Increasing use of timber in larger buildings
Challenges for regulators and industry

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Short report about 6 to 9-storey timber buildings in Switzerland and Italy

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One example of full timber construction

2 x 2 family units at duplex
ground area: ca. 130 m²
6-storey timber building in Lugano 2007

Residential building
- probably at first time 6 storey as full timber construction
- frame timber structure for a tower
- fire safety for timber buildings
6-storey timber building in Lugano 2007

Challenge 1: the timber frame structure

Usual timber frame elements for some parts

Timber frame
- timber beams/piles
- timber panels OSB
**6-storey timber buildings in Lugano 2007**

**Challenge 1: the timber frame structure**

Piles + beams and bracing with thin panels

- **Frame piles**
- **Timber piles: GL**
- **OSB panel**
Challenge 1: the timber frame structure

Piles + beams and bracing with thin panels

6-storey timber building in Lugano 2007
Challenge 2: the fire safety and the fire protection

- principle: by more than 3 storey: stair shaft as evacuation way on non-combustible material
- in this case special situation ...

Entrances on more levels

- independent units up to 3 levels (not 6)
- evacuation way up to 3 levels
- rules for three levels apply
- global stability of the building in case of fire
Challenge 2: the fire safety and the fire protection

**Approach for fire safety**
- REI 60 on the units separation

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**Normal deck solution: REI 15**
- 140 mm

**Fire safety deck: REI 60**
- 220 mm
Challenge 2: the fire safety and the fire protection

Approach for fire safety
- REI 60 on the units separation

Wall elements with ca. 9 m "free" height

Wall REI 60: h = ca. 9 m
- protection by double panel
- accidental fire loading conditions
6-storey timber building in Lugano 2007

The challenges:
- full timber structure
- special - and favourable - situation for fire safety

The conclusions:
- demonstration of the feasibility of the structure and of the construction
- costs interesting for the market
6-storey CLT-timber building in Lugano 2007

Residential building Sirio, CH-Lugano - 2011

6 - storey with CLT-timber structure
- part of the stairs-shaft walls on concrete
- main structure as 3D CLT-structure
6-storey CLT-timber building in Lugano 2007

Residential building Sirio, CH-Lugano - 2011

6 - storey with CLT-timber structure
- part of the stairs-shaft walls on concrete
- main structure as 3D CLT-structure

Concrete

Openings

CLT - timber

CLT-decks

Env. 19 m

8.85 m

20.7 m
Timber buildings for residential area in Milan

A project under construction - Via Cenni in Milan: 4 towers with 9 storey

Residential units
- 124 residences
- 2 to 4 rooms (1 to 3 sleeping rooms - 100/75/50 m² area)

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

Surfaces
- 9300 m² gross floor area
- 17000 m² gross built floor area

Materials
- 6100 m³ CLT
- very small quantity GL/Kerto

Costs*
- 17 Mio. € all inclusive

* approximately
Timber buildings for residential area in Milan

A project under construction - Via Cenni in Milan

Building companies
- Carron Spa
- Servicelegno srl
- ETS engineering

Building timetable
- begin excavation: January 2012
- begin timber construction: June 2012
- building time all inclusive: 15 months
- completion expected without delay, according program
Timber buildings for residential area in 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

≈ 150 m
≈ 80 m
13.6 m
9.1 m
Multi storey construction on CLT

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

- ca. 27 m
- 19.1 m
- 13.6 m
Multi storey construction on CLT

The load bearing structure on CLT

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stairwell and elevator shaft
Multi storey construction on CLT

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Multi storey construction on CLT

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

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Multi storey construction on CLT

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
CLT 9 storey building - via Cenni, Milan

Structure composed of CLT-decks and walls

Decks - horizontal structural sheets
- intermediate decks
- horizontal bracing elements
- main component of the structure

Walls - vertical bearing elements
- **continuous**, not interrupted, vertical **part of wall needed**
- vertical bracing elements
- openings are possible, but the wall part above opening are not relevant for the structure
- other walls - without structural function - are always possible

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, ...)

Position - axis - of the walls over 9 storeys
CLT timber engineering for large buildings

The 3D CLT structure is given by the CLT panels and by the connections

The main CLT timber structure
- 3D structure
- structural panels (2D)
- connections - or "line connections" (1D) - are a fundamental component

3D Structure

Connection lines

3D = 2D + 1D

The absolute dimension of each panel is relevant for the load bearing

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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
The 3D CLT structure
- exists only when the CLT panel are correct connected
- all connection are important
- stiffness of the connection is one of the most important characteristics
- stiffness requirements or stiffness design for the connections ??

Monolithic structure: usual by concrete and masonry

3D CLT structure

Connection with lower stiffness

Connections with too lower stiffness (punctual connections ... ??)
CLT timber engineering for large buildings

The connection line between CLT panels

Connection line for high performances of the structure

Design of the connections
- the consideration of the MOR is not always sufficient
- requirement on minimal stiffness
- "continuity and regularity" along the connection line
- simple production and construction

Connection with steel plates, bolts and screws

- high forces
- high stiffness

Section:

View:

<table>
<thead>
<tr>
<th>Section</th>
<th>View</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) m = 3</td>
<td>self tapping bolts</td>
</tr>
<tr>
<td>b) m = 2</td>
<td></td>
</tr>
<tr>
<td>c) m = 1</td>
<td></td>
</tr>
</tbody>
</table>

VG-Screws

VG φ 10 mm; a = 30°;
ℓ = ca. 540 mm
a) s = 100 mm = 40 Pc./m'
b) s = 150 mm = 28 Pc./m'
c) s = 200 mm = 20 Pc./m'

WS φ 7; s = 40 mm
25 Pc./m'
CLT timber engineering for large buildings

The connection line between CLT panels
CLT timber engineering for large buildings

The connection line between CLT panels
The connection line between CLT panels

Connection line for high performances of the structure

Design of the connections
- the consideration of the MOR is not always sufficient
- requirement on minimal stiffness
- "continuity and regularity" along the connection line
- simple production and construction

Screws VG $\phi$ 8; $\alpha = 30^\circ$; $\ell = \text{ca. } 300\text{ mm}$

a) $s = 100\text{ mm} = 2 \times 10 \text{ /m'}$
b) $s = 50\text{ mm} = 2 \times 20 \text{ /m'}$

Screws VG $\phi$ 8; $\alpha = 45^\circ$; $\ell = \text{ca. } 450\text{ mm}$

a) $s = 100\text{ mm} = 2 \times 10 \text{ /m'}$
b) $s = 50\text{ mm} = 2 \times 20 \text{ /m'}$

Connection with full threated screws
- high forces
- high stiffness
- simple construction

- without steel

Connection line for CLT panels

Cross section

View
The connection line between CLT panels
CLT timber engineering for large buildings

The connection line between CLT panels
Connections for high performance 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'
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'

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

compression: contact
tension: mechanical connection
shear: mechanical connection

connection axis: articulation
Modelling of the connections
- consideration of the rigidity of the connection
- the only verification of the resistance is not sufficient
Connections for high performance structures

The performance of the usual and simple connections

Resistance of the connection with punctual connectors

<table>
<thead>
<tr>
<th></th>
<th>1 side</th>
<th>2 sides</th>
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</thead>
<tbody>
<tr>
<td>$V_{Rd}$</td>
<td>5 - 15%</td>
<td>10 - 31%</td>
</tr>
<tr>
<td>$N_{Rd}$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$M_{Rd}$</td>
<td>3 - 17%</td>
<td>4 - 31%</td>
</tr>
</tbody>
</table>
Connections for high performance structures

L'efficacia del collegamento continuo

CLT Resistance

Resistance of the continuously connection

<table>
<thead>
<tr>
<th>$V_{Rd}$</th>
<th>$N_{Rd}$</th>
<th>$M_{Rd}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 - 100%</td>
<td>7 - 48%</td>
<td>5 - 52%</td>
</tr>
<tr>
<td>67 - 100%</td>
<td>14 - 90%</td>
<td>9 - 98%</td>
</tr>
<tr>
<td>13 - 38%</td>
<td>7 - 21%</td>
<td>7 - 15%</td>
</tr>
</tbody>
</table>

$VRd = 100\%$

$N_{Rd} = 100\%$

$M_{Rd} = 100\%$

Continuously connection - connection line
CLT 9 storey building - via Cenni, Milan

CLT-decks elements

Main direction (outside layers) of the deck

- span < 5.80 m
- span < 6.70 m

- 200 mm - 5 layers
- 230 mm - 7 layers

appoggi sulle pareti

deck span
ev. cantilever
CLT 9 storey building - via Cenni, Milan

**CLT-connection elements**

- **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

**Connection with screws**

- level 4 - 9
- high stiffness
- high stiffness by middle forces
- easy on the working

**Connections with steel plates**

- screws and bolts
- high stiffness
- very high resistance
- for high forces
- more expensive
- steel elements needed

**Connection with the foundation**

- high stiffness
- high resistance

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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
Earthquake behaviour

Connection with screws
- not very ductile
- ductility possible but not known

In case of consideration of the ductility, to demonstrate
- the effective ductility
- behaviour of the "stiff" panels in case of ductility in the connections
- effect of the ductility of some connection on the behaviour of the entire construction

Bolted and screwed
- effective ductility?
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

**Design conditions**
- demonstration of the compatibility of the not elastic deformations of the structure components not needed
- elastic behaviour in case of earthquake needed
- value of q = 1.0 over dimensions of some structural components
- “no damage” in case of design-earthquake

**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
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Numerical modelling and calculation

Static structural analysis
- confirmation
  - internal forces
    - $M_x$, $M_y$, $V_x$
  - forces on connections
    - $V_y$, $N_x$, $N_y$, $N_{xy}$
Dynamic analysis
- resonance
  - frequencies
Parametric numerical analysis
- earthquake
  - stiffness of connections $K_{ser}$
  - have to be considered
Modelling
- high performance software required
  - user interfaces not optimized for this kind
  - sensibility of the modelling

Modelling of systems

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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
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
- Installations inside of fire-protected space
- Installations outside of fire-protected space

Safer solution
- timber directly protected
- installations not relevant for fire protection

Special solution required
- protection of sheeting perforations
- later interventions by residents not under control
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Remarks about fire protection

Principle of fire protection: fire resistant sheeting to obtain EI60
- sheeting should be so near as possible to the protected element (CLT wall)
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Some remarks about fire protection

Possible and interesting way to obtain the required protection

- Definition of the requirements
- Carbonisation of the timber principally not considered as "protection"
- Full protection always required for evacuation ways: EI60 (stairs ...)
- Decks and Wall with protection panels only if needed
- Performance as fire resistance not modified: R60 possible, to design and to verify
CLT multi-storey building and fire protection

Some remarks about fire protection

Actually principle and solutions
- full protection by panels

Remarks
- easy but very expensive
- maintenance and control needed
- easy as principle
- efficient
- "hidden reserve" available - redundant

Ideas to be developed
- protection panels "just" if and where necessary

Remarks
- easier but complicated
- delicate by the project and realisation
- complicate as principle
- not very redundant
- at this time not in use
- may be interesting
The robustness of the 9 storey towers - via Cenni, Milan

The successive collapse, due to not foreseen accident, have to be avoided

The history of Ronan Point: the big consequences on a small accident
- Case: Ronan Point Apartment Building, London 1968, 23 storey
- Construction principle: concrete prefabricated panels
- A small and local explosion on level 18 is the cause of the collapse of a part of the tower
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"

- upper wall as load bearing element
- lack - no wall
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
  - principally not acceptable, or special connections needed

ok
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 wall

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
CLT 9 storey building - via Cenni, Milan

Evolution on the building site
CLT 9 storey building - via Cenni, Milan

End march 2013
Conclusions

Timber building in the last 15 years:
- speedy evolution from the "house" to the larger building structure
- new materials - for example CLT - are fundamental for this

The challenges:
- fire resistance and protection: which performance have to be reached and how
- mechanical behaviour: connection (stiffness) as structural relevant component
- requirements on robustness: new for timber construction, but "well-known"
- earthquake: "all-inclusive q-values" not always accepted for larger structures

The technology and the knowledge are available ...
may be not overall accessible ... but they ask for applications