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Research title: Design of mid-size Cross Laminated Timber (CLT) building according to European building codes.

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Disclaimer

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Design of mid-size Cross Laminated Timber (CLT) building according to European building codes

Abstract

Cross laminated timber (CLT) is a new engineered wood material with a wide range of applications as a structural member in residential, commercial, and educational buildings. CLT is developed in Austria and its production and application are increasing in Europe and around the world. One of the utilization fields of CLT is midrise residential and commercial buildings including single and multi-family residential buildings, educational institutions, and office buildings.

This report is the outcome of an extensive three-month research project aimed at acquainting stakeholders with Austrian CLT producers and related companies. The study delves into the practical applications of CLT panels in building structures and explores the European standards governing the design of CLT buildings. The project centers around the design of a midrise building, exemplifying the utilization of CLT. Utilizing Revit software, both two and three-dimensional drawings were meticulously crafted. The focus of the design process was on the creation of diverse wall and floor components, with the final dimensions of these elements determined by employing CLT Engineering software and calculated design values.

Introduction

Cross-laminated timber (CLT) originated in Austria roughly two decades ago, as documented by Lehmann in 2012, and has since become firmly entrenched in European countries, particularly in Austria. The composition of CLT involves multiple layers of lumber intersecting at a 90-degree angle. Notably, each layer comprises different pieces of lumber oriented in the same direction, as outlined by Brandner, Flatscher, et al. in 2016. The quantity of layers is typically uneven and varies based on the intended application of the panels (refer to Fig. 1).

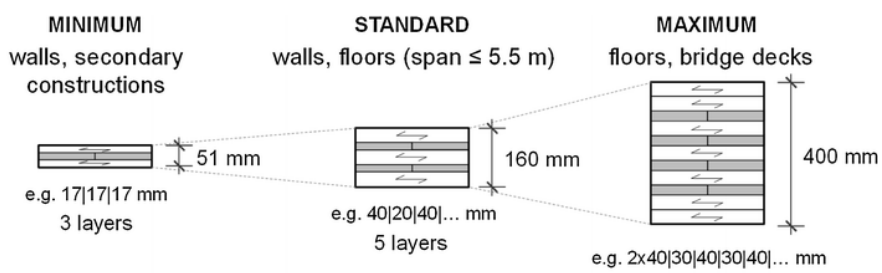


Fig. 1 Examples of different layups of CLT layers for different applications (Schickhofer, Brandner et al. 2016)

This innovative engineered wood product, has found diverse applications in construction, ranging from single and multi-family residential buildings to educational institutions and office structures (Mallo and Espinoza, 2015). Although CLT has enjoyed two decades of successful use in European countries, particularly in Austria, its adoption as a construction material is still in its early stages in the United States. Despite architects and designers being cognizant of CLT and the increasing research focused on CLT panels, the United States anticipates a promising future for CLT construction.

However, a notable gap exists between awareness and proficiency, as highlighted by Mallo and Espinoza in 2014, due to a lack of education, knowledge, and practical experiences in utilizing CLT in construction projects in the United States. In contrast, Austria boasts a robust background in working with CLT as a structural material, contributing to a wealth of information on its applications in buildings and structures. Leveraging this extensive knowledge, the primary objective of the presented research was to design a mid-sized CLT building adhering to European building codes. The secondary objective was to acquaint oneself with Austrian CLT producers, understand the implementation of CLT panels in buildings, and grasp the European standard for designing CLT buildings.

Sustainable midrise buildings

Buildings account for more than 40 percent of global energy use and one-third of global greenhouse gas emissions, both in developed and developing countries (UNEP 2009). With the growing population, it has been predicted that by 2060, the world population will increase by 30% (Roser and Ortiz-Ospina 2017). Population growth leads to increasing demands for more buildings and, consequently, more building materials. Due to the negative environmental effects associated with common building materials such as concrete and steel, sustainable buildings are gaining popularity, and their growth is expected to continue in the future.

Advancements in the understanding of timber building behavior, coupled with the refinement of engineered wood product design and performance, have demonstrated the applicability of using wood as a primary structural support system in mid-rise building construction (Robertson, Lam et al. 2012). Mid-rise CLT buildings, including both residential and nonresidential structures, could be considered as alternatives to current steel and concrete buildings, meeting the requirements of green building materials. The successful earthquake tests conducted on 3 and 7-story buildings in Japan have approved the efficient use of CLT as a multistory building material (Ceccotti 2008).

In Europe, CLT competes with other building materials for the construction of midrise buildings (Espinoza, Rodriguez Trujillo et al. 2015), and its production is on the rise. Global CLT production was approximately 625 thousand m3 in 2014, and it was forecasted to increase to about 700 thousand m3 in 2015 (Fig. 2). About 90% of worldwide CLT production is located in Europe, with Austria accounting for 60% of it (Espinoza, Rodriguez Trujillo et al. 2015).

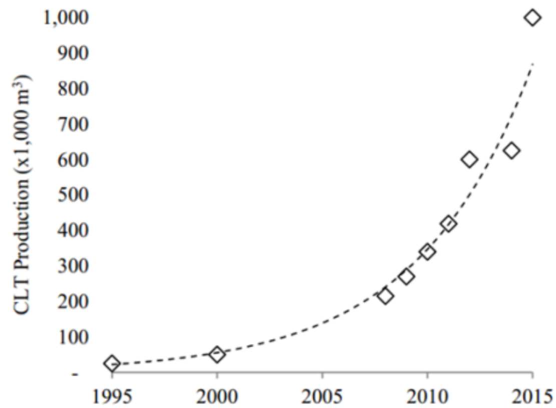


Fig. 2 Global production of CLT (Espinoza, Rodriguez Trujillo et al. 2015)

Top manufacturers in Europe and the amount of their production in 2016 are listed in **Error! Reference source not found.**.The produced CLT panels either are utilized in Europe or exported to the other countries.

Table 1. European manufacturers of CLT and the production capacity.

Product	Manufacturer	(1000) m3
Binderholz BBS 125	Binderholz Bausysteme GmbH	[1]200
Stora Enso CLT	Stora Enso Timber Bad St. Leonhard GmbH	[2]150
KLH-Massivholzplatte	KLH Massivholz GmbH	[3]125
MM - BSP	Mayr-Melnhof Holz Gaishorn GmbH	[4]70

1- https://www.binderholz.com/en/service-contact/news/details/press-release-binderholz-clt-bbs-extends-its-capacity/
2- http://www.storaenso.com/about/mills-capacities
3- http://www.mm-holz.com/en/company/locations/timber-processing-division/mm-holz-gaishorn/
4- http://bct.eco.umass.edu/wp-content/uploads/2014/10/KLH_Company-presentation_UMass-Amherst.pdf

A number of factors have contributed to current interest amongst construction professionals in the use of cross-laminated timber. Amongst these factors, enhanced mechanical properties (Silva, Branco et al. 2013), the interest of designers for a low-carbon building material for reducing the atmospheric carbon emission , higher-value product of CLT from lower value timbers produced from fast grown and small diameters trees and stimulation of rural economy that rely on forest products are main reasons of the increasing interest in CLT (Podesto and Breneman 2016). Also, CLT construction has important construction benefits such as (Wilson and Taylor 2010, Brandner 2013):

- Speed of construction and short erection times
- On site Accuracy of construction
- Simple connections
- Dry and clean construction techniques
- Reduced foundations requirements

The ease, speed, accuracy, and simplicity of construction associated with timber handling and prefabrication contribute to a significant reduction in construction time, simplify on-site apparatus, and enhance on-site safety. A study showed that the cost of an 8- story building with a two-story concrete platform would be four percent less than a 10-story concrete building (Andrews 2016).

Other provisions can be counted as:

Furthermore, CLT panels serve as load-carrying plate elements in structural systems, including walls, floors, and roofs (Mohammad, Gagnon et al. 2012). The crossing of layers provides higher strength and stiffness properties to CLT panels in both directions, enabling them to withstand forces in-plane as well as perpendicular to the plane(Silva, Branco et al. 2013). Consequently, CLT panels can be effectively employed as shear walls, floor slabs, and roof slabs.

The dimensional stability and rigidity of CLT panels contribute to an effective lateral load-resisting system. During the assembly of CLT structures, multiple small connectors are utilized, providing ductile behavior and energy dissipation in the final structure. Numerous studies on the seismic performance of CLT structures, especially in multi-story buildings, have revealed no residual deformations.

Despite the fire resistance of CLT being dependent on the type of applied adhesive, various studies have shown that the slow charring of thick outer layers protects the rest of the panel from further degradation, offering valuable fire resistance in thick cross-sections.

Moreover, the thermal conductivity of CLT panels is much lower than that of metals commonly used in buildings. The higher R-value of wood material, when compared to steel and concrete, results in significantly higher thermal resistivity (Rethinkwood, 2013).

Advantages of mid-rise wood construction

In regions with poor soil conditions, particularly in terms of strength, wooden mid-rise buildings present a superior option due to their lighter weight. The reduced weight of wooden structures translates to less demanding ground preparation, leading to a more economical foundation.

Furthermore, the construction of wooden mid-rise buildings allows for the use of prefabricated units, which can be assembled at the job site. This prefabrication approach not only streamlines the construction process but also significantly reduces the amount of onsite work required, resulting in a notable reduction in construction time. The combination of lighter weight and prefabrication makes wooden mid-rise buildings a practical and efficient choice, particularly in areas where soil conditions pose a construction challenge. (2016).

The International Building Code (IBC) permits the construction of wood-frame buildings with up to five stories in various occupancies, including multi-family, military, senior, student, and affordable housing. For business occupancies, the IBC allows wood-frame construction of up to six stories (Sargent 2015).

In the context of multi-story Cross-Laminated Timber (CLT) building design, European projects adhere to the Eurocode standards, while in the United States, the American National Standards Institute (ANSI) provides the relevant guidelines and standards. These codes and standards ensure the structural integrity, safety, and compliance of CLT buildings with the applicable regulations in their respective regions.

Design Process

A systematic approach has been adopted, consisting of six steps, to organize the design process of a structure into a logical sequence, progressing from early scheme considerations to detailed design (Steelconstruction.info) (Fig. 3). In the context of multi-story buildings, the design of the primary structure is significantly shaped by a multitude of interconnected factors. In practice, building design is a comprehensive integration of considerations spanning architectural, structural, services, logistics, and buildability concerns. However, it is essential to note that the central focus of this project is specifically directed towards the structural design aspect of the buildings.

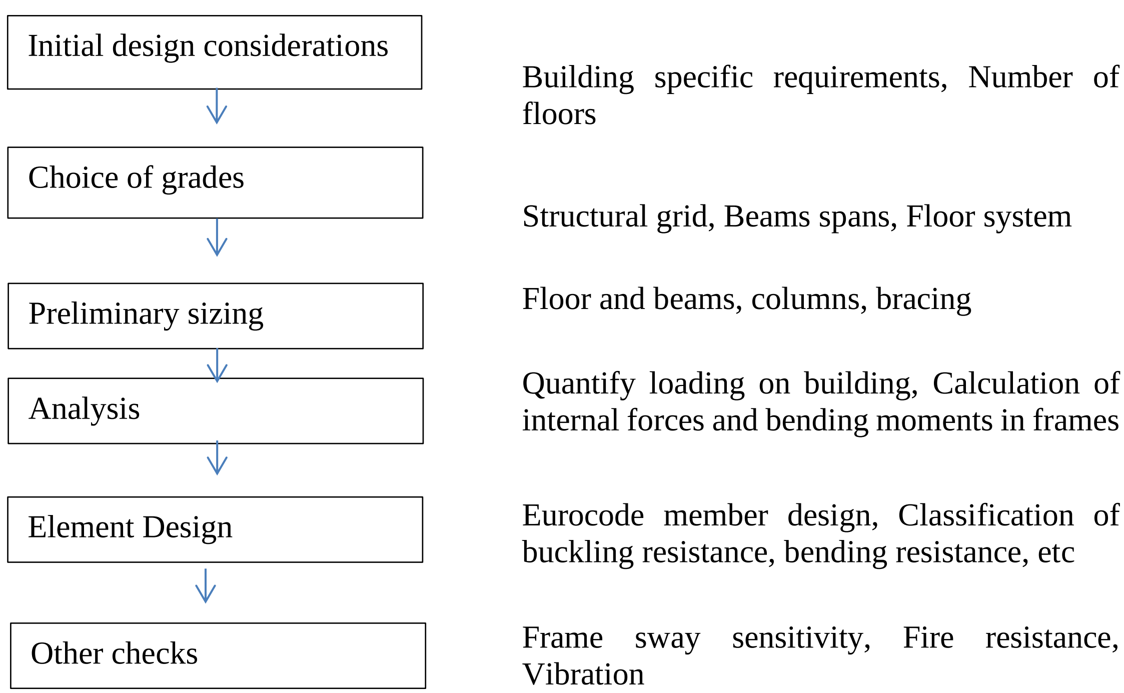


Fig. 3 The general design process of a buildings

Methodology

In the methodological section, this project focused on the latter four steps among the six outlined, aligning with the defined objective. The emphasis was placed on structural analysis, incorporating load sheet development, load combinations, various limit states according to the Euro code, roof system design encompassing roof slabs, beams, and girders, as well as floor system design involving floor slabs, beams, and girders. Additionally, the project delved into braced frame design, covering columns and bracing, as well as the design of gravity columns and connection designs. The final stage involved the creation of detailed drawings for the buildings.

Given the inherent self-bracing capability of CLT panels, traditional bracing elements were not considered in the building design. The drawing phase encompassed cross-sectional depictions, building elevations, wall details, floor plans, and other pertinent components, all created using drawing software.

The project activities were scheduled as follows, considering the various components described in this research:

1. Evaluation of applied loads
2. Governing load combinations
3. Cross section drawing
4. Floor and roof slabs design
5. Visualization of floor plan in software
6. Design of shear walls
7. Design of connections
8. Presentation of detailed calculations and final result drawings.
9. Preparing of final research report

The 3D building drawings and floor plans were crafted using Revit software, while the component drawings were prepared utilizing CLT Engineer software(StoraEnso 2016). The designed building is conceptualized as a six-story structure with a reinforced concrete ground level.

Following the development of the building plan, the entire design process was executed using the CLT Engineer software, an online tool accessible via the internet. The primary building components are comprised of Austrian Pine CLT panels, manufactured by Estora Enso Company in Austria. The relevant values associated with these CLT panels were taken into consideration throughout the design process, with detailed production information provided in Table 2.

Table 2 General properties of cross laminated panels produced in Stora Enso company (EstoraEnso 2015)

Structure	At least 3 layers (layers arranged perpendicular to each other with 3, 5 and 7 layers
Thickness	42-350 mm
Width* Length	Max 3.0*16.5 m
Classes of utilization	1 and 2
Wood species	Spruce, Fir, Pine, Larch
Adhesive	Type I Poly Urethane

The building dimensions are as follows: a total length of 24 m, a width of 16 m, and a total height of 20 m. The CLT floor area covers a total of 1920 square meters. To enhance structural support, each floor design incorporates four steel beams.

The plan view of the first story of the building and the 3D view of the structure are shown in Fig. 4 and Fig. 5. These figures offer a comprehensive view of the building layout and design.

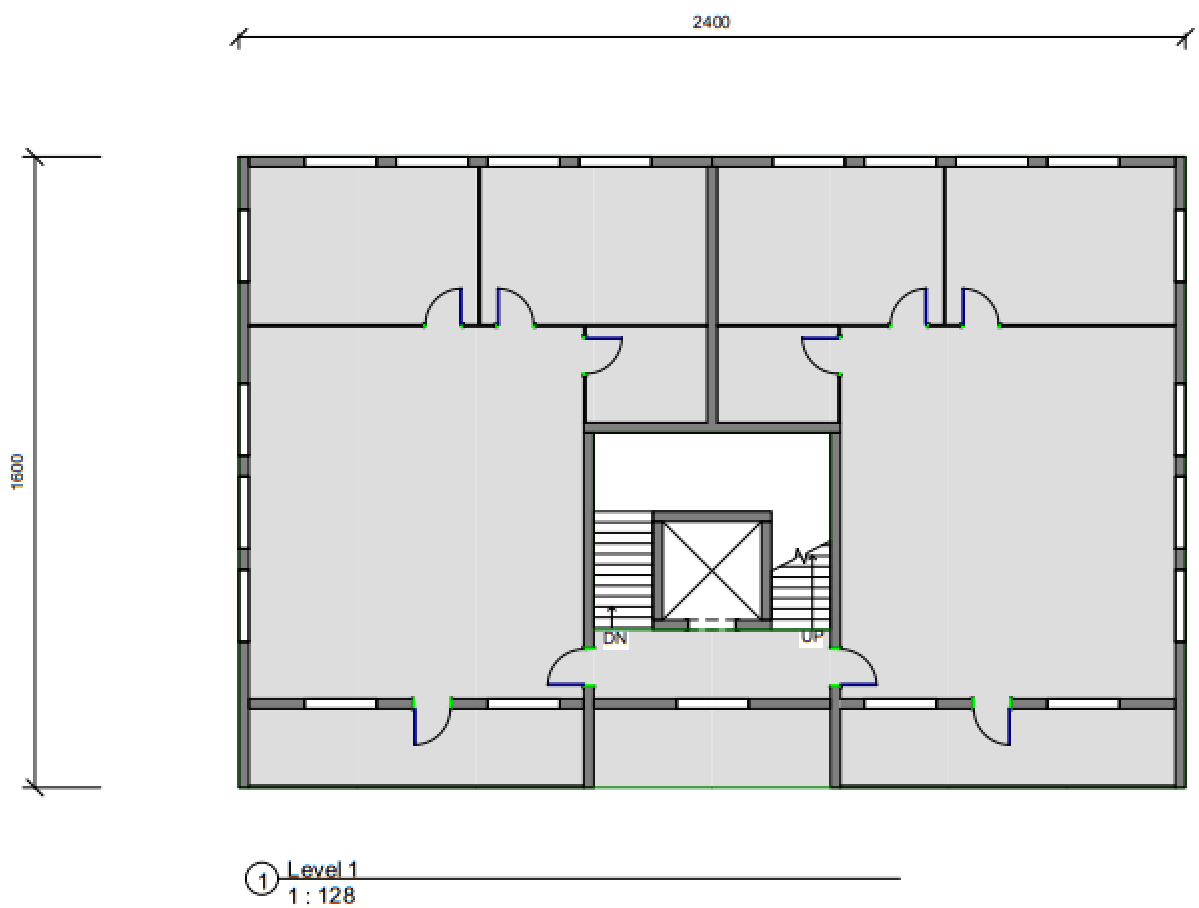


Fig. 4. Plan view of the first story of the building.

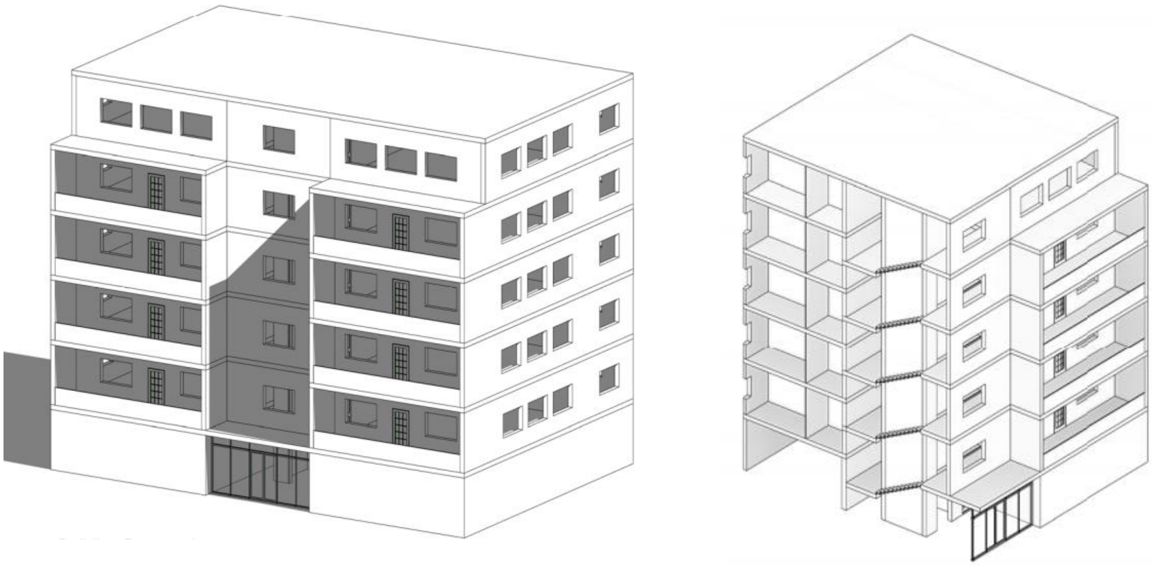


Fig. 5. 3D view and cross section of the building.

Evaluation of applied loads

The characteristic values of snow load and wind load for the Salzburg area were obtained from the Dlubal website. These values are crucial inputs for the structural design and analysis, ensuring that the building is designed to withstand the specific environmental conditions of the Salzburg region. The accurate determination of snow and wind loads is essential for ensuring the safety and stability of the structure under various weather conditions (Dlubal n.a). Snow load is according to ÖNORM B 1991-1-3 and EN 1991-1-3 is 1.74 kN/m2, wind load is according to ÖNORM B 1991-1-4 and EN 1991-1-4 is 0.39 kN/m2 (1998-1:2011-06-15) and EN 1998-1.

Basic components of a CLT building

Fig. 6 presented the basic components of a multistory CLT building. As it is shown CLT panels could be applied in different part of the structure such as floor, roof, load bearing walls, non-load bearing walls, stairs, and elevator shafts.

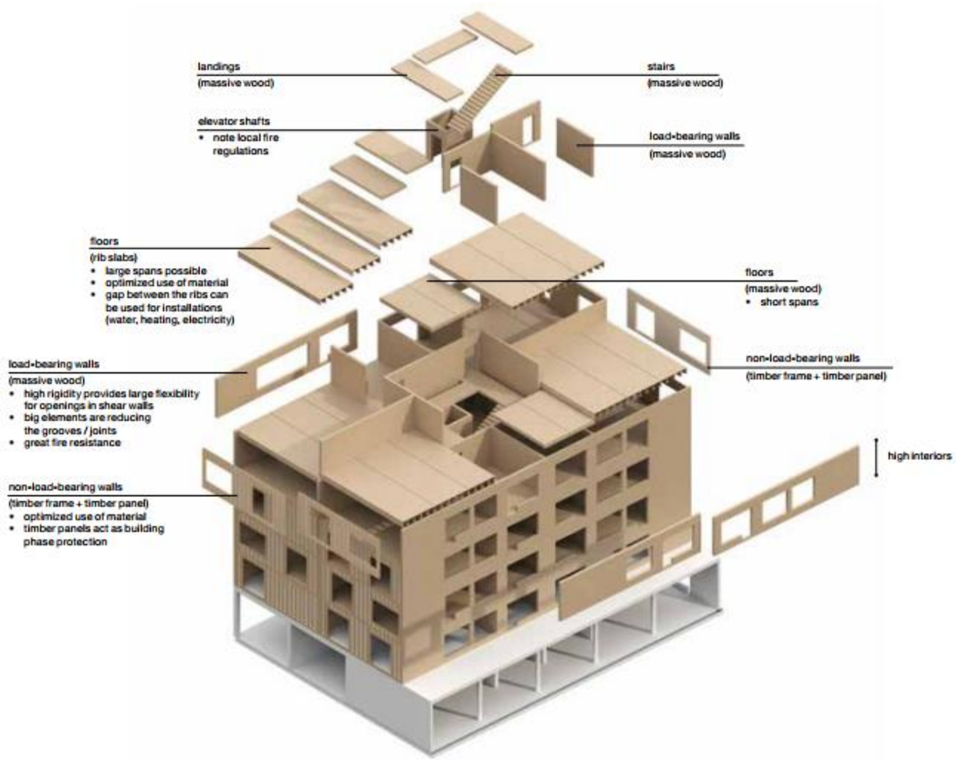
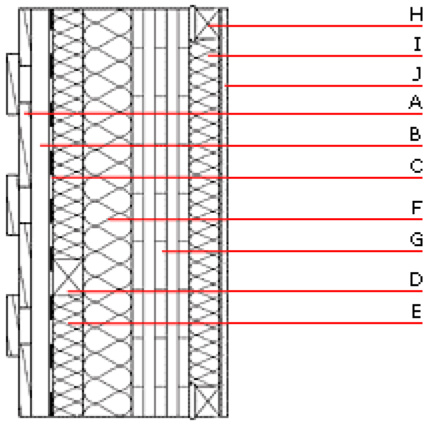


Fig. 6 Application of CLT panels for different component of a multistory building (StoraEnso 2016).

Various components considered in the design of the mid-rise building are detailed below. Wall members encompass external walls, internal walls, and compartment walls. External walls, clad or adorned with façade systems, feature fire-resistant and insulation layers. Compartment walls serve as fire-resistant barriers within the building, delineating distinct areas and ensuring fire resistance. Internal walls, typically non-loadbearing, function as partitions. The floor design incorporates a compartment floor with cement screed.

External wall

Fig. 7 depicts the cross-sectional configuration and a 3D view of the external wall. This particular external wall comprises various layers: on the inner side, there is a single layer of 12.5 mm Type F gypsum plasterboard, followed by a 50 mm cavity for installations. On the external side, the wall is adorned with 20 mm of larch wood external wall cladding. The cumulative thickness of layers D, E, F, G is 336.5 mm. Table 3 shows more detailed understanding of the external wall component. Additionally, the details of layers D-G, including thickness, fire performance, and acoustic performance, are presented in Table 4.



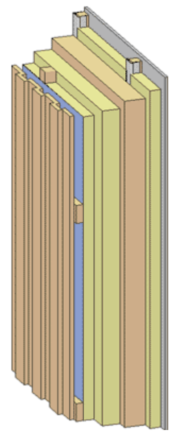


Fig. 7 Cross-section of standard configuration and 3D view for external wall (dataholz.com 2017)

Table 3. External wall component properties, (from outside to inside) (dataholz.com 2017)

Layer	Thickness mm	Building material	λ	μ min - max	ρ	c	Reaction to fire EN
A	20.0	larch wood external wall cladding	0,155	50	600	1,600	D
B	30.0	spruce wood battens (30/60)	0,120	50	450	1,600	D
C		vapor-permeable membrane sd ≤ 0,3m					
D	*	spruce wood battens (40/50 or 80/60; e=625)	0,120	50	450	1,600	D
E	*	Insulation material					
F	*	Insulation material					
G	*	solid wood (e.g. cross laminated timber)	0,130	50	500	1,600	D
H	50.0	spruce wood battens (40/50; e=625) mounted on resilient clips	0,120	50	450	1,600	D
I	50.0	Exchangeable layer					

J	12.5	gypsum plasterboards with improved properties at high temperatures (fire)	0,250	10	800	1,050	A2
J	12.5	gypsum fibre board	0,320	21	1000	1,100	A2

λ: thermal conductivity [W/mK], μ: water vapor resistance factor, ρ: density [kg/m³], c:specific heat capacity [kJ/kgK].

Table 4. Detail properties of the external wall components (dataholz.com 2017)

Thickness of the layers (mm)					Fire Performance	Thermal properties			Acoustic performance	Eco Sustainability	Mass
D*	E*	F*	G*	Σ	REI	U [W/(m²K)]	$m_{w,B,A}$ [kg/m²]	Diffusion	Rw(C,Ctr)	$OI3_{Kon}$	M [kg/m²]
0,0	50,0	80,0	94,0	336,5	90	0,19	16,6	adequate	51	1,1	71,8

$OI3_{Kon}$ Is the ecological index which is ranged between -30 to 120. The higher the rate the ecological impact is more.

As it is shown in Fig. 8 a cross-section configuration and 3D view of a typical internal wall are presented. Layers A and C consist of two 12.5 mm gypsum plasterboards or fiberboards each, while layer B is a five-layer Cross-Laminated Timber (CLT) panel situated in the middle. The properties of various layers in the external wall, including thermal conductivity, water vapor resistance factor, density, and specific heat capacity, along with layer details, are elaborated in Table 5.

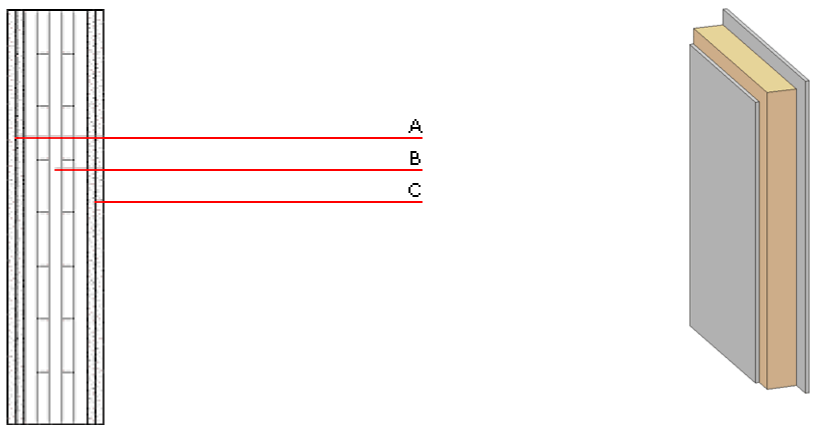


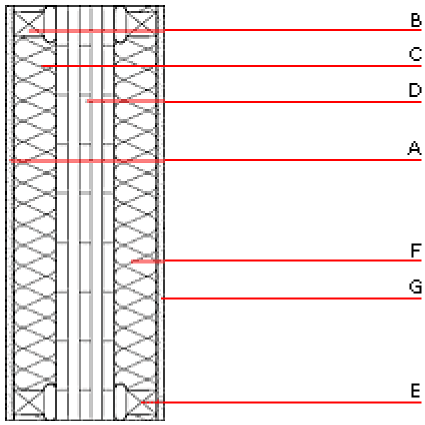
Fig. 8. Cross-section of standard configuration and 3D view for fire resistant internal wall (dataholz.com 2017)

Table 5. Internal wall component properties, (from outside to inside, dimensions in mm) (dataholz.com 2017)

Layer	Thickness	Building material	λ	μ min - max	ρ	c	Reaction to fire EN
A	25.0	gypsum plasterboards with improved properties at high temperatures (fire) (2x12,5 mm) or	0,250	10	800	1,050	A2
A	25.0	gypsum fibre board (2x12,5 mm)	0,320	21	1000	1,100	A2
B	78.0	solid wood (e.g. cross laminated timer: thickness ≥ 78mm; 3-ply at least, surface layer at least 25mm)	0,130	50	500	1,600	D
C	25.0	gypsum plasterboards with improved properties at high temperatures (fire) (2x12,5 mm) or	0,250	10	800	1,050	A2
C	25.0	gypsum fibre board (2x12,5 mm)	0,320	21	1000	1,100	A2

λ: thermal conductivity [W/mK], μ: water vapor resistance factor, ρ: density [kg/m^3], c:specific heat capacity [kJ/kgK].

In Fig. 9 the cross-section configuration and 3D view of the compartment wall are presented. Layers A and G consist of a 12.5 mm gypsum plasterboard or fiberboard, while layers B and F incorporate insulation materials with a five-layer Cross-Laminated Timber (CLT) panel positioned at the center. The thermal conductivity, vapor resistance, and density of the various wall layers are detailed in Table 6. The combined thickness of layers B and F is 262 mm. The specific properties of these two layers are elaborated in Table 7.



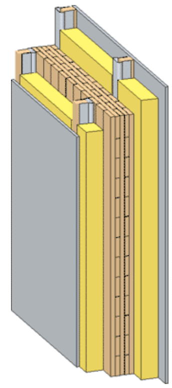


Fig. 9 Cross-section configuration and 3D view of compartment wall (dataholz.com 2017).

Table 6. Compartment wall component properties, (from outside to inside, dimensions in mm) (dataholz.com 2017)

Layer	Thickness	Building material	λ	μ min - max	ρ	c	Reaction to fire EN
A	12.5	gypsum plasterboards with improved properties at high temperatures (fire) or	0,250	10	800	1,050	A2
A	12.5	gypsum fibre board	0,320	21	1000	1,100	A2
B	*	Insulation material					
C	70.0	spruce wood batten mounted on resilient clips	0,120	50	450	1,600	D
D	95.0	solid wood (e.g. cross laminated timber)	0,130	50	500	1,600	D
E	70.0	spruce wood batten mounted on resilient clips	0,120	50	450	1,600	D
F	*	Insulation material					
G	12.5	gypsum plasterboards with improved properties at high temperatures (fire) or	0,250	10	800	1,050	A2

G	12.5	gypsum fibre board	0,320	21	1000	1,100	A2

λ: thermal conductivity [W/mK], μ: water vapor resistance factor, ρ: density [kg/m³], c:specific heat capacity [kJ/kgK].

Table 7. Detail properties of the compartment wall components (dataholz.com 2017)

Thickness of the layers (mm)			Fire Performance	Thermal properties			Acoustic performance	Eco Sustainability	Mass
B*	F*	Σ	REI	U [W/(m²K)]	$m_{w,B,A}$ [kg/m²]	Diffusion	Rw(C,Ctr)	$OI3_{Kon}$	M [kg/m²]
60,0	60,0	262	90	0,25	15,7	adequate	57	-11,0	74,9

Compartment floor

Cross-section configuration and 3D view of the wall is shown in Fig. 10. The compartment floor is composed of a 50 mm cement screed top layer, a 40 mm of sound absorbing layer, a 40 mm of filling layer, 50 mm of glass wool a 12.5 mm of gypsum board and a 5 layer CLT panel. Property of different layers is listed in Table 8.

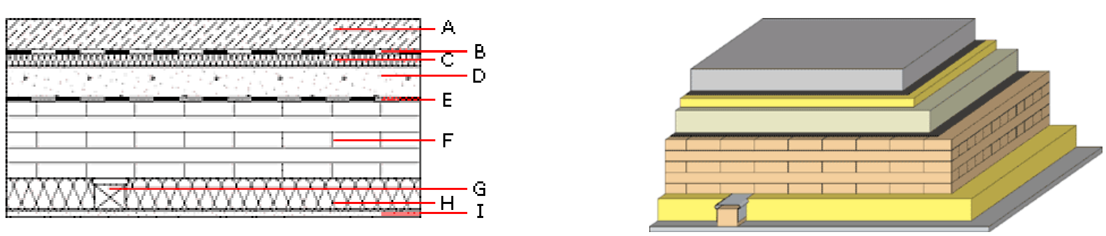


Fig. 10 Cross-section of standard configuration and 3D view of compartment floor (dataholz.com 2017).

Table 8 . Compartment floor component properties, (from top to bottom) (dataholz.com 2017)

Layer	Thickness mm	Building material	λ	μ min - max	ρ	c	Reaction to fire EN
A	50,0	cement screed or anhydrite screed	1,330	50 - 100	2000	1,080	A1
B		plastic separation layer	0,200	100000	1400	1,400	E
C	40,0	impact sound absorbing subflooring MW-T	0,035	1	68	1,030	A1
D	50,0	fill	0,700	1	1800	1,000	A1
E		trickling protection					E
F	134,0	solid wood (e.g. cross laminated timber); ≥ 134,0; at least 5-layers, top layer at least 26 mm)	0,130	50	500	1,600	D
G	70,0	spruce wood battens (40/50) mounted on resilient clips	0,120	50	450	1,600	D
H	50,0	glass wool [0,0040; R=16]	0,040	1	16	1,030	A1
I	12,5	gypsum plasterboards with improved properties at high temperatures (fire) or	0,250	10	800	1,050	A2
I	12,5	gypsum fibre board	0,320	21	1000	1,100	A2

λ: thermal conductivity [W/mK], μ: water vapor resistance factor, ρ: density [kg/m³], c:specific heat capacity [kJ/kgK].

When designing CLT members, it's crucial to consider the cross-laminating nature of the panels. This involves accounting for layers oriented in the longitudinal direction (machine direction) and others positioned crosswise to the longitudinal direction. While the crosswise layers may be weaker, they still influence the mechanical properties and internal stresses of the panels. Various analysis methods, such as the Modified Gamma Theory, the Shear Analogy, Timoshenko Theory, and Finite Element Analysis, consider the impact of these cross layers in CLT design. Notably, the CLT Engineer software developed by Stora Enso company is founded on the principles of Timoshenko Theory. (StoraEnso 2016).

Fire design

Fire design is carried out in accordance with EN1995-1-2 and its national annexes. Alternatively, the software provides fire design, including the determination of the residual timber section, based on the guidelines outlined in the "Fire Safety in Timber Buildings."

The Eurocode establishes fire resistance classes, as detailed in Table 9. Classification is based on the length of time the structural ability can be maintained, referred to as the fire resistance duration. According to the table, the range of resistance duration spans from 30 to 180 minutes.

Table 9. Resistant to fire classification according to European standard (EN13501-2 2016)

Class	Resistance to fire (Minute)
REI 30	≥ 30
REI 60	≥ 60
REI 90	≥ 90
REI 120	≥ 120
REI 180	≥180

Enhanced fire resistance in CLT components can be achieved through the use of multiple layers. For example, a three-layer CLT panel, without any cladding, can achieve a fire resistance rating of REI 60. Introducing a single layer of plasterboard can significantly elevate the fire resistance to REI 90. In practice, heightened fire resistance is attainable through strategies such as increasing the thickness of the CLT panel, augmenting the number of layers in the CLT element, or applying fire-resistant cladding (Golger 2014).

The CLT panels in the software are documented to exhibit fire resistance for up to 120 minutes. In this design procedure, R90, characterized by 90 minutes of fire resistance, has been chosen for the panels. The load combination factor for fire design is denoted as Ψ2. Various options for fire protection, including single or double ply cladding, are available in the CLT Engineer software. In this instance, a single ply of 12.5 plasterboard has been selected as the fire protection cladding.

Service classes

According to Eurocode there are three service classes defined for environmental conditions as is shown in Table 10. Service classes 1 and 2 are permitted for Stora Enso panels. Class three is for moisture amount of more than 20 percent and relative humidity of more than 80 % and is not allowed. Class 2 is selected conservatively through the design process (EN1995-1-1 2004).

Table 10 Service classes according to Eurocode (EN1995-1-1 2004)

Service class	Average amount of moisture content (%)	Defined environmental conditions
1	≤ 12	20˚C and % 65 relative humidity
2	≤ 20	20˚C and % 85 relative humidity
3	> 20	Climatic conditions leading to higher moisture contents than in service class 2

Vibration analysis

For the vibration analysis of the floor system, the tributary area of each individual bay was entered. Properties of a five cm screed layer with the damping coefficient of 0.04 and young modulus of 26000 N/mm^2 was added for vibration analysis.

Floor design

According to Stora Enso product information and design software, C24 pine 5 layers CLT panels with the thickness of 180 mm was sufficient for bearing the floor loads. Modulus of elasticity, bending and shear strength value of pine species used for the design process is listed in (Table 11) as mentioned in the design software. No edge gluing option was used for analysis. According to the place of floor panels some panels run perpendicular and some parallel to the span direction. The self-weight of panels was included in the calculation automatically in the software.

Table 11. Strength value of the pine used for the building design (StoraEnso 2016)

material	$f_{m,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{v,k}$	$f_{r,k\ min}$	$E_{0,mean}$	G_{mean}	$G_{r,mean}$
	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]
C24 pine	24.00	14.00	0.35	21.00	2.40	4.00	1.70	11,600.00	460.00	50.00

A sample sketch of floor system is provided in Fig. 11. It is part of the floor system with the spans of 2 m, 1.45 m and 0.55 m. and width of 3 meter with the direction of surface layers perpendicular to the support systems.

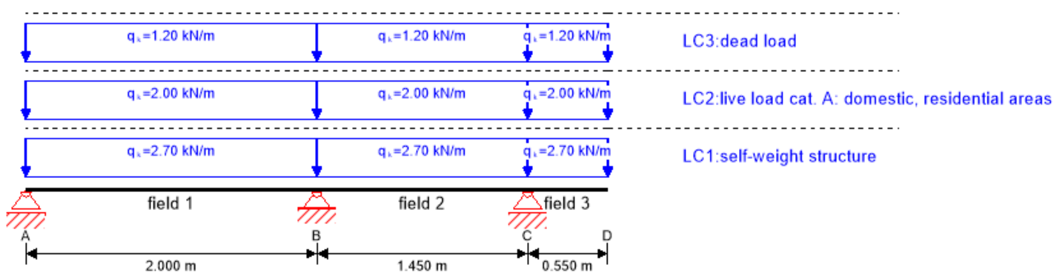


Fig. 11. Example sketch of a floor system as a continuous beam

For each step of analysis the software provides four different design ratios for the member. The best calculated ratio according to thickness of layers and assumed properties in the design process is shown, as well. For the example floor shown in Fig. 11 the ratios are as 21 %, 41 %, 34 % and 29 % for CLT 180 L5s, CLT 140 L5s – 2, 34 % CLT 240 L7s - 2 and 29 % CLT 160 L5s, respectively. Ratios above 100% are an indication of member overloading. According to suggested calculations and thickness of the other panels of the floor system a 3 m by 4 m CLT 180 L5s was selected for the specified part of floor. Thickness of the layers and the profile properties of the five layer CLT panel with the thickness of 180 cm are presented in Table 12.

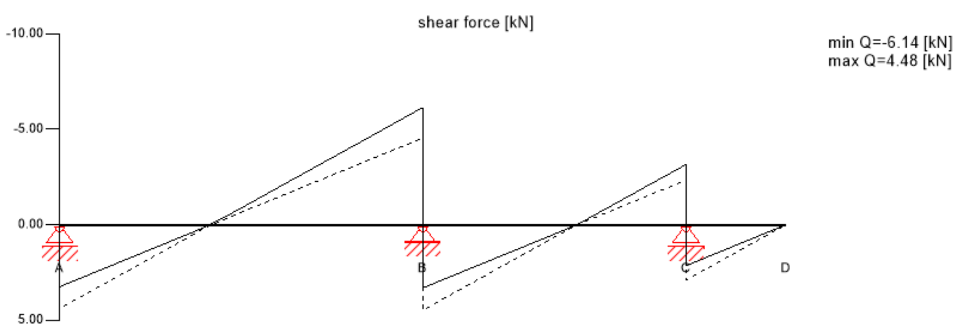
Table 12. Properties of the example CLT panel			
layer	thickness	type	material
1	40.0 mm	L	C24 pine
2	30.0 mm	C	C24 pine
3	40.0 mm	L	C24 pine
4	30.0 mm	C	C24 pine
5	40.0 mm	L	C24 pine

L:Longitudinal layer, C: Crossed layer

Design for Ultimate limit state

Ultimate limit state calculations were based on out of plan flexural properties, shear properties and rolling shear properties.

Some details of the calculation of example floor beam which was part of the software calculation are presented below. Shown in Fig. 12, the maximum shear force in this example was – 6.14 kN and maximum moment was 1.83 kN.m. Ultimate limit states design results are shown in Table 13 ,Table 14 and 15.



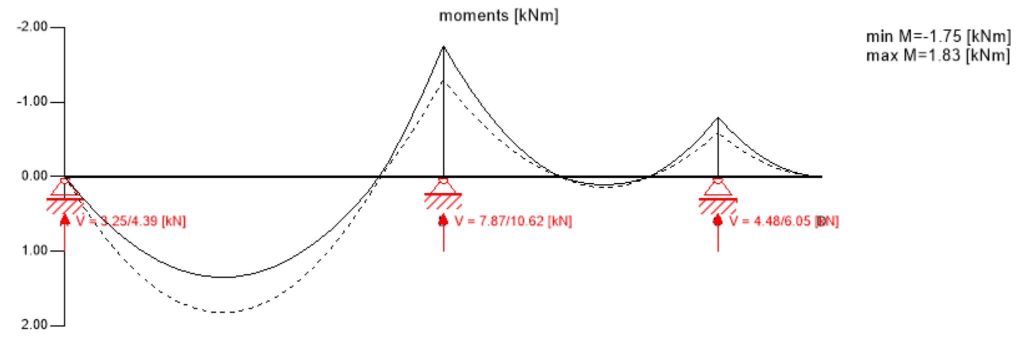


Fig. 12 Static analysis for hear (top) and moment (bottom) diagram of the example floor beam. Result of load combination.

Table 13 presented flexural design properties of example floor. Out of plane bending strength is 24 N/mm^2 and bending stress is 2.33 N/mm^2. The ratio of design bending stress to design bending strength should be equal to or less than 1.0 which here it is obtained as 0.02 and 0.04.

Table 13. Flexural design properties of the example floor beam

Span	$f_{m,k}$	γ_m	k_{mod}	k_{sys}	$f_{m,d}$	M_d	$\sigma_{m,d}$	Ratio
	[N/mm²]	[-]	[-]	[-]	[N/mm²]	[kNm]	[N/mm²]	%
First	24.00	1.25	0.80	1.10	16.90	2.98	0.64	4
Second	24.00	1.25	0.80	1.10	16.90	-2.80	0.60	4
Third	24.00	1.25	0.80	1.10	16.90	-1.25	0.27	2

$f_{m,k}$: Characteristic out of plan bending strength, **γ_m**: partial safety factor (is 1.25 in Austria), **k_{mod}**: modification factor, **$f_{m,d}$**: Design bending stress **M_d**: design moment, **$\sigma_{m,d}$**: maximum design bending stress on the edge.

Longitudinal layers shear analysis of the example floor beam is shown in Table 14. Longitudinal out of plan shear strength is 4 N/mm^2, design shear strength of the longitudinal layer is 2.56 N/mm^2

and longitudinal shear stress is 0.02-0.04N/mm^2. The ratio of design shear stress to design shear strength should be equal to or less than 1.0 which is 0.01 to 0.02.

Table 14. Shear analysis of longitudinal layers in the example floor beam

Span	$f_{v,k}$	γ_m	k_{mod}	$f_{v,d}$	V_d	$\tau_{v,d}$	ratio
	[N/mm²]	[-]	[-]	[N/mm²]	[kN]	[N/mm²]	%
First	4.00	1.25	0.80	2.56	9.67	0.04	2
Second	4.00	1.25	0.80	2.56	7.38	0.03	1
Third	4.00	1.25	0.80	2.56	4.55	0.02	1

$f_{v,k}$: longitudinal out of plan shear strength, **γ_m**: partial safety factor (is 1.25 in Austria), **k_{mod}**: modification factor, **$f_{v,d}$**: Design shear strength of the longitudinal layer, **V_d**: design shear force, **$\tau_{v,d}$**: shear stress of the longitudinal layer

Analysis for rolling shear or shear properties for transverse layers is shown in Table 15. Out of plan rolling shear strength is 1.23 N/mm^2 and rolling shear stress is 0.04 N/mm^2. The ratio of shear stress and design shear stress of the transverse layers should be equal or less than 1 which is 0.03 to 0.06 for different spans of for this floor panel.

Table 15. Rolling shear analysis of the example floor beam

Span	$f_{r,k}$	γ_m	k_{mod}	$f_{r,d}$	V_d	$\tau_{r,d}$	Ratio
	[N/mm²]	[-]	[-]	[N/mm²]	[kN]	[N/mm²]	%
First	1.23	1.25	0.80	0.78	9.67	0.04	6
Second	1.23	1.25	0.80	0.78	7.38	0.03	4

Third	1.23	1.25	0.80	0.78	4.55	0.02	3

$f_{r,k}$: Out-of-plane rolling shear strength, **γ_m**: Martial safety factor, **k_{mod}**: Modification factor, **$f_{r,d}$**: rolling shear strength of the transverse layer, **V_d**: design shear force, **$\tau_{r,d}$**: shear stress of the transverse layers

Ratio calculation shows that flexural, longitudinal and rolling shear, respectively are using % 4, % 2 and % 6 of the design capacity. Therefore, rolling shear properties were the controlling value of the ultimate limit state.

Flexural, shear and rolling shear stresses diagrams and their maximum values of 0.64, 0.04 and 0.04 N/mm^2 are shown in Fig. 13.

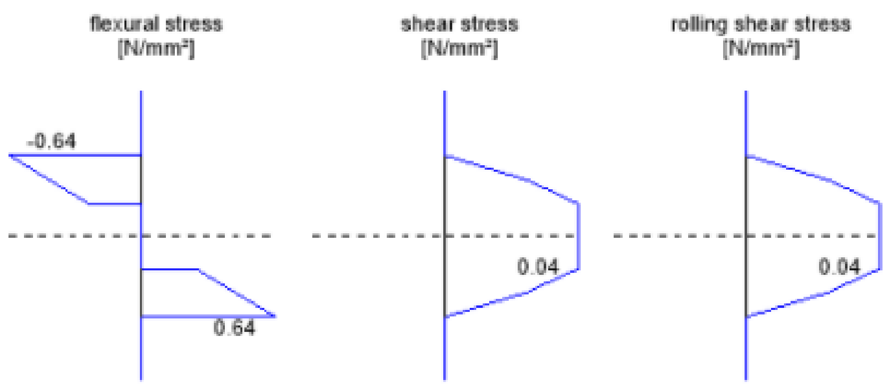


Fig. 13. Flexural stress, shear stress and rolling shear stress diagrams of the example floor beam

Ultimate limit state of fire design

Ultimate limit state calculations for fire were based on out of plan flexural properties, shear properties and rolling shear properties, as well. Ultimate limit states design results are shown in **Error! Reference source not found.**Table 17 and 18.

Flexural design properties of example floor Shown in Table 16 are out of plane bending strength with the value of 24 N/mm^2 and maximum bending stress of 3.72 N/mm^2. The design ratio is 0.05 to 0.12 percent.

Table 16. Flexural properties for fire design of the example floor beam

Span	$f_{m,k}$	γ_m	k_{mod}	K_{fire}	$f_{m,d}$	M_d	$\sigma_{m,d}$	Ratio

	[N/mm²]	[-]	[-]	[-]	[N/mm²]	[kNm]	[N/mm²]	%
First	24.00	1.25	1.00	1.15	30.36	-1.67	3.72	12
Second	24.00	1.25	1.00	1.15	30.36	-1.67	3.72	12
Third	24.00	1.25	1.00	1.15	30.36	-0.68	1.51	5

$f_{m,k}$: Characteristic out of plan bending strength, **γ_m**: partial safety factor (is 1.25 in Austria), **k_{mod}**: modification factor, **$f_{m,d}$**: Design bending stress **M_d**: design moment, **$\sigma_{m,d}$**: maximum design bending stress on the edge.

Fire design shear analysis of longitudinal layers of the example floor beam is shown in Table 17. Design shear strength of the longitudinal layer is 5.34 N/mm^2 and longitudinal shear stress is 0.04 - 0.09 N/mm^2. The design shear ratio for fire is 0.01 to 0.02.

Table 17. Shear analysis of fire design of the example floor beam

Span	$f_{v,k}$	γ_m	k_{mod}	$f_{v,d}$	V_d	$\tau_{v,d}$	ratio
	[N/mm²]	[-]	[-]	[N/mm²]	[kN]	[N/mm²]	%
First	4.00	1.25	1.00	4.60	5.34	0.09	2
Second	4.00	1.25	1.00	4.60	4.01	0.07	1
Third	4.00	1.25	1.00	4.60	2.48	0.04	1

$f_{v,k}$: longitudinal out of plan shear strength, **γ_m**: partial safety factor (is 1.25 in Austria), **k_{mod}**: modification factor, **$f_{v,d}$**: Design shear strength of the longitudinal layer, **V_d**: design shear force, **$\tau_{v,d}$**: shear stress of the longitudinal layer

Presented in Table 18, , the out-of-plan rolling shear strength is determined to be 1.23 N/mm². The maximum design rolling shear stress under fire conditions is 0.03 N/mm², and the corresponding design rolling shear ratio for fire is calculated to be 0.04, indicating that it is less than 1.

Table 18. Rolling shear analysis of fire design of the example floor beam

Span	$f_{r,k}$	γ_m	k_{mod}	$f_{r,d}$	V_d	$\tau_{r,d}$	Ratio
	[N/mm²]	[-]	[-]	[N/mm²]	[kN]	[N/mm²]	%
First	1.23	1.25	1.00	1.41	5.34	0.00	0
Second	1.23	1.25	0.80	0.78	7.38	0.03	4
Third	1.23	1.25	0.80	0.78	4.55	0.02	3

$f_{r,k}$: Out-of-plane rolling shear strength, **γ_m**: Martial safety factor, **k_{mod}**: Modification factor, **$f_{r,d}$**: rolling shear strength of the transverse layer, **V_d**: design shear force, **$\tau_{r,d}$**: shear stress of the transverse layers

Design for service limit state

Service limit states (SLS) were assessed for initial or instantaneous deflection caused by both permanent and variable loads. The specified limits for these states were set at L/300. Additionally, the final deflection, comprising instantaneous deflection and deflection due to creep, was considered at L/150. The net final deflection, which accounts for both final deflection and creep deflection, was evaluated against a limit of L/250 mm.

The design value calculated by software for these limit states is presented in Table 19. The initial deflection is capped at 0.5 mm, well below the limit state of 6.7 mm. Subsequent analyses yield maximum final and net final deflections of 0.8 mm and 0.6 mm, respectively, both comfortably below the calculated limit states of 13.3 mm and 8.0 mm. The deflection factor stands at 1, and the maximum allowable span length for the given floor example is 2 meters.

Table 19. Maximum amount of Initial, final and net final deflection calculated for different spans of the example floor beam

Initial deflection	Final deflection	Net final deflection
[mm]	[mm]	[mm]
0.5	0.8	0.6
Initial, final and net final deflection limits are 6.7, 13.3 and 8.0 mm.		

Design for vibration

For vibration which is a controlling design value for floor system design, four criteria are defined in two classes I and II Table 20. The vibration design value was calculated conservatively according to Class I criteria. The overall design ratio for the vibration of the sample floor was determined to be 21%.

Table 20. Vibration criteria and the value obtained for the example floor

Criterion	Class I	Class II	Calculated
Frequency criterion min [Hz]	4.50	4.50	38.11
Frequency criterion [Hz]	8.00	6.00	38.11
Acceleration criterion [m/s^2]	0.05	0.10	0.0
Stiffness criterion [mm]	0.25	0.50	0.022

The final size of floor panels

The design calculation has been conducted with the same design consideration of ULS, ULS fire, SLS and vibration for the other floors. The number and size of the panels and the direction of the surface layers are listed in Table 21.

Table 21. Size and the number of the panels used for the first floor

Amount of panel	Size (m^2)	The direction of the surface layer with the span
8	2*6	Perpendicular
4	1.5*3	Perpendicular

20	1*9	Perpendicular
2 (just for the first floor)	3*4	Perpendicular
8	2*6	parallel
2	3*2	parallel
The other floors have the same panel sizes		

Flexural design properties for different floor panels

The summary of flexural design properties for the other floor panels is listed in Table 22. Percent of flexural design capacity usage is between 7-25 percent.

Table 22. Flexural design properties floor beam

Span	$f_{m,k}$	$f_{m,d}$	$\sigma_{m,d}$	Ratio
	[N/mm²]	[N/mm²]	[N/mm²]	%
1*9	24	12.67	3.13	25
1.5*3	24	16.90	1.07	6
2*6 (Perpendicular)	24	12.67	2.33	18
3*4	24	12.67	1.17	9
2*6 (Parallel)	24	12.67	2.33	18
3*2	24	12.67	0.84	7

The summary of shear analysis and rolling shear analysis for the other floor panels are shown in Table 23 and Table 24. Percent usage of Shear and rolling shear capacities are between 2-4 percent and 5-12 percent.

Table 23. Summary of shear analysis of longitudinal layers in floor beams

Span	$f_{v,k}$	$f_{v,d}$	$\tau_{v,d}$	Ratio
	[N/mm²]	[N/mm²]	[N/mm²]	%
1*9	4	1.92	0.13	2
1.5*3	4	2.56	0.05	2
2*6 (Perpendicular)	4	1.92	0.08	4
3*4	4	1.92	0.04	2
2*6 (Parallel)	4	1.92	0.08	4
3*2	4	1.92	0.04	2

Table 24. Summary of rolling shear analysis of the floor beams

Span	$f_{r,k}$	$f_{r,d}$	$\tau_{r,d}$	Ratio
	[N/mm²]	[N/mm²]	[N/mm²]	%
1*9	1.23	0.59	0.13	6
1.5*3	1.42	3.91	0.04	5
2*6 (Perpendicular)	1.50	0.72	0.08	12

3*4	1.50	0.72	0.04	5
2*6 (Parallel)	1.50	0.72	0.08	12
3*2	1.60	0.77	0.03	5

Referring to Table 25 it is revealed that the controlling limit state is vibration, considering class I criteria conservatively. The maximum vibration capacity utilization belongs to floor panels with a length of 9 meter which spans three equal 3- meter spans.

Table 25. Summary of vibration analysis of the floor beams

Criterion	1*9	1.5*3	2*6 (Perpendicular)	3*4	2*6 (Parallel)	3*2
Frequency criterion [Hz]	8.123	28.851	38.11	15.088	23.791	23.791
Acceleration criterion [m/s²]	0.016	0	0.0	0.014	0	0
Stiffness criterion [mm]	0.149	0.053	0.022	0.063	0.032	0.032
Maximum utilization of vibration capacity %	98	28	77	53	34	34

Design of the wall system

According to the software analysis, it was determined that C24 pine 5-layer Cross-Laminated Timber (CLT) panels, each with a thickness of 200 mm, are suitable for designing load-bearing walls. The CLT panel consists of 5 layers, each with equal thickness. The cross-section profile properties of the wall panel are detailed in Table 26. Notably, no edge gluing option was employed for the analysis. The entire load-bearing panels are considered in the horizontal direction.

The software automatically accounted for the self-weight of the panels in the calculations. The analysis is based on the first CLT floor, with the self-weight of all upper floors factored in as the dead load on the first-floor wall system. The self-weight of one floor is calculated as 5.85 kN/m.

Table 26 CLT section profile properties of panels used for wall system

layer	thickness	type	material
1	40.0 mm	L	C24 pine
2	40.0 mm	C	C24 pine
3	40.0 mm	L	C24 pine
4	40.0 mm	C	C24 pine
5	40.0 mm	L	C24 pine
L:Longitudinal layer, C: Crossed layer			

Plan view of 12 m wall with four window cut is shown in Fig. 14 Wall Type 1 with length of 12 meter. The direction of cover layers is parallel to the length of wall The calculated design ratios for different controlling limit states of ULS, fire ULS and SLS for 12 meter wall are %10, % 43 and % 3. Controlling property for ULS and for ULS fire is buckling. The values and model obtained for ULS and ULS fire from CLT designer software are shown in Table 27 and Table 28.

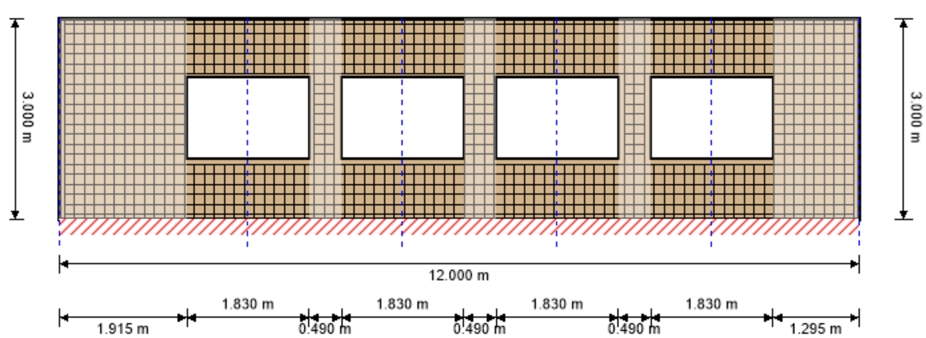
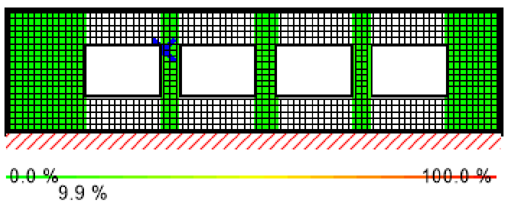


Fig. 14 Wall Type 1 with length of 12 meter. The direction of cover layers is parallel to the length of wall

Table 27 Maximum utilization rate for buckling of 12-meter wall.

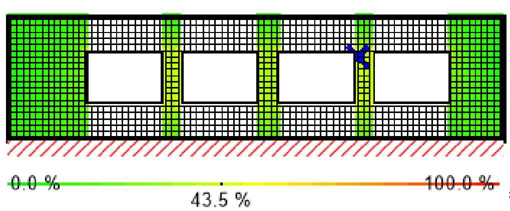
*Node$_{Id}$	X	Z	l_k	λ_y	βc	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
1146	3.825	2.025	3.0	72	0.2	0.627	15.12	0.94	0.00	10



*Node with maximum utilization is shown in blue mark.

Table 28 Maximum fire utilization rate for buckling of 12-meter wall.

*Node$_{Id}$	X	Z	l_k	λ_y	β_c	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
1177	8.475	2.025	3.0	260	0.2	0.062	24.15	0.65	0.00	43



*Node with maximum utilization is shown in blue mark.

The calculated design ratios of ULS, fire ULS and SLS for 8.8-meter wall are %4, % 18 and % 1. The values and model for ULD of buckling and ULS fire are shown in Table 29 and Table 30.

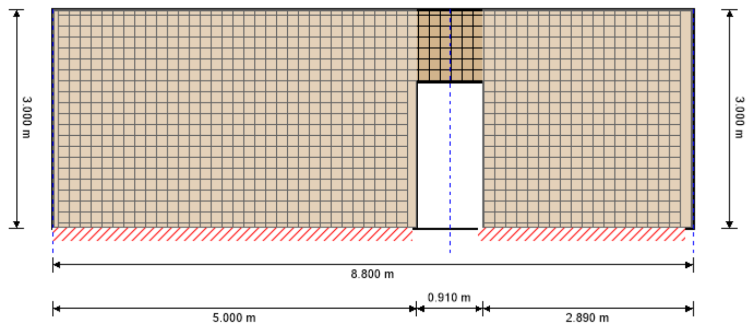
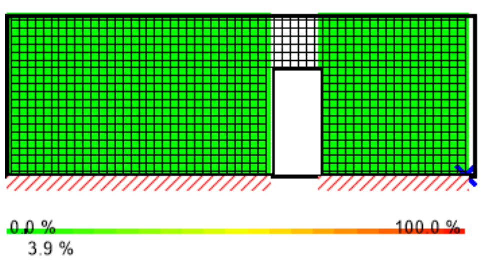


Fig. 15 Wall Type 2 with the length of 8.80 meter and one opening. The direction of cover layers is parallel to the length of wall.

Table 29. Maximum utilization rate for buckling for wall of 8.80 meter.

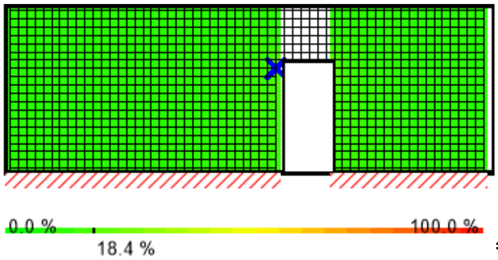
*$Node_{Id}$	X	Z	l_k	λ_y	βc	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
58	8.625	0	3.0	72	0.2	0.627	15.12	0.37	0.00	4



*Node with maximum utilization is shown in blue mark.

Table 30. Maximum fire utilization rate for buckling of 8.80-meter wall (18 %).

*$Node_{Id}$	X	Z	l_k	λ_y	β_c	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
787	4.875	1.875	3.0	260	0.2	0.062	24.15	0.28	0.00	18



*Node with maximum utilization is shown in blue mark.

Global utilization ratios of ULS, fire ULS and SLS of respectively % 8, % 38 and % 2, were obtained for 8.6-meter wall. The values and model obtained for ULD buckling and ULS fire buckling is shown in Table 31 and Table 32.

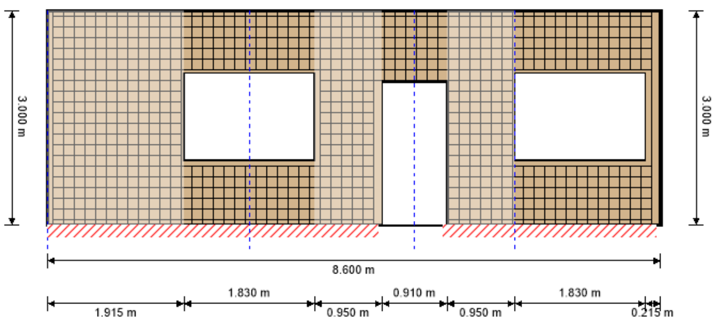
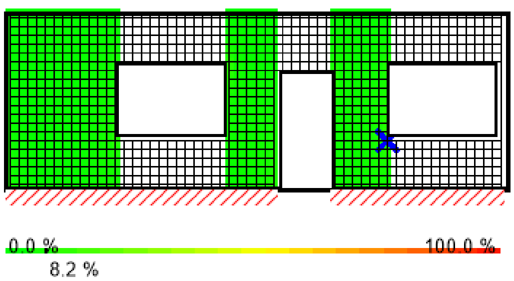


Fig. 16. Wall Type 3 with a length of 8.6 meters and three openings. The direction of the cover layers is parallel to the length of the wall

Table 31. The maximum utilization rate for buckling of 8.6-meter wall.

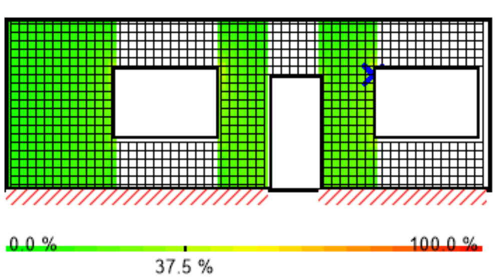
*Node$_{Id}$	X	Z	l_k	λ_y	βc	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
386	6.525	0.825	3.0	72	0.2	0.627	15.12	0.78	0.00	8



*Node with maximum utilization is shown in blue mark.

Table 32. Maximum fire utilization rate for buckling of 8.6 meter wall.

*Node$_{Id}$	X	Z	l_k	λ_y	β_c	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
842	6.525	2.025	3.0	260	0.2	0.062	24.15	0.56	0.00	38



*Node with maximum utilization is shown in blue mark.

The computed design ratios for ultimate limit state (ULS), fire ULS, and serviceability limit state (SLS) for an 8-meter wall are 11%, 73%, and 2%, respectively. Table 33 displays the values and model details for ultimate limit state (ULS) buckling, while Table 34 provides the corresponding information for ULS under fire conditions. These results were obtained using the CLT designer software.

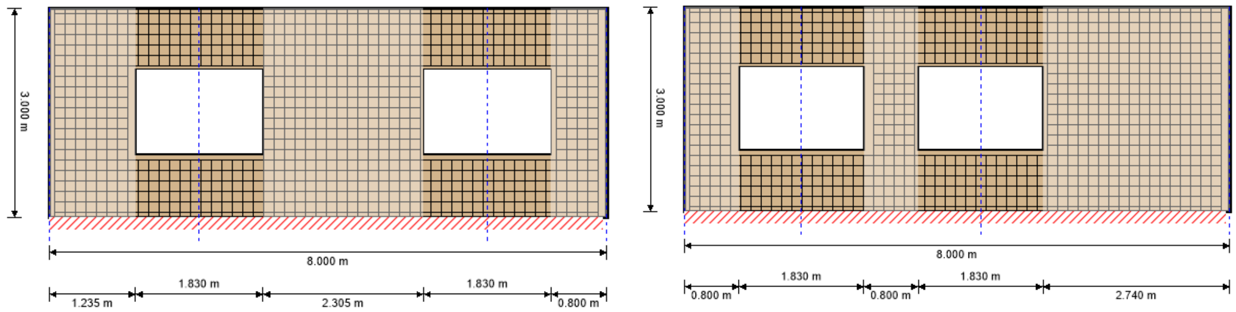
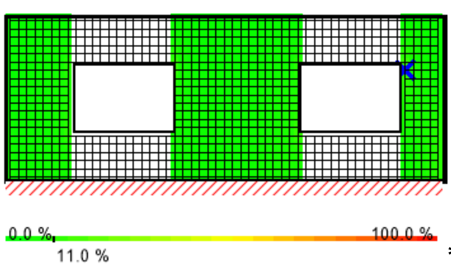


Fig. 17. Wall Type 4 (two configurations) with the length of 8 meter and two openings. The direction of cover layers is parallel to the length of wall

Table 33. Maximum utilization rate for buckling of 8-meter wall

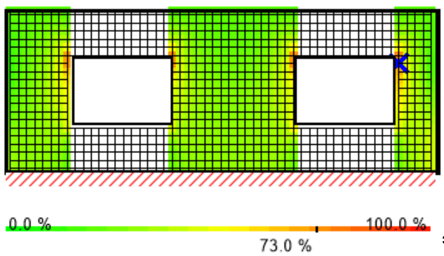
*Node$_{Id}$	X	Z	l_k	λ_y	βc	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
791	7.275	2.025	3.0	83	0.2	0.511	15.12	0.85	0.00	11 %



*Node with maximum utilization is shown in blue mark.

Table 34. Maximum fire utilization rate for buckling of 8 meter wall

*Node$_{Id}$	X	Z	l_k	λ_y	β_c	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
791	7.275	2.025	3.0	346	0.2	0.035	24.15	0.63	0.00	73 %



*Node with maximum utilization is shown in blue mark.

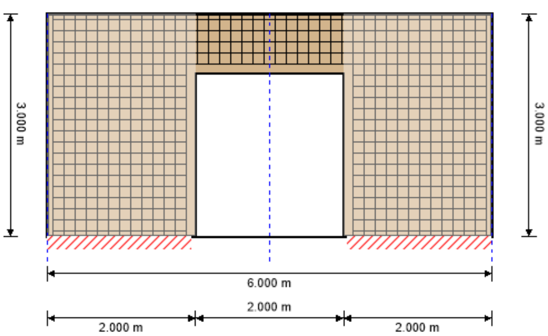
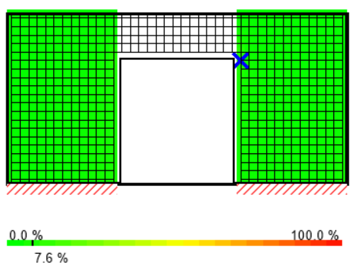


Fig. 18. Wall Type 5 (two configurations) with the length of 6 meter and one opening. The direction of cover layers is parallel to the length of wall

The designated design ratios for Ultimate Limit State (ULS), Fire Ultimate Limit State (fire ULS), and Serviceability Limit State (SLS) for a 6-meter wall are 8%, 42%, and 2%, respectively. The corresponding calculated values and the model results for Ultimate Limit State with buckling (ULD) and Fire Ultimate Limit State (ULS fire) can be found in Table 35 and Table 36.

Table 35. Maximum utilization rate for buckling of 6-meter wall

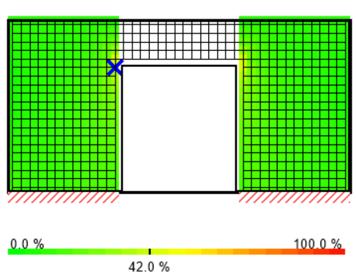
*$Node_{Id}$	X	Z	l_k	λ_y	βc	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
628	4.125	2.175	3.0	72	0.2	0.627	15.12	0.72	0.00	8 %



*Node with maximum utilization is shown in blue mark.

Table 36. Maximum fire utilization rate for buckling of 8-meter wall

*$Node_{Id}$	X	Z	l_k	λ_y	β_c	$k_{c,y}$	$f_{c,d}$	$\sigma_{c,0,d}$	$\sigma_{m,y,d}$	ratio
[-]	[m]	[m]	[m]	[-]	[-]	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
613	1.875	2.175	3.0	260	0.2	0.062	24.15	0.63	0.00	42 %



*Node with maximum utilization is shown in blue mark.

All the obtained design ratio values for the wall system are below the % 100 rate; there for all of the walls with the selected properties are adequate for bearing loads in the building.

Size and number of walls

The height of wall panels considered as 3 meter with both cover layers horizontally directed. Length and number of the wall panels used for the first floor is listed in Table 37.

Table 37. Size and the number of panels used for walls in first floor

Number of panels	Length (m)	Direction of surface layer
4	8	Horizontal
2	12	Horizontal
1	6.04	Horizontal
1	6	Horizontal
2	8.80	Horizontal
2	8.60	Horizontal

Consulting to the CLT producers, it is mentioned that for long distance shipping such as shipping to other countries or US; it is better to use smaller length of the panels for reducing shipping cost and more shipping flexibility.

CLT connection

Connection information was gathered during a site visit to Rotho Blaas Company, complemented by insights from the company's catalogue. The prevailing connections utilized in Cross-Laminated Timber (CLT) building construction primarily involve angle brackets and perforated plates.

For shear and tensile connections of wooden walls to wooden substructures, angle brackets play a pivotal role, as depicted in Figure 19. Shear connection angle brackets are available in two variants, with heights of 120 and 240, and widths of 71 and 200 mm, respectively. Tensile angle brackets are introduced in four distinct types, featuring heights of 340, 440, and 540 mm, accompanied by a washer hole of 17 mm, and a height of 620 mm with a washer hole of 21 mm.

Specifically engineered for robust shear stress resistance, shear brackets ensure high-performance connections, while angle brackets are tailored for exceptional tensile resistance. Both connector types are well-suited for applications in seismic-prone areas, fortified to exhibit commendable torsional behavior. The utilization of screw fastening allows these connectors to achieve optimal performance levels.

Fig. 19.Shear (left) and tensile (right) angle brackets employed for wall to floor connections (Rotho Blaas catalogue).

Perforated plats are produced according to EN 14545 and are available in length up to 120 cm, width up to 40 cm and thickness up to 0.2 cm (Fig. 20).

Fig. 20. Perforated plates for wooden wall connection to substructures (other wooden walls or concrete foundation). Left form Rotho Blass catalog, right photo credit to Ermanno Akler, Holzpak.

Recently, Rotho Blaas has introduced an innovative connector known as X-Rot, intended for wall-to-wall connections as a replacement for traditional splines and screws. However, the calculation of connectors was omitted in this project due to time constraints and a lack of detailed information.

Benefits/relevance/expected results

This report outlines the process of designing a mid-rise 6-story Cross-Laminated Timber (CLT) building with the initial floor made of concrete. The design of wall and floor systems adhered to Eurocode standards and was executed using the CLT Engineer software from Estora Enso Company. Notably, the calculation for connection design was not incorporated into the overall design process.

The key takeaways from this project include gaining familiarity with Eurocode regulations for the design of CLT buildings and establishing connections with CLT panel and connection-producing companies in Europe. The final results of the project are intended for use in comparing the design of CLT buildings according to Eurocode 5 with the National Design Standard of the United States. Furthermore, the aim is to explore the possibility of adopting European CLT design methods to enhance the design of CLT buildings in the United States.

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