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HUT – INDOOR CLIMBING CENTRE, SKIEN, NORWAY

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ABSTRACT: HUT, Høyt Under Taket, is an indoor climbing centre in Skien, Norway designed by Degree of Freedom in collaboration with the architect Snøhetta. The building combines a single-storey climbing hall, with a maximum clear height of 14.6m, and a three-storey annex. The architectural concept is based on a variable series of 12.5m wide timber portals forming the signature element of this building, the climbing hall. All structural members above ground level are timber, principally cross-laminated timber (CLT). CLT is also used both for the climbing hall façades and for the load bearing walls of the three-storey annex building. Glued-laminated timbers are used as framing elements in the glazed façades at either end of the climbing hall, as part of the CLT rib slabs, and as long span beams supporting the annex roof. Structural analysis has been performed using a finite element model that models the CLT panels as shells and uses link elements to model the connection stiffnesses. Timber-to timber connections are principally realized using timber screws. All timber elements have been fabricated using a LOD400 BIM model fully coordinated with all other disciplines during the design process.

KEYWORDS: Timber, cross-laminated, glued-laminated, CLT rib slab, screws, connections, BIM, portal.

1 INTRODUCTION

HUT Skien is a signature building for the indoor activity centre Høyt Under Taket (High under the Roof), located in Skien, Norway. The load bearing structure is 100% timber above ground level. The project was developed in close collaboration with Snøhetta, Betonmast and Degree of Freedom.

Figure 1: HUT Skien – Finished building

From the start there was a high level of ambition regarding sustainability and innovation in timber construction.

This paper is a case study describing how the architectural concept has been translated into a structural frame that reflects the original architectural vision.

The timber structure was erected early in 2022 and the building was opened to the public in late 2022. The finished building can be seen in Figure 1.

2 ARCHITECTURAL CONCEPT

The building is designed to be a landmark, of high architectural quality that provides a unique experience whilst being functional, climate smart and cost-effective.

The building, named 'Portal' at its inception, was conceived by the architects as a low threshold entrance portal to provide access to indoor climbing for all skill levels. The result is a 1,500 m^2 climbing centre with a focus on activity and inclusion for the local community.

The aim was to have a recognizable profile, with internal activity visible from the outside through large glass façades. These large glass surfaces bring natural light into the building and provide extra airiness and connection to nature complemented by the extensive use of exposed timber surfaces throughout.

The architectural identity was based on the concept of a cave, similar to the image in Figure 2, a portal to a world which one would want to explore further. In a cave the distinction between wall and ceiling is blurred, replicated here in the timber structural form. Timber was chosen early in the concept design phase as the main material for both structural and architectural purposes.

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Figure 2: *Architectural inspiration*

A key feature of the building are the frames, or portals, with a changing geometry as you move through the space. The starting architectural geometry is shown in Figure 3. At concept design phase the construction of these portals as cross-laminated, CLT, elements was proposed and evaluated to ensure that an adequate lateral stiffness could be achieved.

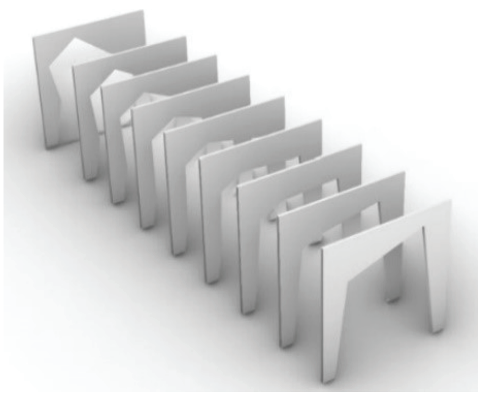

Figure 3: *Portal concept geometry*

An architectural aim was to leave the structural timber exposed as much as possible as seen in Figure 4.

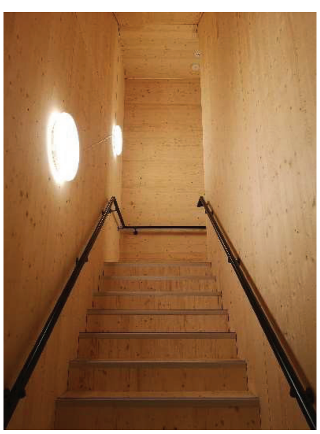

Figure 4: *Exposed timber structure in staircase*

Timber was also chosen as the main cladding material. There is no vapor barrier/plastic used in the external walls, which allows the timber's hygroscopic properties to naturally help regulate humidity, improving the indoor climate. Externally the structure is clad in a dark timber façade as both a protective outer layer and visually to highlight the building's bright interior.

Figure 5: *Building exterior with dark timber cladding*

3 STRUCTURAL SYSTEM

3.1 DESCRIPTION

The building is divided into two parts, the climbing hall and the annex each with a different structural system.
The climbing hall has a series of CLT portals as vertical load bearing elements Portals are spaced at 6m centres generally, and with a single 9m end span. Portal height steps from 11m up to 14.5m. The portals are clad with CLT panels to provide out of plane stability with the portals having an in-plane stiffness to act as moment frames.

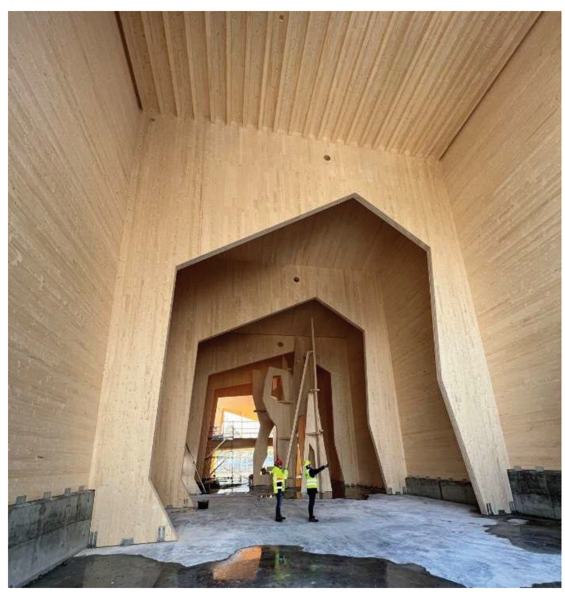

Figure 6: *Climbing Hall structure*

The portals support the roof which is a combination of CLT slabs and CLT rib slabs. The rib slab is used for the single span where portals are separated 9m. Figure 6 shows an overview of the climbing frame structure once erected on site.

The climbing hall also includes a mezzanine floor at one end which spans 12.5m across the full width of the hall using CLT rib slabs.

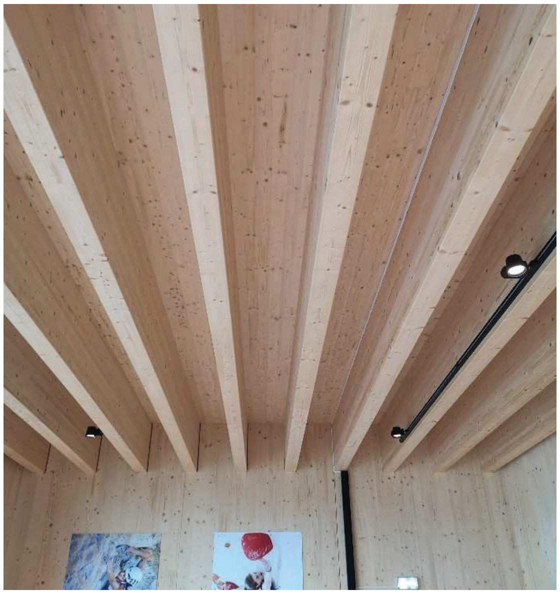

Figure 7: *Soffit view of mezzanine rib slab*

The glazed façades at either end of the climbing hall have vertical and horizontal glulam members for additional restraint as seen in Figure 8.

Figure 8: *View of glazed façade from mezzanine*

The annex building has a combination of CLT walls and glulam columns as vertical load bearing elements. Floor slabs are standard CLT slabs with glulam beams used at roof level where larger open spaces were required. A view of the finished annex structure can be seen in Figure 9.

Figure 9: *View of annex from mezzanine*

The timber superstructure is anchored to the concrete substructure with a combination of both proprietary and bespoke steel brackets.

3.2 MATERIALS

Different thicknesses and build-up of CLT slabs are used in the building ranging from three-layer 100mm CLT panels as part of the roof CLT rib slab to seven-layer 240mm thick CLT panels for the tallest portal frames.
Glulam elements are typically GL24h but with GL28h for the ribs of the CLT rib slab.
The building contains 62m^3 of glulam elements and 627m^3 of CLT panels in total, of which 130m^3 are in the portal frames.

3.3 DESIGN

The building is designed for R30 fire resistance, and all elements have been designed using the reduced cross section method from NS-EN 1995-1-2 [1]. In general all timber elements are exposed with no additional protection provided.
The slip modulus, k_{serv}, for all connections has been considered in the design based on NS-EN 1995-1-1 [2]. The connection stiffness is of particular importance when calculating the overall horizontal sway of the timber portal frames. The slip modulus of both CLT-to-CLT panel connections and CLT to concrete connections was allowed for in the detailed design.
For the long span mezzanine floor the governing criteria for the design of the CLT slab were vibration limits.

3.4 FINITE ELEMENT MODEL

Structural analysis was carried out using a full 3D finite element model in SAP2000, shown in Figure 10. This model allowed for both ULS and SLS design of the CLT panels, and for the design of the connections.

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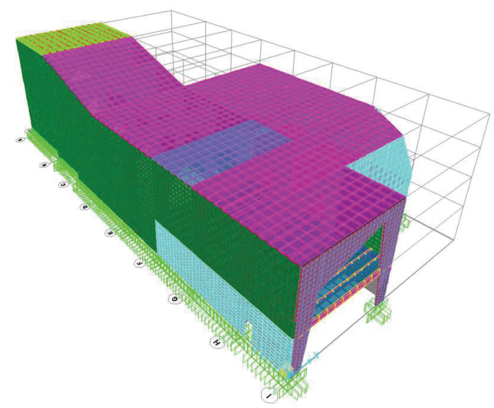

Figure 10: *3D view of FE model*

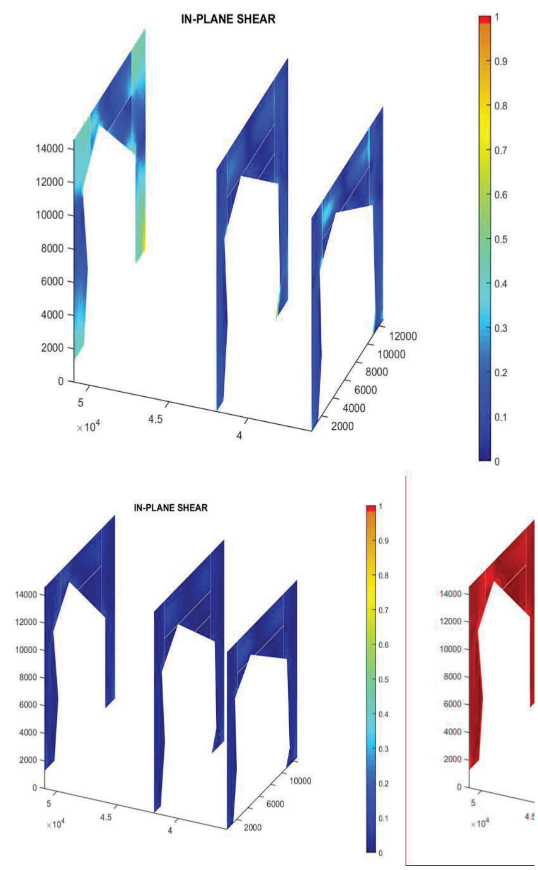

Figure 11: *ULS and Fire design verifications for 240mm CLT portals*

For the orthotropic CLT panels the values for the stiffness matrix were calculated using the software CLT designer created by the Institute for Timber Engineering and Wood Technology of Graz University of Technology (©holz.bau forschungs gmbh). All CLT models were modelled as shell elements with link elements modelling the joints. The stiffness for each degree of freedom was defined based on the calculated slip modulus for the connection type.

Verifications for the CLT panels were carried out for the Ultimate Limit State, the Serviceability Limit State and the fire design situation. An example is shown in Figure 11 for the 240mm thick portal frames demonstrating the check for in-plane shear. For the same 240mm thick CLT portal frames the horizontal displacement for the envelope of characteristic SLS load combinations is shown in Figure 12.

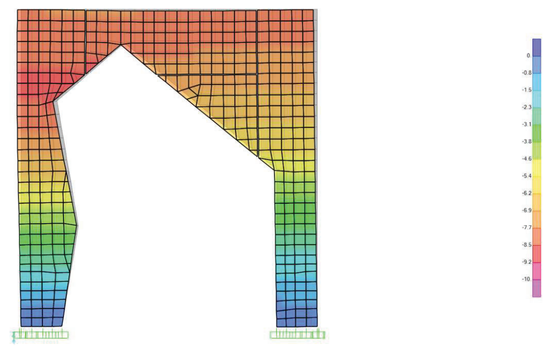

Figure 12: *SLS verifications for 240mm CLT portal*

3.5 CONNECTIONS

The two main types of connections to be resolved for this project were the timber-to-concrete connections and the connections between the different parts of the CLT portal frames.

Timber-to-concrete connections, dependent on location, were required to resist in-plane horizontal loads, out-of-plane horizontal loads, and in some locations uplift. Due to the extent of exposed timber structure in this building alternative solutions had to be found to give a concealed connection. A combination of proprietary angle brackets, see Figure 13, and bespoke, dowelled, steel plate connections were used.

Figure 13: *Proprietary angle bracket to base of portal frame*

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Figure 14: View of timber concrete interface details

Where a concealed connection was required architecturally a dowelled connection with an central steel plate was used as shown in the detail in Figure 15. The central steel plate is 8mm thick and the connection has 39no. 12nn diameter steel dowels. For this detail the steel baseplate was cast in-situ with the ground floor slab to a detail by the concrete designer. The central steel plate was subsequently welded in the correct position on site before installing the portal frame.

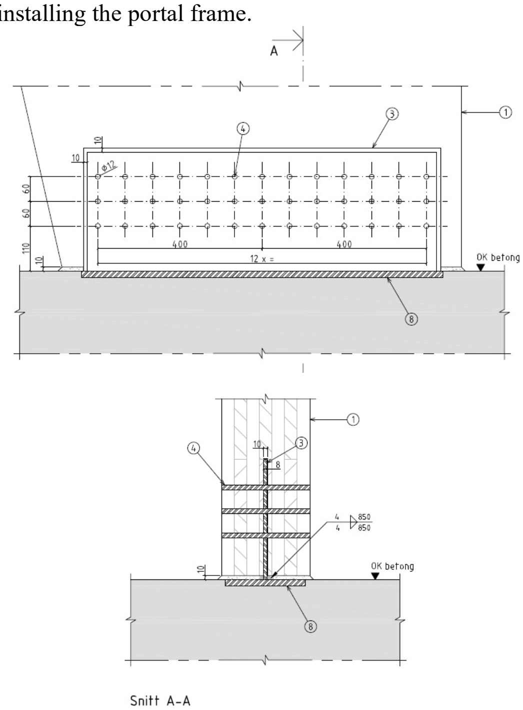

Figure 15: Concealed doweled connection for portal frame

Timber-to-timber connections for the portal frames were realized using fully threaded, cylindrically headed, timber screws installed at 45°, 9mm VGZ screws from Rotho Blaas. The detail is shown in Figure 16. Crossed screw connections, with screws at 45°, give the most robust connection detail for the critical CLT panel to CLT panel connections. The position of these screws can be seen in Figure 17, during construction, prior to the final timber plugs being installed.

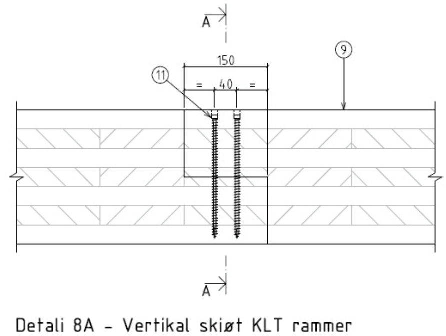

Figure 16: CLT portal frame connection – screws at 45°

Figure 17: Screwed connection between portal frame panels

In the finished building these divisions between CLT panels are barely visible as seen in Figure 18.

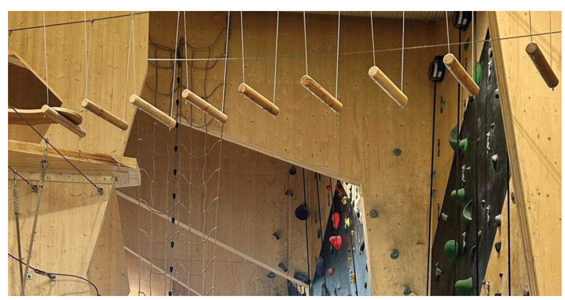

Figure 18: Portal frame joints

4 BIM

From the initial concept phase through to the construction phase information was shared and coordinated between disciplines using BIM. Degree of Freedom produced the LOD400 model in Tekla (Figure 19) as the basis for the timber fabrication model.
Included in the BIM model were all the different steel brackets needed at the timber-to-concrete interface. This use of the BIM model allowed for full coordination with the concrete designer, coordination with the Architects to

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check visibility, in addition to providing the complete information to the timber supplier for fabrication.

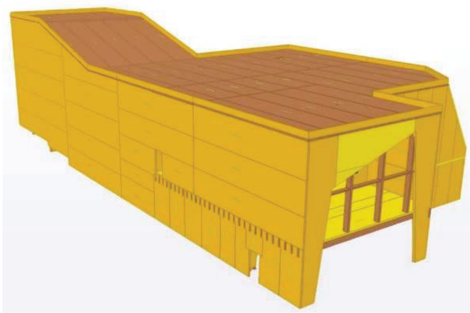

Figure 19: Overview of BIM model

An example of the detail of the LOD400 BIM model is shown below in Figure 20 for the 240mm CLT portal with steel brackets at the portal base.

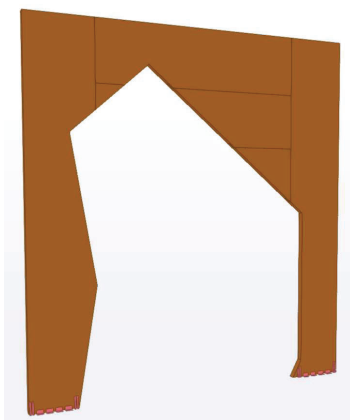

Figure 20: 240mm CLT portal in LOD400 BIM

The erection drawings were then produced in Tekla directly from the BIM model.

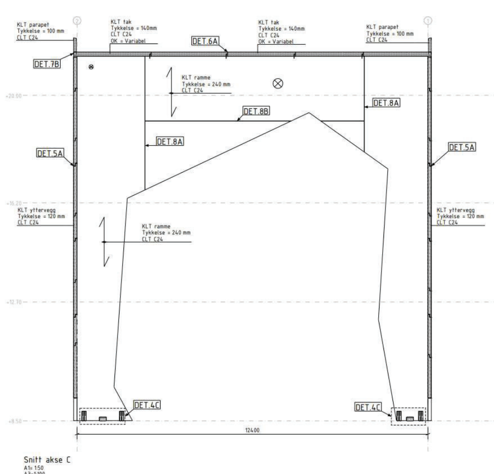

Figure 21: Portal frame erection drawing

5 CONSTRUCTION

A combination of LOD400 production models for off-site fabrication, and the site-handling of lighter timber parts, facilitated a rapid erection process on site, despite the adverse weather conditions of the Norwegian winter. Total time for timber erection was five weeks. The use of timber elements also led to less environmental impact on and around the construction site with a reduced number of deliveries and a faster and cleaner construction method with significantly less noise.

Figure 22: HUT under construction – climbing hall

Figure 23: HUT under construction – annex building

The location of all steel brackets on the erection drawings, produced directly from the BIM model, facilitated their installation on site as shown in Figure 24.

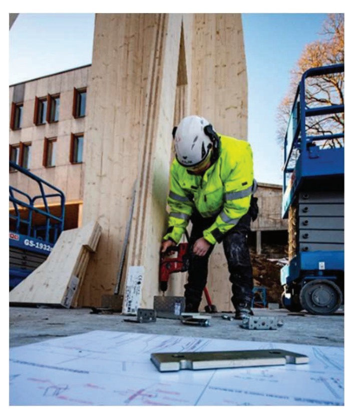

Figure 24: Installation of steel brackets between timber and concrete

6 CONCLUSIONS

This project successfully demonstrates how timber has been used to realise the original architectural vision whilst providing both a cost-effective design and a rapid site erection procedure. The load bearing structure has become multi-functional as it also forms part of the building finishes. The use of timber has given a solid, durable, natural and sustainable solution to this singular building as can be seen below in the finished building both without fittings and its final use as a climbing centre.

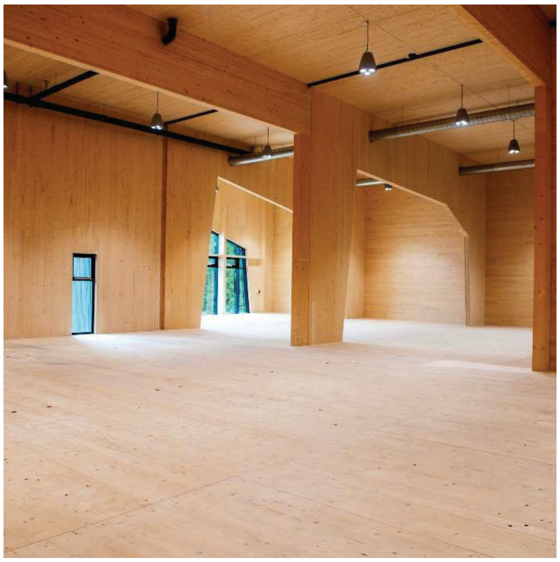

Figure 25: *Finished building before fitting out*

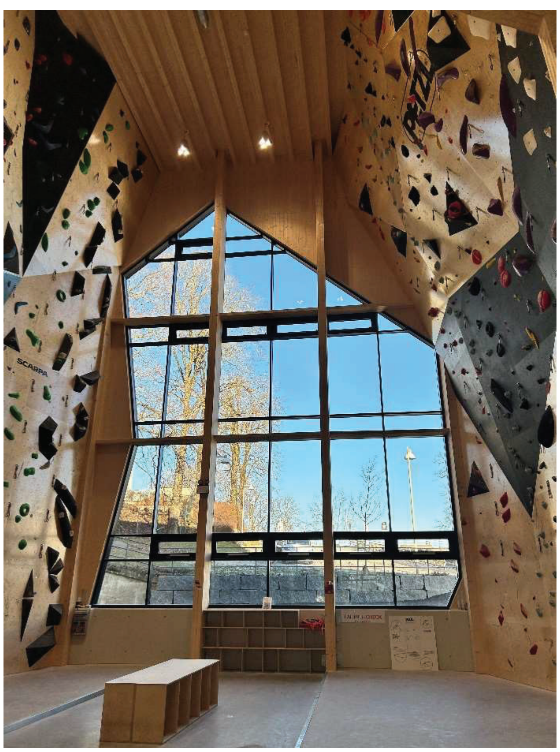

Figure 26: *Finished building as climbing centre*

ACKNOWLEDGEMENT

This project has been realised in collaboration with the client, Høyt Under Taket, the architect, Snøhetta (https://snohetta.com/) and the Contractors, Betonmast (https://www.betonmast.no/).
Additional photographs by Kai-Otta Melau/Høyt & Lavt.

REFERENCES

[1] NS-EN 1995-1-2:2004+NA:2010 Eurocode 5: Design of timber structures - Part 1-2: General - Structural fire design.

[2] NS-EN 1995-1-1:2004+A1:2008+NA:2010 Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings.

https://doi.org/10.52202/069179-0567