Mjøstårnet – Construction of an 81 m tall timber building

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1. Introduction

1.1. The building

Mjøstårnet is an 18-storey timber building which is currently under construction. Ground works started in April 2017. Installation of timber structures started in September 2017, and the building will be structurally topped out in June 2018. The building will be completed and opened in March 2019. The net area is 11300 m^2, and there will be offices, hotel, apartments, restaurant and a roof terrace. Next to the tower there will be a large indoor swimming arena, see Figure 1. "Mjøstårnet" is Norwegian and means "The tower of lake Mjøsa".

The initiative to build Mjøstårnet comes from Arthur Buchardt. His vision is that the project will be a symbol of the green shift, and a proof that tall buildings can be built using local resources, local suppliers and sustainable wooden materials.

Figure 1: Mjøstårnet. 3D-rendering

1.2. Location

The building site is in the small town of Brumunddal, about 140 km north of Oslo. It is about an hour's drive from OSL Airport. The building is next to highway E6 and faces lake Mjøsa – Norway's largest lake.

Figure 2: Building location in Brumunddal next to highway E6

1.3. Project organization

The building owner is AB Invest. This is a property developing company owned by Arthur and Anders Buchardt (father and son). The Norwegian contractor HENT builds Mjøstårnet for AB Invest as a turnkey contract. Moelven Limtre is HENT's subcontractor for structural timber components. Sweco does engineering for HENT and structural timber design for Moelven Limtre. Voll Arkitekter were hired as HENT's architects.

All the participants have been active in the development of this innovative project.

Rambøll has done third party reviewing of the structural design and the fire design.

2. Structural System

The main load bearing consists of large scale glulam trusses along the façades as well as internal columns and beams, see Figure 3. The trusses handle the global forces in horizontal and vertical direction and give the building its necessary stiffness. CLT walls are used for secondary load bearing of three elevators and two staircases. The CLT does not contribute to the building's horizontal stability.
Mjøstårnet has many similarities with the 14-storey timber building Treet in Bergen, which was completed in December 2015. The two most significant differences are that Mjøstårnet will be about 30 m taller, and that the building modules used in Treet are exchanged

with prefabricated floor and wall elements. Building modules restrict the flexibility of the areas, and this was not compatible with the mixed functions required for Mjøstårnet. The large prefabricated façade elements are attached to the outside of the timber structures and make up the envelope of the building. These sandwich type elements come with insulation and external panels already fixed. Wall elements do not contribute to the global stiffness of the building. In total there are about 2600 m^3 of timber structures in Mjøstårnet.
The building has a footprint of about 17 x 37 m^2. The huge concrete slab on the ground floor is supported by piles that are driven to the bedrock below. These piles can handle compression and tension forces.

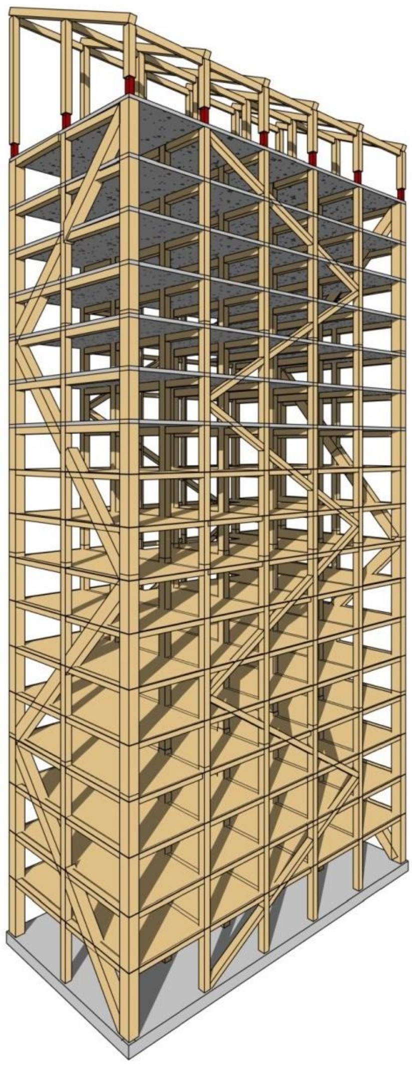


Figure 3: Structural system

The largest axial forces occur in the four corner columns. The ULS maximum compression force is 11500 kN, and the ULS maximum tension force is 5500 kN. The cross-section of these columns is 1485 x 625 mm^2. Typical internal column cross-sections are 725 x 810 mm^2 and 625 x 630 mm^2.

Floors 2 to 11 are prefabricated wooden decks based on Moelven's Trä8 building system, see Figure 7. Floors 12 to 18 are 300 mm concrete floors. The concrete floors are a composite of a prefabricated bottom part which acts as formwork for a cast in place upper part. Replacing wood with concrete in the upper floors means that the building will be heavier towards the top. This building is slender in its weak direction, so the extra mass is necessary to comply with comfort criteria for apartments. The concrete decks also make it somewhat easier to get a high standard acoustic performance in the apartments. Each floor acts as a diaphragm.

Typical glulam beams supporting timber floors are 395x585 mm2 and 395x675 mm2. Typical glulam beams supporting concrete floors are 625x585 mm2 and 625x720 mm2. The largest diagonal cross section is 625x990 mm2.

The maximum calculated horizontal deflection at the top of the building is 140 mm.

On the roof there is an apartment and a pergola to give the building a distinct architectural look. The pergola is a large wooden structure that is fixed to the concrete deck on level 18. The height of the building is over 81 m to its architectural top, according to the height definitions given by CTBUH (Council on Tall Buildings and Urban Habitat) http://www.ctbuh.org/. The height to the highest occupied floor is 68 m. The height of the CLT shafts for stairs and elevators is 74 m.

All glulam elements are connected by use of slotted-in steel plates and dowels. This is a high capacity connection which is commonly used in bridges and large buildings. The structural timber is on the inside of the façade and glass elements. This protects the timber from rain and sun, increases durability and reduces maintenance. It also lets the glulam breathe freely on the inside. Climate class 1 is used for all timber members except the pergola.

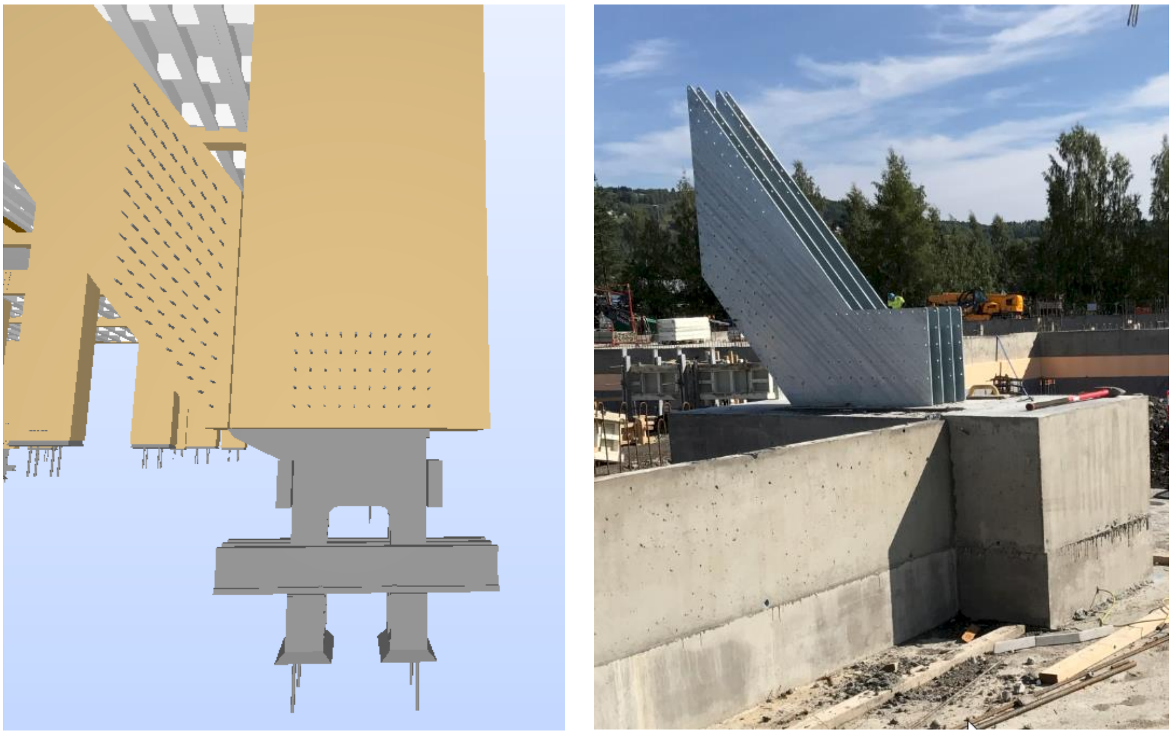


Figure 4: Corner column foot detail from 3D-model and building site

The structural design of the timber structure is done according to Eurocode 5 by the engineering company Sweco.

CTBUH has recently finished a project to propose criteria for tall timber buildings [10]. According to this the Mjøstårnet building will be regarded as a single material timber building – and most likely become the tallest of its kind worldwide when it is completed.

3. Materials

The glulam in the building has been produced by Moelven Limtre. The CLT is produced by Stora Enso. Untreated Norway spruce is the main species used for structural timber parts. Exposed timber in the pergola is made of CU-impregnated Scots pine.

For the structural design, glulam strength classes GL30c and GL30h according to EN 14080:2013 and CLT with bending strength f_{mk}=24 MPa are used.

The wooden floor elements are a combination of glulam from Moelven and LVL from Metsä Wood. The elements are insulated with Rockwool® and are fitted with a diffusion open sheething on top. Most elements have a 50 mm concrete screed on top.

Powder coated S355 steel is used in connections combined with acid-proof steel dowels.

The wooden cladding is supplied by Woodify and has fire retardant properties.

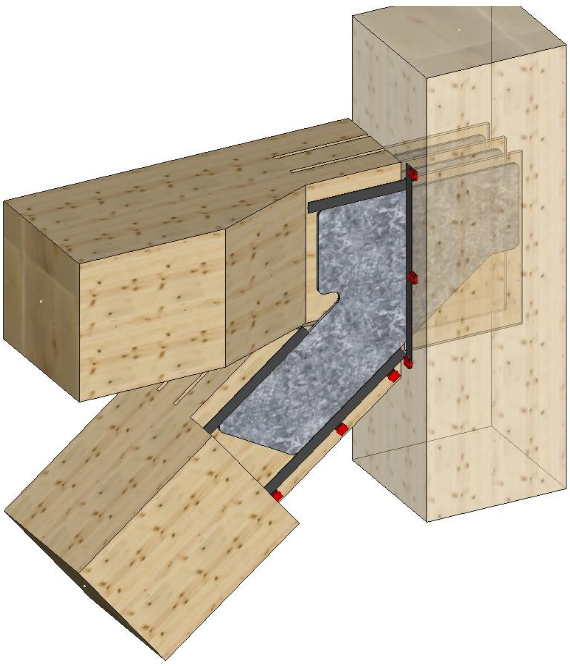
4. Fire design

The fire strategy report for this project states that the main load bearing system must be designed to withstand 120 minutes of fire. Secondary load bearing such as floors must withstand 90 minutes of fire. The fire resistance can be obtained by calculating the remaining cross section after charring according to Eurocode. In this way the large glulam sections will be visible inside the building.

Furthermore, the fire design is strengthened by burnout tests that were performed in 2016 at SP Firetech in Trondheim, Norway. In this test large glulam columns were put in a furnace to undergo an ISO-fire for 90 minutes. When the burners were shut off the glulam continued to char a little more, see Figure 5. After several hours the temperature in all columns were declining and the burning stopped. This proves that the large glulam columns will self-extinguish and prevent a building from collapse.

Visible wood in escape routes as well as internal walls in the main staircase and elevators will have fire retardant painting. To obtain high fire safety for the CLT the fire engineer stated that exposed walls in the escape staircase has to be covered with plasterboard. Testing shows that neighbouring CLT walls may entertain each other during a fire. There is a concern that you may have several flashovers, which eventually could mean that the material burns out.

Figure 5: Fire test of glulam at SP Firetech. Standard ISO fire for 90 minutes and observation in the cooling process. This specimen has an internal steel connection



In addition, several other means of fire protection measures are incorporated. The whole building is sprinkled. There is Firestop in the façade to prevent fire from spreading upwards. Steel plates and dowels in the connections are embedded deep into the timber (85+ mm). Gaps and slots between beams, columns and plates will be fitted with an intumescent fire strip. This material expands about 20 times when the temperature reaches 150 degrees. Figure 5 shows this connection after the fire. Holes for dowels will not be plugged, as the fire testing done at SP Firetech shows that doing so does not critically affect the temperature of the internal steel.
When it comes to robustness the structure is designed to sustain the loss of the horizontal stiffness of one timber floor.
It can also carry the impact load of a timber deck falling down on the floor below.

Figure 6: Fire protection of connections with Intumex fire strips

5. Loading

Eurocodes with national annexes for Norway determine the design loads. Wind loading turned out to be the dominating load in the design combinations. The wind load is applied as a static load. Wind tunnel tests were not found to be necessary because of the structure's regular geometry.
Seismic design is rarely decisive for buildings in Norway. The ground acceleration in Brumunddal is small compared to most other countries. According to Norwegian regulations, earthquake loads were not necessary to incorporate in the design because wind prevails.

6. TRÄ8 Floor elements

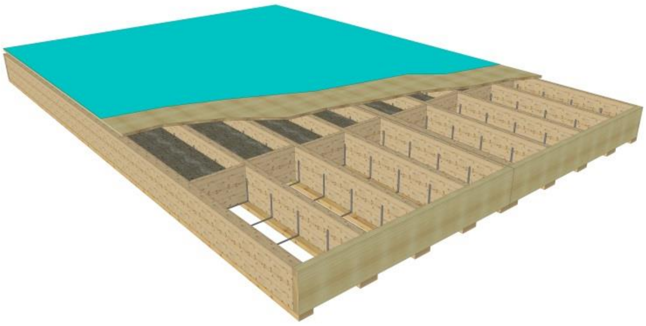


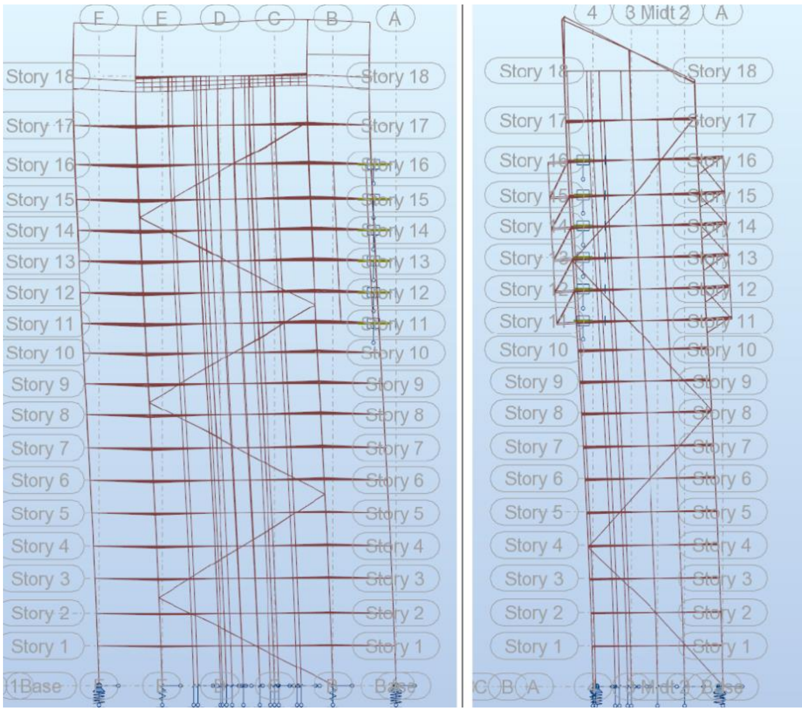
Figure 7: Floor element layout

Moelven's Trä8 floor elements are used in Mjøstårnet. These are based on Metsä Woods RIPA deck system. The main difference is that the girders and flanges are made of glulam instead of LVL.
The LVL top plate is glued to the girders as shown in Figure 7. To obtain R90 fire resistance the Rockwool is kept in place by steel brackets.
Max span in Mjøstårnet is 7,5 m.

Figure 8: Typical Trä8-building in Sweden

These elements use less wood materials compared to CLT decks. They are light and quick to assemble. Moelven has done many tests of different build-ups in Sweden and Norway. The floors become very stiff and perform well. They can handle both acoustic requirements and fire requirements. The carbon footprint is particularly low, estimated at about 65 kg CO_2/m^2. Floor spans of almost 10 m is within reach with this technology. This increases flexibility compared to other timber based floors.
The Trä8 building system can be combined with stabilizing concrete cores, steel trusses, CLT shear walls and glulam trusses.

7. Dynamic Design

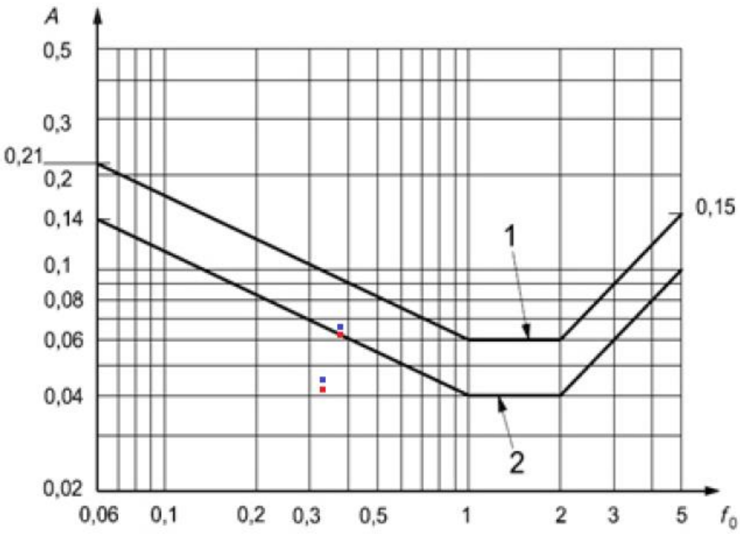


Accelerations are critical for timber highrises. Mjøstårnet is a tall building with low structural weight. Its natural frequencies lie in the domain where wind can cause annoying motions or nausea. The stiffness and mass properties for glulam and concrete are well known, and based on calculations and measurements done at Treet in Bergen we can predict the structural damping of a glulam truss system quite well.

A basic wind speed of 22 m/s and a structural damping ratio of 1,9% was used for Mjøstårnet.

Figure 9: Screenshot from dynamic model. The two first natural eiqenfrequencies

A master thesis from NTNU in 2016 [10] shows that the measured structural damping in Treet is very close to that what was used in the calculations.
Eurocode 1991-1-4 [4] gives guidelines on how to calculate the peak accelerations. ISO 10137 [5] gives recommended design criteria for wind-induced vibrations to evaluate the serviceability of the building. [6] also gives guidance for human response to vibrations. To analyze the dynamic behaviour of the building a FEM-model was made using Robot Structural Analysis Professional 2016.



The peak accelerations are plotted in Figure 10. The Red dots are for level 17 and the blue dots are for level 18.
We are on the limit on level 17, and slightly above on level 18. The client has accepted that this apartment will be sold with this info.

Figure 10: ISO-curve for comfort criteria

In D. Boggs, "Acceleration index for human comfort in tall buildings-peak or rms" the acceleration limit for nausea is given as 0,098 m/s2 and perception limit as 0,049 m/s2 for approximately 50 % of the population. The perception limit for approximately 2 % of the population is 0,020 m/s2. Most probably there will be insignificant effects from vibrations caused by wind exposure.

8. Vertical and horizontal sections

Figure 12: Typical sections for Mjøstårnet. Please note that the final elevations are somewhat different to what is shown here

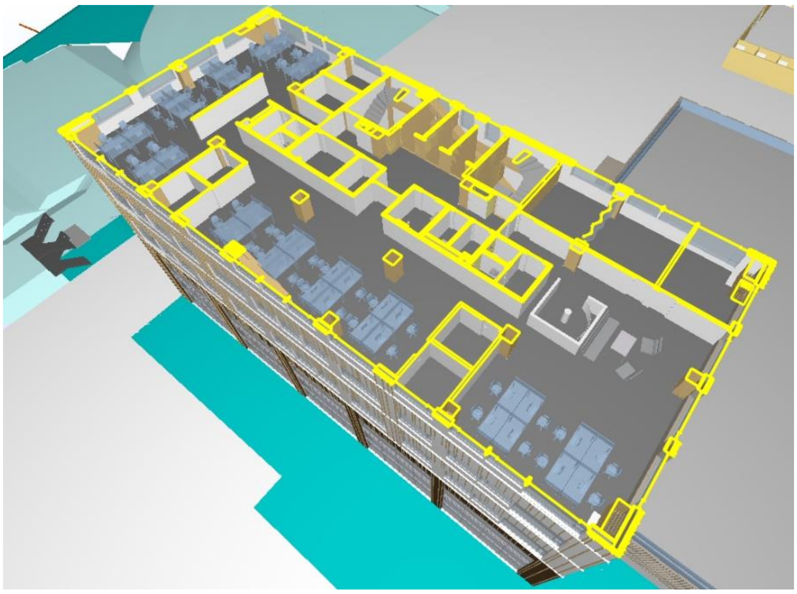


Figure 11: Horizontal section from BIM at typ. office floor

9. Assembly

The assembly of Mjøstårnet is mostly about installing prefabricated elements on site. Optimizing the logistics and installation is important to get a smooth assembly. In addition, considerable measures have been taken to ensure safe working conditions on site. The main contractor HENT has a large tower crane that Moelven Limtre and other subcontractors can use to install elements.
The timber structure is exposed to weather during construction. Based on our extensive experience this works fine as long as the structures will have the possibility to air out after the floors and the building shell have been installed. All glulam surfaces have been painted with one layer of varnish. Visible surfaces will be painted with a top layer at a later stage. Endgrain of columns at the ground floor has been sealed with epoxy. Exposed endgrain of column tops and exposed sides of LVL are also protected. A moisture control plan has been developed to ensure correct handling of wood on site. This plan includes measuring and monitoring moisture content of specified parts of the structure.
To get updated on images, videos, webcam and further information on the assembly, please follow the project's Facebook page: www.facebook.com/mjostarnet and Moelven's Mjøstårnet page: www.moelven.com/mjostarnet

Pictures from the start of the assembly in September 2017

Figure 13: Images from the building site October 26, 2017

10. Acknowledgments

The author would like to thank colleagues and all collaborating parties for their great efforts at Mjøstårnet. In particular this goes to Arthur Buchardt, without whom this building would never have become a reality. A special thanks goes to structural engineer Magne Bjertnæs at Sweco for input on structural issues.
Many thanks also to Innovation Norway for covering some of the design and development costs in this project.

11. References

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