# First 14-storey wood building in the world at Bergen in Norway

## Premier bâtiment en bois à 14 niveaux au monde à Bergen en Norvège

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## 1. Introduction

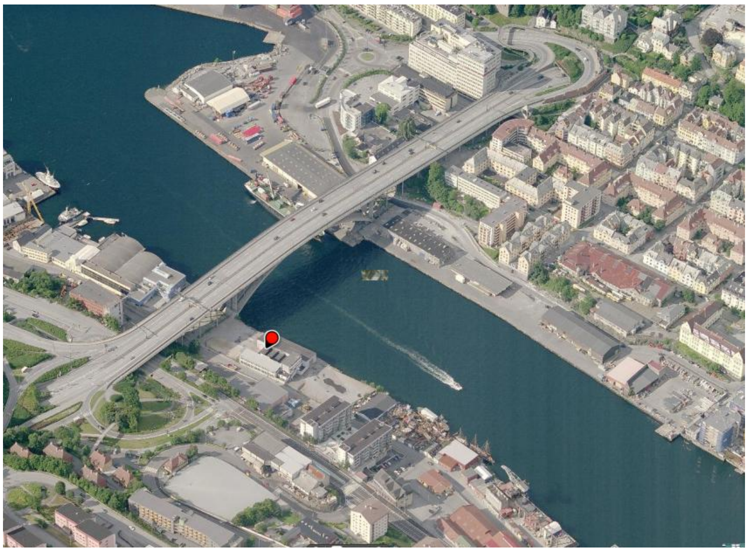
### 1.1. The building

"Treet" is a 14-storey timber apartment building that is currently under construction in Norway. At present, it will become the tallest building in the world of its kind. In the autumn of 2015 a total of 62 apartments will find their new owners in the building shown in Figure 1. "Treet" is Norwegian for "The tree"


"Treet". 3D-view from the south

### 1.2. Location

The building site is in an urban area in central Bergen. Bergen is Norway's second largest city, and lies on the country's west coast.



The building is next to a fairly large road bridge that crosses the fiord "Puddefiorden"

### 1.3. Project group

The building owner is BOB, Bergen og Omegn boligbyggelag, a Norwegian housing association. Moelven Limtre and their subcontractor Merk supply glulam and CLT. Prefabricated building modules are manufactured and supplied by the Estonian company Kodumaja. The architect for the project is Artec. SWECO Norway is responsible for complete technical design and design management.

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

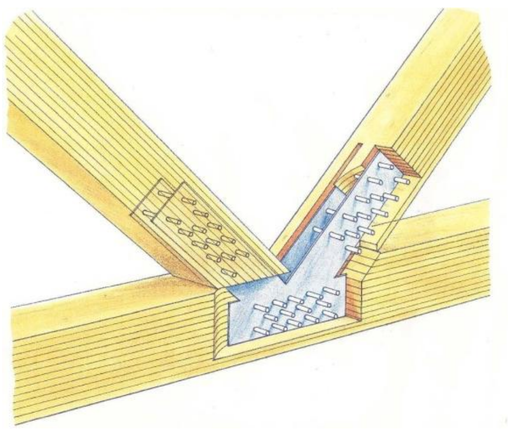
## 2. Structural System

The glulam trusses along the façades give the building its necessary stiffness. The CLT walls are independent of the main load bearing system, and do not contribute to the building's horizontal stability. Standardized and prefabricated building modules comprise the main volume of the building. The modules are stacked at a maximum of four storeys, and are found on levels 1-4, 5, 6-9, 10 and 11-14.

Levels 1-4 are resting on the deck of a concrete garage. Level 5 is a strengthened glulam storey connected to the façade trusses, denoted "power storey", which has its own special building modules and carries a concrete slab on the top that acts as a base for the next four levels (6-9) of modules. Then the system repeats itself with an additional "power storey" (level 10) and modules on top (levels 11-14). The roof is a concrete slab. The concrete slabs are incorporated to connect the trusses, but their main function is to increase the building's mass and hence improve the dynamic behaviour.

Typical column cross-sectional dimensions are: 405x650 and 495x495 mm, and typical diagonal cross-section is 405x405 mm. The base of the building is a rectangle with length of baselines equal to 23 x 21 m. The height of the building is 49 m according to the definition given by CTBUH (Council on Tall Buildings and Urban Habitat). http://www.ctbuh.org/

The maximum vertical distance between the lowest and highest points of the timber components is 52.8 m.



All glulam elements are connected by use of slotted-in steel plates and dowels, see figure to the left. This is a high capacity connection, which is commonly used in bridges and large buildings. The structural timber is with few exceptions covered behind either glass or metal sheeting. This protects the timber from rain and sun, increases durability and reduces maintenance. Climate class 1 is used for most timber members.

# 3. Materials

All main load bearing structures in “Treet” are wooden: Glulam is used for trusses. CLT is used for elevator shafts and staircases. The building modules are made of timber framework. 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. S355 steel is used in connections together with acid-proof steel dowels. Spruce is the main species used for the timber parts in this project. Two internal decks as well as the roof deck are made of concrete. Corten steel and glass is used in the façades.

# 4. Fire design

The fire strategy report for this building describes that the main load bearing system must be designed to withstand 90 minutes of fire. Secondary load bearings are designed for 60 minutes of fire exposure. The fire resistance can be obtained by calculating the remaining cross section after charring according to Eurocode. The prefabricated modules are also designed for 90 minutes fire resistance.

In addition, several other means of fire protection measures are incorporated, such as sprinkling and elevated pressure in escape stair shafts. Gaps between beams and columns will be sealed with a fire proof joint filler. All exposed timber surfaces in escape routes are coated with fire resistant paint.

# 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.

Bergen is in one of Norway’s earthquake zones, but the ground acceleration 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. Statical analyses

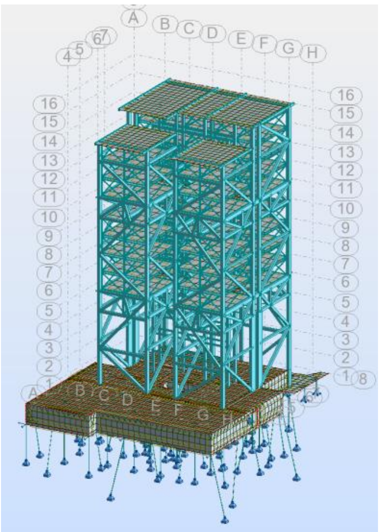
Robot Structural Analysis Professional 2013 was used for the structural analyses of the building. Excel spreadsheets were used to do the code checks according to [1].

Most structural dimensions are decided by the ULS check. A few elements are governed by fire design. Since the building is relatively light, much attention is paid to the dynamic analyses. Robot was used for this.

An independent third party reviewer verified the structural design and the fire design. The structural system of “Treet” is also verified in a master thesis at NTNU [3].

# 7. Dynamic design

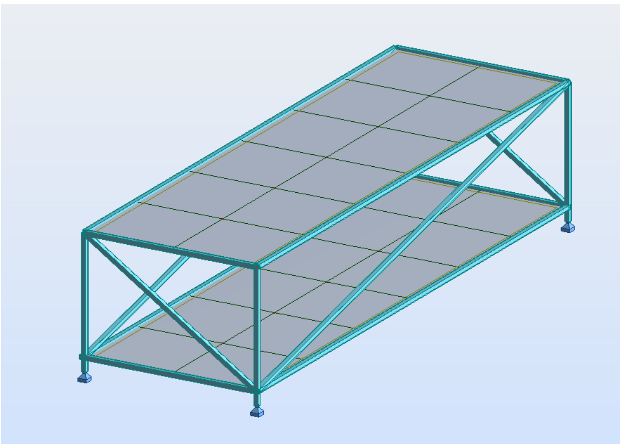
"Treet" is a relatively high building with low structural weight. Its natural frequencies lie in the domain where wind can cause annoying motions or nausea. The stiffness and mass properties for glulam and concrete are well known, but poorly described for complex, complete building modules. To get better knowledge of dynamic behaviour of the prefabricated building modules, testing was needed. Based on the structural design and the module testing, a FEM analysis model was generated in order to calculate the building's natural frequencies and modal mass. These parameters were used to determine the wind-induced accelerations of "Treet".



[4] gives guidelines on how to calculate the peak accelerations. [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 2013. The global model is shown to the left.

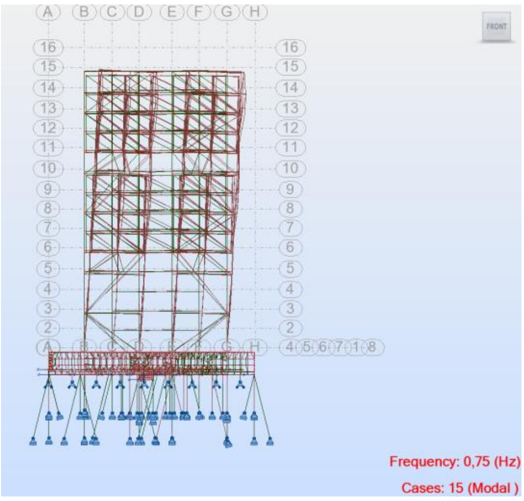
# 8. Module testing

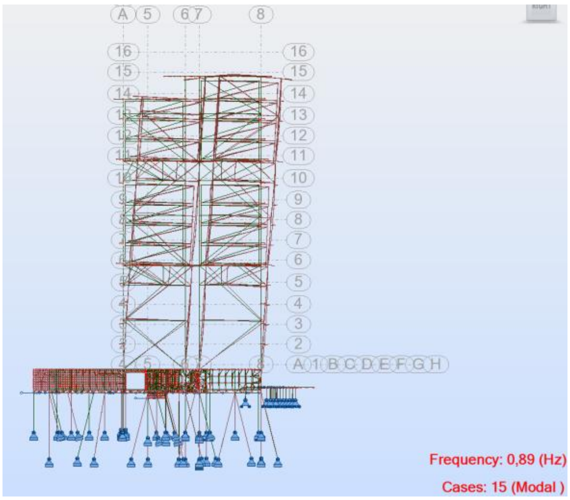
Due to the lack of information regarding the dynamic behaviour of building modules, Sweco contacted the Norwegian University of Science and Technology, NTNU, for non-destructive testing of modules delivered by Kodumaja. The tested modules were very similar to the modules that are used in "Treet". Both single and stacked modules were tested. The test is described in the report [7]. Based on the test results a simplified FEM-model of a module was made. The module's walls were represented using vertical beam elements with braces. For the module's floor and ceiling, we used shell elements. The mass distribution of the module was added to the shell elements.



# 9. Results

The module testing showed that the stack of four modules had much higher natural frequencies than the global response of the building. Therefore, it was decided to avoid further connections than between the modules and the slab. A concrete slab was added to the top level of the building in order to interconnect the different truss-works, but mainly to add more weight to the structure. This gave the building higher modal masses and decreased the accelerations. The figure below shows the two first natural frequencies of the building.



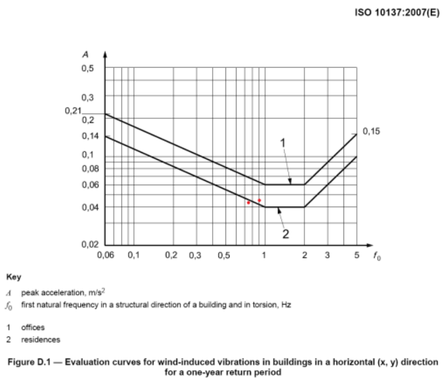



Figure D.1 — Evaluation curves for wind-induced vibrations in buildings in a horizontal (x, y) direction for a one-year return period

From the results of the module testing the equivalent viscous damping ratio was estimated to approximately 3%. The modules are stiff in the relation to the trusses, so their damping is of minor significance to the overall behaviour. A damping of 1.9 % was chosen based on [4].

The modal masses were found using the global FEM-model. The peak accelerations for mode 1 and 2 were calculated based on annex C in [4]. The peak accelerations at the top floor are plotted with red dots into Figure D.1.

## 10. Assembly

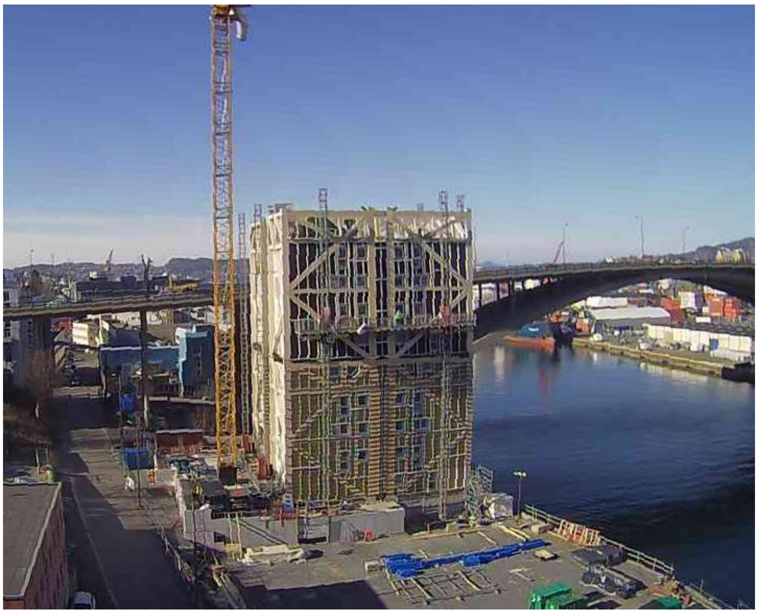
The assembly of “Treet” is mostly about installing prefabricated elements on site. Optimizing the logistics and installation is important to get a smooth assembly. Kodumaja and Moelven Limtre use a tower crane as well as a climbing scaffolding system during the building erection. Temporary roofs are used to protect apartments, joints and timber from moisture during the building process. A detailed step-by-step model is established to ensure that the building can be built correctly.

# 11. Conclusive remarks

The calculated maximum acceleration for "Treet" for mode 2 is slightly higher than the recommended values, but this is considered to be acceptable. In reference [6] the acceleration limit for nausea is given to be above 0,1 g. Based on this some of the residents in the top floors might in rare cases feel vibrations, but it is very unlikely that they will become uncomfortable. The chosen structural solution for "Treet" using glulam truss works and stacked prefabricated building modules gives a robust design and most probably insignificant effects from vibrations caused by wind exposure.

The building is under construction and will be finished autumn 2015. It will truly become an iconic landmark in Bergen city. You can enjoy live pictures and follow the construction process via this website:

http://www.sweco.no/no/Norway/Nyheter/2014/Webcam_Treet/



Picture from website taken March 19, 2015. 10 out of 14 storeys are installed.

# 12. 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] I. Utne: Numerical models for dynamic properties of a 14 storey timber building. Trondheim, December 2012

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

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

[6] D. Boggs, Acceleration index for human comfort in tall buildings-peak or rms. Submitted to CTBUH Monograph Chpt. 13, Motion Perception Tolerance and Mitigation 1997, July 1995

[7] Anders Jørstad and Kjell Arne Malo, Measurements of structural damping in prefabricated residential modules fabricated by Kodumaja, Estonia, R-01-12, Oct. 2012

[8] Rune B. Abrahamsen and Kjell Arne Malo, Structural design and assembly of "Treet" – A 14-storey timber residential building in Norway, WCTE Québec 2014

[9] M. Bjertnæs and K. Malo.: Wind-induced motions of “Treet” - A 14-storey timber residential building in Norway. WCTE Québec, 2014.