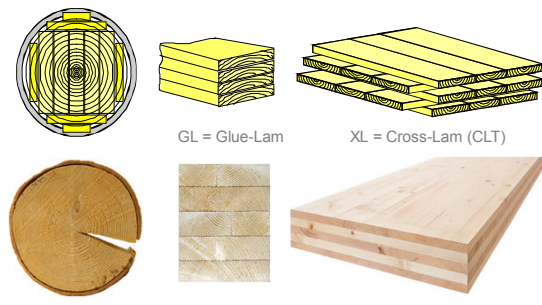





**CLT and seismic**  
**CLT structure**



GL = Glue-Lam      XL = Cross-Lam (CLT)



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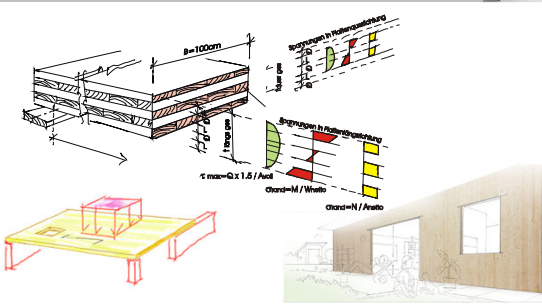
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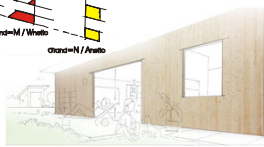
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**CLT and seismic**  
**CLT structure**



$b = 1000\text{mm}$   
 $t = 18\text{mm}$   
 $t_{max} = 0.2 \times 1.5 / \text{Avol}$   
CLT-M / Waffle  
CLT-N / Avolo



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**CLT and seismic**  
**General behaviour**



**CLT 7 stories**

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**CLT and seismic**  
**General behaviour**

**CLT seismic response**

- Rocking
- Slip + Friction

**Benefits**

- Self-centering (minimal residual deformations)
- Low-cost no damage design

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**CLT and seismic**  
**Multi-storey timber buildings**

2006 3 storey  
SOFIE project, Weiskirchen, IT

2007 7 storey  
SOFIE project, Weiskirchen, IT

2009 8 storey  
STADHUSEN, Wragby, Threlketh, Arch., GB

2013 9 storey  
POLARIS project, JMAKCHIES, IT

**TREND ...**

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**CLT and seismic**  
**Multi-storey timber buildings**

12 storey

20 storey

30 storey

40 storey

Force values: 250 kN, 500 kN, 215 kN, 270 kN, 340 kN, 550 kN

Author: Prof. Dr. Gerhard Schickhofer, TU Graz

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
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**Building design codes**  
**Eurocodes**



Vertical loads;  
•Self weight  
•Live load  
•Snow load

Horizontal load;  
•Wind

**Eurocode 1**  
**Eurocode 5**

Even though crosslam is not yet included in EC5, most of these load cases can be dealt with using the current standard (with some sensible interpretations)

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
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**Building design codes**  
**Eurocodes**



Earthquake → **Eurocode 8**

Eurocode 8 is in general heavily lacking guidelines for the seismic analysis of timber structures. Crosslam is of course no exception.

**Specific design rules in EC8 – number of pages:**

Concrete	Steel & Composite	Masonry	Timber
59 pg.	51 pg.	9 pg.	6 pg.

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
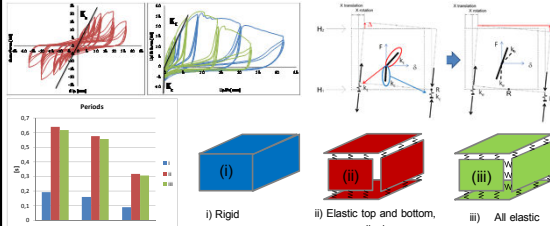
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**State of the art procedures**  
**Linear modal response spectrum analysis**

Periods

i) Rigid      ii) Elastic top and bottom, no perpendicular      iii) All elastic

**Procedure**

- Timber – in global seismic analysis (always) modelled elastically (E, G)
- Connections – linearised (substitute vertical stiffness of springs)

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**State of the art procedures**  
**Nonlinear static („pushover“) analysis**

**Procedure**

- Connection backbone response (1st / 3rd ?)
- Pushover curve
- N2 method (procedure in EC8)

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**State of the art procedures**  
**Nonlinear dynamic analysis**

**Exact finite element modelling of connections in timber**

- (cyclic) Stiffness degradation
- (cyclic) Strength degradation
- A pinching effect
- Slip

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**Seismic activity in Slovenia**

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**Seismic activity in Slovenia**



**1895 Ljubljana**



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**Seismic activity in Slovenia**



**1998 Posočje**



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**CLT Case studies**  
**Family housing 1**



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**CLT Case studies**  
**Family housing 2**



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**CLT Case studies**  
**Family housing 3**



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**CLT Case studies**  
**Family housing 4**



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**CLT Case studies**  
**Bivouac**



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**CLT Case studies**  
**Office areas**



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**CLT Case studies**  
**Storage halls**



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**CLT Case studies**  
**Renovation**



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**CLT Case studies**  
**Upgrades 1**



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**CLT Case studies**  
**Upgrades 2**



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**CLT Case studies**  
**Upgrades 3**



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**CLT Case studies**  
**Exhibitions**



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**Innovations in CLT**  
**Seismic strengthening**



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**Innovations in CLT**  
**Seismic strengthening**



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**Innovations in CLT**  
**Seismic strengthening**



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**Innovations in CLT**  
**Seismic strengthening**



Story drift comparison

	UNSTRENGTHENED	STRENGTHENED
2-1	0,88 %	<b>0,68 % (-23%)</b>
1-0	2,16 %	<b>1,52 % (-30%)</b>

Period changes

	FREQUENCY (PERIOD)
Unstrengthened before	<b>6,93 Hz</b> (0,14 s)
Unstrengthened after	<b>2,97 Hz</b> (0,34 s)
Strengthened before	<b>6,23 Hz</b> (0,16 s)
Strengthened after	<b>5,66 Hz</b> (0,18 s)

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**Innovations in CLT**  
**Ribbed CLT**



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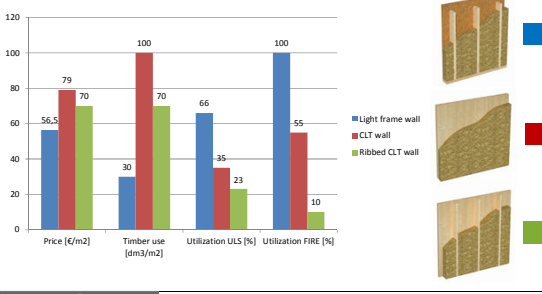
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**Innovations in CLT**  
**Ribbed CLT**



Metric	Light frame wall	CLT wall	Ribbed CLT wall
Price [€/m <sup>2</sup> ]	56.5	79	70
Timber use [dm <sup>3</sup> /m <sup>2</sup> ]	30	100	70
Utilization ULS [%]	66	35	23
Utilization FIRE [%]	100	55	10

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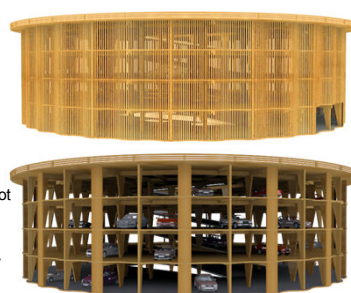
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**Innovations in CLT**  
**PSILOS garage system**

**Concept**

- 3 basic shapes
- 1 to 5 floors
- 46 to 488 parking spots
- 7000 €/parking space on



**Facts**

- 13.5 tons/CO<sub>2</sub>/parking spot
- 5 times lighter than in RC
- lower foundation cost
- deassembly – reassembly
- 1 week/floor

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**Innovations in CLT**  
**PSILOS garage system**



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**Conclusions**

- **Experiments** prove that **CLT** is a **perfect** material for buildings in **seismic areas**.
- **Cases** show that **CLT** can be used even for **extreme seismic demands** (multi-stores construction, building strengthening).
- Many cases of **CLT** constructions in **seismically unactive** areas can be **designed** with the use of the **material's technical approvals** and **sensible interpretations of Eurocode 5** guidelines.

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**Conclusions**

- The current state of the European seismic design code (**EC8**) is far **behind the demands of the market** (investors, architects) for **timber structures**.
- However for lower structures designing a **seismically resistant CLT** building is **easier than a light timber frame** due to **simpler details** and a more **desirable response** of the system.
- More **research papers** are being **published** on the topic of seismic CLT design every year.

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**Conclusions**



Thank you for your attention!

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