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# SPOR X – 10-STOREY TIMBER OFFICE BUILDING, DRAMMEN, NORWAY

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**ABSTRACT:** SporX is a ten-storey office building in Drammen, Norway. Timber, as the main structural material, was chosen at the start of the project being a readily available local material and to support the ambition for maximum sustainability to achieve a BREAM-NOR Outstanding certification. Another advantage was to minimise building loads at the riverside location with poor ground conditions. Based on an optimal architectural layout SporX makes use of timber elements, both glued-laminated and cross-laminated, for all load-bearing structure above ground floor. Two large central CLT cores, combined with two façade shear walls, act as bracing elements for the 600m$^2$ floor plate giving a robust timber structural solution designed for R90 fire resistance. The element removal method is used to resist progressive collapse. Timber connections are made using fully threaded, cylindrically headed, wood screws and proprietary concealed connectors. BIM was used by all disciplines for design coordination and to produce a digital twin controlled throughout the construction process. Timber structural elements were fabricated from a LOD400 BIM model developed by Degree of Freedom. Fabrication with strict tolerances allowed for a rapid construction process. Larger element sizes were chosen as having design advantages both for robustness and for connections design.

**KEYWORDS:** Timber, CLT, cross-laminated, fire, connections, BIM, fabrication, LOD, BREAM_NOR, digital twin

## 1 INTRODUCTION

Degree of Freedom were responsible for the structural design of SporX, an innovative, ten-storey, timber-framed office building, built on behalf of the property developer Vestaksen Eiendom AS.

*Figure 1:* *SporX - Location*

The building, in Drammen, Norway, is adjacent to both the river and the main train station, and was conceived by the architects, Dark, to become the most sustainable office building in the Nordic countries. The use of structural timber as a low-carbon construction material was therefore a fundamental part of the project from the start. This paper describes the advantages of using timber compared to more standard solutions in concrete or steel, for all the main load bearing elements above ground level. Key aspects and challenges related to the design, modelling, fabrication, and construction process are explained. There is a focus on design aspects where special attention was needed including fire design, connection details, horizontal sway, vibrations and progressive collapse.

## 2 DESIGN PRINCIPLES

### 2.1 ARCHITECTURAL CONCEPT

The architectural intent was for a sustainable office building and as the building's location has excellent links to public transport only the provision of bicycle parking was needed. Features such as this, combined with the use of timber as the main structural material were key to achieving the BREEAM-NOR Outstanding certification. Harvested responsibly, and in this case locally, timber is arguably one of the best tools both architects and engineers have for reducing greenhouse gas emissions and storing carbon in buildings. Timber, as a construction

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material also has inherent benefits for the health and well-being of the building users, for the environment and for the construction process. Advantages include reducing CO2 emissions and construction time whilst maintaining a competitive overall cost.

Architecturally an aesthetically pleasing interior design can be achieved taking advantage of the exposed structure as seen in Figure 2.

**Figure 2:** *Interior with exposed timber*

The building is divided into nine-storey and ten-storey parts with a two-storey lateral extension, as shown in the architectural section below, and provides approximately 6800m$^2$ of office space.

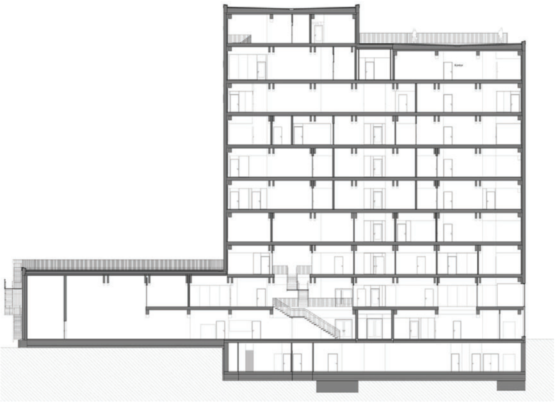

**Figure 3:** *Architectural section*

## 2.2 STRUCTURAL CONCEPT

Below the main building is a single storey reinforced concrete basement founded on steel HP piles to bedrock at a depth of approximately 100m. The use of timber was shown to give a 50% cost saving for the foundation design due to the reduced overall building loads.

The architectural requirement for two large cores servicing a relatively small floor plan allowed the original concrete core walls as planned at concept design phase to be substituted by cross laminated timber shear walls. Additional CLT shear walls were introduced on the two side façades to increase the stiffness in the weaker direction. Figure 4 shows a typical floor plan highlighting the location of the shear walls. Glulam timber "columns" are used to reinforce both the corners of the cores and the ends of the shear walls.

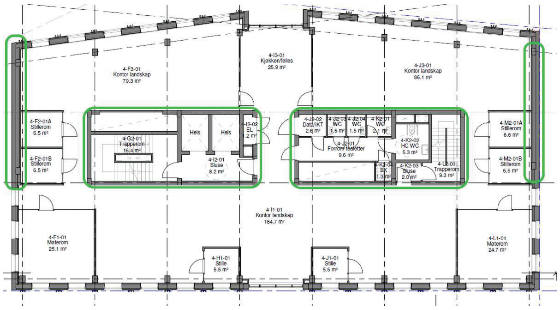

**Figure 4:** *Architectural floor plan showing shear wall location*

The structural grid is 4.85m with vertical loads transferred via CLT floor slabs to a system of double glulam beams and columns as can be seen during construction in Figure 5. The CLT floor slabs act as diaphragms for the transfer of horizontal actions to the shear walls. At ground level all loads, both horizontal and vertical are transferred to the concrete substructure. This load transfer is one of the key details in timber building design.

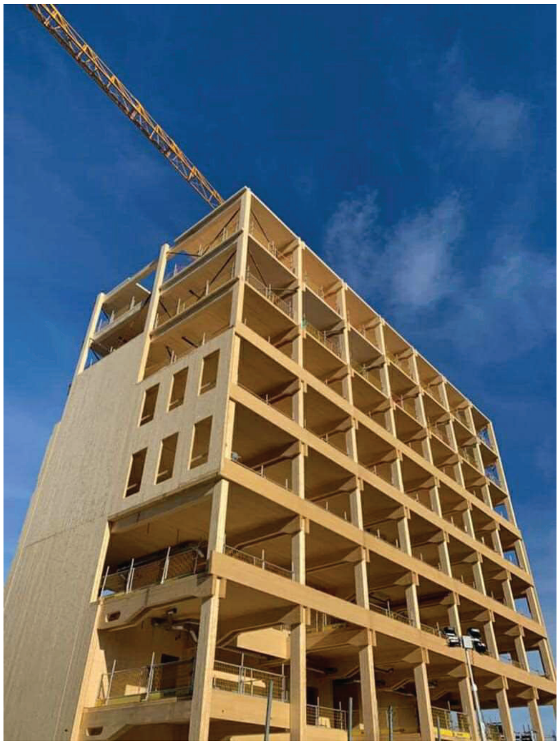

**Figure 5**: *SporX under construction showing the exposed structural frame*

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## 2.3 MATERIALS

### 2.3.1 Glued laminated timber

GL30c glulam was used for both columns and beams based on standard Nordic production dimensions. Column sizes are typically 355mm by 450mm. In addition, 280mm by 450mm GL30c columns were used to reinforce the ends of the CLT shear walls and facilitate the connection between the timber superstructure and concrete substructure.

Variable depth beams, 190mm wide were adopted to suit both the architectural concept and the integration of openings for services as can be seen in Figure 6.

For the structural design only the beam section over the large openings is considered for calculations, however the timber section adjacent to the holes is reinforced with screws to control possible cracking.

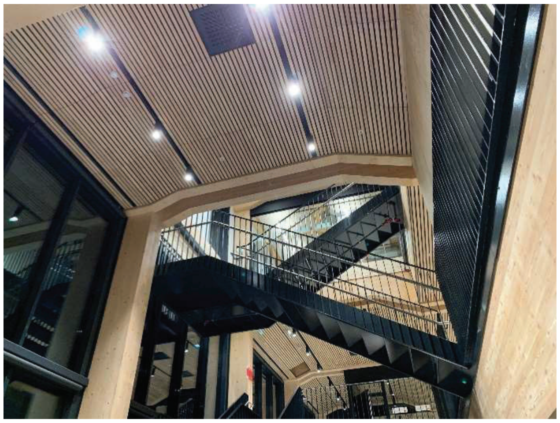

***Figure 6:*** *Double glulam beam & glulam column*

***Figure 7:*** *Opening for services through glulam beam*

### 2.3.2 Cross laminated timber

Floor slabs are 180mm five-layer cross-laminated timber. Main shear walls are 260mm seven-layer CLT, as shown in Figure 8, with 220mm secondary walls in seven-layer CLT.

***Figure 8:*** *CLT layers in shear walls*

### 2.3.3 Connectors

The connections between timber elements are by using fully threaded, cylindrically headed timber screws, or by either proprietary or bespoke timber connectors.

### 2.3.4 Quantities

A summary of the total structural building materials above ground incorporated in the finished building is shown in Table 1.

***Table 1:*** *Material quantities*

| Material | Quantity |
|---|---:|
| GL30c glulam | 520m3 |
| 180(5s) CLT slabs | 940m3 |
| 260/220(7s) CLT walls | 950m3 |
| Timber screws | ≈64,000no. |
| Proprietary brackets | ≈64,000no. |
| Timber nails | ≈64,000no. |
| Steel plates | 2,650kg |

# 3 STRUCTURAL DESIGN

## 3.1 GENERAL

The building is designed in accordance with the relevant Eurocodes to the Norwegian National Annexes [1][2].

No requirement for seismic verifications was established early in the design process by confirming a seismic ground acceleration of 0.2596m/s$^2$ with NORSAR. The subsequent publication of the 2021 version of the Norwegian National Annex [3] confirmed a value of $a_{gR}$ = 0.25m/s$^2$ for Drammen Kommune.

For consideration of progressive collapse, the building is classified as consequence class 2b (upper risk group)[4] for an office building less than 15 storeys. The structure allows for the notional removal of columns and beams. Double-storey height columns, triple-storey height CLT walls, continuous façade beams and triple-span CLT floor slabs enhance the structural redundancy and result in a robust overall design. This also minimises the number of connections.

Sway imperfections, based on ϕ equal to 0.005 radians are accounted for by applying Equivalent Horizontal Forces to the structure at each level.

### 3.2 SERVICEABILITY LIMIT STATE

Timber structures are commonly governed by the Serviceability Limit State, both by vertical and horizontal deflections and vibrations. The design of the 180mm thick CLT floor slabs, spanning 4.85m, was governed by deflection and vibration criteria.

The inclusion of the slip modulus ($k_{serv}$) for all timber connections was critical for evaluating the overall sway of the structure under horizontal loads. This was particularly relevant for the joints between the panels that formed the CLT shear walls and for the connections between CLT walls and concrete substructure.

The lateral stiffness of the structure is also relevant to checking the effects of the deformed frame geometry and whether a second order linear analysis is needed although EC5 does not give an explicit limit unlike the concrete and steel codes.

### 3.3 FIRE DESIGN

Well defined and predicable fire behaviour is an intrinsic property of mass timber elements. All the principal structural elements are designed to guarantee a load bearing resistance for 90 minutes in the fire design situation, R90. Generally the structural timber elements are partially or completely exposed to fire as can be seen in Figure 9.

***Figure 9:*** *Timber structure exposed to fire*

Columns have been designed as exposed on all four sides, double beams exposed to fire on one side and all CLT floor slabs exposed to fire on one side only. The CLT shear walls in the cores are designed for fire exposure on both sides, although with a reduced fire duration on the second side based on the separation into fire cells with R60 fire doors.

Timber columns and beams have been designed using the reduced cross section method from NS-EN 1995-1-2 [2]. This method defines a charring depth of 70mm for R90. This char layer insulates the core of the section preventing it heating up. The reduced section maintains its full strength and is verified for the critical fire load combination. In some locations particular elements are considered as redundant in the fire design situation. An example of this is the timber diagonal bracing element in the façade shear wall seen below in the Architectural model.

***Figure 10:*** *Architectural model showing timber diagonal bracing*

Timber-to-timber connections were also verified for R90 fire resistance. Generally this was achieved by providing the calculated depth of timber cover to the concealed connections.

### 3.4 FINITE ELEMENT MODELLING

A finite element model in SAP2000 of the complete timber structure was used for the verification of both the mass timber elements and for the connections. This model enabled aspects related to the structural design to be considered including:

- Timber as an orthotropic material.

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- Orthotropic panel build-up for CLT.
- Connections slip modulus, $k_{serv}$.
- Nonlinearity.
- Imperfections.
- Fire design situation.

Glulam elements, both beams and columns, were modelled using the frame element of the software. CLT panels, both slabs and walls were modelled using the thick shell element which combines both membrane and plate degrees of freedom.

Timber is an orthotropic material thus modifications of the elastic parameters need to be carried out for both frame and shell elements. To correctly model the shear deformation of the timber frame elements a reduction factor is required for the shear stiffness. For the orthotropic CLT panels, modelled as shell elements, 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).

For the connections between different timber parts links were used with the stiffness for each degree of freedom defined according to the calculated slip modulus for the connection type. For vertical loads, a high stiffness value is defined to ensure that the loads are transferred as expected. Non-linear links were used to model connections in the core walls that are very stiff for compression loads but have a reduced stiffness, or no capacity for the transfer of tension loads.

The concrete substructure is not included in the timber FE model, as shown in Figure 11 and at the base of each column or CLT panel links were used to model the actual connection stiffness and behaviour at the timber-concrete interface.

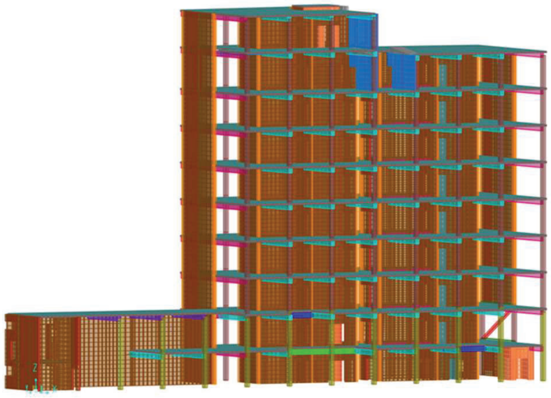

***Figure 11:*** *3D view of FE model*

Degree of Freedom have developed a design tool, compatible with SAP2000, Timber Interactive Modelling and Post-Processing Software (TIMPS) for the purpose of the analysis, design and optimization of timber structures based on the relevant design codes and technical approvals. This tool can provide visual plots of the results for both CLT panel and connection verifications. Selected images are shown below in Figure 12 with the results of both the in-plane shear check and the combined axial load, bending check for a section of the 260mm CLT shear wall.

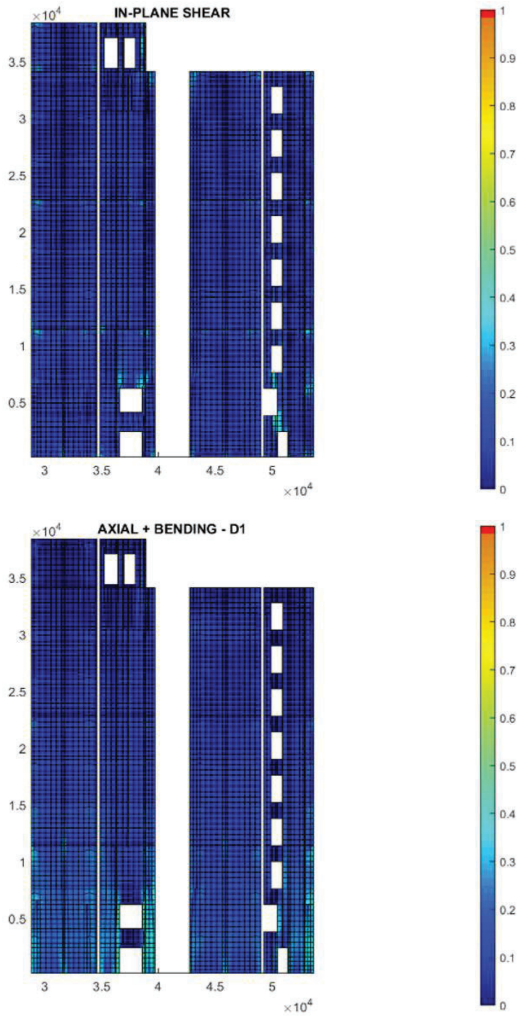

***Figure 12:*** *TIMPS output for CLT verification*

Similarly output for the connections between CLT panels can be plotted. Figure 13 shows the plot for vertical shear forces, an envelope for all ULS load combinations, at the connection between the CLT panel and the glulam column at the corner of the cores.

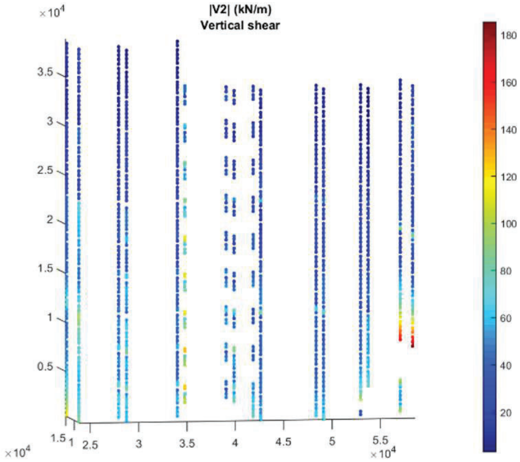

***Figure 13:*** *TIMPS output for connection forces*

## 3.5 CONNECTIONS

### 3.5.1 Timber-to-concrete connections

At the base of the CLT shear walls a combination of proprietary steel angle brackets and plates are used to transfer horizontal shear forces to the concrete substructure as seen in Figure 14 and Figure 15.

At the corners of the CLT cores and at the ends of the CLT shear walls a bespoke steel column shoe was designed. This needed to be hidden within the depth of the floor finishes and can be seen in both Figure 14, before floor finishes were installed, and in the construction detail in Figure 16.

***Figure 14:*** *Timber to concrete connection – CLT panel and glulam column*

***Figure 15:*** *Proprietary timber to concrete connector plate*

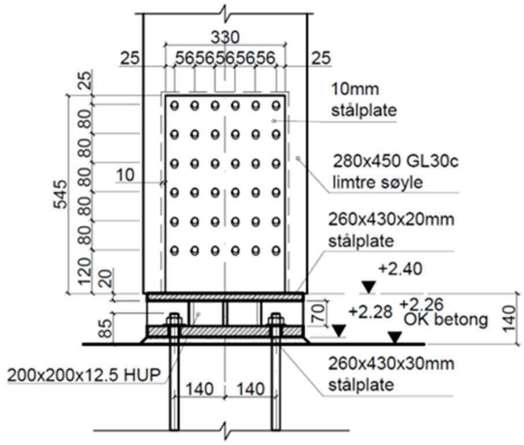

***Figure 16:*** *Construction detail – column shoe*

Careful detailing was required for all timber to concrete connections to allow for different construction tolerances and because of the limited architectural finishes to conceal connections as can be seen in the finished building in

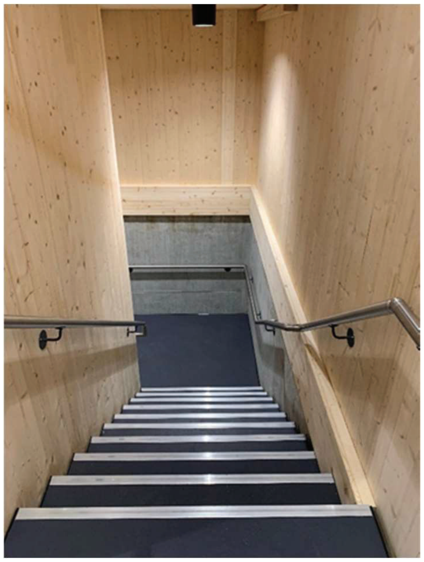

***Figure 17:*** *Timber- concrete interface in finished building*

### 3.5.1 Timber-to-timber connections

Principal timber-to-timber connections include the double beam to column connections which uses fully threaded timber screws at 45°, WT-T ø8.2x300mm screws from SFS intec. This resulted in a concealed connection with a good load carrying capacity. To facilitate erection the columns are notched to allow for temporary support. The construction detail is shown in Figure 18. Images from both during construction and in the finished building show how timber plugs were used both for aesthetic reasons and to protect the timber screws for the R90 fire design situation.

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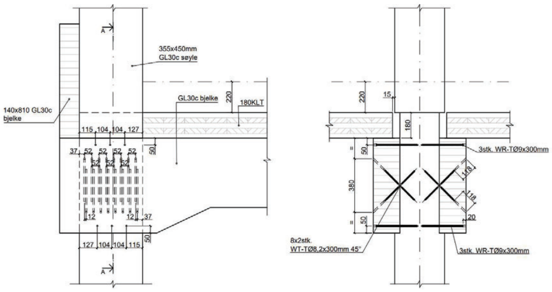

**Figure 18:** *Timber double beam to column connection*

**Figure 19:** *Timber beam to column connection – without timber plugs*

**Figure 20:** *Timber beam to column connection – finished detail*

For timber beam to CLT wall connections both the LOCKT and ALUMAXI concealed connectors from the supplier Rothoblaas were used. This combination of proprietary connector at one end of the beam and screwed connection at the other allowed for erection tolerances. Between CLT slabs and the CLT core walls proprietary steel angle brackets were detailed to transfer horizontal forces due to wind loads from slab diaphragm to shear walls. Figure 21 shows the typical distribution of angle brackets.

**Figure 21:** *Steel brackets at CLT slab to CLT shear wall interface*

The connection between CLT panels make use of fully threaded timber screws installed at 45°.

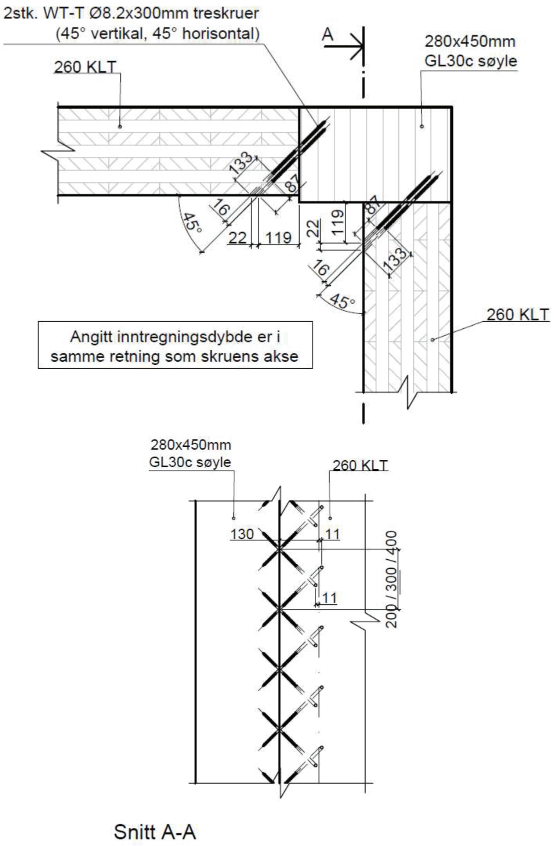

**Figure 22:** *Timber screws at CLT shear wall to glulam column connection wall interface*

## 4 BUILDING INFORMATION MODELLING

The project used the most up to date BIM methods during both design and construction. A digital twin was also created and during construction a weekly scan was used to control non-conformances by comparison with the digital twin.

BIM models were developed by all disciplines and coordinated during the design phase. This resulted in a fully integrated LOD350 model at the end of the design phase.

This timber structural model was then advanced to a LOD400 fabrication model on behalf of the contractor. Figure 23 shows the LOD400 timber model as used by the timber supplier for production.

Erection drawings were then produced directly from the BIM model using the software Cadworks.

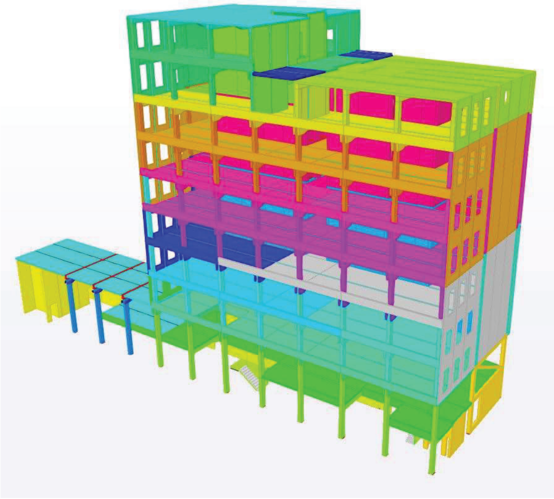

***Figure 23:*** *LOD400 timber production model*

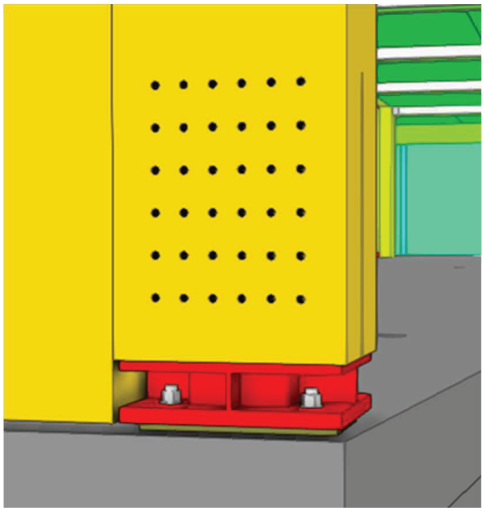

***Figure 24:*** *LOD400 timber production model – connection detail*

Erection drawings were then produced directly from the BIM model using the software Cadworks. An example of the drawings for the 260mm CLT panels that form one of the cores can be seen in Figure 25.

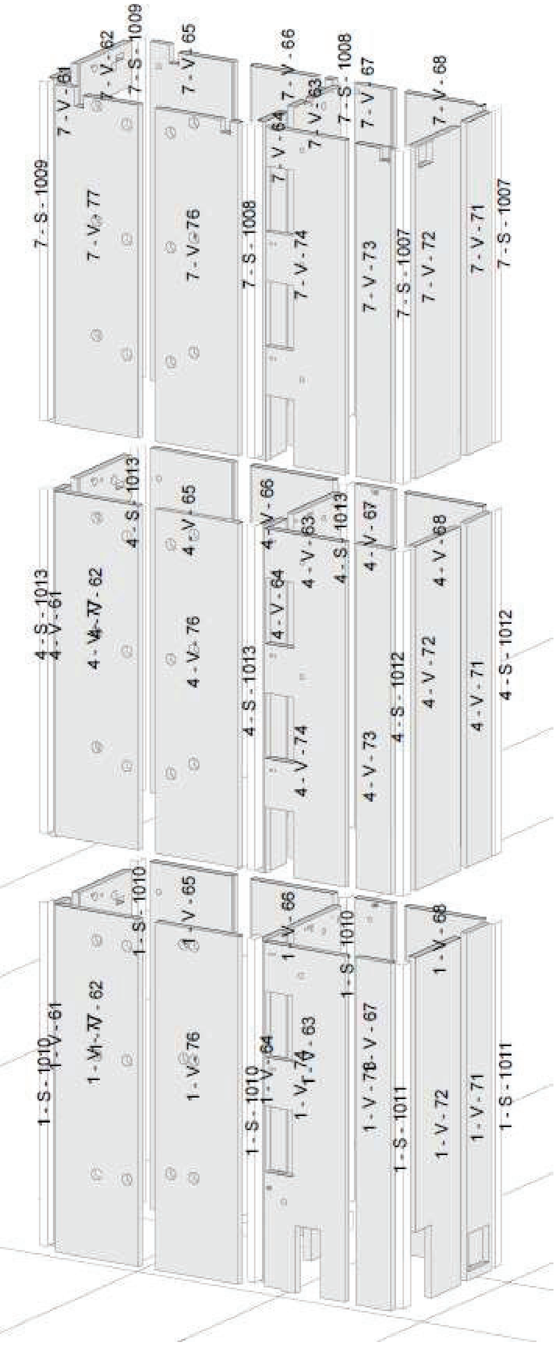

***Figure 25:*** *Timber erection drawing for CLT core*

## 5 CONSTRUCTION PROCESS

The timber frame was erected over a period of 15 weeks in early 2021 and the building completed in 2022. A key feature of timber construction is the rapid work on site due to the precision of the prefabricated elements. Figure 26 and Figure 27 show the progression of the timber erection from start to finish.

***Figure 26:*** *Start of timber erection*

***Figure 27:*** *Completion of timber erection*

## 6 CONCLUSIONS

The design of SporX uses a traditional building material, timber, as the load bearing structure for a ten-storey office building. It takes advantage of BIM modelling for the timber elements that can then be prefabricated with strict tolerances for a rapid construction process. The result is an innovative building that makes the best use of a traditional building material with the most up to date construction aids with the use of BIM and precision fabrication.

The result of the architectural and engineering vision of this project can be seen in the images below of the building in its final stages of fit out.

***Figure 28:*** *SporX – finished interior*

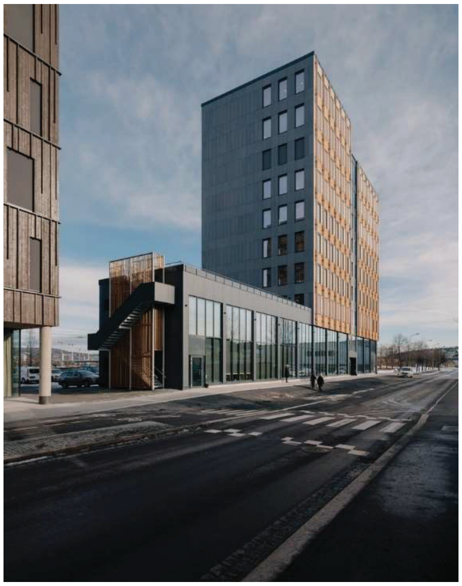

***Figure 29:*** *SporX – finished building*

## ACKNOWLEDGEMENT

The realisation of this project is thanks to a dedicated design team including the architects, DARK Arkitekter (https://darkarkitekter.no/) The completion of the project has been in collaboration with the main contractor, Betonmast (https://www.betonmast.no/) and the timber fabricator, Splitkon (https://splitkon.no/).

Additional photos by Zinc/Thomas Mellbye

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[3] NS-EN 1998-1:2004+A1:2013+NA:2021 Eurocode 8 - Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings.

[4] NS-EN 1991-1-7:2006+NA:2008 Eurocode 1: Actions on structures - Part 1-7: General actions - Accidental actions

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