Mjøstårnet – 18 storey timber building completed

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1. Introduction

1.1. The building

Mjøstårnet is an 18-storey timber building which reached its top height on the 4th of September 2018 – exactly one year after the installation of the timber structures started. The facades were completed in October 2018 and the main construction works are now finished. In the coming months interior works, landscape works and technical systems will be completed. The building will be opened on the 1st of March 2019 – in accordance with the original time schedule.

Mjøstårnet consists of offices, technical rooms, 32 apartments, 72 hotel rooms, one hotel suite on level 15, a cafeteria, a restaurant, a conference room on level 17 and a rooftop terrace. All apartments are sold out. The rooftop terrace will be accessible for residents, hotel guests and employees from the rented offices. Other guests may visit the terrace upon purchasing an access card. The hotel will be named "Wood Hotel" and it has opened for bookings here:
https://www.frich.no/no/booking
Mjøstårnet is 85,4 m tall and is currently the world's tallest timber building

Figure 1: Mjøstårnet. Photo taken Oct 19, 2018

1.2. Location

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

The initiative to build Mjøstårnet comes from investor Arthur Buchardt. He grew up in Brumunddal and wanted to build the world's tallest timber building using local resources, local suppliers, local competence and sustainable wooden materials. The completed building will have the majority of wooden components originating from nearby sustainable forests. The glulam structures have been produced at Moelven's glulam factory only 15 km from the building site.

1.3. Involved parties for construction

The building owner is AB Invest A/S. 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. Voll Arkitekter from Trondheim have been the project's architects. Moelven Limtre have been HENT's subcontractor for supply and installation of all structural timber components, balconies and pergola. Sweco did the engineering for HENT and structural timber design for Moelven Limtre. Ringsaker vegg- og takelementer (RVT) supplied and installed the prefabricated façade elements.

The CLT used in staircases and balconies was supplied by Woodcon / Stora Enso. LVL used in wooden floor elements was supplied by Mëtsa Wood. Nordic Steel supplied the metal used in timber connections. Gunnar Hippe AS did the metal sheeting of outdoor glulam structures. Additionally, several more companies have been involved in various subtasks.

1.4. Paper from IHF 2017 [6]

The construction of Mjøstårnet was presented at Holzbau-Forum in Garmisch-Partenkirchen in December 2017. The corresponding conference documentation [6] provides information about Mjøstårnet on the following topics which is not repeated in this document:

- Structural system
- Materials
- Fire design
- Loading
- Wooden floor elements
- Dynamic design

2. Monitoring of Mjøstårnet

When designing tall timber buildings it is crucial to find smart ways to cope with horizontal accelerations induced by wind. Recommended comfort criteria are given in ISO 10137 [3] and guidelines for calculations are given by EN 1991-1-4 [4]. Particularly important is the structural damping ratio, which influences the result very much. The damping can be derived from measurements and data collection taken on site.

During construction of Mjøstårnet NTNU installed accelerometers temporarily to monitor the building's behaviour. This data will provide important information on how the structural skeleton behaves, see figures 2 and 3.

Figure 2: Monitoring equipment

Figure 3: Accelerometers were installed directly onto structures

When the building is completed NTNU will install monitoring equipment once more together with a corresponding anemometer. This will give important information on how the total building behaves compared to the skeleton structure. The result of this monitoring will be published later. Hopefully this information can be used to optimize future tall timber buildings.

3. Extending the building's height

When measuring the height of a building there are definitions given by CTBUH [7] on how to do this. The height is given as the level of the lowest, significant, open-air, pedestrian entrance to:

a) … the architectural top of the building
b) … the finished floor level of the highest occupiable floor
c) … the highest point of the building

The height to architectural top is the most widely utilized and is employed to define the CTBUH rankings of the world's tallest buildings. Please note that to be considered a building, at least 50 percent of its height must be occupiable. Telecommunications or observation towers that do not meet the 50 percent threshold are not eligible for inclusion on CTBUH's "Tallest" lists.

When the Mjøstårnet project was initiated the height to architectural top was set to be 81 m. The structural analyses were performed based on this. Well into the design process, and after the foundations were built, the client challenged the design team to come up with a solution to make the building as high as possible and also make the pergola with larger glulam sections that looked nicer. The client wanted a pergola that gives an impression of the structures that are used inside the building.

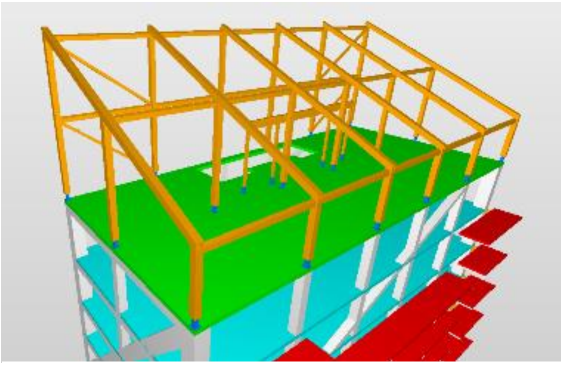


Figure 4: Original pergola design. H=81 m

This proved to be a huge challenge, as the primary structure and foundations were already optimized for the existing height.
Sweco's engineers came up with the idea to produce the pergola with rounded edges. This reduces the wind load and made it possible to stretch the top of the building to 85,4 m, see Figure 6. From the production side this was quite complicated, as about 1 km of large glulam sections had to be rounded with r=140 mm on all edges, see Figure 7. The actual processing was done at Aanesland Fabrikker's flagpole factory in the south of Norway.

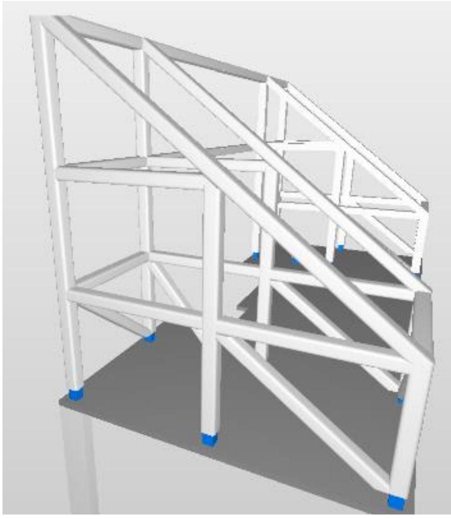


Figure 5: Revised pergola design. H=85,4 m

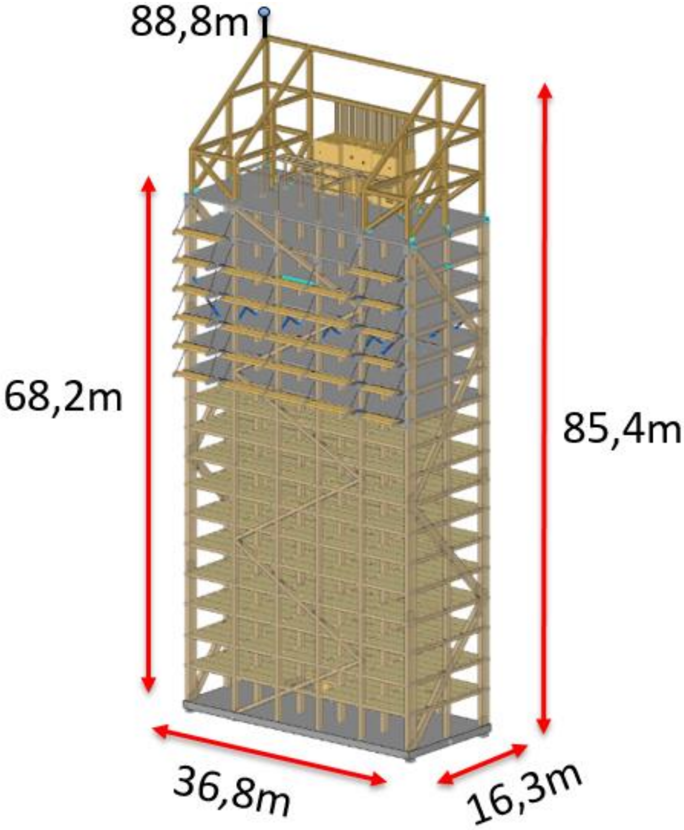


Figure 6: Official heights at Mjøstårnet as confirmed and ratified by CTBUH:

Highest occupied floor: **68,2 m** (level 18)
Architectural top: **85,4 m** (the top of the pergola)
Height to tip: **88,8 m** (top of lightning rod)

Figure 7: Glulam sections throughout the pergola have rounded edges to reduce the wind load

4. Actual volumes of structural components

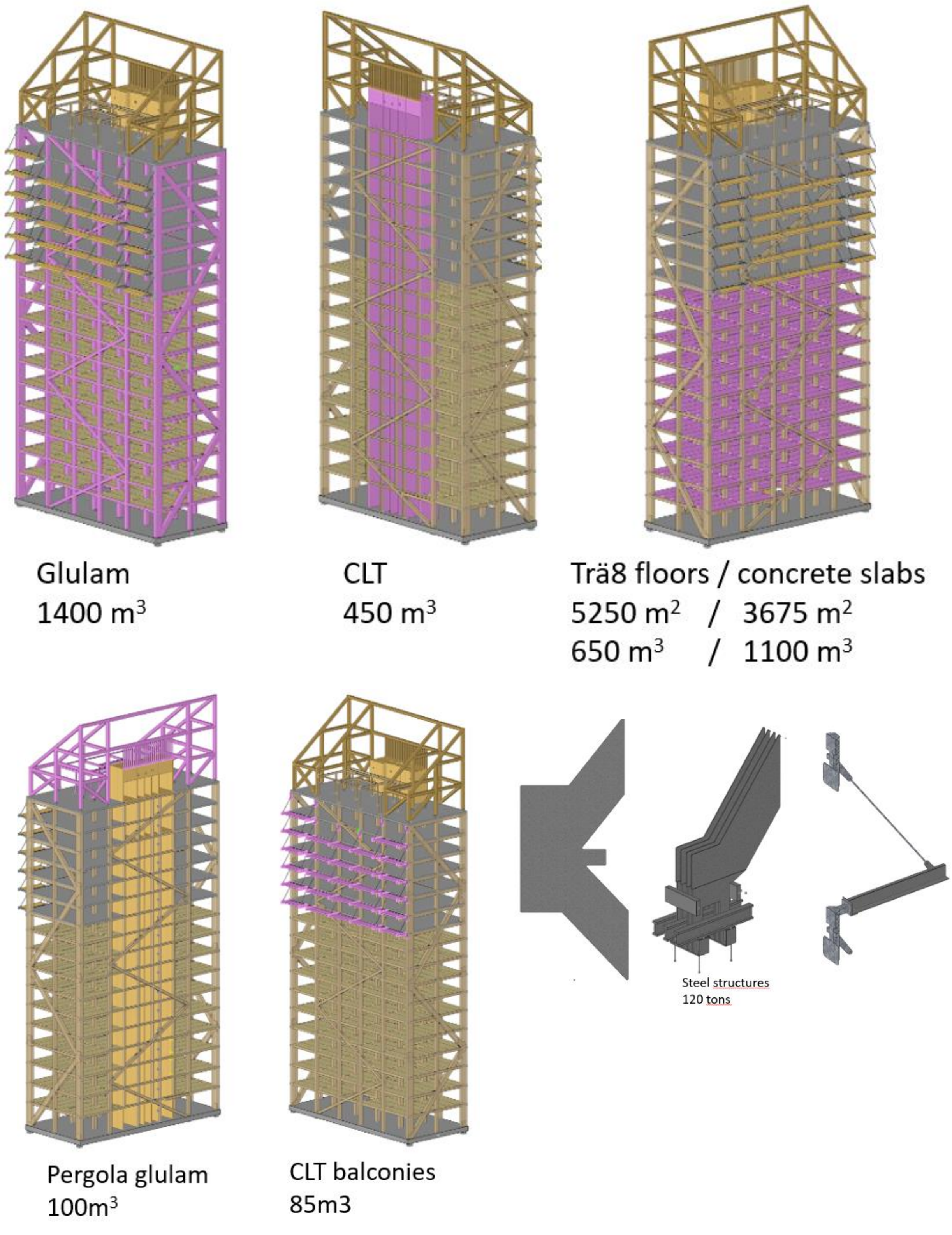


Figure 8: Highlighted volumes used in the building’s structure.
Please note that timber volumes used in exterior wall elements are not included

5. Assembly

The installation of structures at Mjøstårnet was done according to plan. No major delays occurred. The assembly is mostly about installing prefabricated elements on site, but on a scale that is much bigger than previous projects undertaken by Moelven Limtre.
Mjøstårnet is groundbreaking for more than just its height. For the installation Moelven employed a completely new and untested assembly technique. Outsiders may perhaps think that there is great risk involved in using a new assembly method on such a large and prestigious project. However, following many years of development, Moelven decided to follow a new path. Previously, large and complicated trusses were first assembled at the factory in Moelv before being transported to the building site for final assembly. This was done to ensure that everything would fit perfectly. At Mjøstårnet the individual members were transported directly to the building site, without any form of trial assembly.

The beams arrive fully processed and have to fit down to a millimetre. There is no scope for errors in the assembly. All of the pieces have a specific place and must fit. This construction method ensures a quicker production process and made it possible to build Mjøstårnet faster and less expensive.

Out of the several hundred large glulam parts produced for Mjøstårnet only one piece did not fit. This particular diagonal had to be removed and replaced with a new piece. The new diagonal was produced within a week and did not lead to delays on site.

During construction, the timber structures were directly exposed to weather. This worked quite well. End grain of columns, diagonals and walls were protected temporarily using plastic cover or wooden plates. The floor elements' topside were protected with a membrane. Using a roof tent would have been troublesome and was not considered necessary. During installation the moisture level of the wood was monitored in numerous places and depths. After the walls were installed, warm air was distributed and dried the structures in a controlled way.

Our experience is that both glulam and CLT handle direct weather exposure well. A lesson learned is that LVL (used in floor elements) demand extra attention. This material soaks up water along the edges, and we should have protected the sides better using tape or epoxy.

After installation of all structures on level 18 the maximum deviation that was measured was 19 mm out of theoretical position. Most structures were installed within a 10 mm deviation.

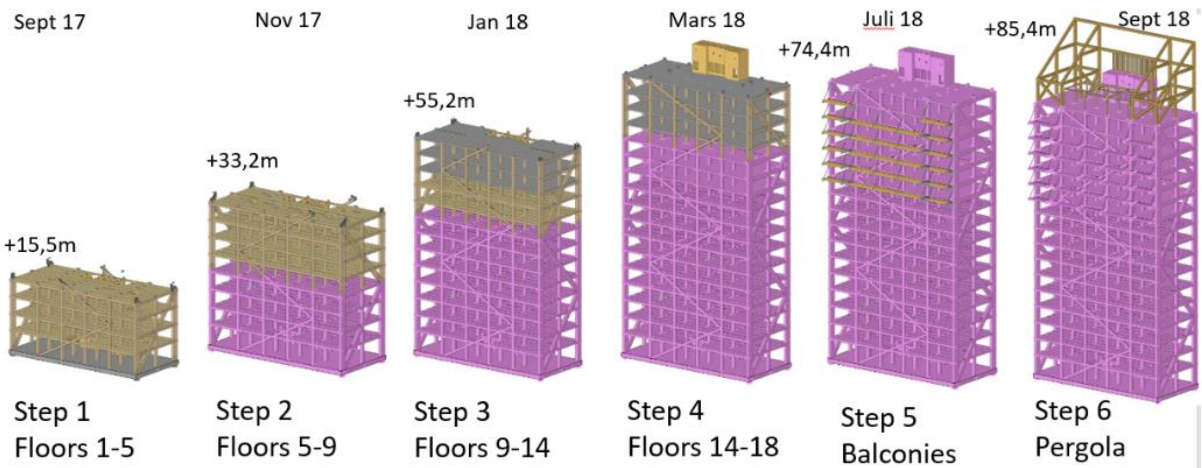


Figure 9: Installation steps

Figure 10: Step 1

Figure 11: Step 2

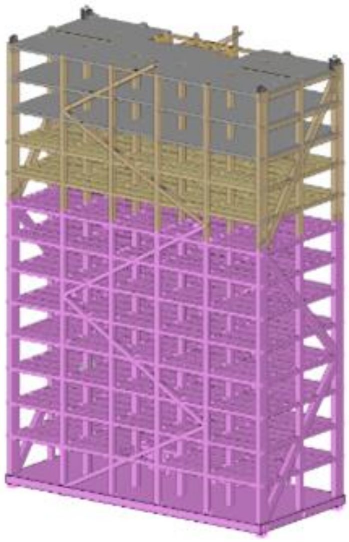
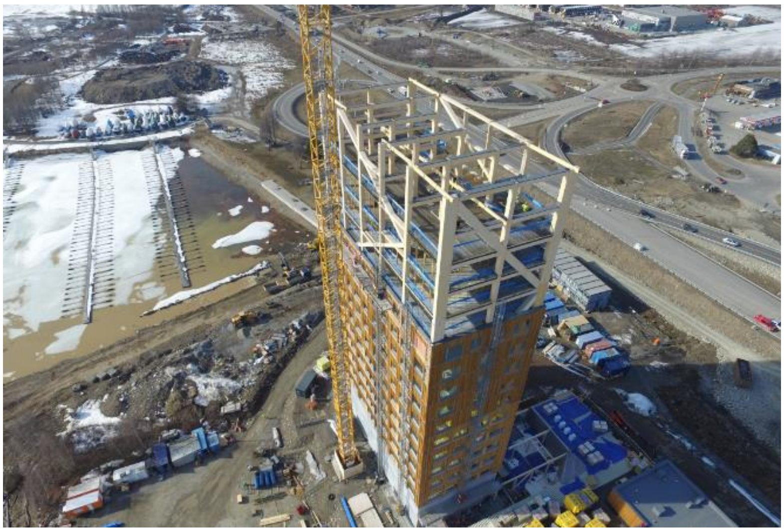


Figure 12: Step 3



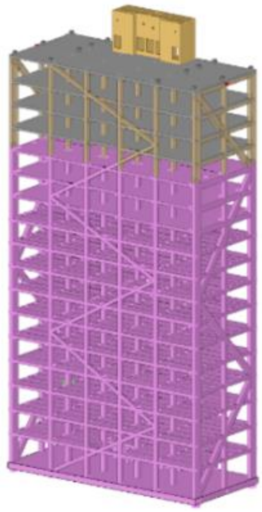
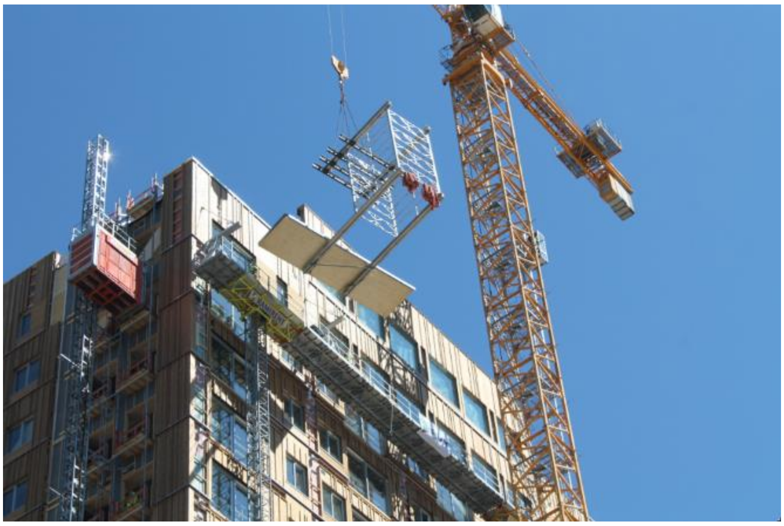


Figure 13: Step 4



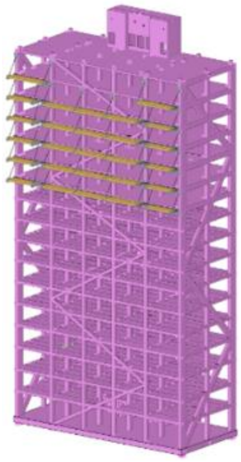


Figure 14: Step 5

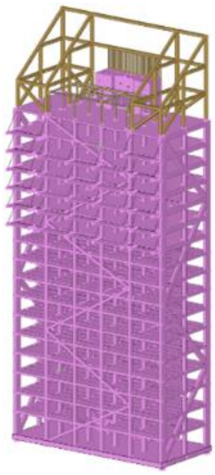


Figure 15: Step 6

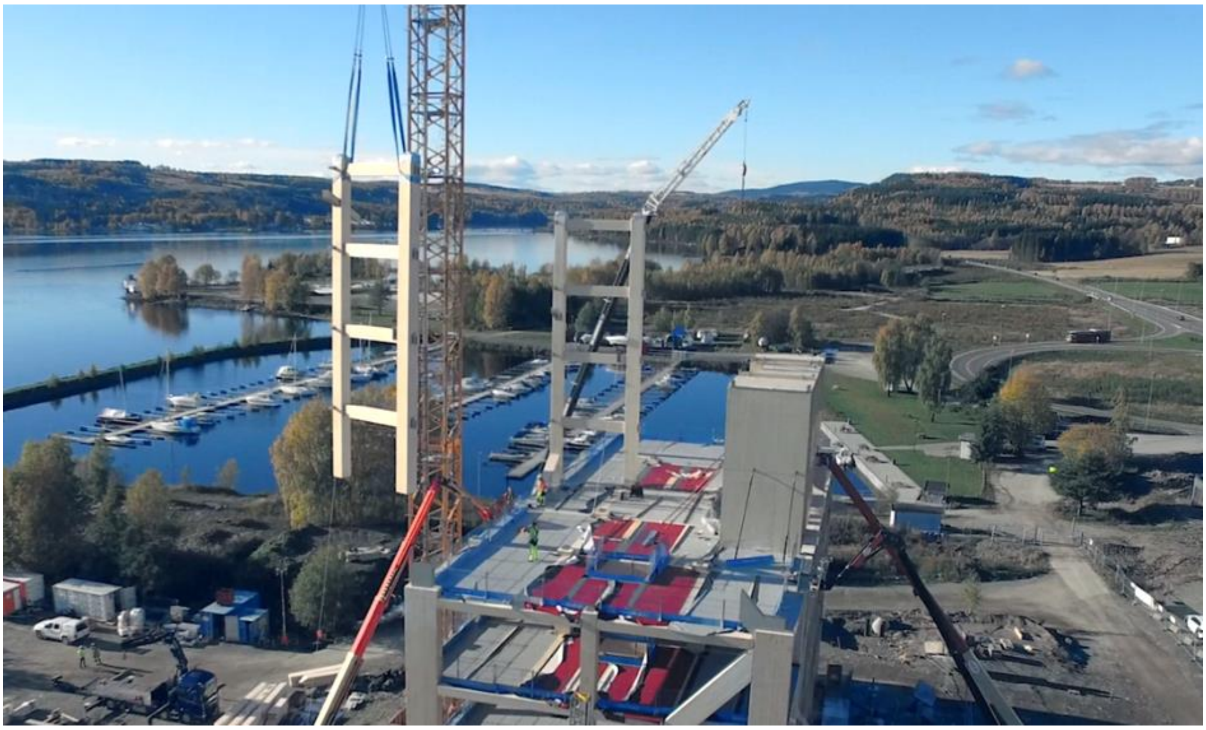
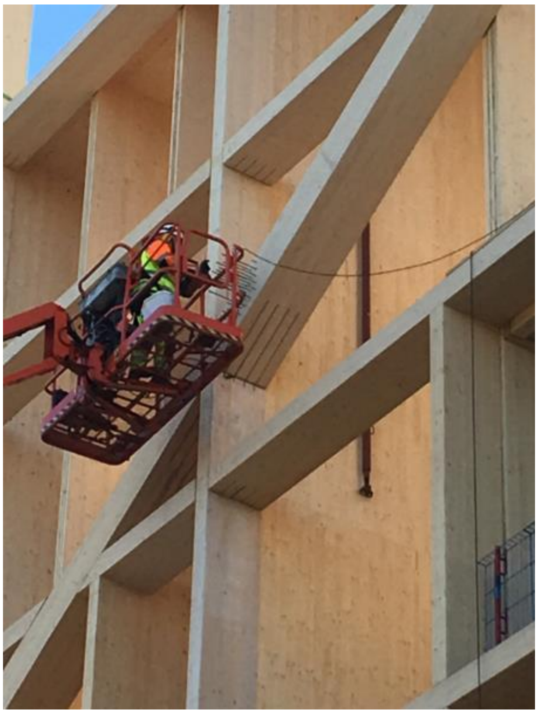


Figure 16: Installation of large glulam structures preassembled on site



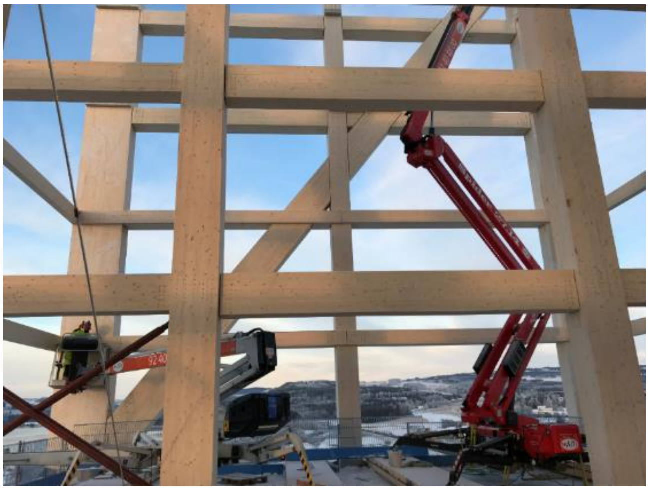


Figure 17: The timber structure was installed with the help of a tower crane as well as lifts positioned on the decks. No external scaffolding was used

A mast climbing scaffolding (mast climber) was used for the installation of prefabricated wall elements onto the timber skeleton

6. Visitors

Throughout the building period several thousand people and dozens of reporters have visited the construction site. Apart from Africa, there have been visitors from every continent of the world. Here are some examples of the feedback given to the project:

- It’s astonishing what can be built using wood!
- Mjøstårnet is a showcase of sustainable construction
- The building inspires us to build tall timber buildings
- Enjoy the record for tallest timber building while you have it!
- How tall can you build?

Figure 18: Japanese delegation visiting Mjøstårnet on Sep 21, 2018

Figure 20: Representatives from Chinesebuilding authorities inside a corner apartment

Figure 19. Harald Liven (Moelven Limtre) and Øystein Elgsaas (Voll arkitekter) explain Mjøstårnet to reporter from Le Monde, France.

7. Acknowledgments

The construction of Mjøstårnet was completed without anyone getting injured or having a work-related sick leave. This can never be taken for granted, and the workers and planners deserve a well-earned credit for keeping a high HSE-focus throughout the project.

Thanks also to everyone that have followed the construction through media and Facebook.
www.facebook.com/mjostarnet www.moelven.com/mjostarnet

The author would like to thank colleagues and all collaborating parties for their great efforts at Mjøstårnet.

Figure 21: Image taken before the installation of the top beam on Sep 4, 2018

8. References

[1] European Standard EN 1995-1-1:2004/A1:2008 Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings. *Bruxelles, Belgium, November 2004/2008.*

[2] European Standard EN 1990:2002 Eurocode - Basis of structural design. European Committee for Standardization, *Bruxelles, Belgium, April 2002.*

[3] Eurocode 1 NS-EN 1991-1-4: 2005+NA:2009 Windloads

[4] ISO 10137, Bases for design of Structures - Serviceability of Buildings and Walkways against Vibrations. ISO, *2007*

[5] Rob Foster. Rethinking CTBUH height criteria in the context of tall timber. *CTBUH 2017 International Conference, Sydney, October 2017*

[6] Rune Abrahamsen. Mjøstårnet – Construction of an 81 m tall timber building. *Internationales Holzbau-Forum IHF 2017, Garmisch-Partenkirchen, December 2017*

[7] Council on tall buildings and urban habitat. CTBUH Height Criteria. Published on the following webpage: *http://www.ctbuh.org/TallBuildings/HeightStatistics/Criteria/tabid/446/language/en-US/Default.aspx*