

# STRUCTURAL DESIGN AND ASSEMBLY OF “TREET” - A 14-STOREY TIMBER RESIDENTIAL BUILDING IN NORWAY

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**ABSTRACT:** “Treet” is a 14-storey timber apartment building in Norway currently under construction. Ground works started in April 2014, and the residents can move in autumn of 2015. The building will be one of the tallest timber buildings in the world. The building consists of load-carrying glulam trusses and two intermediate strengthened levels. Prefabricated building modules are stacked on top of the concrete garage and on top of the strengthened levels. There is CLT in the elevator shaft, internal walls and balcony. But, CLT is not a part of the main load bearing system. Glass and metal sheeting protect the structural timber from rain and sun.

**KEYWORDS:** Multi-storey buildings, assembly, glulam, CLT, building modules, high-rise

## 1 INTRODUCTION



**Figure 1:** “Treet”. 3D-view from the south

The fourteen storey residential building “Treet” is located in the city of Bergen, Norway. “Treet” means “The tree” in Norwegian. The design process started in 2011 and was finalized in 2013. The first ground works took place in April 2014, and the building will be finished in autumn 2015. At present, the building seems to become the tallest in the world of its kind. 62 apartments will find their new owners in the building visualized in Figure 1.

The building has a net area of 5830 m<sup>2</sup>. The basement, which holds parking facilities, technical rooms and storage rooms, has a net area of 920 m<sup>2</sup>. There is a gym on the 9<sup>th</sup> floor and a roof terrace at disposal for the residents.

The building owner is BOB, Bergen og Omegn Boligbyggelag, a Norwegian housing association and a major residential player in Bergen. Moelven Limtre is Norway’s largest glulam manufacturer, and delivers and installs the glulam and CLT. A subcontractor provides the CLT to Moelven Limtre. The Estonian company Kodumaja delivers the prefabricated building modules that comprise the apartments. The architect for the project is the Bergen-based company Artec. SWECO Norway is responsible for the technical design and design management. All participants have been active in the development of the project.

## 2 LOCATION

The building site is in an urban and central area of Bergen. Bergen is the second largest city in Norway, and is located on the west coast of the country. See map on Figure 2. The building is close to a large road bridge that crosses the fiord “Puddefiorden”, see picture on Figure 3. The

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uppermost seven storeys have elevation above the highest point of the bridge.



**Figure 2:** Bergen is marked on the map



**Figure 3:** The building site (red dot) close to Puddefjorden

### 3 STRUCTURAL SYSTEM

The idea of the structural design concept may be explained by an analogy to a cabinet rack filled with drawers. Here, the cabinet rack is formed by large glulam trusses, and the drawers consist of prefabricated residential modules. The glulam truss work has close resemblance to the design concepts used in modern timber bridge structures.

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 horizontal stability of the building. Prefabricated building modules comprise the main volume of the building. The modules are stacked up to four storeys, and are found on levels 1-4, 5, 6-9, 10 and 11-14. Confer Figure 4 and Figure 8. The ground floor is denoted level 1.

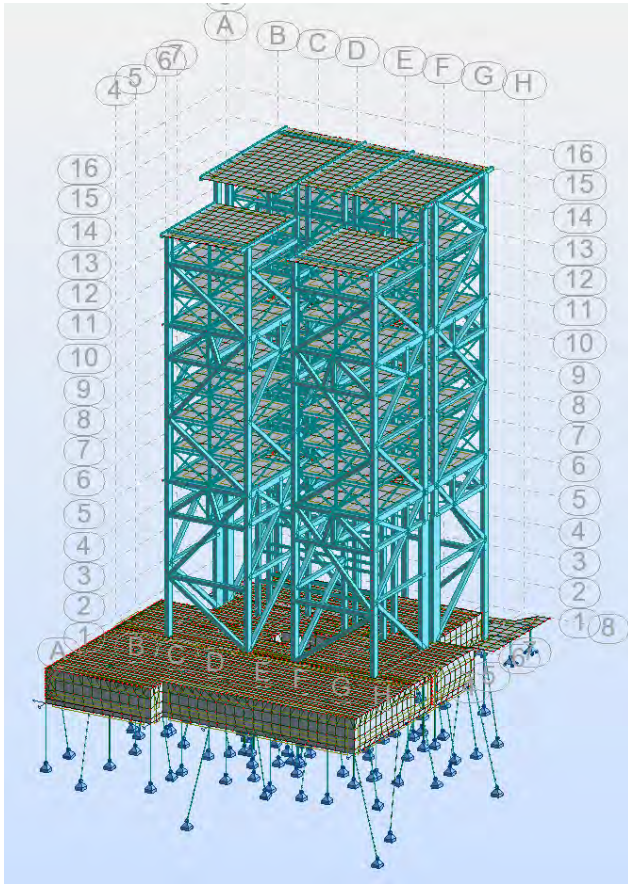
Levels 1-4 rest on the deck of a concrete garage and are not connected to the surrounding load bearing structure. Level 5 is a strengthened glulam storey connected to the façade trusses, denoted “power storey”. The special modules on level 5 are connected to the glulam structure and do not rest on the building modules below. The “power storey” carries a prefabricated concrete slab on top, which acts as a base for the next four levels of stacked modules (6-9), just like levels 1-4. The modules on levels 6 to 9 do not connect to the main load bearing structure at any other point than at their foundation, which is the concrete slab.

Then the system repeats itself with an additional “power storey” (level 10) and modules on top of that again (levels 11-14). The roof is also a prefabricated and element-based concrete slab. The concrete slabs are incorporated to connect the trusses, but an additional main function is to increase the mass of the building and hence to improve the dynamic behaviour, more on this in [1].

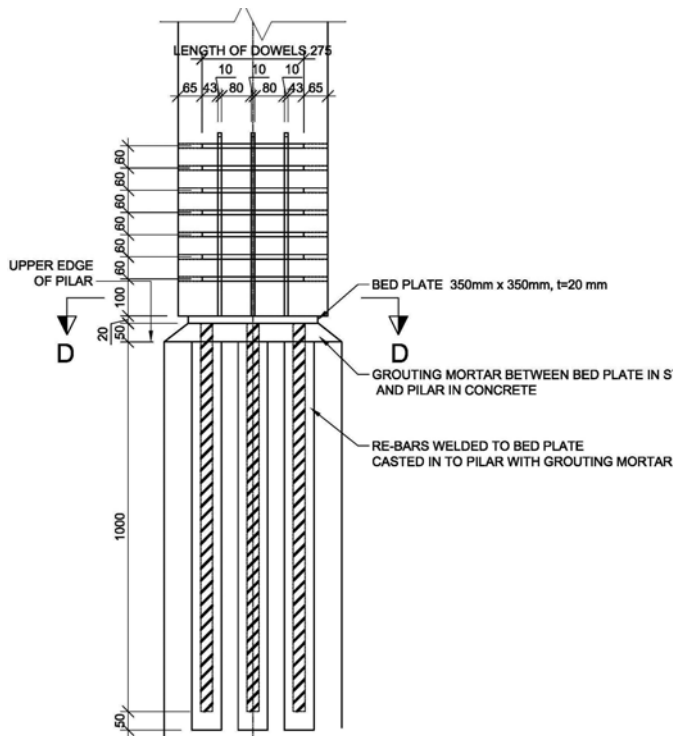


**Figure 4:** 3D view of structural model





**Figure 5:** Global FEM-model of "Treet"

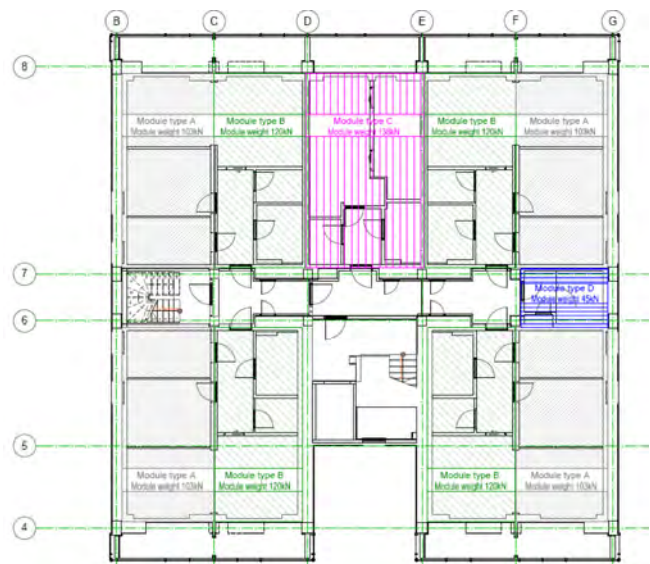


**Figure 6:** Anchoring glulam to concrete

The bedrock is about 5 meter below the garage floor. More than a hundred vertical and tilted steel core piles are driven into the bedrock acting as a foundation for the building. Some of the piles must also handle tension forces.

When the building is exposed to wind loading, some of the diagonals and columns can get tensile forces. These forces are transferred to the ground by anchoring the joints to the concrete foundation as shown in Figure 6.

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. Figure 7 shows a typical plan of the building. Module types A and B are 4 m x 8,7 m and module type C is 5,3 m x 8,7 m.



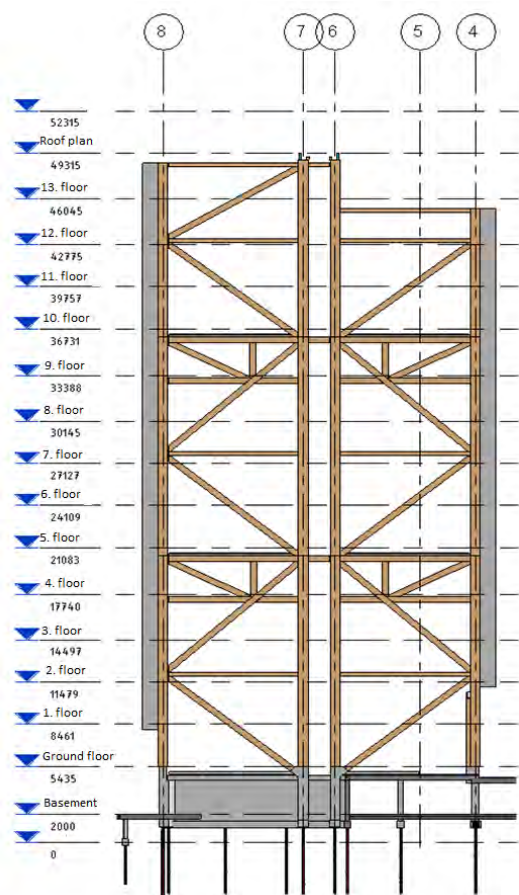
**Figure 7:** Typical plan of building

There is a theoretical clearance of 34 mm between building modules and glulam trusses. This is enough to ensure the necessary building tolerances, and to avoid that possible horizontal movement of modules and trusses do not interfere.

The height of the building is about 45 m, see Figure 8. The maximum vertical distance between the lowest and highest points of the timber components is about 49 m.

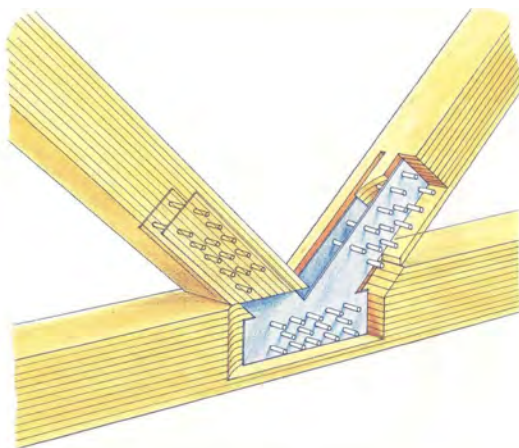
The external cladding and glazing of the building are attached to the load bearing trusses and to the balconies. The wind load will not affect the residential modules directly, except during the erection phase.

The structure is given a robust design. In case of a failing member the building will not collapse, e.g. the load bearing structure for the corridor can also handle the additional load from an impact due to an overlying corridor falling down. The removal of a truss member will lead to other members taking more force, and this is verified in the accidental limit state.



**Figure 8:** Vertical section of load bearing structure

All glulam elements are connected by use of slotted-in steel plates and dowels. This is a high capacity connection commonly used in bridges and large buildings. See also illustration on Figure 9. Typically, 8 mm steel plates and 12 mm dowels are used in Norway. Both the engineers of the project as well as the glulam manufacturer have confidence in and experience with this type of connections, so other connection designs were not discussed.



**Figure 9:** Slotted-in steel plates with dowels

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 (service class 1) is used for members that are indoors, and climate class 2 is used for members that are on the cold side of the external walls.

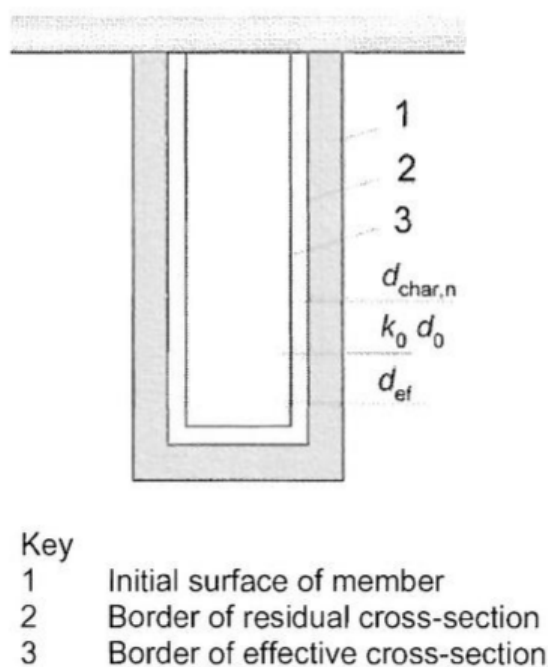
## 4 STRUCTURAL FIRE DESIGN

The fire strategy report for this building states that the main load bearing system must resist 90 minutes of fire without collapse. Secondary load bearing systems, such as corridors and balconies, must resist 60 minutes of fire exposure. In addition, several other means of fire protection measures are incorporated, such as fire painting of wood in escape routes, sprinkling and elevated pressure in escape stair shafts.

The structural fire design is performed according to the Eurocode 5 [5]. The so-called reduced cross-section method has been used, which determines the effective residual cross-section after charring, see Figure 10.

A notional charring rate of 0,7 mm/min leads to a charring depth of 63 mm after 90 minutes. In addition, one must add 7 mm to get the effective residual cross-section. Consequently all steel connectors, plates and dowels, are placed at a minimum distance of 70 mm from the outer surface, see Figure 6. All gaps between connected timber members are blocked with a fireproof joint filler.

The Norwegian company Skansen Consult AS was independent third party reviewer for the fire design. The fire design was approved February 2013.



**Figure 10:** Definition of residual cross-section and effective cross-section



The effect of possible slip at the joints is not included in the design. Every connection consists of a considerable amount of dowels, so we believe that the slip will be insignificant. This is based on experience from similar connections in timber bridges built over the last decades. However, the sensitivity to joint slips was investigated in a parametric study [2] and it was concluded that in this case it will have minor impact on the force distribution as well as on the fundamental frequencies and level of displacements. Furthermore, a typical column of 45 m height will be delivered in three pieces, while all diagonals

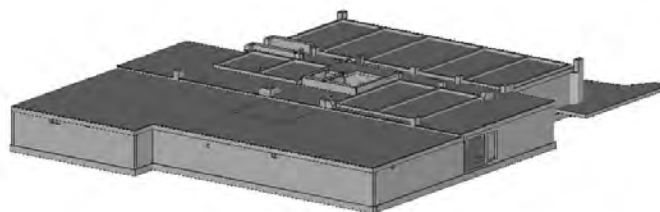
will be produced in full length. Consequently, there will be few connections where slip can occur.

In 2012 the structural concept of “Treet” was modelled and studied in a master thesis at NTNU [2], using an independent computer system. Here, also the possibility for instrumentation of the building followed by a system identification procedure were evaluated. Hopefully this can be performed within the first year after the building has been finished, leading to a needed documentation of the dynamic properties of this class of buildings.

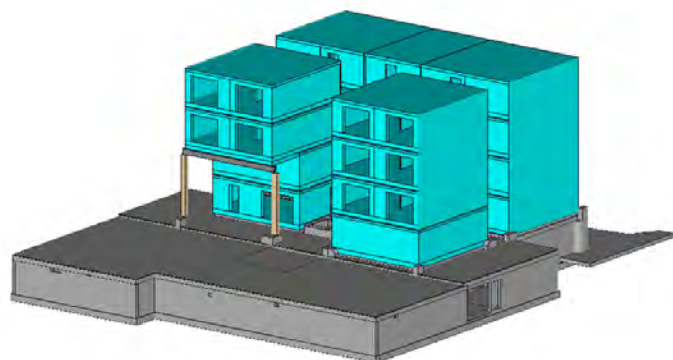
The Norwegian engineering company Norconsult was independent third party reviewer for the structural design. The structural design was approved autumn 2013.

## 8 ASSEMBLY

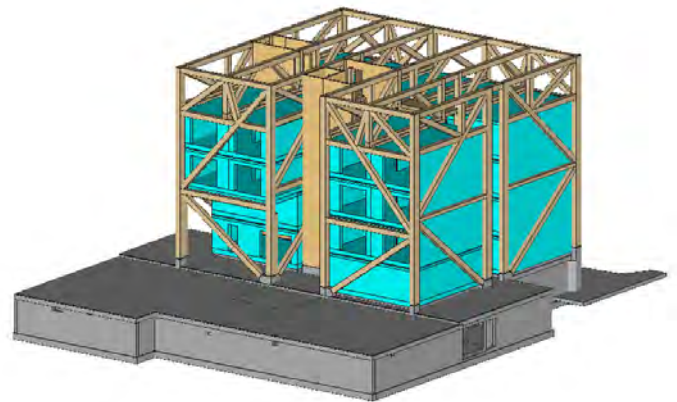
The assembly of “Treet” is mostly about installation of prefabricated elements on site. Optimizing the logistics and installation procedures are important to get a smooth building process. Kodumaja and Moelven Limtre use a tower crane as well as a climbing scaffolding system during the building erection.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



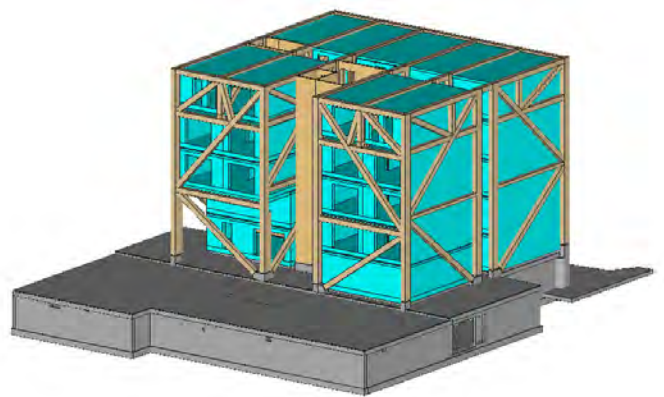
**Figure 12:** Step 1



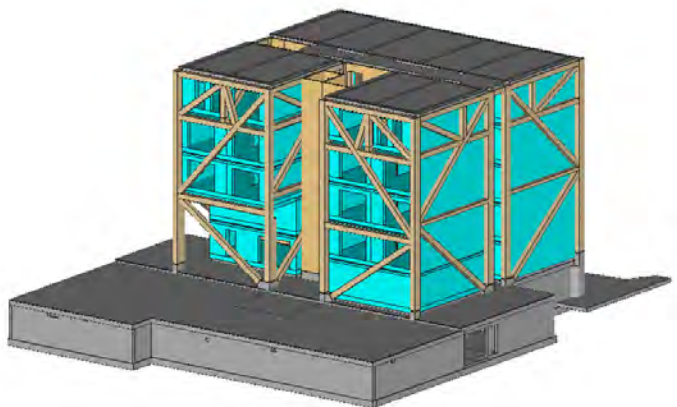
**Figure 13:** Step 2



**Figure 14:** Step 3

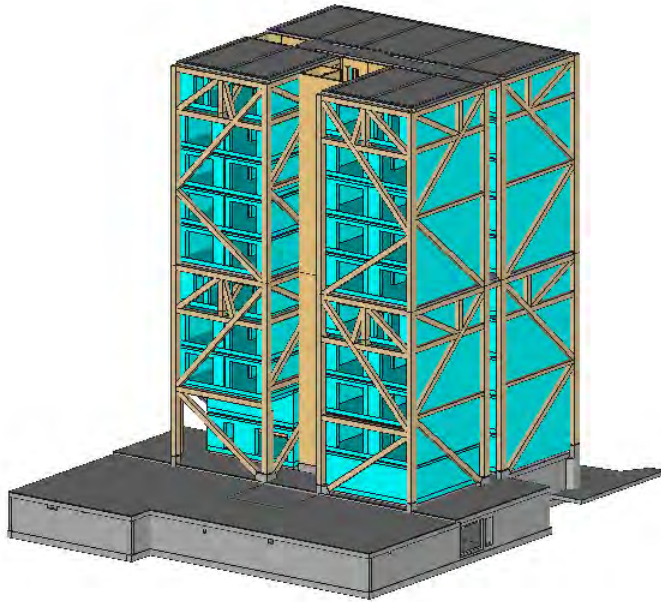


**Figure 15:** Step 4

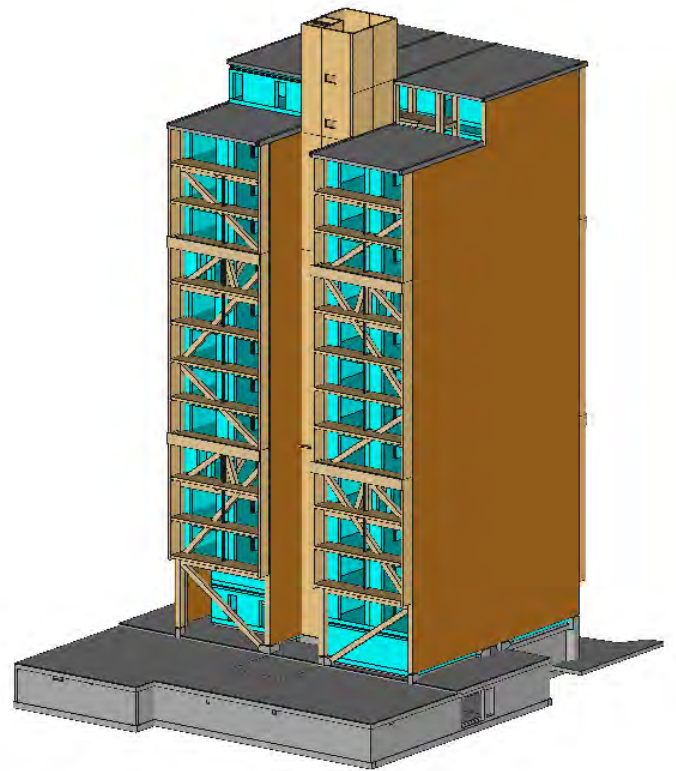


**Figure 16:** Step 5

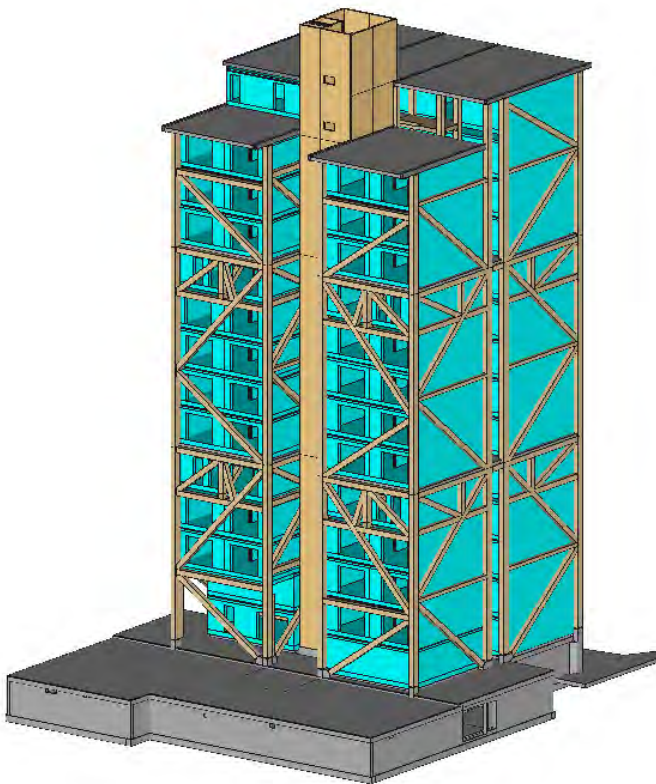




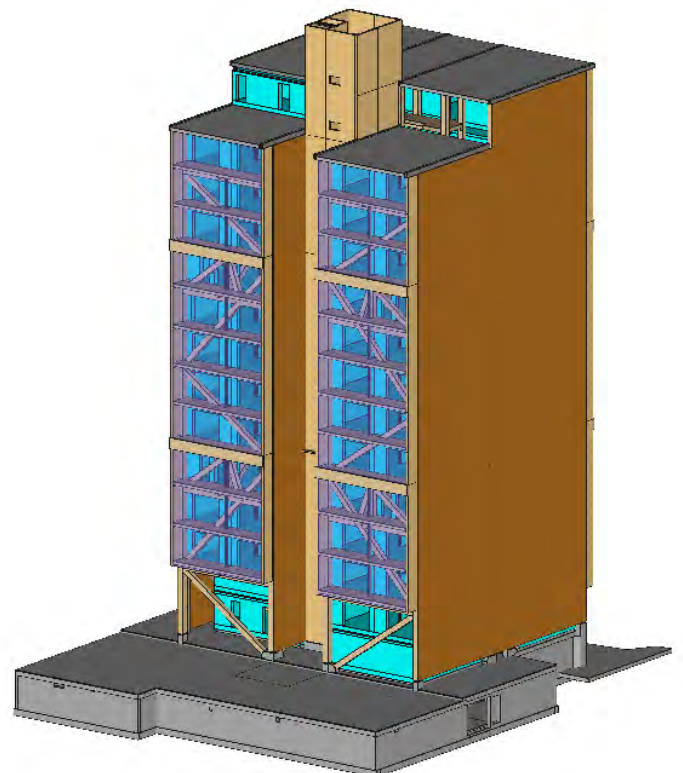
**Figure 17:** Step 6. Similar to step 2-5



**Figure 19:** Step 8. Cladding of gable walls



**Figure 18:** Step 7



**Figure 20:** Step 9. Glazing



**Figure 21:** Step 10. Finished building

## 9 CONCLUSIVE REMARKS

The chosen structural solution for "Treet" using glulam truss works and stacked prefabricated building modules gives a robust design.

The detailed design of the building is completed and the construction works have started. This building will truly become an iconic landmark in Bergen city.

## ACKNOWLEDGEMENT

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**ARTEC**

**MOELVEN®**

**KODUMAJA**

**NTNU**

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