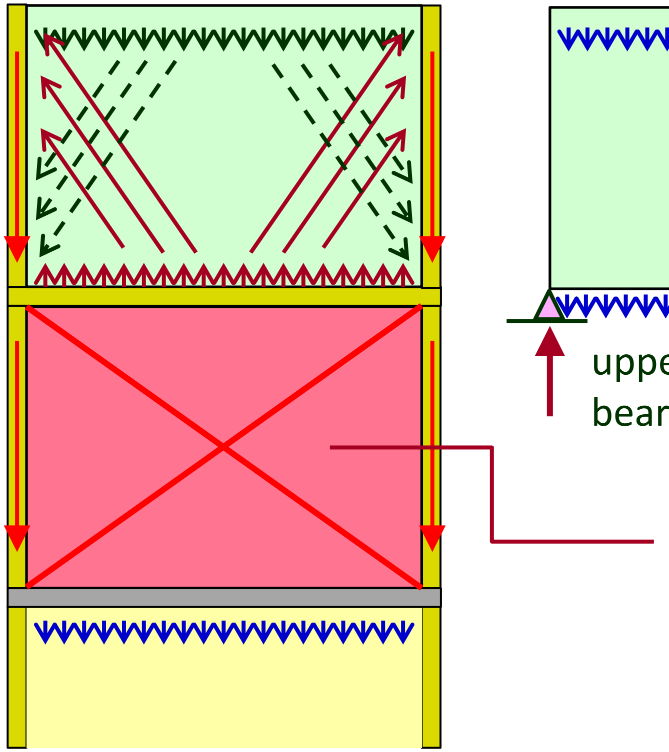
The robustness of the 9 storey towers - via Cenni, Milan

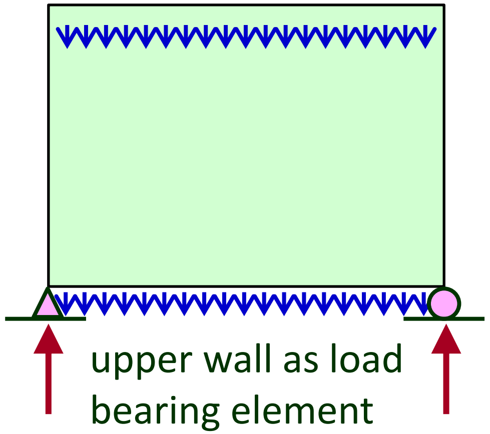
Principle of the alternative flow of the forces

Normal situation:
- continuous walls
- direct load transfer

Accidental situation:
- lack of the wall
- upper wall element as "local load bearing element"



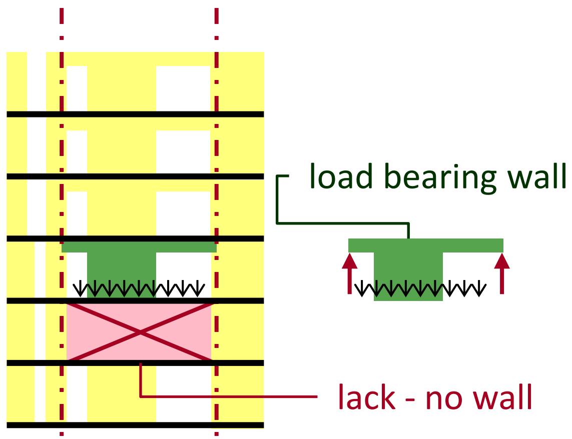


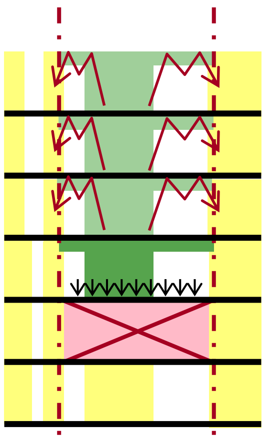


The robustness of the 9 storey towers - via Cenni, Milan

Effectively and really conditions of the accidental situation

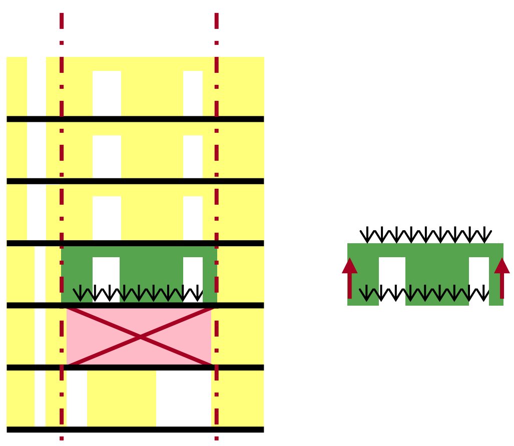
More, different situations are possible in the towers - some examples:





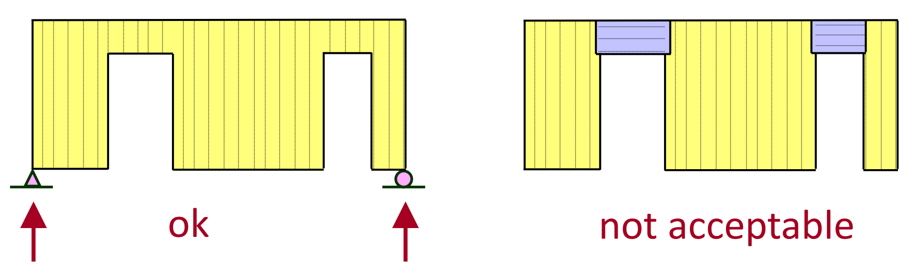
Principle of the alternative flow of forces

- distribution in more elements
- reduced forces
- connections have to be checked for this case



Consequences for the design

- monolithic, high dimension of the CLT panels
- walls as one CLT panel



The robustness of the 9 storey towers - via Cenni, Milan

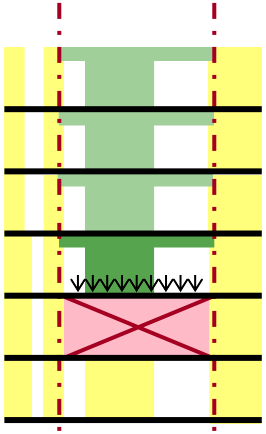
Effectively and really conditions of the accidental situation

Check of the failure of each wall element needed

- in this case requirement form the authority
- needed for the validation of the project

Consequences of the robustness requirement

- careful check of the dimension of the CLT panels
- check of the connections
- reinforcement of connection in some case (rarely) necessary
- some local reinforcement by the openings in the walls needed



Conclusions and statement about robustness

- the principle of the 3D CLT structure is confirmed as "good solution"
- in some cases local reinforcements of structure an connection are necessary
- robustness - on this way - is a very efficient way to check the goodness of the entire structure

The project of the Via Cenni, Milan

Equipement and installations

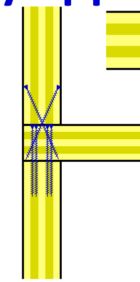
The project of the Via Cenni, Milan

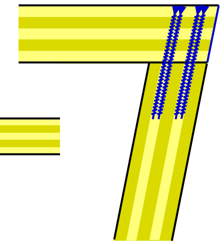
Internal

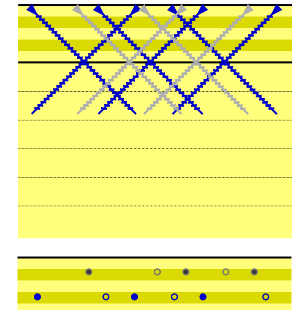
Applied solutions for the building via Cenni, Milan

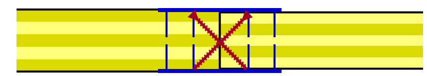
Modern and innovative engineering solutions -

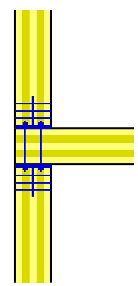
but already applied in recent buildings

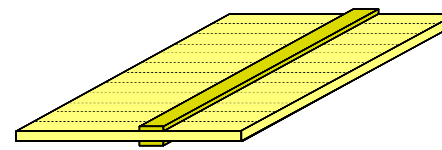


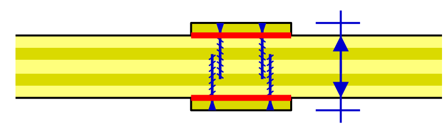












The project of the Via Cenni, Milan

Progress on the building site

Timetable

- begin: January 2012
- begin timber: July 2012
- end timber: February 2013
- end: September 2013

Timber quantity

- CLT: 6100 m^3
- GL - LWL: very low

The project of the Via Cenni, Milan

Progress on the building site


10.07.2012


07.08.2012


13.08.2012


13.08.2012


11.10.2012


11.10.2012


24.10.2012


07.11.2012


20.11.2012


28.02.2013


04.03.2013


23.9.2013

The project of the Via Cenni, Milan

End of November 2012

The project of the Via Cenni, Milan

March 2013

The project of the Via Cenni, Milan

May 2013

The "activator"

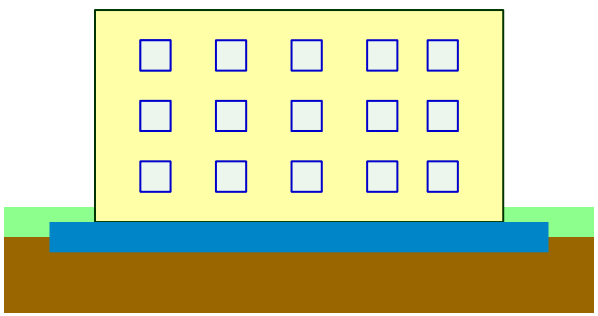
- the 6. April 2009, 3.32'
- 5.8 on the Richter Scale

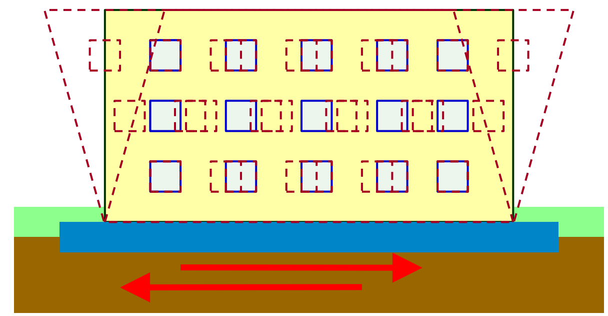
- 300 dead persons
- 1500 injured persons
- 17'000 (?) homeless pesrons

The solution

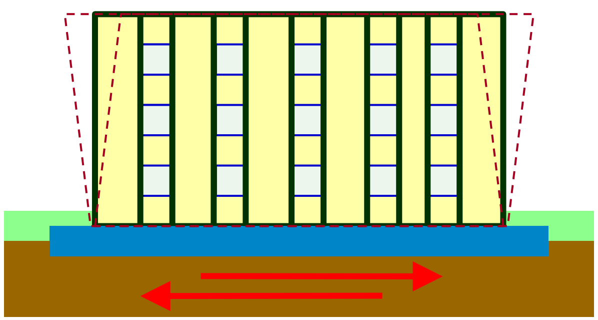
Proposal for a solution for earthquake safety before building

- fast in the implementation and "independent" from the building project
- preparation of the foundation during planning of the buildings



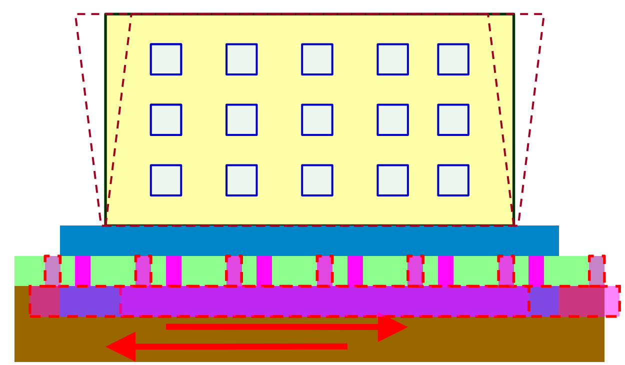


Big earthquake: to high damages



Earthquake design:

- small/ no damages



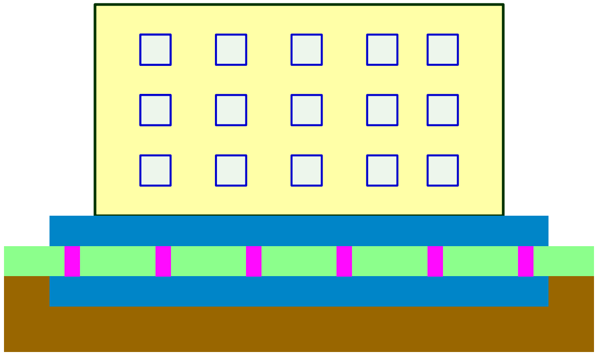
Earthquake separation :

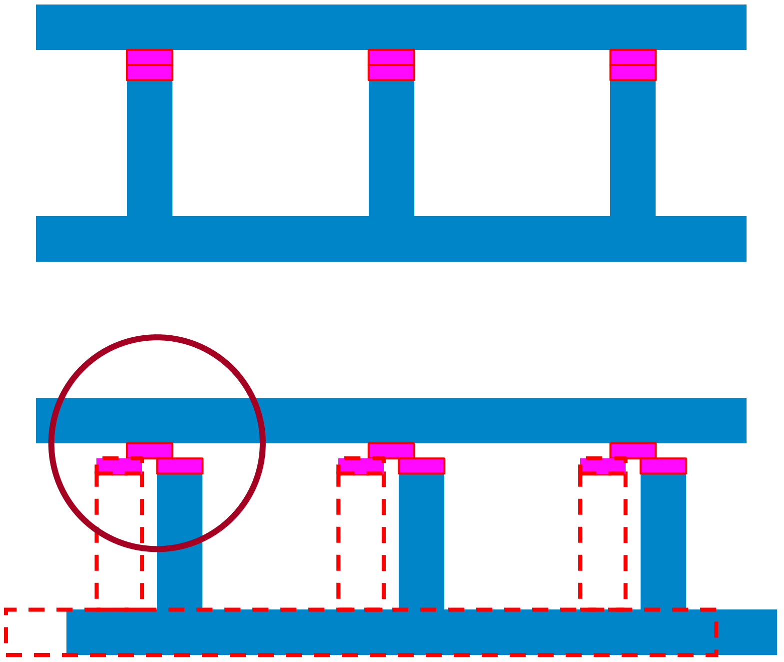
- small or no damages

The solution

Proposal for a solution for earthquake safety before building

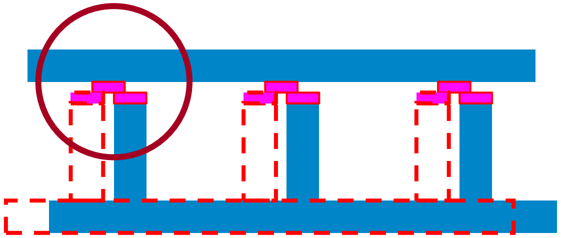
- fast in the implementation and "independent" from the building project
- preparation of the foundation during planning of the buildings

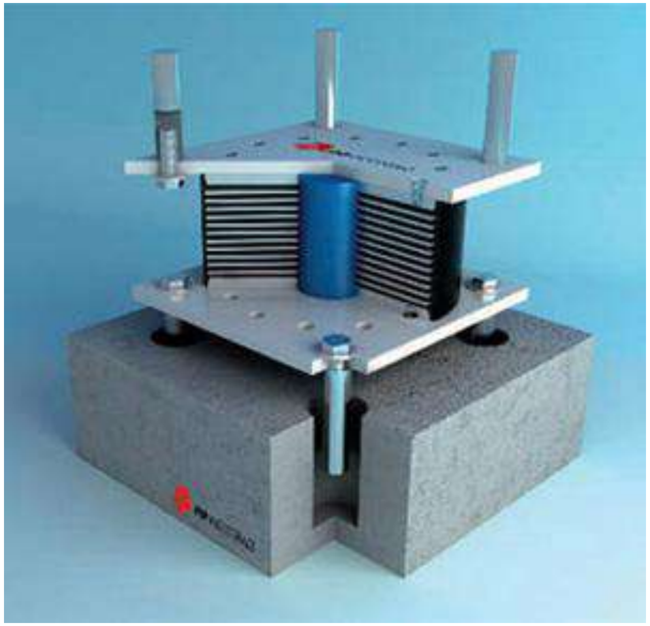




The principle of the solution

- Separation between ground and building
- some horizontal displacement are possible
- strong stiffness in the vertical direction





The solution

The principle of the solution

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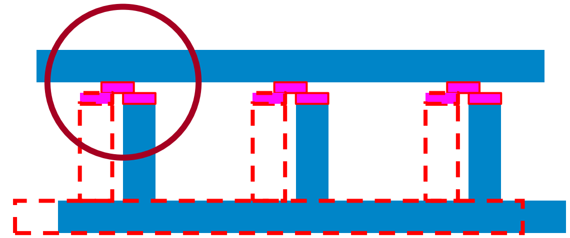
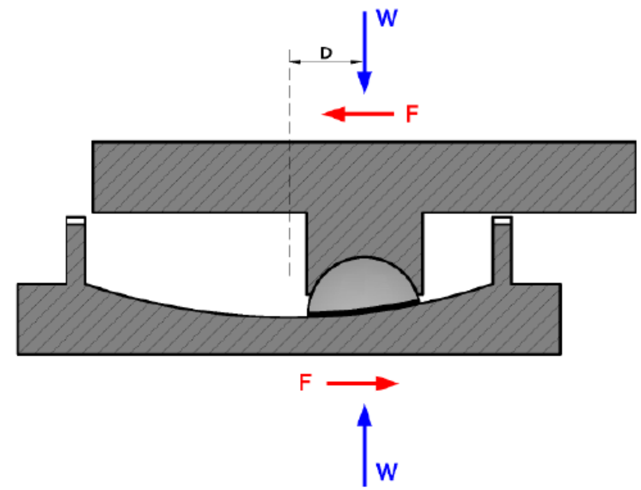


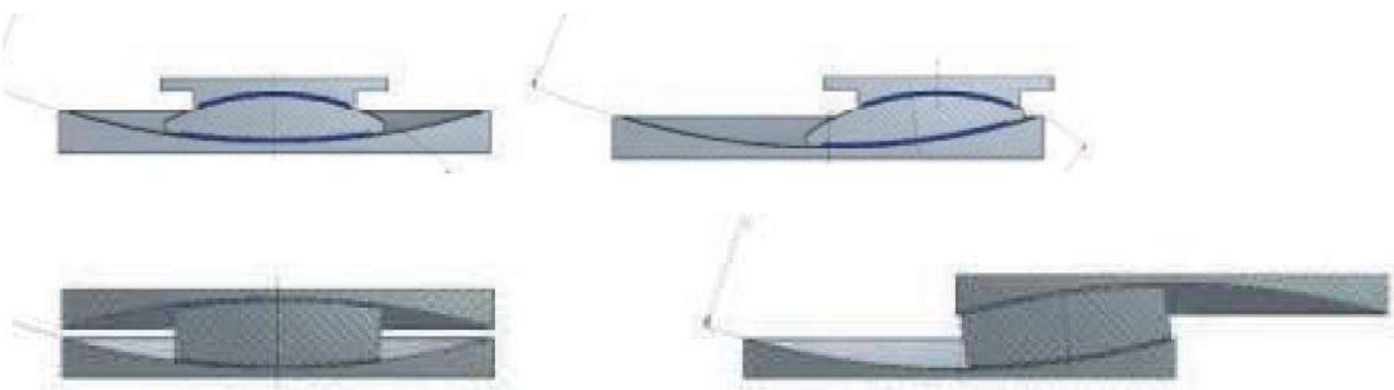
Bearing on curved surfaces

- principle of the pendulum



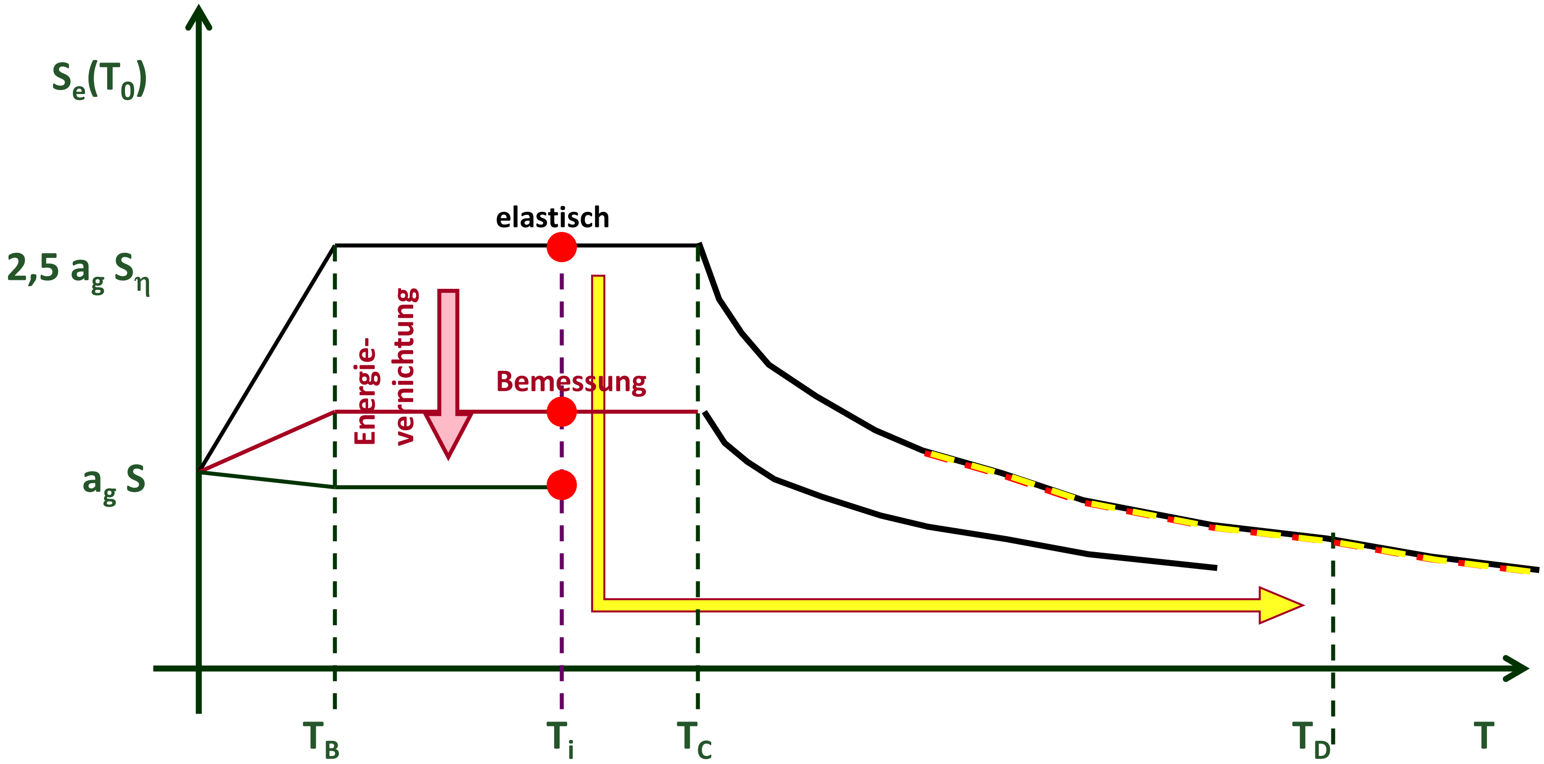
Alternative

- bearing on synthetic materials



The effect of the solution

- lower effect of the earthquake on the building



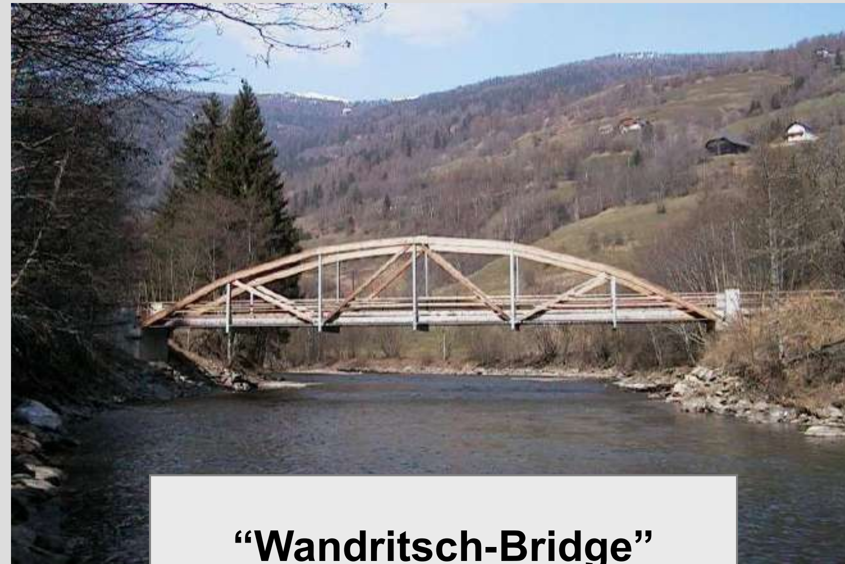
CLT – Examples of erected buildings

“Austria-House” (2006)
Turin / Italy

Building Research Centre
Step 2 (2007)
Graz / Austria

CLT – Examples of erected buildings

Multi-storey building
(2001)
Vienna / Austria



“Wandritsch-Bridge”
(1998)
St. Lorenzen / Austria

AREA 1_SSTC

Shell and Spatial Timber Constructions (SSTC)

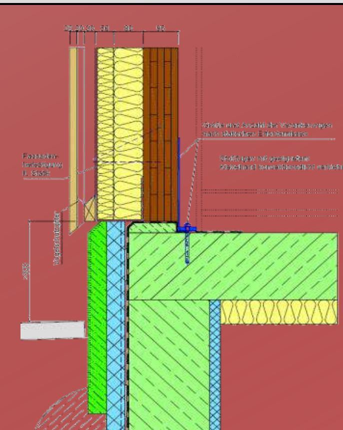
TMC using CLT

MODULE 1

Mechanical Aspects
Structural Analysis
Verification Procedure

MODULE 3

Guidelines
Building Physics
Leading Details



MODULE 2

Connection Technique

MODULE 4

Development of Systems
Architectural Potential
Case Studies

Limit states

Ultimate Limit State

Topics: "System effects"
"Laminating effects"

Subproject
"Load carrying capacity"
(for elements loaded as plates and panels)

Load carrying model CLT

Serviceability Limit State

Topic: Creep behaviour

Subproject
"Creep"

Deformation factor CLT

Objective

Further tests:

Properties perpendicular to grain

Vibration properties of CLT-floors

Eurocode 1995-1-1

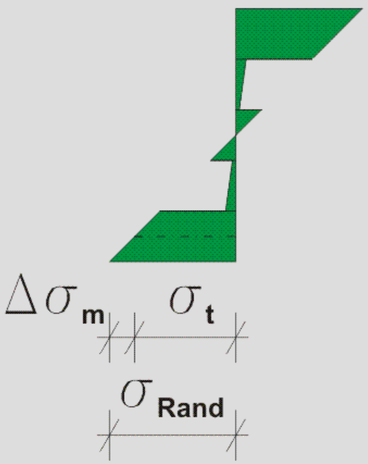
Currently no proposals for the verification of CLT-elements

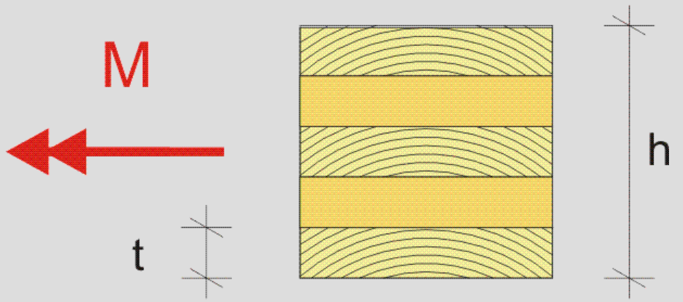
→ The development of an European standard is initiated by the Austrian Standardisation Organisation (ON).

DIN 1052-2004.08

A verification procedere is given in this standard

Verification of stresses on each single layer: $$\frac{\sigma_t}{f_{t,d}} + \frac{\Delta\sigma_m}{f_{m,d}} \leq 1$$



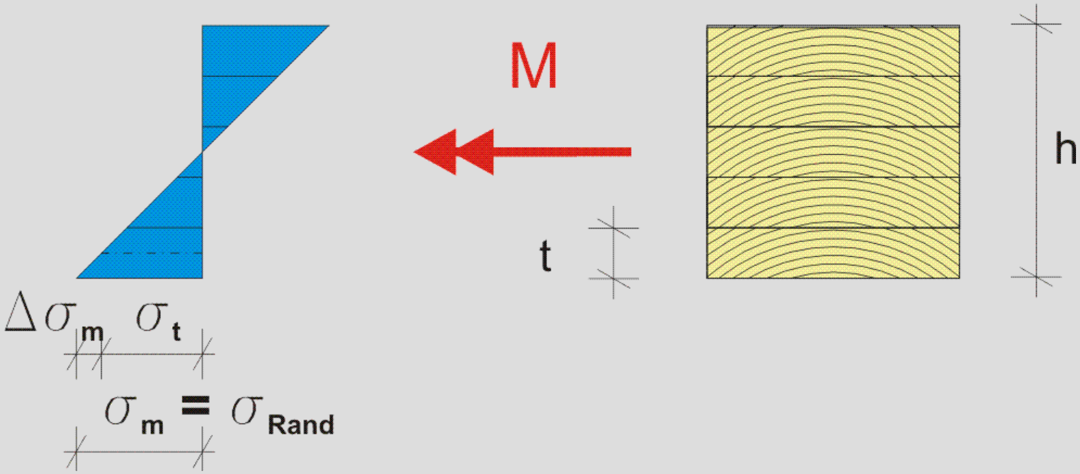


$$\boxed{f_{t,0,k} = 0{,}6 \cdot f_{m,k}}$$

in accord. with EN 338D

→ This procedere leads to conservative results because no “homogenisation effects“ are considered !

Applied to layered products: e.g. Glulam



$$\Delta\sigma_m = \sigma_m \cdot \frac{t}{h}$$

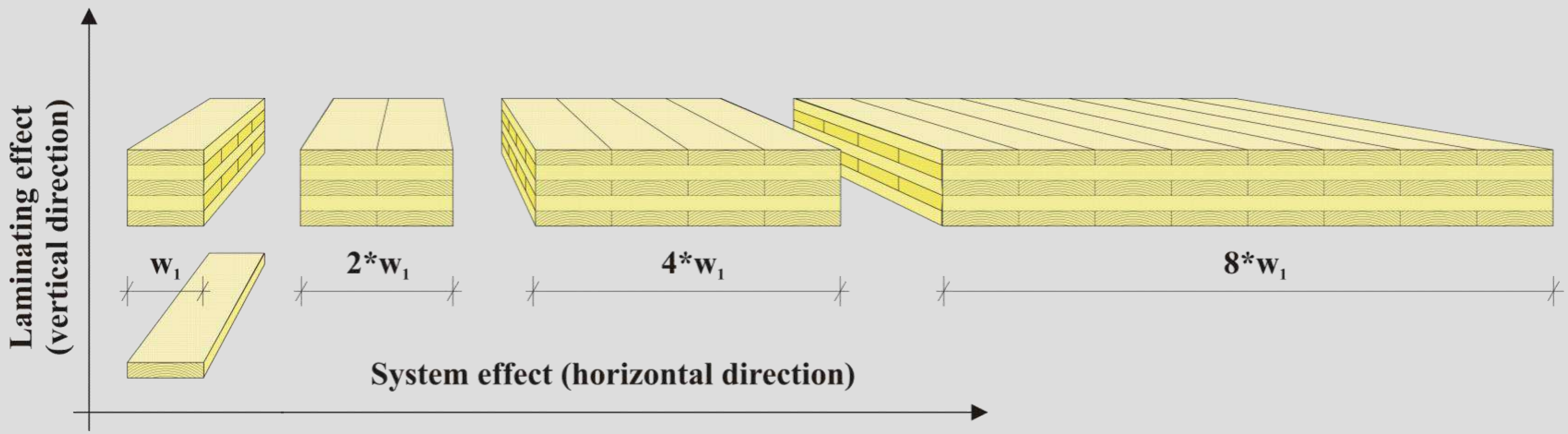
$$\sigma_t = \sigma_m \cdot \frac{h-t}{h}$$

$$\frac{\sigma_t}{\frac{3}{5}\cdot f_{m,d}} + \frac{\Delta\sigma_m}{f_{m,d}} = \frac{\frac{5}{3}\cdot\sigma_t + \Delta\sigma_m}{f_{m,d}} = \frac{\frac{5}{3}\cdot\frac{h-t}{h}\cdot\sigma_m + \frac{t}{h}\cdot\sigma_m}{f_{m,d}} = \frac{\left(\frac{5}{3} - \frac{2}{3}\frac{t}{h}\right)\cdot\sigma_m}{f_{m,d}} \leq 1$$

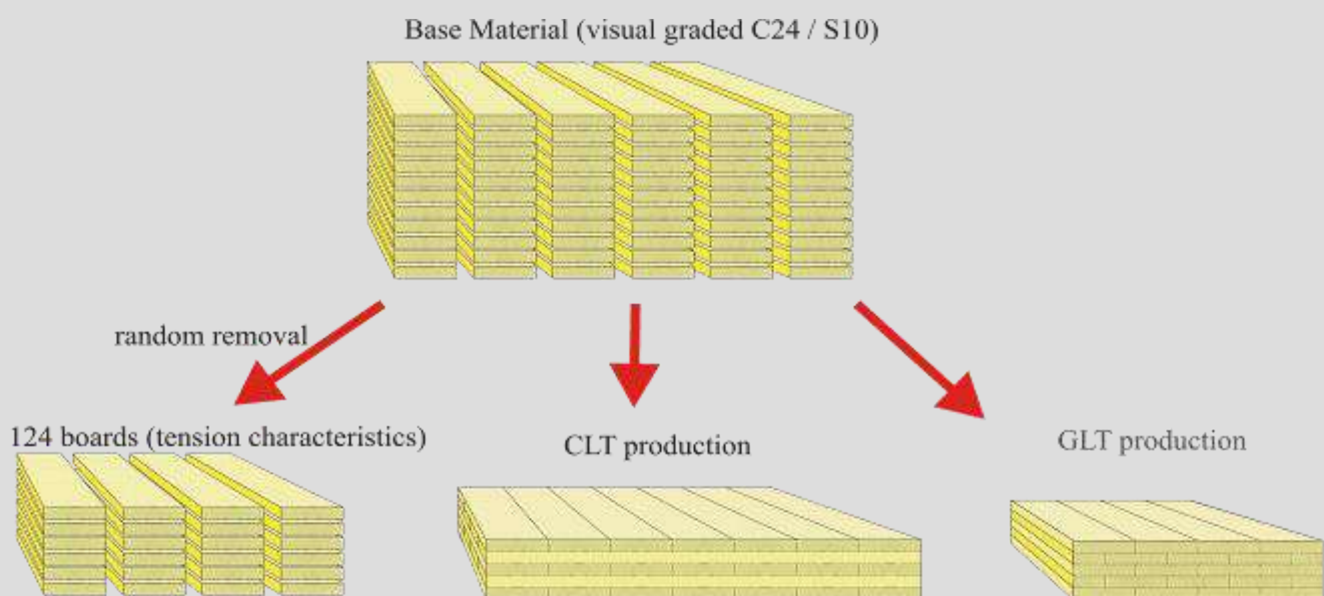
-35%

$$\frac{\left(\frac{5}{3} - \frac{2}{3}\frac{t}{h}\right)\cdot\sigma_m}{f_{m,d}} = \frac{\frac{23}{15}\cdot\sigma_m}{f_{m,d}} \cong \frac{\sigma_m}{0,65\cdot f_{m,d}} \leq 1$$

Objective of the research work



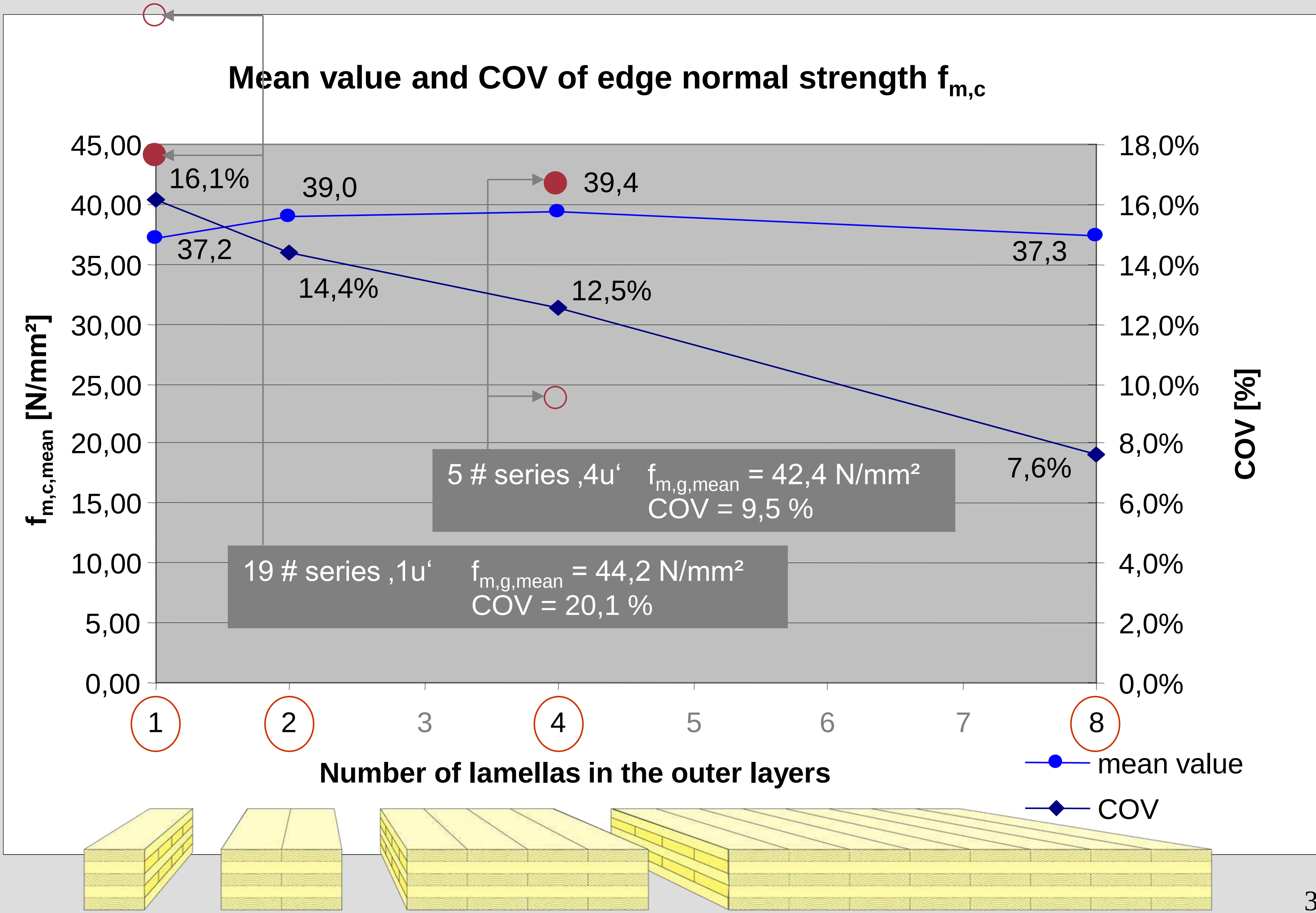
Method



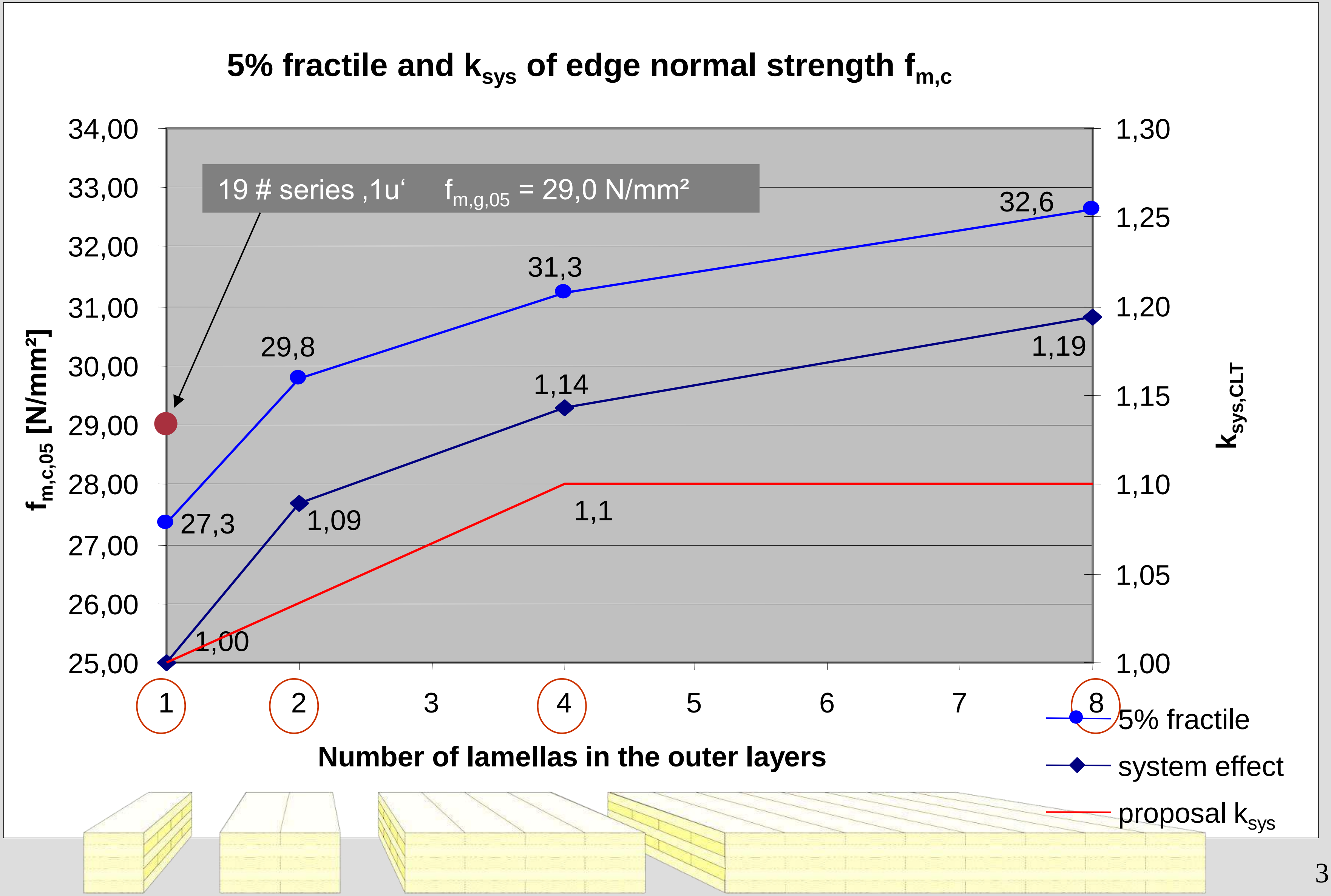
Results of tension tests:

$f_{t,0,l,05}$ **= 12,5 N/mm²**

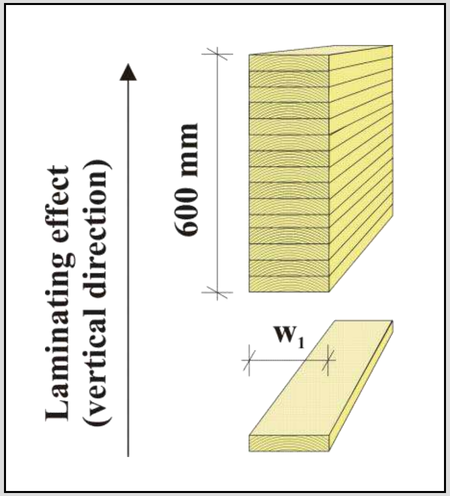
COV_t **= 39,4 %**


Mean value and COV of edge normal strength f_m,c
45,00
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
f_m,c,mean [N/mm²]
18,0%
16,0%
14,0%
12,0%
10,0%
8,0%
6,0%
4,0%
2,0%
0,0%
COV [%]
16,1%
39,0
39,4
37,2
37,3
14,4%
12,5%
7,6%
5 # series ‚4u‘ f_m,g,mean = 42,4 N/mm²
COV = 9,5 %
19 # series ‚1u‘ f_m,g,mean = 44,2 N/mm²
COV = 20,1 %
1
2
3
4
5
6
7
8
Number of lamellas in the outer layers
mean value
COV

5 % - quantile values
and system factor for CLT



Beam Model for GLT



$$f_{m,g,k} = 7{,}0 + 1{,}15 \cdot f_{t,0,l,k}$$ according to EN 1194:1999

including the variation of the base material

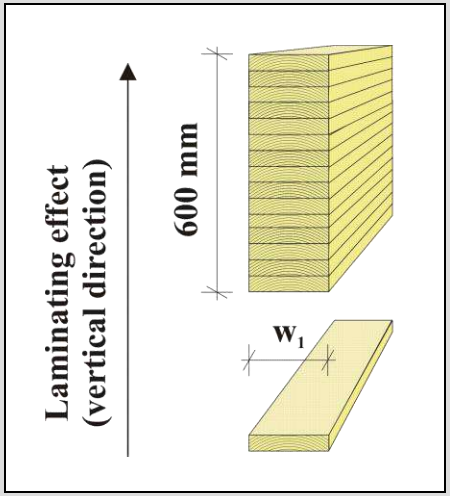
$$f_{m,g,k} = a_{GLT} \cdot f_{t,0,l,k}^{\;0,82}$$

e.g.: $a_{GLT} = \begin{Bmatrix} 2{,}422 & COV_t = 0{,}25 \\ 2{,}811 & COV_t = 0{,}35 \end{Bmatrix}$

$$f_{m,g,k} = \underbrace{1{,}06 \cdot \left(1{,}4 + 4{,}0 \cdot COV_t\right)}_{a} \cdot f_{t,0,l,k}^{\;0,8}$$

$$\boxed{f_{m,c,k,\geq 4} = \quad \cdot\, a \cdot f_{t,0,l,k}^{\;0,8}}$$

Beam Model for GLT

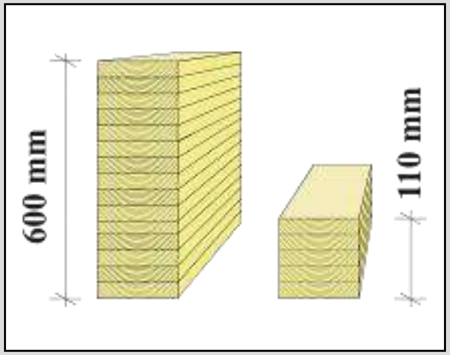


$$f_{m,g,k} = 7{,}0 + 1{,}15 \cdot f_{t,0,l,k}$$

including the variation of the base material

$$f_{m,g,k} = a_1 \cdot f_{t,0,l,k}^{\;0{,}82} \qquad a_1 = \begin{Bmatrix} 2{,}422 & COV_t = 0{,}25 \\ 2{,}811 & COV_t = 0{,}35 \end{Bmatrix}$$

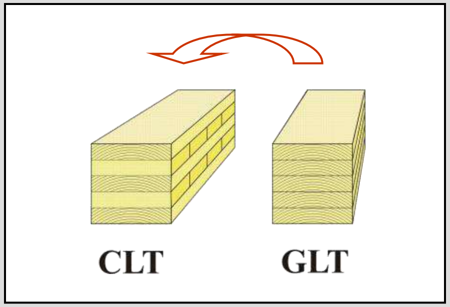
$$f_{m,g,k} = 1{,}06 \cdot \left(1{,}4 + 4{,}0 \cdot COV_t\right) \cdot f_{t,0,l,k}^{\;0{,}8}$$



$$k_h = \left(\frac{600}{h}\right)^{0{,}1} = \left(\frac{600}{110}\right)^{0{,}1} = 1{,}18$$

$$\boxed{f_{m,c,k,\geq 4} = \qquad \cdot k_h \cdot a \cdot f_{t,0,l,k}^{\;0{,}8}}$$

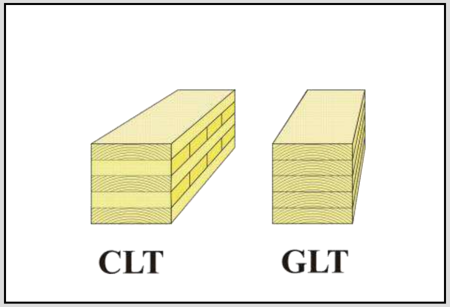
Model for CLT



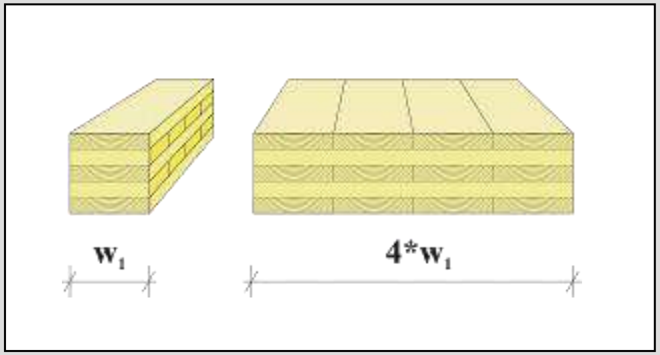
$$k_{CLT/GLT} = \frac{f_{Edge,CLT,05}}{f_{m,GLT,05}} = \frac{27{,}3}{29{,}0} \approx 0{,}94$$

$$f_{m,c,k,\geq 4} = k_{CLT/GLT} \cdot k_h \cdot a \cdot f_{t,0,l,k}^{\;0{,}8}$$

Model for CLT



$$k_{CLT/GLT} = \frac{f_{Edge,CLT,05}}{f_{m,GLT,05}} = \frac{27{,}3}{29{,}0} \approx 0{,}94$$



$$k_{sys,\geq 4} = 1{,}1$$

$$\boxed{f_{m,c,k,\geq 4} = k_{sys} \cdot k_{CLT/GLT} \cdot k_h \cdot a \cdot f_{t,0,l,k}^{\;0,8}}$$

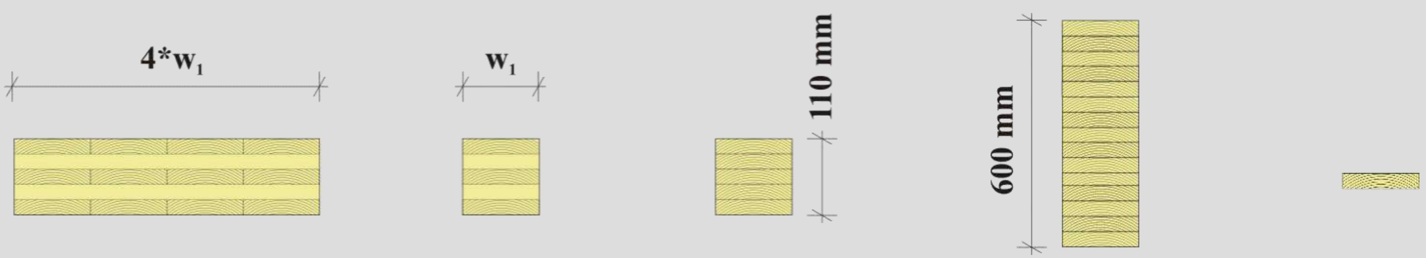
Load carrying model for CLT in bending - based on test results

$$f_{m,c,k,\geq 4} = k_{sys} \cdot k_{CLT/GLT} \cdot k_h \cdot a \cdot f_{t,0,l,k}^{\;0,8}$$

$$k_h = \left(\frac{600}{h}\right)^{0,1} \cdot \left(\frac{150}{b}\right)^{0,05} = \left(\frac{600}{110}\right)^{0,1} \cdot \left(\frac{150}{110}\right)^{0,05} = 1{,}20$$

$$a = 1{,}06 \cdot (1{,}4 + 4{,}0 \cdot COV_t) = 1{,}06 \cdot (1{,}4 + 4{,}0 \cdot 0{,}394) = 3{,}15$$

	$\mathbf{k_{sys}}$	$\mathbf{k_{CLT/GLT}}$	$\mathbf{k_h}$ (h = 110 mm, b = 110 mm)	**a** (COV_t = 39,4 %)	$\mathbf{f_{t,0,l,05}}$
Factor	1,1	0,94	1,20	3,15	
Analy. results	**29,6**	**26,9**	**28,6**	23,8	**12,5**
Test results	**31,3**	**27,3**	**29,0**	-	**12,5**



Proposed Model for CLT

$$\boxed{f_{m,c,k,\geq 4} = k_{sys} \cdot k_{CLT/GLT} \cdot k_h \cdot a \cdot f_{t,0,l,k}{}^{0,8}}$$

for reference higth h = 150 mm (without considering of width)

$$k_{sys} \cdot k_{CLT/GLT} \cdot k_h \cdot a = 1{,}1 \cdot 0{,}94 \cdot 1{,}15 \cdot 1{,}06 \cdot (1{,}4 + 4{,}0 \cdot COV_t)$$

$$k_{sys} \cdot k_{CLT/GLT} \cdot k_h \cdot a = 1{,}76 + 5{,}0 \cdot COV_t$$

$$\boxed{f_{m,c,k,\geq 4} = (1{,}76 + 5{,}0 \cdot COV_t) \cdot f_{t,0,l,k}{}^{0,8}}$$

$$f_{m,c,k,\geq 4} = a_{CLT} \cdot f_{t,0,l,k}{}^{0,8} \qquad a_{CLT} = \left\{ \begin{array}{ll} 3{,}0 & COV_t = 0{,}25 \\ 3{,}5 & COV_t = 0{,}35 \end{array} \right\}$$

Proposal of a Beam Model for CLT – Comparison with older data

$$f_{m,c,k,>4} = (1{,}76 + 5{,}0 \cdot COV_t) \cdot f_{t,0,l,k}^{\;0{,}8}$$

	$f_{t,0,l,05}$	COV_t	$f_{m,c,05,=4}$ test results	$f_{m,c,05,\geq 4}$ calculated	
	[N/mm²]	[%]	[N/mm²]	[N/mm²]	
presented	**12,5**	**39,4 %**	**31,3**	**28,1**	☑
New results 1)	**26,8** (n = 50)	**30,4 %**	**47,8**	**45,5**	☑
old results (1998)	**19,3** (n = 80)	**~ 35 %**	**39,1** 2) **42,9** 2) **39,4** 3)	**37,5**	☑

1) 5 layer CLT made of solid edge glued panels (spruce);

2) Single result of one 7 layer CLT element (width 2000 mm);

3) Single result of one 9 layer CLT element (width 2000 mm);

Specifications in technical approvals

$$\frac{\sigma_{m,d}}{k_l \cdot f_{m,d}} = \leq 1$$

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Allgemeine bauaufsichtliche Zulassung

Zulassungsnummer: Z-9.1-680

3.2 Bemessung

3.2.1 **Beanspruchung rechtwinklig zur Bauteilebene**

3.2.1.1 Der Nachweis der Spannungsverteilung und der Schnittgrößen eines "HMS-Elementes" rechtwinklig zur Bauteilebene ist nach der Verbundtheorie unter Berücksichtigung von Schubverformungen[2] zu führen.

Beim Biegespannungsnachweis ist nur die Normalspannung der Bretter am Querschnittsrand nachzuweisen, der Nachweis der Schwerpunktspannung im Brett darf unberücksichtigt bleiben.

Beim Biegespannungsnachweis darf die zulässige Biegespannung bzw. der Bemessungswert der Biegefestigkeit mit einem Systembeiwert k_ℓ multipliziert werden:

$$k_\ell = \min \begin{cases} 1 + 0{,}025\ n \\ 1{,}1 \end{cases}$$

mit n = Anzahl der nebeneinander liegenden Bretter.

Comparison of verification proposals

DIN 1052

$$\frac{\sigma_{t,d}}{f_{t,d}} + \frac{\Delta\sigma_{m,d}}{f_{m,d}} \leq 1$$

$$\frac{\sigma_{m,d}}{0{,}65 \cdot f_{m,d}} = \frac{\sigma_{m,d}}{\frac{k_{\mathrm{mod}}}{\gamma_M} \cdot 0{,}65 \cdot f_{m,k}} = \leq 1$$

Proposal TUG

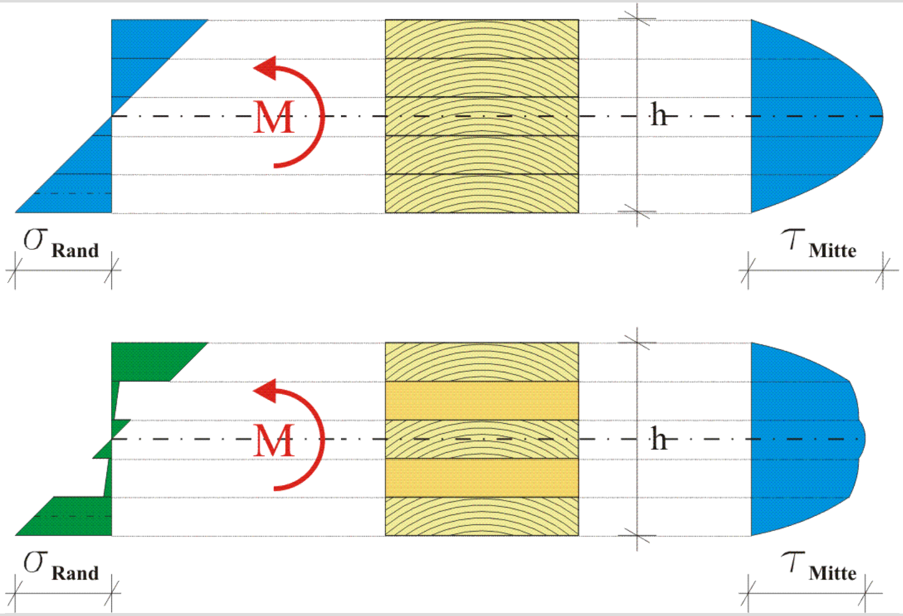
$$\frac{\sigma_{m,d}}{f_{m,c,d}} = \frac{\sigma_{m,d}}{\frac{k_{\mathrm{mod}}}{\gamma_M} \cdot \left(a_{CLT} \cdot f_{t,0,l,k}{}^{0{,}8}\right)} \leq 1$$

C 24 $f_{t,0,l,k}$ = 14,0 COV = **35 %**	**C 40** $f_{t,0,l,k}$ = 24,0 COV = **25 %**
15,6 0,65·$f_{m,k}$	26,0 0,65·$f_{m,k}$
29,0 1,21·$f_{m,k}$	38,3 0,96·$f_{m,k}$

Determination of stresses for CLT

Normal stresses

Shear stresses



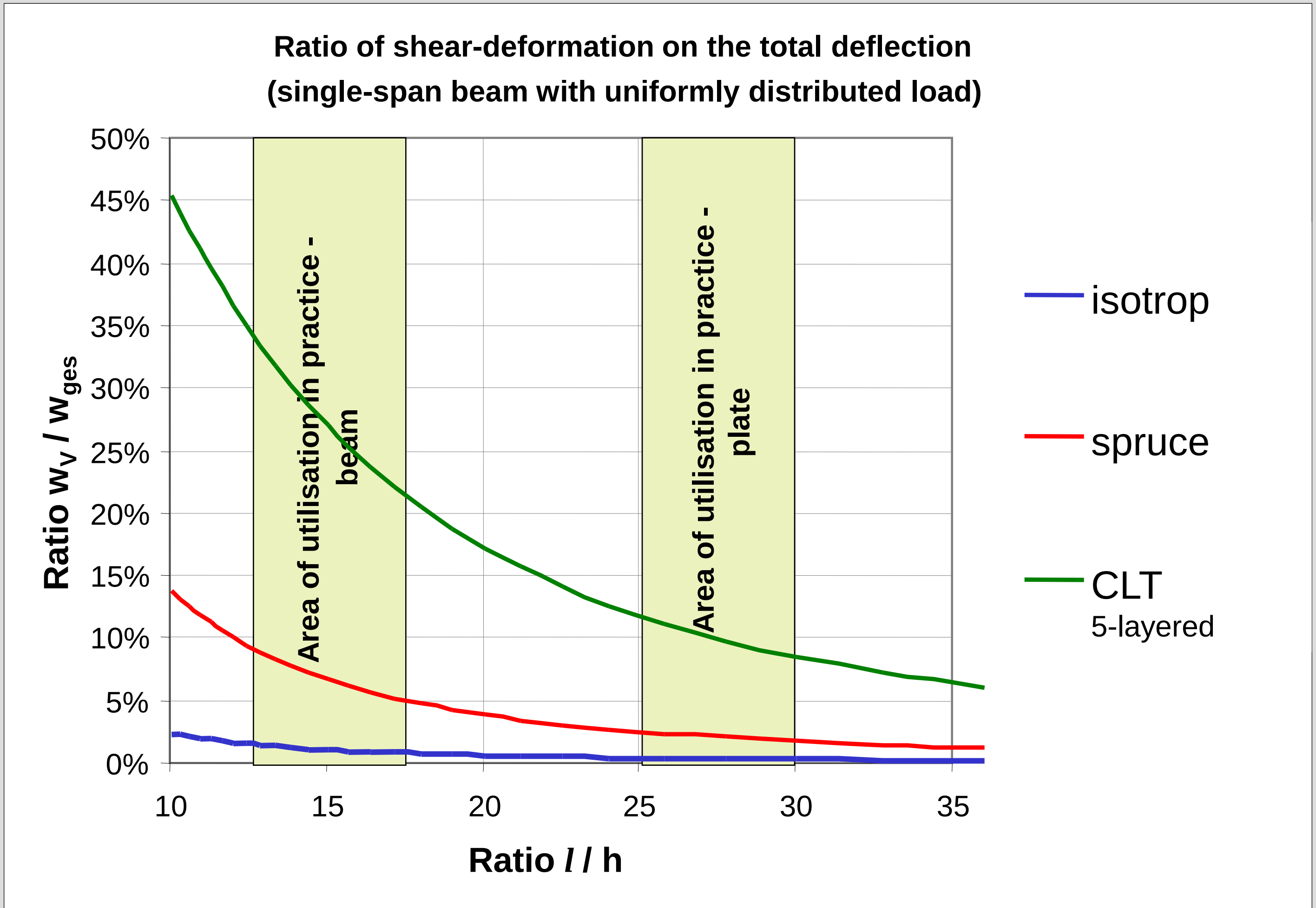
$$\sigma(z) = \frac{M}{I_{eff}} \cdot z \cdot \frac{E_i}{E}$$

$$\tau(z) = \frac{V \cdot S_{eff}}{I_{eff} \cdot b}$$

I_{eff}	S_{eff}		

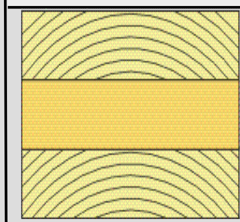
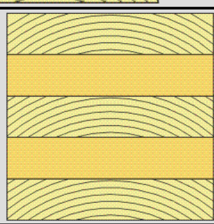
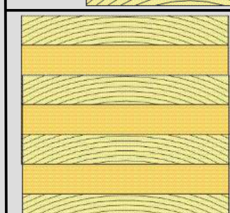
Determination of deformations for CLT

$$w_{ges} = \frac{1}{E \cdot I_{eff}} \int M\overline{M}ds + \frac{1}{G \cdot \frac{A_{eff,G}}{\kappa}} \int V\overline{V}ds$$



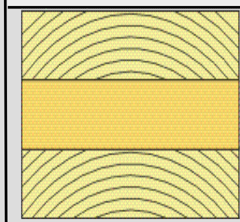
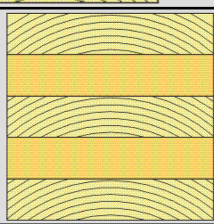
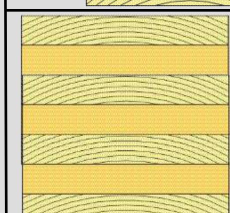
Effective second moment of area of the cross section

$$I_{eff} = \sum \frac{E_i}{E} \cdot I_i + \sum \frac{E_i}{E} \cdot A_i \cdot e_i^{\,2}$$

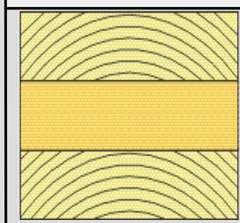
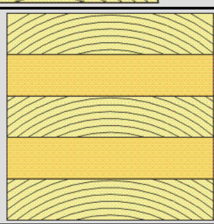
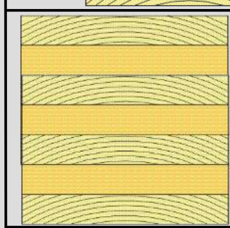
Number of layers	$E_{90} \neq 0$	$E_{90} = 0$
 3	$\frac{b \cdot h^3}{12} \cdot \frac{1}{27} \left(26 + 1 \cdot \frac{E_{90}}{E_0} \right)$	$\frac{b \cdot h^3}{12} \cdot \frac{26}{27}$
5 	$\frac{b \cdot h^3}{12} \cdot \frac{1}{125} \left(99 + 26 \cdot \frac{E_{90}}{E_0} \right)$	$\frac{b \cdot h^3}{12} \cdot \frac{99}{125}$
 7	$\frac{b \cdot h^3}{12} \cdot \frac{1}{343} \left(244 + 99 \cdot \frac{E_{90}}{E_0} \right)$	$\frac{b \cdot h^3}{12} \cdot \frac{244}{343}$

Effective statical moment of the cross section

$$S_{eff} = \sum \frac{E_i}{E} \cdot A_i \cdot e_{s,i}$$

Number of layers	$E_{90} \neq 0$	$E_{90} = 0$
 3	$\frac{b \cdot h^2}{8} \cdot \frac{1}{9}\left(8 + 1 \cdot \frac{E_{90}}{E_0}\right)$	$\frac{b \cdot h^2}{8} \cdot \frac{8}{9}$
5 	$\frac{b \cdot h^2}{8} \cdot \frac{1}{25}\left(17 + 8 \cdot \frac{E_{90}}{E_0}\right)$	$\frac{b \cdot h^2}{8} \cdot \frac{17}{25}$
 7	$\frac{b \cdot h^2}{8} \cdot \frac{1}{49}\left(32 + 17 \cdot \frac{E_{90}}{E_0}\right)$	$\frac{b \cdot h^2}{8} \cdot \frac{32}{49}$

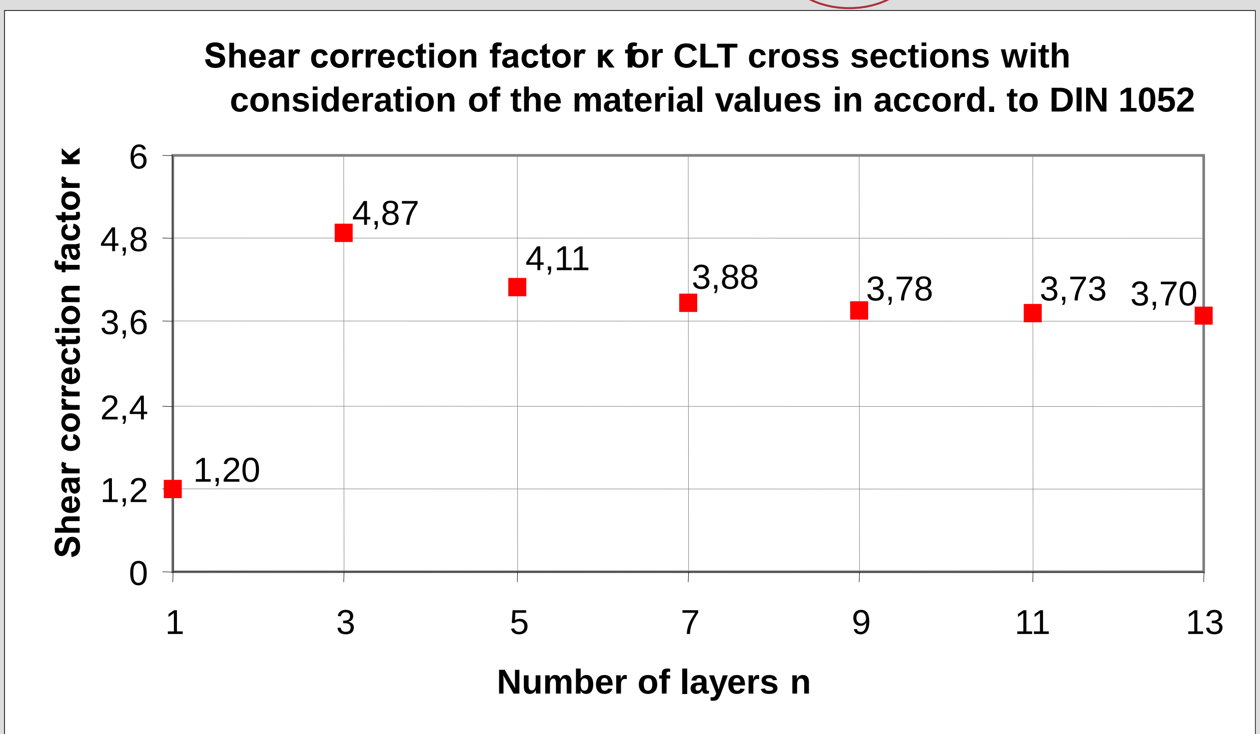
Effective area of the cross section

Number of layers	$A_{eff,G} = \sum \frac{G_i}{G} \cdot A_i$	$\frac{G_{090}}{G_{9090}} = 10$
 3	$b \cdot h \cdot \frac{1}{3}\left(2 + 1 \cdot \frac{G_{9090}}{G_{090}}\right)$	$b \cdot h \cdot \frac{2{,}1}{3}$
5 	$b \cdot h \cdot \frac{1}{5}\left(3 + 2 \cdot \frac{G_{9090}}{G_{090}}\right)$	$b \cdot h \cdot \frac{3{,}2}{5}$
 7	$b \cdot h \cdot \frac{1}{7}\left(4 + 3 \cdot \frac{G_{9090}}{G_{090}}\right)$	$b \cdot h \cdot \frac{4{,}3}{7}$

I_{eff}	S_{eff}	$A_{G,eff}$	k

Shear correction factor

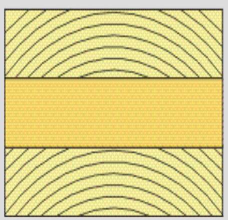
$$w_{ges} = \frac{1}{E \cdot I_{eff}} \int M\overline{M}ds + \frac{1}{G \cdot \frac{A_{eff,G}}{\kappa}} \int V\overline{V}ds$$



I_{eff}	S_{eff}	$A_{G,eff}$	k

Shear correction factor for a three layered-element

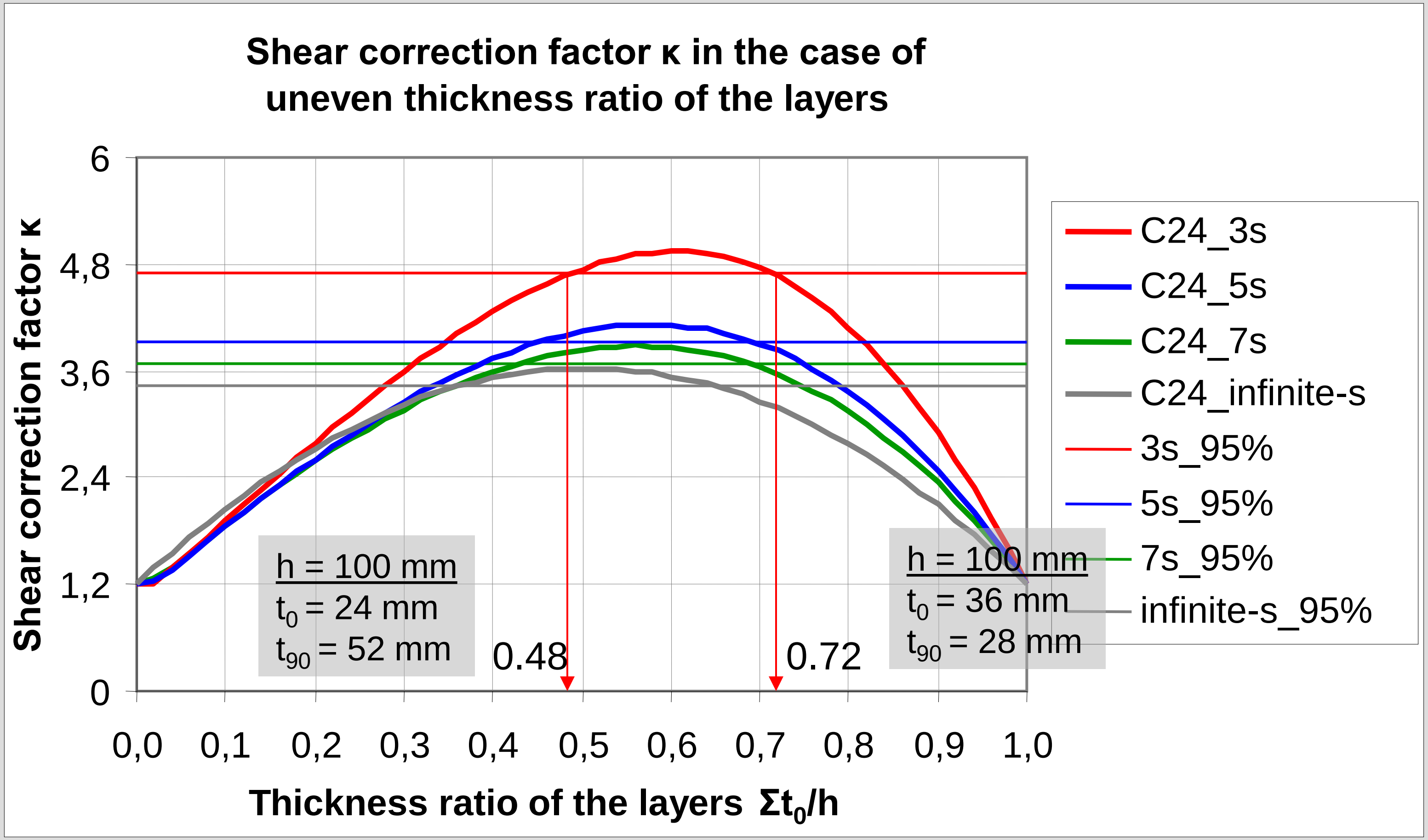
$$\kappa_{z,3S}=\frac{12^2\cdot\left(2+\frac{G_{9090}}{G_{090}}\right)}{\left(26+\cancelto{E_{90}=0}{\frac{E_{90}}{E_0}}\right)^2}\cdot\left[\frac{G_{090}}{120\cdot G_{9090}}\cdot\left(\cancelto{E_{90}=0}{\left(\frac{E_{90}}{E_0}\right)^2}+20\cdot\cancelto{E_{90}=0}{\frac{E_{90}}{E_0}}+120\right)+\frac{17}{20}\right]$$



$$\kappa_{z,3S}=\frac{6}{5}\cdot\frac{\left(2+\frac{G_{9090}}{G_{090}}\right)}{26^2}\cdot\left[120\cdot\frac{G_{090}}{G_{9090}}+102\right]$$

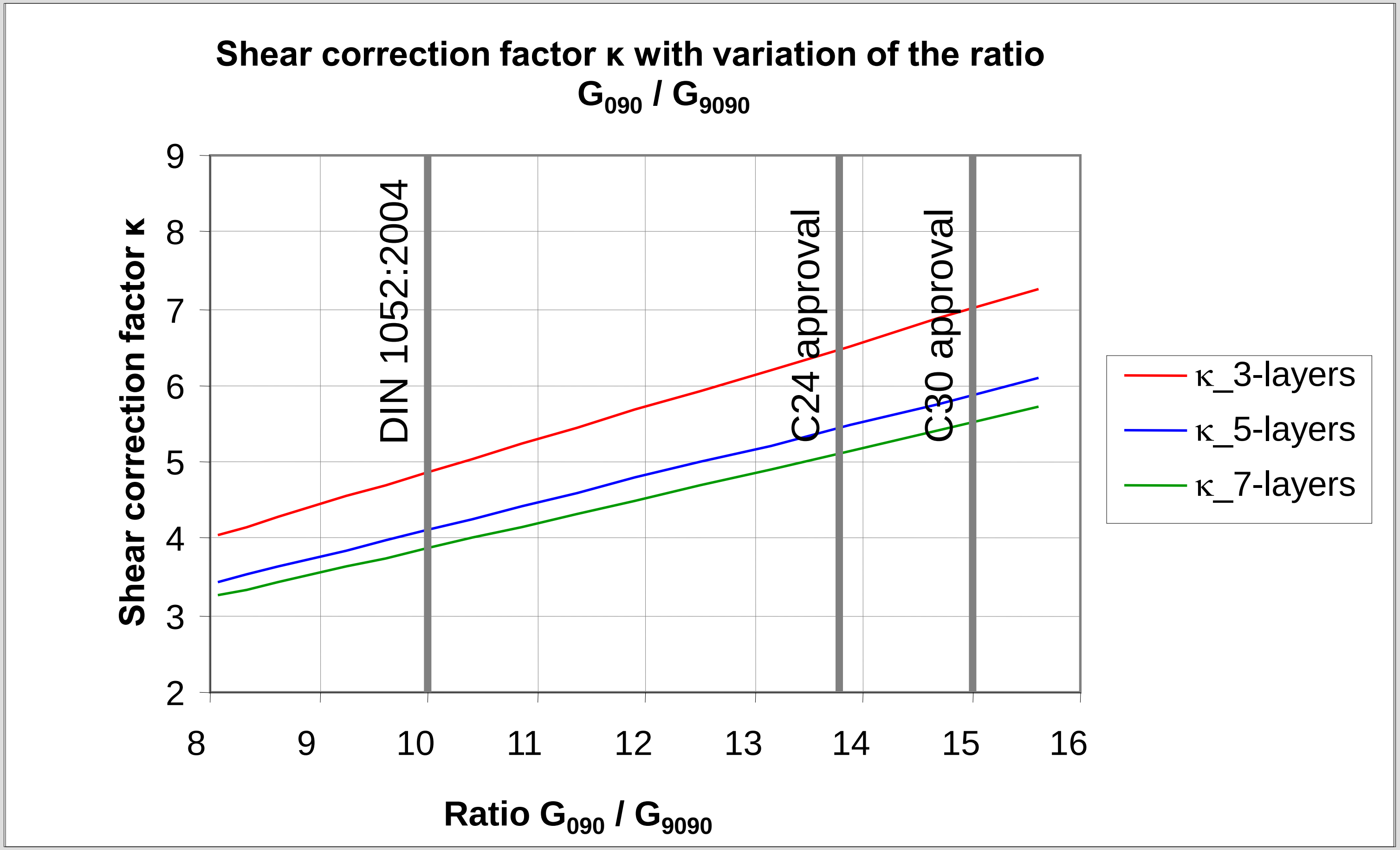
I_{eff}	S_{eff}	$A_{G,eff}$	k

Shear correction factor for CLT built up with uneven layers thickness



I_{eff}	S_{eff}	$A_{G,eff}$	k

Shear correction factor with variation of the ratio G_{090} / G_{9090}



I_{eff}	S_{eff}	$A_{G,eff}$	k

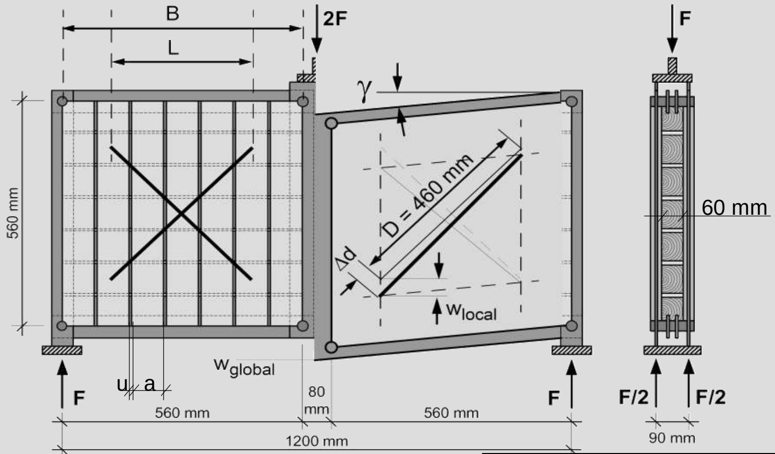
Shear correction factor with values from standards

Material properties	EN 338 (all strength-classes) [1)]	C 24 (in accord. with the approvals) [2)]	C 30 (in accord. with the approvals) [2)]
	$G_{9090} = G_{090}/10$	$G_{9090} = 50$ [N/mm²]	$G_{9090} = 50$ [N/mm²]
3-layered	**4,9**	**6,5**	**7,0**
5-layered	**4,1**	**5,4**	**5,9**
7-layered	**3,9**	**5,1**	**5,5**
1)	$E_0/E_{90} = 30$; $E_0/G_{090} = 16$; $G_{090}/G_{9090} = 10$		
2)	Für C24: $E_0/E_{90} = 30$; $E_0/G_{090} = 16$ Für C30: $E_0/E_{90} = 30$; $E_0/G_{090} = 16$		

I_{eff}	S_{eff}	$A_{G,eff}$	k

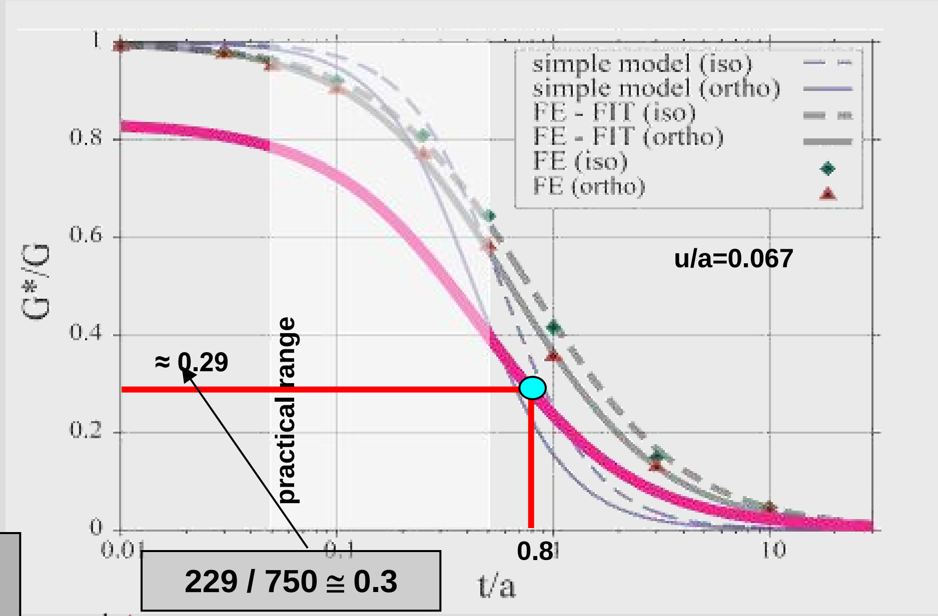
CLT wall elements under homogeneous shear (shear stiffness)
experimental and theoretical solution (doctoral thesis in process: Th. Moosbrugger)

- without openings

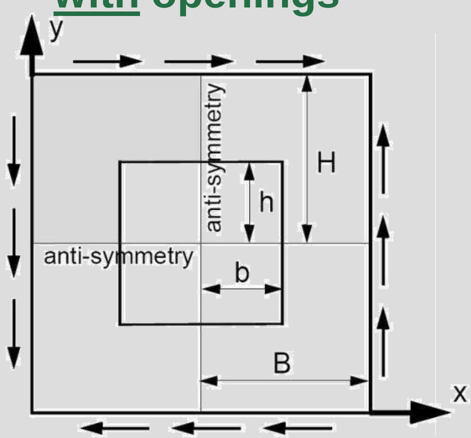


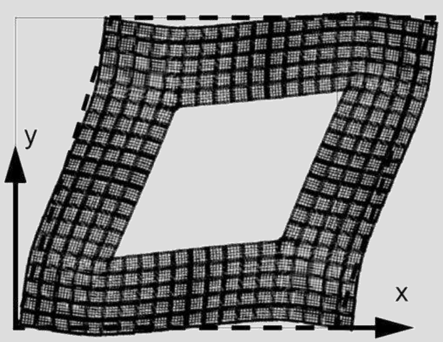
board spacing: u = 5 mm
board width: a = 75 mm → **u/a= 0.067**

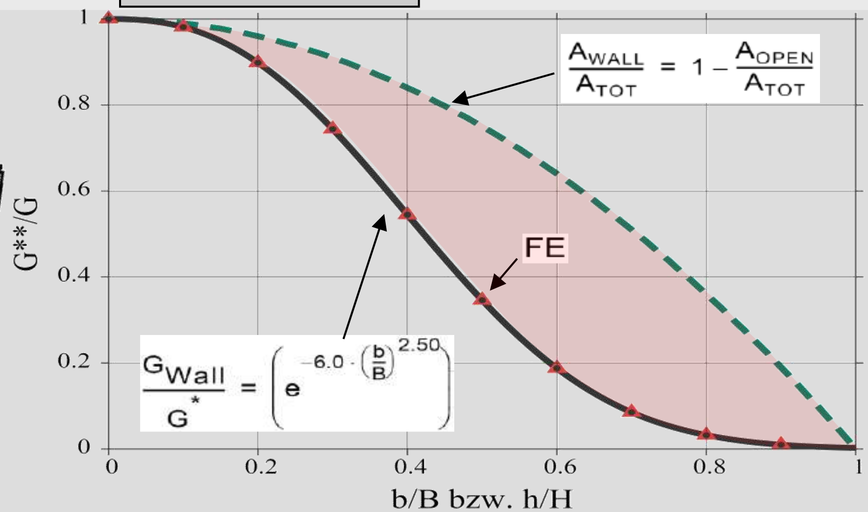
$G_{plate,mean}$= 229 N/mm²
(5 tests, COV = 0.16)



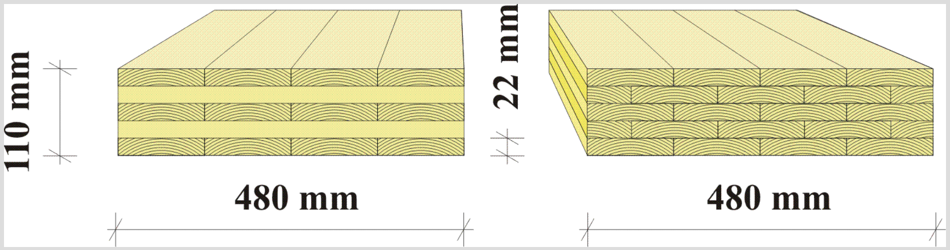
- with openings



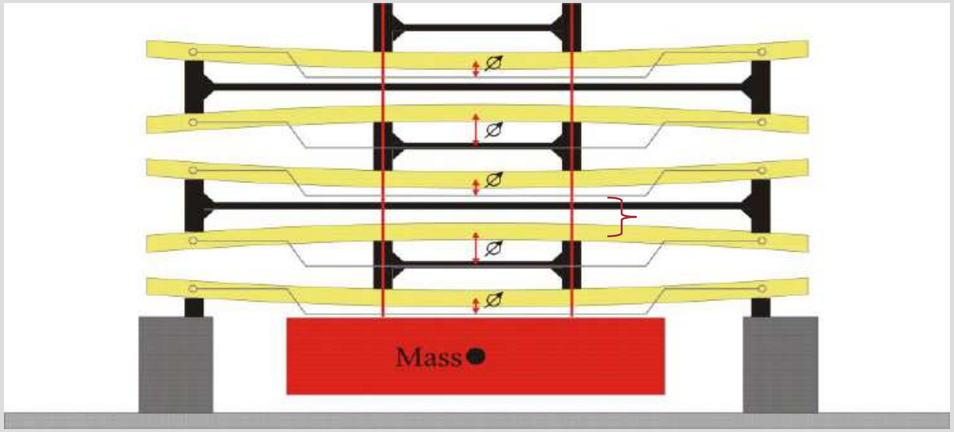




Specimens with two cross sections: GLT and CLT



Test setup: 4 – point – bending test according to EN 408



Futher details tests:

Tests with two climates (55%/20°C; 78%/20°C) and two stress levels (about 3 N/mm² and 8 N/mm²)

Results

Climate	Stress - level	GLT ⇨ CLT
Climate 2	**Sl.2 - high**	**+ 38,5 %**
	Sl.1 - low	**+ 46,5 %**
Climate 1	**Sl.2 - high**	**+ 19,3 %**
	Sl.1 - low	**+41,9 %**

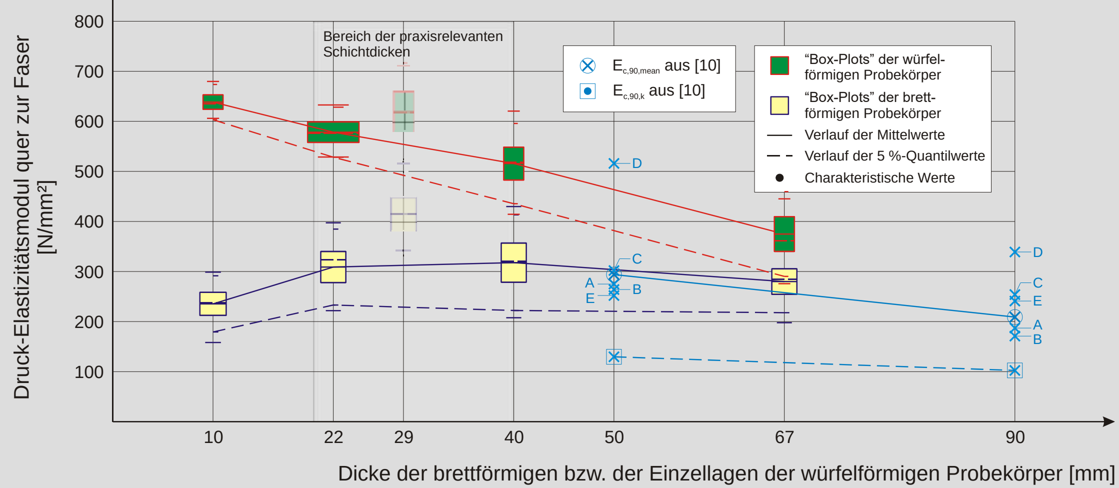
Proposals for standardisation

	$k_{def,\text{CLT,5-layer}}$
SC 1	**0,85**
SC 2	**1,10**

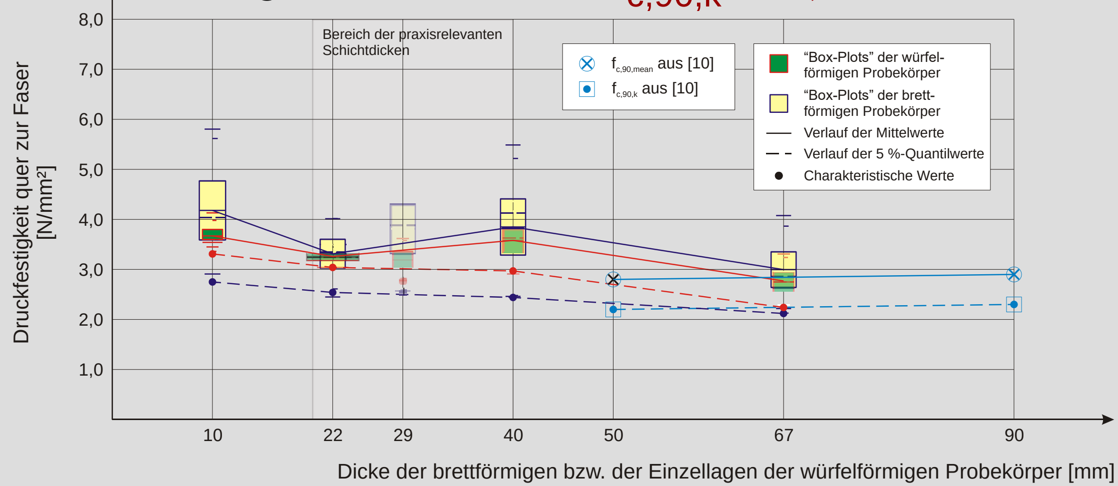
Approximatly values for Plywood

Compression perpendicular to grain of CLT-cubic specimens

Stiffness $E_{c,90,mean} = 500\ N/mm^2$



Strength $f_{c,90,k} = 3,0\ N/mm^2$



Test setup:

Tests on specimens with different number of layers, position of the board in the log, built-up factor and loading situations

Timber buildings are a modern and interesting solution

- **for urban buildings**
- for structural application of timber

Timber technology offers

- **modern material for high performance**
- safety for building - including earthquake

An interesting development is just beginning …

https://www.youtube.com/watch?v=pNr635IIUWg

https://www.youtube.com/watch?v=SC7ND_dMnT4

Σας ευχαριστώ για την προσοχή σας