# Mid-Rise Wood Construction

# CASE STUDY

# CLEARWATER

# QUAYS

**INTRODUCTION**

**GENERAL CONSIDERATIONS**

**DESIGN**

**CONSTRUCTION**

**LEARNINGS**

**APPENDICES**

## 1. EXECUTIVE SUMMARY

This case study uses a five-level, luxury, residential apartment building to highlight the holistic benefits of engineered-timber construction compared with a traditional steel & concrete approach. The Clearwater Quays Apartments has a total floor area of 2,130 m$^2$ (including garages) with two open-plan apartments per level overlooking the lakefront of the prestigious Clearwater development in Christchurch, New Zealand.

This document has been designed to educate industry professionals about consenting, acoustic performance, fire risk, façade protection and durability, building envelope performance, cost management and analysis, fabrication and installation, environmental analysis and risk management. It is also intended to support architects, quantity surveyors, engineers, builders, project managers, property owners and developers considering a mass-timber build. For ease, the document has been divided into four main sections that reflect the phases of a building project: General Considerations, Design, Construction and Learnings.

Throughout this document the following key learnings are discussed:

- The need for good communication
- When and how the team should be put together
- Where extra time is needed and where time can be saved
- Material transportation, protection and storage challenges
- The value of using Building Information Modelling (BIM)
- Compromises between fire safety and wood-exposure protection
- The comparison of carbon content between a mass timber build and concrete and steel builds.

## 2. INTRODUCTION

Mid-Rise Wood Construction is a four-year partnership between the Ministry for Primary Industries (MPI) and Red Stag Investments Ltd. The aim of this $6.75 million programme is to encourage widespread adoption of precision-engineered timber in mid-rise building construction. Since its inception in 2018, the programme has assembled a pool of New Zealand professionals experienced in mid-rise wood building design and construction to help share and grow knowledge and expertise with the broader industry.

Engineered timber is not only naturally beautiful but also provides a very strong, low carbon and comparably low-cost alternative to steel & concrete. It is easy to transport, relatively light, and has outstanding earthquake and fire resilience. The use of prefabrication can decrease construction time by as much as 30 percent, and reduces costs compared with traditional building methods. Combining cross-laminated timber (CLT), laminated veneer lumber (LVL), glulam and panelised framing timber (eg structural insulated panels) creates a cost-effective, fast, resilient and sustainable system for mid-rise construction.

This case study showcases Clearwater Quays, a high-end residential development overlooking Clearwater Golf Course in Christchurch's most sought-after resort community. The Clearwater Quays project is the first in a range of reference buildings of different types proposed under the Mid-Rise Wood Construction Programme.

MID-RISE
Wood Construction

RED STAG
INVESTMENTS

Ministry for Primary Industries
Manatū Ahu Matua

## 3. ARCHITECTURAL

### The attraction of a Mass Timber Project:

The construction industry contributes roughly 16% of New Zealand's greenhouse gas emissions. Trees sequester carbon as they grow and timber stores this carbon for the life of a building, making mass-timber structures a significant step towards a regenerative form of architecture and thereby reducing net emissions.

For architects, the attraction of working with timber goes beyond the environmental benefits of net-zero carbon buildings. There is a sensory connection to timber and a tactile experience with enduring appeal. Architects know that humans have an innate need to connect with nature, and timber construction plays a part in this connection. Revealing wooden interior surfaces is also a key biophilic design principle for Phillip Howard, the project's lead architect.

### The Clearwater Quays Apartments:

The Clearwater Quays project was commissioned by a company with an interest in the timber industry. Showcasing timber both structurally and visually was a driving factor of the design brief.

The challenge for Mid-Rise Wood Construction was to maximise opportunities to highlight the aesthetic and structural quality of timber. This goal was achieved by incorporating dramatic, sculptural staircase structures projecting from the southern façade of each residential tower. These curvaceous forms create a counterpoint to the otherwise linear road-facing southern façade.

The spacious entrance lobby was designed to draw people into the building via a large portico structure. The apartment living areas face north with bedrooms and services areas orientated to the south.

The structural frame of each residential tower is entirely timber including CLT panel floors, and a lift featuring light-framed timber. The only non-timber elements to the structural system are the concrete slab ground floor, and footings. Mass-timber construction is very much the hero of this project.

***Fig. 1 -*** *Section through separate garages and apartment buildings*

## 4. CONSENTING AND CODE COMPLIANCE

### Design & Architecture

A pre-application meeting was held between key council staff, the architects, project manager and key engineers involved in the Clearwater Quays project. This meeting opened up early lines of communication so that contacts, approaches and expectations were set prior to the application for a building consent.

The consenting process for this project was split into two stages: (1) the floor slab and foundations; and (2) the superstructure. Stage 1 was very straightforward as it was a typical gravel raft and concrete construction.

Generating requests for information relating to architectural and structural items during the consent processing were also relatively straightforward although more drawn out due to the two-stage approach, some overlapping detailing between consultants that had to be worked through, peer review and Covid-19 lockdowns. The Council's focus was on the detail as expected considering the relatively unfamiliar primary structural system.

### Engineering

The design of CLT is outside the scope of the verification method of NZS 3603:19921[1] under clause B1 of the New Zealand Building Code. Therefore, structural design of the CLT was an alternative solution under the Building Code. The CLT Handbook prepared by FPInnovations[2] was used to provide support for the design and construction of CLT as an alternative solution, and to provide technical information and structural analysis methods for CLT. Eurocode 5 (EC 5)[3] was also adopted to provide characteristic strengths and capacities for structural timber elements that use large-gauge screws and steel dowels, as these types of fasteners are also beyond the scope of the current verification method of clause B1.

### Construction

As with a traditional build, the Council reviewed the consultants' site reports for the Clearwater Quays project and addressed any identified issues to ensure everything had been closed out by the consultants and the contractors on site. To date, Council inspections have been consistent with other projects, and the inspectors have been very interested to see how the structure has progressed during construction. The process has been a positive learning curve for everyone involved.

All documentation and requirements around the Code of Compliance remained the same for a mass-timber building as for a traditional steel building. Code compliance certification is no different to any other structure. The builders endeavour to continue to work with the inspectors to assess each apartment as they are finished for a code compliance certificate to help them understand the different type of construction and to develop confidence in the process. By allowing the inspectors to see each stage of the process, the final consent should be easier to obtain at the end with a focus on the main compliance issues rather than doing a final inspection for each apartment.

## 3. ACOUSTIC PERFORMANCE

DESIGN

### Acoustic Engineering

Acoustic engineering is challenging because the human ear is so sensitive that sound must be reduced by 50% to make a noticeable difference. In fact, sound transmission must be reduced by five orders of magnitude to less than 0.001% to achieve the Building Code requirement of STC 55.

The heavy mass of concrete provides an effective barrier to sound so buildings made from heavy materials can be designed to give good sound insulation between dwellings using well-known techniques. There are standard solutions for most situations and, on the whole, acoustic design can be "added on" to the structural and architectural design process. Although acoustic design influences material selection, it does not need to be at the forefront of the design process.

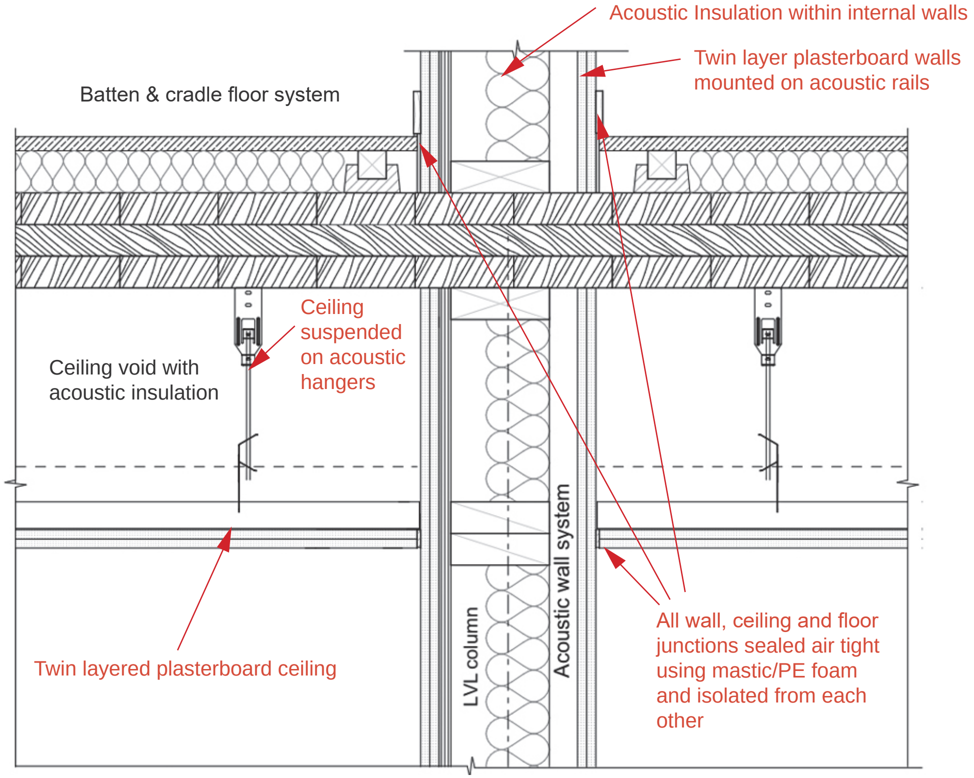


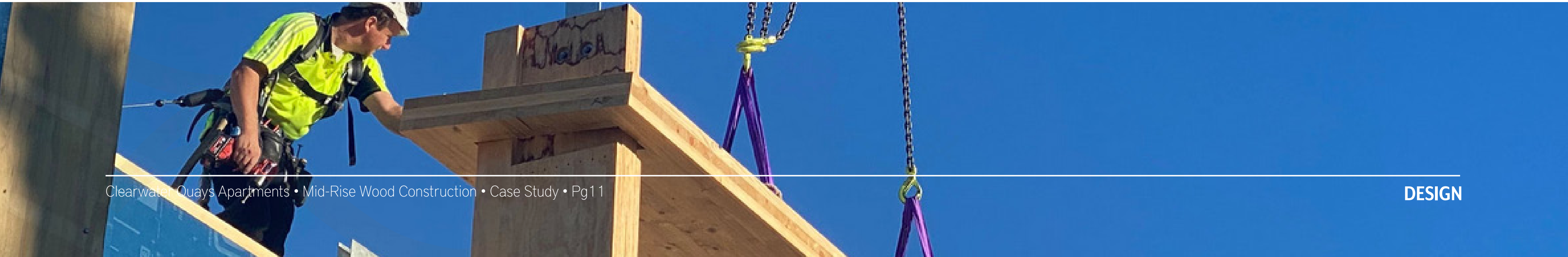
***Fig .2*** *- Typical Intertenancy Wall with central CLT panel and lightweight linings*

Unlike concrete, wood is light and stiff – ideal properties for converting vibration into sound. Therefore, mass-timber construction needs a quite different noise-control approach, as acoustic considerations must be tightly integrated with the whole structural, thermal, fire protection and architectural design process rather than being added on at the end. It is very important that the structural engineer and the acoustic engineer work together early in the design process and develop the basic building structure with a thorough understanding of each other's constraints.

Wall linings such as plasterboard over an air gap are required to reduce the direct sound transmission through walls and floors. Unfortunately, this approach clashes with architectural desires to expose the natural beauty of timber. In certain situations, some direct exposure of timber is achievable, but it must be carefully planned. There is also a requirement to control impact sound such as footsteps and likewise a single layer of timber, even one 200 mm or thicker, is not adequate on its own to achieve the Building Code requirement of IIC 55 for impact sound.

Fortunately, considerable research both in New Zealand and overseas (in Canada, in particular) has been done recently into the design of walls and floors using mass timber that will achieve good airborne and impact-sound insulation. As this form of construction becomes more common, further research will focus on optimising designs to achieve Building Code requirements in different situations. However, good walls and floors by themselves are not sufficient.

A more challenging aspect to achieving good acoustics is to limit flanking sound transmission, i.e. the sound that travels between apartments indirectly as, for example, through a continuous floor platform.



Sound will be transmitted into the floor of one apartment, travel underneath the separating wall and re-emerge from the floor of the second apartment. No matter how good the wall, it will be short circuited by the flanking path. For this reason, close cooperation between the structural and acoustic designers is required to achieve optimal outcomes so that transmission paths are interrupted by resilient materials, or such paths are shielded by wall or floor linings. Various types of wall/floor junctions can block or attenuate sound transmission and, by understanding how effective these are, the structural requirements can be achieved together with the acoustic requirements.

The Clearwater Quays project is an example of such integrated design with structural breaks incorporated into floor panels to reduce flanking sound transmission and with double-stud, timber-framed walls that will achieve design ratings of STC 58 and comfortably exceed the Building Code requirements of STC 55 for design and STC 50 for the finished building. The walls incorporate ply in an innovative way to achieve structural and acoustic requirements at the same time, with the same materials, rather than the acoustic design coming at a later stage and being laid over top of the structural design.

Accommodating acoustic requirements in the floor design for Clearwater Quays is more complex than for the walls. A floating floor is required on top of the CLT floor plate to reduce both the impact sound to the apartment below, and the flanking sound to the adjacent apartment. As noted before, a continuous CLT floor plate could reduce the noise-control performance to the adjacent apartment to less than STC 40 and a single CTL floor panel would achieve well below IIC 50 to the room directly below. The solution for the Clearwater Quays build was to install a separate floating floor in each apartment that was sitting on recycled rubber blocks. This approach attenuates sound transmission into the main CLT floor and so controls both impact to below and flanking to adjacent apartments at the same time. A suspended ceiling also provides not only sound insulation in the vertical direction but also reduces flanking sound horizontally.

## 3.1 DEVELOPMENT'S ACOUSTIC DESIGN CRITERIA

### Protection from internal noise

The Clearwater development has been designed to have an enhanced performance above the standard of the NZBC, see T+T design report. The performance criteria for the development are included in Table 4.1. The field or on-site requirement (FSTC) was specified to be 5 points better than the minimum performance standard of Clause G6 (i.e, 55 rather than the Clause G6 minimum of FSTC no less than 50).

***Table-*** *Development design criteria and minimum requirements for field measurements - acoustics*

| Element | Location | Design | Field (on-site) | Verified in this report? |
|---|---|---|---|---|
| Airborne sound insulation | Walls from common areas to apartments (stairwell) and IT walls | STC 58 | FSTC 55 | Yes |
| | Enhanced IT walls | STC 63 | > FSTC 55 | Yes |
| | Floors between apartments | STC 60 | FSTC 55 | Yes |
| | Floors between apartments (enhanced) | STC 62 | > FSTC 55 | Yes |
| Impact sound insulation | Hard floor covering between apartments | IIC 58 | FIIC 55 | Yes |
| | Hard floor covering between apartments (enhanced) | IIC 61 | > FIIC 55 | Yes |
| Rain noise (40mm/hr) | Apartments | NC 35 | NC 40 | No |
| HVAC | Bedrooms | NC 25 | NC 40 | No |
| | Living / dining areas | NC 30 | NC 35 | No |
| Plumbing noise | Bedroom | 30 dB $L_{Aeq\ (10s)}$ | 35 dB $L_{Aeq\ (10s)}$ | No |
| | Living / dining areas | 35 dB $L_{Aeq\ (10s)}$ | 40 dB $L_{Aeq\ (10s)}$ | No |

For rain-noise, HVAC and plumbing noise, the criteria are based on acceptable levels of internal noise as established from AS/NZS 2107:20167 and best practice.

## 6. FAÇADE PROTECTION AND DURABILITY

### Design & Architecture

It proved impossible to use timber cladding up the entire height of each tower due to fire/spread of flame regulations. The architects opted to use the Vulcan timber-cladding system from Abodo within the deck/balcony areas with the CLT floors acting as the fire separation, and for the ground-level garaging and separate garages. The remainder of the wall cladding was extruded aluminium Dualbord and Euro-suite Flashclad products from Flashman Flashing Systems installed in both vertical and horizontal orientations. The fire engineer was able to persuade Council that the balcony areas were internal so these were able to be clad in timber because these were also covered by the sprinkler system.

### Engineering

The external envelope for the Clearwater Quays project was designed to ensure a weathertight system keeping the internal space dry and free from external moisture to promote long life and durability.

The design of the façade was a combination of engineering of the structural timber CLT framings and the building envelope systems. It consisted of:

- Prefabricated timber frames, which were delivered to site with the gypsum rigid air barrier already installed.
- The structural CLT walls with a rigid air barrier installed over the walls to form the airtight layer
- The aluminium over cladding (Flashman Flashclad system) was then installed on site over the prefabricated frames.
- A light-gauge steel roof with timber trusses
- A Thermoplastic Polyolefin (TPO) membrane over the CLT + plywood balcony
- Windows and doors that were post installed into the prefabricated timber framing in the apartment areas, and a large curtain wall supported from the CLT stairs and stair beams

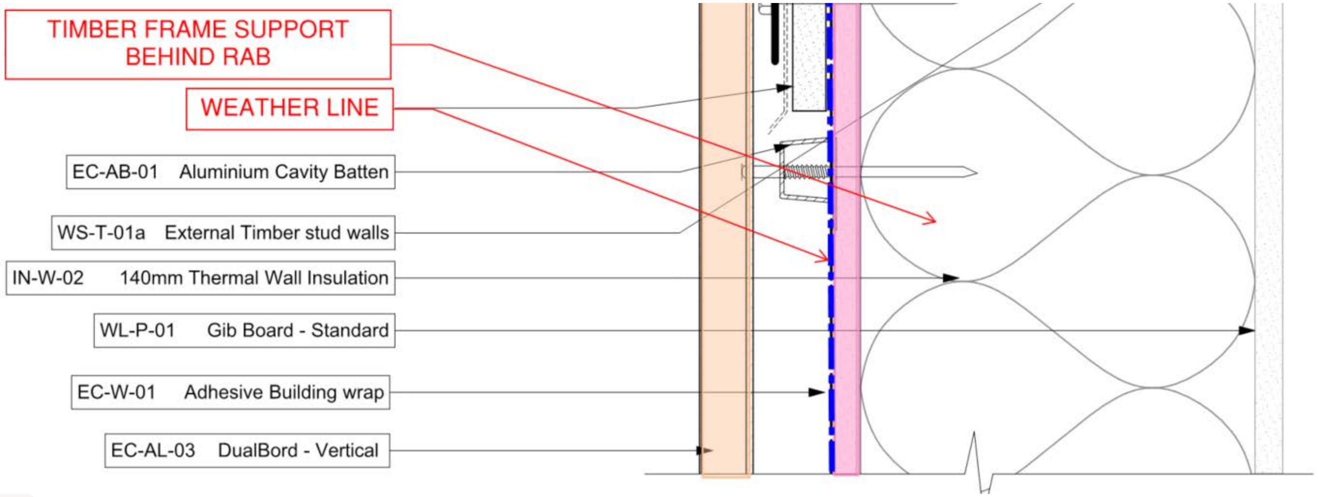


***Fig . 3 -*** *Typical external envelope make-up with aluminium cladding. Snapshot from Pacific Environments architectural Drawing A424 det 53*

Figure 3 shows a typical section through the façade.

The principle of the aluminium-clad façade system was that of a sealed system with a drained cavity. The sealed system (Rigid Air Barrier and Adhesive Wrap) is a solar-sensitive product, so is overclad with an aluminium cladding over cavity batten system to provide protection to the Rigid Air Barrier and Adhesive Wrap. The aluminium cladding over cavity batten system also provides a cavity to the sealed system. This design allows for wind-driven rain to get into the system but also lets the water drain out safely without compromising the sealed line. This approach is in line with good-practice principles used by the industry to prevent water from entering the internal spaces.

Aluminium is a product that is inherently durable and widely used in the industry. It is powder coated to create the colour and the visual intent the architect is looking for. The system used here (Flashclad) has been developed by the façade contractor, Flashman Flashing Systems. It includes bespoke jamb head and sill flashings around the windows to carry the principle of a drained cavity described above through the windows. These have been tested to AS/NZS4284 to ensure they are suitable for use in high-rise spaces.

The fixings of the façade elements were specified to be stainless steel to ensure that they are compatible with the timber substrate and are resistant to rust and corrosion so that the overall system meets load and structural capacity requirements.

The timber framing and Rigid Air Barrier were designed to be fabricated in a factory in Christchurch to maximise the amount of façade construction that could be carried out within a controlled factory setting. This approach improved protection of the timber framing during construction and improved the workmanship of the Installation of the Rigid Air Barrier on site.

***Fig .4*** *- West Elevation External Cladding Site progress*
*– Clearwater project*

***Fig. 5 -*** *Wall membrane applied over the Rigid Air Barrier*
*– Clearwater project*

## 7. MECHANICAL, ELECTRICAL AND PLUMBING

### Design & Architecture

The mechanical design for the building was quite simple, with typical fan extracts from the kitchen range hoods and bathrooms. Some make-up air is provided by trickle vents to the ranch-sliders. Heating is provided by split-cycle heat-pumps/air-conditioners. The lift shaft has a high-level extract. Ventilation is otherwise reliant on natural breeze through openable windows and doors.

The electrical wiring was run up through the main services riser in cable trays and branches out to the apartments from there. The majority of the common-area lighting demand is expected to be offset by the photovoltaic panel array mounted on the roof.

Plumbing layouts have vertical stacks running down shafts in close proximity to the bathrooms/ensuites/kitchens. There are floor-waste gullies in each kitchen and bathroom primarily for property protection of the units below. Large downpipes have been used, running vertically through the deck gutter outlets to drain the roof gutter and deck areas, and simplify the runs. Each deck was designed with an overflow plus an ability to discharge over the edges of the decks should the overflow block for any reason.

## 8. FIRE PROTECTION

### Design & Architecture

The building has a floating acoustic floor on all levels above ground, and suspended ceilings for acoustics, resulting in the internal fire-walls running all the way up between the CLT floor slabs through these elements. This approach was feasible because the solid CLT floors provide the horizontal fire-separation required without a need for additional fire-rated ceilings.

Similar levels of acoustic and fire protection have been provided between the apartments to the fire-separation measures installed in the stair/lift lobby. Most of the external walls were considered load-bearing so there was no need for either deflection heads or external movement joints, although these will be required for internal non-load-bearing walls. Some of the joinery units required seismic frames, as designed by the façade engineer and joinery manufacturer.

## Engineering Fire Safety Design

The New Zealand Building Code (NZBC) and the Fire Engineering Report required that the suspended CLT floors were fire rated for 30 minutes for a fire-sprinklered apartment. The required fire-resistance rating for the intertenancy floors was achieved by the fire-test data from the CLT manufacturer.

The LVL beams and columns were considered large timber sized members (now commonly known as mass timber) so they were designed for charring to support the floor during the fire-load case (G, ΦIQ). Bolts that were used to transfer the vertical shear from the beam into the column for the fire load case were countersunk up to the steel internal gusset with

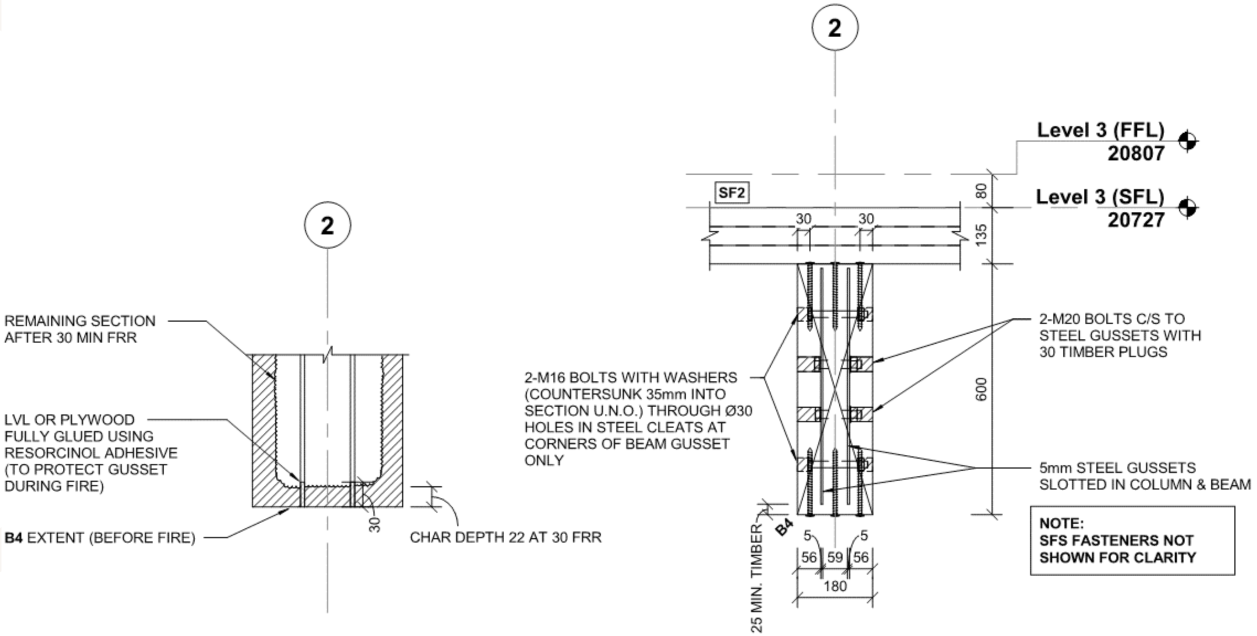


***Fig 6 -*** *Char depth of timber beam shown for 30 minutes of fire, and cross section of LVL portal beam detail* a 30-mm ply plug so were therefore protected from charring of the timber. A minimum 25-mm plywood sacrificial layer was also provided around the bottom edges of the steel gusset to prevent heating during a fire. Edges of the steel gusset were intumescent coated in situations where they are exposed and not protected from charring..

A uniformly distributed lateral load of 0.5 kPa is required for post-fire stability of the structure as a fire is assumed to occur only in one fire cell at any one time. Therefore, the LLRS on the fire cell that is not affected will effectively brace the structure.

## 9. BUILDING ENVELOPE PERFORMANCE

### Design & Architecture

The architects worked closely with the façade engineers, joinery manufacturer and cladding manufacturer to ensure that their designs worked with the expected horizontal wind loads and seismic drifts. There was a considerable amount of conversation, particularly regarding the horizontal inter-storey joints and the method of construction for the curved edge to the curved stair-well wall.

### Engineering

Each element of the façade was checked for its ability to resist a combination of loading to the cladding itself and then to ensure it could accommodate movement of the overall building most likely caused by wind and seismic displacements or drifts. Checks were done via engineering calculations and reviewing the appropriate technical data and test reports of each component.

The loads that are imposed on the façade system were designed to be transferred to the CLT timber framing support. The loads were co-ordinated and then checked by the structural engineers to ensure these load transfer meets the structural design requirements and capacity.

Due to the nature of the CLT and its capacity to drift, the joinery system was reviewed to ensure that it met the building movements as supplied by the structural engineer. The brackets of the curtainwall joinery system were designed by the sub-contractor to meet the requirements of these movements. *(Refer to Figure 7)*

The weather tightness performance of the façade was confirmed by checking the performance of individual system components by respective test reports and technical data information provided by each supplier. An important part of the process was reviewing the details of each system and ensuring the intersections and interfaces of those systems are properly detailed using best practice and architectural detailing with engineering principles.

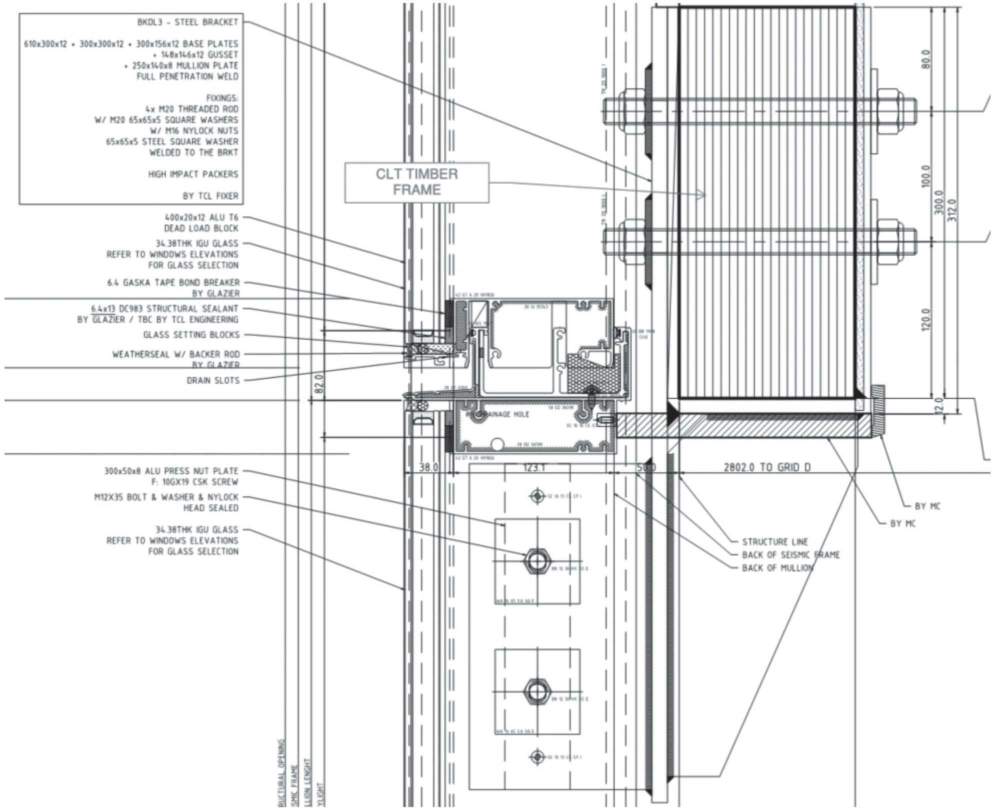


***Fig 7 -*** *Fixing of Curtain Wall System to LVL Timber Frame snapshot from Thermosash Shop Drawing – no. 505*

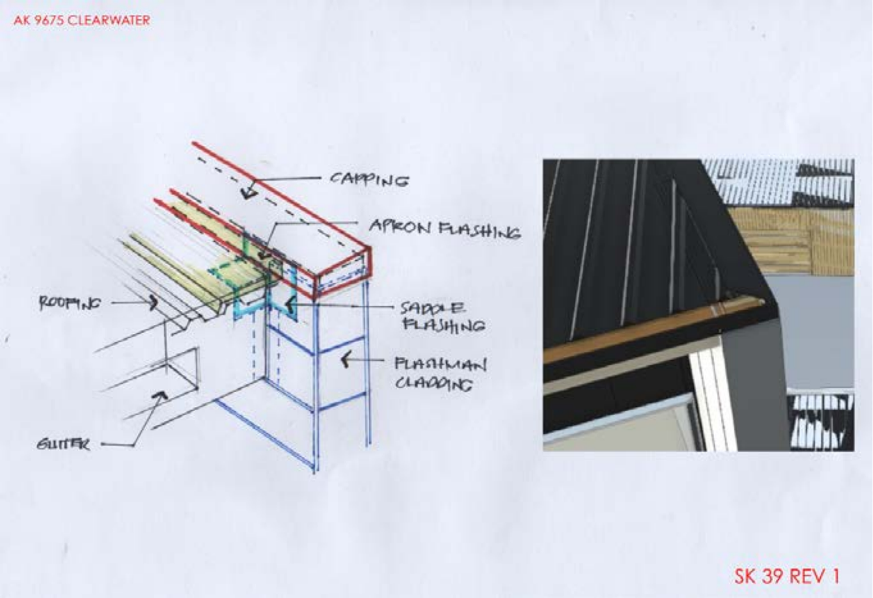


***Fig. 8 -*** *Inhabit Sketch 39 – Roof to Cladding Interface*

***Fig. 9-*** *AAMA 501.2 Site Hose Testing – Clearwater Quays*

The façade engineers (Inhabit) and the architect worked closely together though workshops and use of sketches to ensure that details were clear and established. *(Refer to Figure 8)*
It was also important to verify the façade performance with on-site testing such as conducting a WGANZ501 Site Hose Test on site to selected areas around the window joinery to test the performance of the interfacing details, shown in Figure 9.

There were number of engineering challenges throughout the design and construction but a key one was the curved-wall and the curtain-wall system interface. This feature required co-ordination of loads and design with the structural engineer to ensure that the system can accommodate both load and movement requirements. At the same time, the interface needs to be weathertight.

The construction of the area is in progress as at October 2021 and the curtain-wall supplier will need to site measure to ensure that the manufacture system fits accordingly to the CLT timber structure to ensure weathertightness. *(Refer to Figure 10)*

*UPDATE: Construction as of 3 November 2021*

***Fig. 10** - Curved wall to curtain wall interface*


SMITH

## 10. COST MANAGEMENT AND ANALYSIS

### The cost of a mass timber build compared to concrete and steel

### INTRODUCTION

Mass-timber building using LVL, glulam and CLT is a relatively new method of construction. In the past decade, the building industry has seen an increase in interest, due to awareness of climate change and the need for sustainability leadership. This type of interest means that most mass-timber builds have been "passion" projects or statement buildings that have been developed to show the possibilities as well as the direct and indirect benefits of this type of building. The construction of many bespoke mass-timber buildings has involved a steep learning curve for the industry. Most buildings have been architecturally and structurally different and built to stand out as exemplar projects so extracting meaningful cost data from such project can result in a wide range of information. Using such data can result in invalid comparisons with traditional construction methods, and many projects have defaulted to traditional builds due to this lack of validity.

More recently, the costs of mass-timber builds have been affected by increased industry experience, methodology developments, refined prefabrication techniques and greater competition among suppliers. These factors, combined with more accurate cost estimation software, better understanding of both programme savings and capital return durations, have resulted in more informed cost comparisons. Increasing both the quality and type of information available to developers will continue to increase the uptake in mass-timber builds.

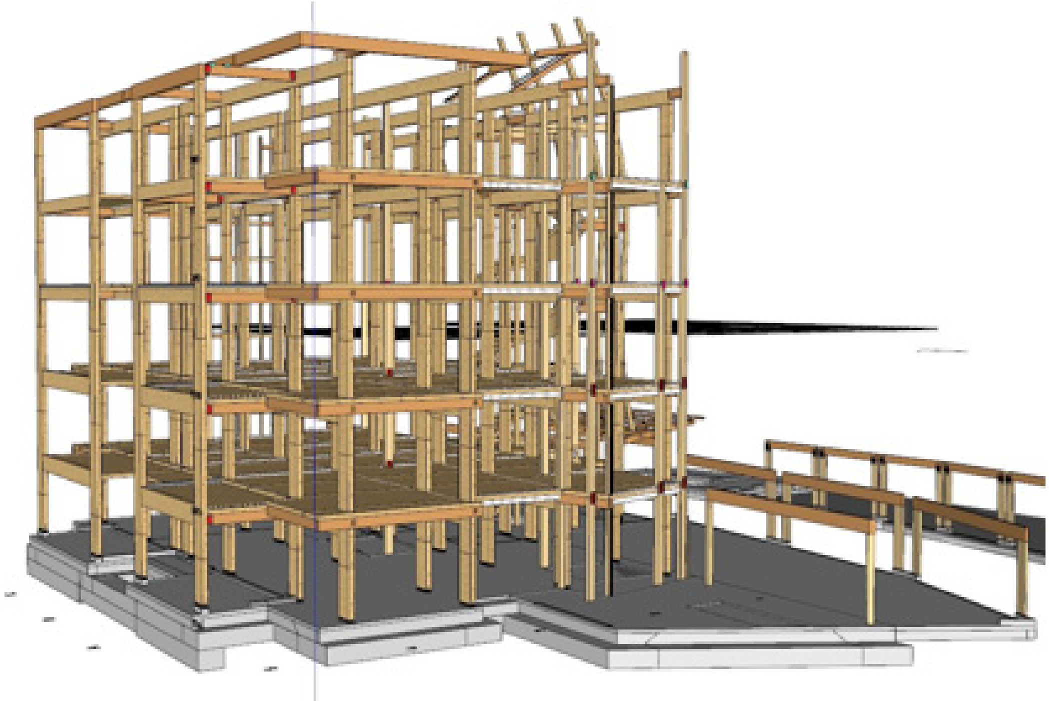


***Fig. 11** - Mass Timber Elements*

## ESTIMATION METHODOLOGY

At the outset of this project, the quantity-surveying team built a 'Digital Twin' cost model for the Clearwater Quays development. (A digital twin in construction, engineering, and architecture is a dynamic, up-to-date replica of a physical asset or set of assets) The structural engineer developed alternative designs to sufficient detail for the construction manager to be able to estimate the build programme time and for the QS to be able to price the structure and foundations, and estimate the cost implications of the time saving from constructing in mass timber. The alternative designs were in:

1. Steel frame & concrete floors
2. Full in-situ concrete

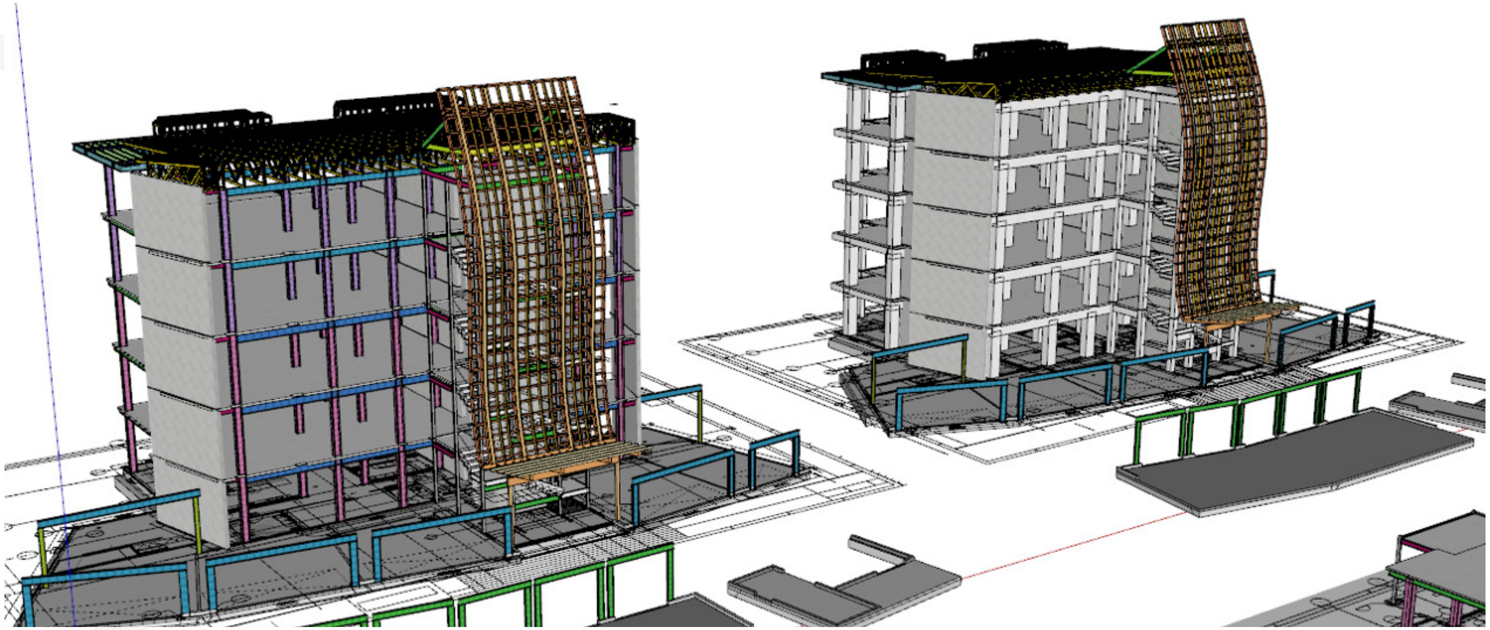


***Fig. 12 -*** *Left: Steel frame & concrete floors Right: Full In-Situ Concrete*

Building digital twin models for the structures was the next best option to constructing these on site. Within these models, design elements were incorporated that would be associated with these build methodologies. For example, CLT floors would require acoustic cradle and batten flooring where concrete floors would not. Mass timber-builds would typically have lighter foundations than other methodologies. The various approaches and considerations of structure, acoustics and fire across each design were addressed and incorporated into the cost estimates.

Utilising a building information modelling (BIM)/virtual design and construction (VDC) approach increases accuracy, and allows cost findings to be communicated in a language that clients and design teams understand. All elements are quickly interchangeable and can be fed back into build budgets. Back and forth discussions with the engineer refined these structures and increased the accuracy of cost estimation.

To fully understand any cost comparisons, there must also be a consideration of intangible inputs within the comparisons. Often such inputs are overlooked or there is simply not enough knowledge or expertise to inform feasibility investigations/comparisons. These are:

- Reduced construction durations
- Development cost - Market risk
- Development cost - Carrying costs
- Development cost - Completion settlement

Typically, the longer it takes to deliver the project, the higher the non-productive costs are. This is true for the construction programme but is also relevant to the developer's capital investment and financing. To put it simply, the longer it takes to complete the project the longer it will take the developer to return capital investment. It leads to longer finance carrying durations, increased risk, and can delay further opportunities to invest in the next project.

## FINDINGS

Utilising the above digital methodology has enabled a more robust and detailed cost estimation to be developed than could previously be completed without physically constructing each design. The results of these feasibility investigations are valid at the time of this case study (September 2021). Since September 2020 the cost of concrete and steel has increased relative to mass timber materials, improving the cost advantages of mass timber. The chart below contains typical cost-data comparisons for different types of construction materials.

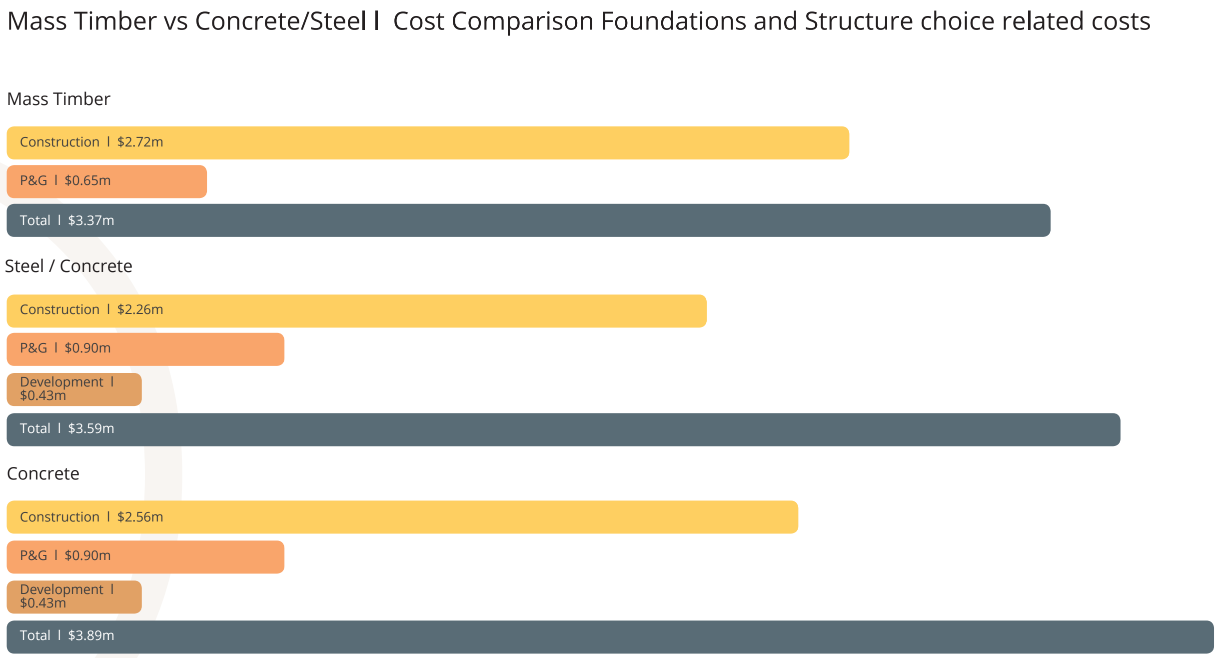


***Fig. 13*** *- Cost Comparison of Mass Timber, Steel/Concrete and Concrete Options*

Comparisons for the Clearwater Quays project across the three construction methods examined show that on a materials-only basis the mass timber had the highest cost. However, once Preliminary & General were factored in, all-concrete options were the most expensive. When the development impacts of the shorter construction programme were taken into account, the mass timber options became the least expensive by 6% compared to concrete and steel and 13% compared to the all-concrete option.

The development items are made up of the following being applied to each week saved or delayed:

- Market Risk – Adverse property market move risk of 5%/year on a $18m value development
- Carrying cost impact – Carry cost of $3m land, design/consent fees $2m and head office overheads $1m. Total $6m at 5%.
- Completion settlement/redeploy profit – Assume developer re-deploys $2.7 (15%) profit in their next development worth $6.75m at 15% profit in the next year.

It is important to note that development costs will be subject to the developers' own financing model, capital & investment structure, and contractual exposure to market risk. The referenced figures are based on internal calculations for this project provided by Clearwater Development Ltd

## The length of time it takes to build a mass timber build compared to concrete and steel, and where savings can be made

Every project has different infrastructures and demands on programme deliverables. Preliminary & General items will usually include project costs that will not physically be left on site, e.g. professional supervision, site fencing, utility costs, insurance etc. On a typical medium sized contract of $10m, the expectation would be for a $30,000 monthly average spend on preliminary and general.

For this project, the Clearwater Quay's construction manager developed alternative delivery programmes for steel & concrete and full concrete structures, and compared these with the known mass-timber programme. (It is worth noting here that the construction manager's background and experience prior to this project had been in traditional building methods, and no allowance was made within the mass-timber programme for efficiencies associated with the learning curve required or lessons and skills attained).

The results of the comparison show that the mass-timber build had a programme saving of 2.5 months. These 2.5

months were saved during what would have been the critical frame-installation process where costs exceeded the average $30k spend and were closer to $70k. Theoretically, savings during this period would have been $175k when compared with an alternative build method.

Less time on site has many positive benefits in addition the financial benefits discussed above. Using mass-timber construction for the Clearwater Quays project has reduced disruption to neighbouring properties and generated interest that has resulted in positive engagement with the local community. Contractors working on site have noted the positive effects of a cleaner site and floors, reduced construction risk and an enclosed weathered environment earlier in the programme.

In summary, mass-timber builds can be cost effective when compared with other construction method but many factors need consideration to ensure comparisons are fair.

# CONSTRUCTION

## 11. FABRICATION AND INSTALLATION

### Design & Architecture

A much greater level of specific detailing was required by the timber fabricators than architects would usually supply in terms of construction drawings for more traditional concrete or steel structures. Therefore, architects need to be aware of the extra detailing required, especially for those working in the mass-timber construction for the first time. This extra detailing can be described as a ‘fabrication stage’, after the detailed design and tender phase, but before construction. The level of detail and tolerances required in the production of the timber components and who is the best party at this stage to specify and communicate critical information to the construction team mean that the fabrication stage will take extra time and will offset gains made from a shorter on-site construction phase due to the prefabricated nature of mass-timber construction.

The following lessons have been learnt as a result of the Clearwater Quays project:

- It is important for key parties to agree the level of BIM modelling appropriate for a project, who should control the BIM model, and if or when it should pass over to the contractor to allow them to work directly with their fabricators and subcontractors to prescribe the tolerances they require.

- Using the term 'Early Contractor Involvement' (ECI) understates the level of participation required early in mass-timber construction project. The term 'Early Contractor Engagement' (ECE) better describes the process, as the construction team and contractors must become part of the design team alongside the architectural, engineering consultants earlier in the process.

- The speed, efficiency and accuracy of making all penetrations to mass-timber panels in the manufacturing process mean that planning among the construction team must be undertaken to ensure worker safety by avoiding penetrations becoming undue risks of tripping. Planning is also important for managing rainwater ingress and egress during construction.

- For mass-timber panel construction, planning is required for the on-site storage and stacking of materials. One approach is to create smaller broken-up packs with spacers inserted to allow air movement and for strops to be pulled through. For wood-component logistics, a balance needs to be achieved between truck capacity and the number of loads required. Sometimes more smaller loads to site can provide a quicker turn around for installation and possible elimination of double handling than fewer larger loads.

Moving forward, there needs to be better engagement and communication between mass-timber fabricators and the on-site construction team. Time also needs to be invested into planning the logistics around the protection and transportation of timber materials on site prior to installation to avoid  problems due to lack of communication and preparation for on-site panel storage and ventilation.


TIMBERLAB
NATURE ENGINEERED
CRATE 7
CRATE 3
CLEAR WATER
JOB 954
CRATE 3

## Construction

The Clearwater Quays structure consists of prefabricated LVL moment-resisting frames, prefabricated light timber-framed (LTF) walls, curved glulam columns and cross-laminated timber (CLT) floors.

Because multiple suppliers were involved in delivering the project, careful 3D BIM co-ordination was required between all parties at an early stage to ensure accurate detailing. Each supplier worked from the same modelling software, which enabled accurate sharing of 3D models for drafting and co-ordination.

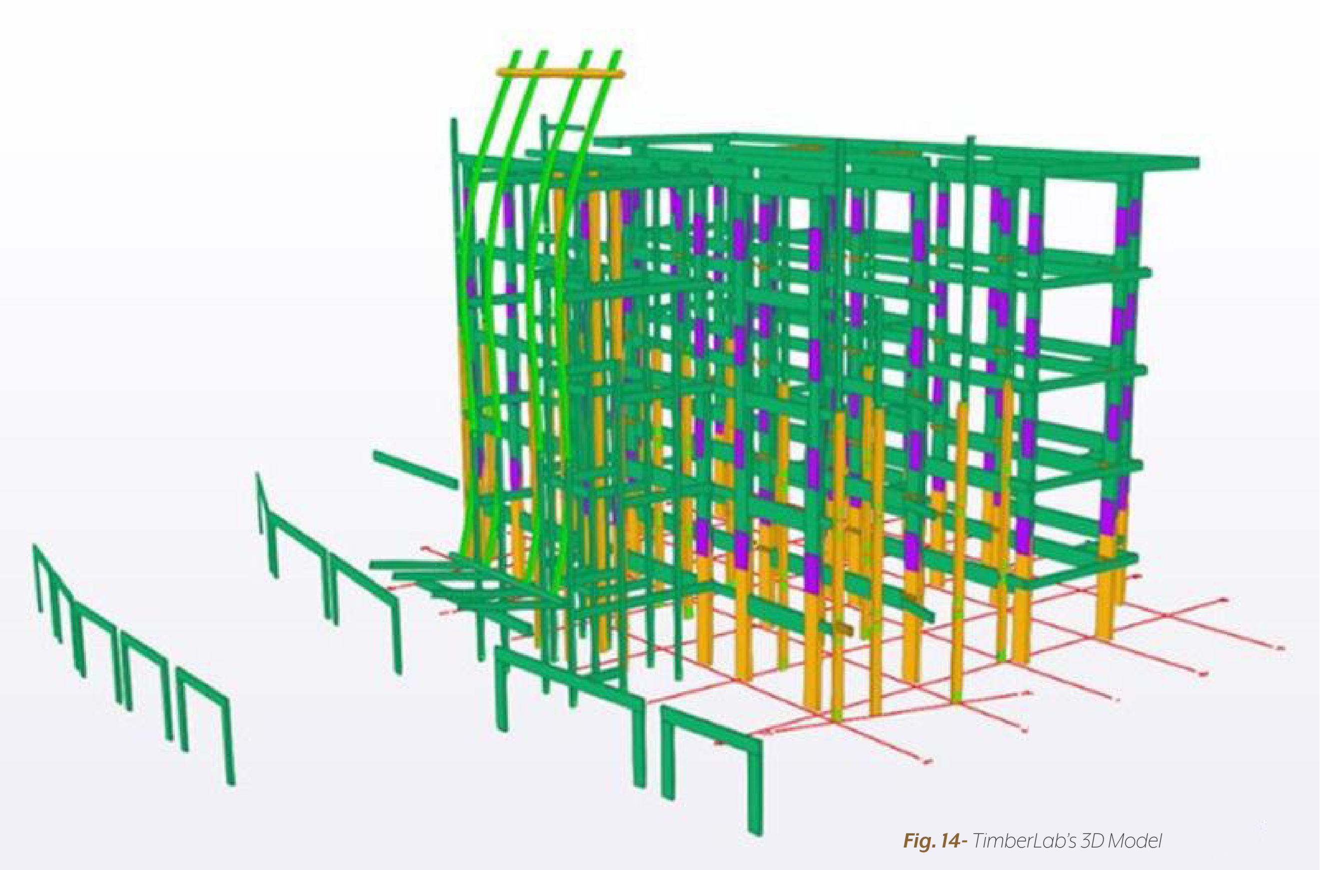


***Fig. 14***- *TimberLab's 3D Model*

Files from the 3D digital model were transferred to the computer numerical control (CNC) machining centres to accurately complete all the cutting, drilling and shaping to suit connections and interfaces with other products. The efficiency of digital fabrication becomes apparent in projects such as this where several suppliers need to work from the same centralised BIM model.

The building structure relies on the LVL moment frames to provide the full lateral load resisting system across the building. Given the high seismic requirements of Christchurch, the frames needed to be designed with ductility in mind which resulted in complex connections at the beam/column joints. To save time on site, LVL prefabrication was undertaken by TimberLab Solutions Ltd in Auckland to fabricate all the complex connections in a controlled and efficient environment. The frames were supplied to site as ‘H-frames’ with a simple connection splice required on site at each mid-height column joint. H-frames were delivered to site in sizes up to 11.8 m long x 4.1 m wide.

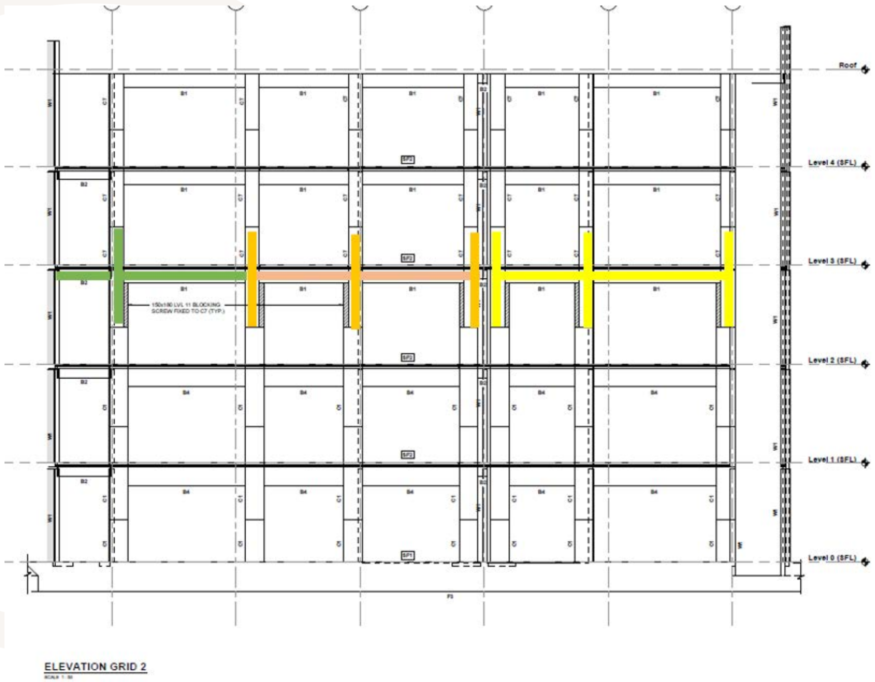


**Fig. 15-** *H-Frames Supplied by TimberLab*

**Fig. 16 -** *H-Frames Supplied by TimberLab*

Because this is a showcase timber building, the visual quality of the structural timber components was an important aspect in the design consideration. As expected, some of the structural details changed the finish of some exposed members as the physical build progressed so the finishing of these had to be reassessed.

All bolts were counter-sunk, plugged with timber to create the required fire char resistance and then sanded to a high aesthetic finish in the factory prior to delivery. Assembly on site highlighted that these units and the plugging of bolt holes could have been left exposed for intumescent painting. Although they were intumescent painted on site, this process could also have been done in the factory to save time on site.

***Fig. 17 -*** *Bolt holes plugged with timber and sanded to an architectural finish in the TimberLab factory*

All TimberLab elements were CNC processed to millimetre accuracy, packed in specific order and carefully co-ordinated with other suppliers before being freighted from the Auckland factory.

Careful attention to detail was required with crating protection and packing order due to the size of the prefabricated H-frames.

***Fig. 18 -*** *One of Five Truck Loads Delivering TimberLab H-Frames*

## Fabrication and Installation Continued

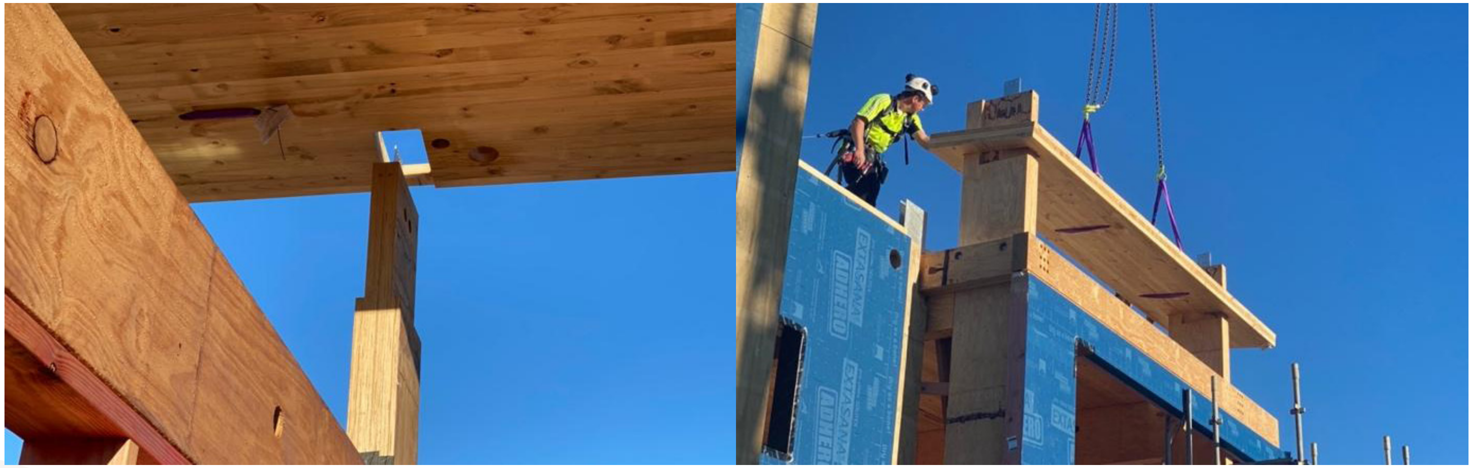


***Fig. 19-*** *Installation of TimberLab H-Frames and floors*

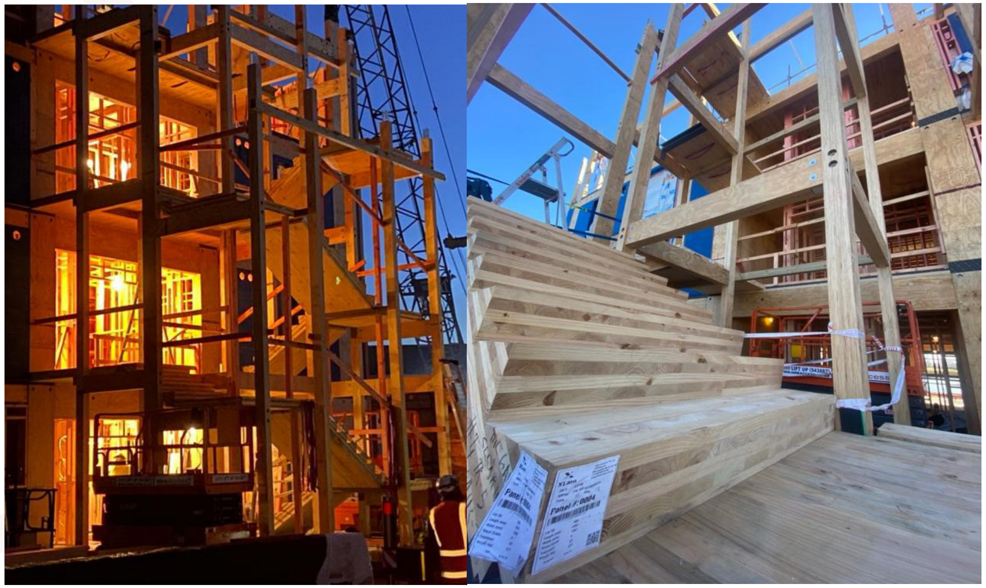


***Fig. 20 -*** *Installation of Timber stairwell*

The stairwell structure was designed to visually expose all timber elements and to emphasise the natural beauty of mass-timber architecture. Curved glulam columns were detailed to the back of the stairwell to provide an elegant entrance façade to the building. The columns had to be carefully detailed to ensure ease of construction and to accurately interface with connections.

After pressing the curved columns, TimberLab CNC machined the profile to ensure they were perfectly dimensioned.

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> *“Incorporating factory prefabrication meant that significant time was saved on site.”*

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Incorporating factory prefabrication meant that significant time was saved on site. The LVL H-frames were very quick to install with one level taking 1.5 days to erect and another 2–3 days to finish screwing off the stitch joints. The CLT floor slabs were also very easy to install taking only 5 hours to install one level. Each floor (LVL frames, CLT floors and LTF walls) were installed on average every 13 days, with the fastest taking only 11 days. This type of construction is not only quicker than steel & concrete but also much easier and cleaner to work with. A significant benefit to a mass-timber build is the ability to continue construction directly below the erected floors. Saving time on site has significant commercial advantages including lower financial holding costs, lower market risk, and lower preliminary and general overheads. When considering these advantages, the use of mass timber for the Clearwater Quays project has proven to be more cost effective than an equivalent steel or concrete structure.

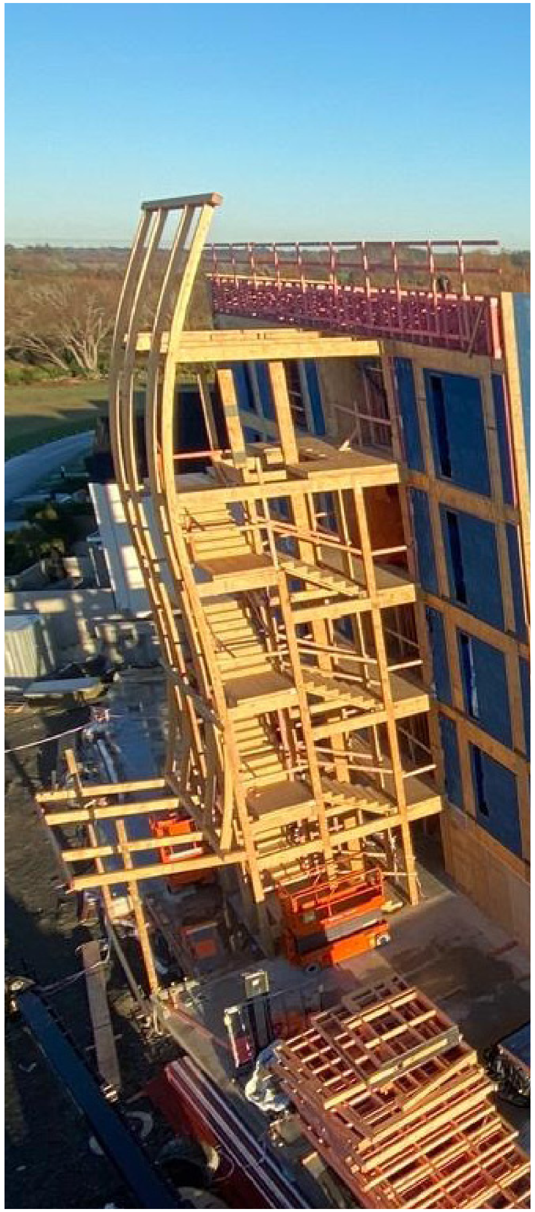


***Fig. 21 -*** *Curved Glulam Column Being Installed*

Advantages of mass-timber construction over steel & concrete:

- No internal scaffolding or back propping
- No curing
- No curing down time
- No reinforcing placers
- No concrete, pumping or finishing
- Not weather dependant for rain, only wind to watch out for
- No core drilling
- No mess or waste
- No noise
- No pre-pour inspections
- Fewer H&S requirements and fundamentally safer
- Fewer workers required
- Light weight construction so only lightweight gear is required

## 12. ENVIRONMENTAL IMPACT ANALYSIS AND $CO_2$ CALCULATOR

### Design & Architecture

The most sustainable aspect of the building is the carbon sink of the building's structure.

The living spaces are heated via reverse-cycle heat pumps, negating the need for a central heating system. Natural ventilation has been used for cooling in lieu of an artificial system and trickle vents were also introduced to provide make-up air (with acoustic baffles to control exterior noise). Low-E glass was originally to be used just for the bay windows as these have the greatest potential for over-heating, but following an upgrade from the glass supplier, all windows will now be double-glazed. Low E. Solar panels will supply the electricity demand to the majority of the common area (lobby and stairwell).

### Environmental benefits

The Clearwater Quays project promotes environmental benefits in serval different processes. These include:

**Carbon** – the processes of manufacturing building materials such as concrete and steel produce far more carbon than mass timber. In fact, there is more carbon already efficiently and safely stored within the timber material than produced during manufacture.

Mass timber is a carbon-negative material so using it results in carbon being extracted from the atmosphere and stored in the building material. That carbon storage can off-set the impact from other materials used in the building process, such as steel fixings, cladding systems and foundations.

**Wastage** – lean construction and minimal waste is synonymous with off-site construction. The core structure of the Clearwater Quays Apartments can be categorised into three main elements: (1) CLT floors replace concrete and steel floors; (2) structural steel is replaced with LVL columns and beams to support these floors; and (3) there are the panelised/prefabricated timber frames. These components have all been manufactured off site in controlled manufacturing environments that utilise technology to control and minimise wastage, which substantially reduced on-site waste output. The Clearwater Quays site was was striving to be as close to zero-waste as practicable with all material being sorted before leaving site. Materials that could be recycled were diverted to the correct facilities.

The use of a QS 3D BIM cost model added significant value in this area. The model not only replicated the construction build and every element, it also accurately quantified every piece of timber, every bolt and tape etc. The model contained information on material specifications, such as sheet sizes, timber supply lengths etc so was able to provide accurate order quantities by unit supply and could produce cutting lists for trades. This process provided key site performance information that encouraged efficient material ordering and use on site.

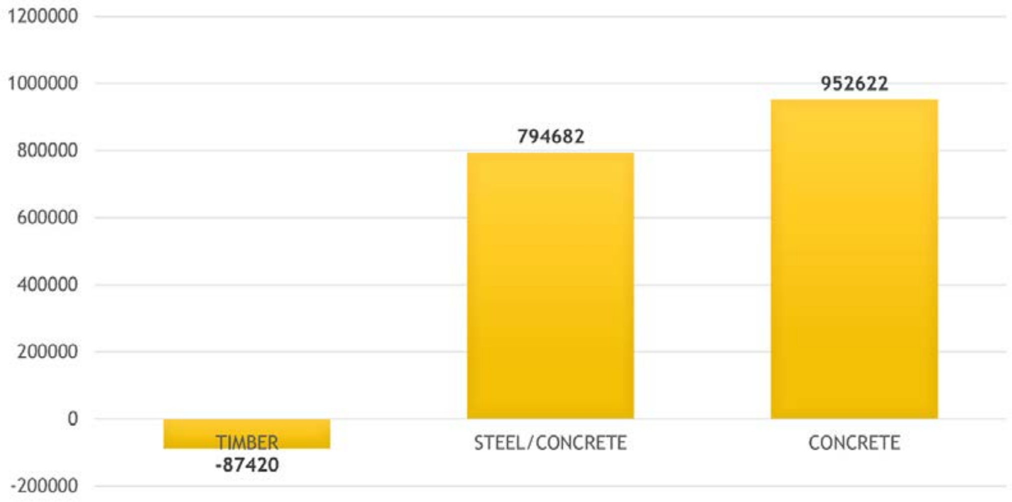
**Traffic** – Most heavy traffic on site was generated from the movement of material. The biggest saving to time and cost of a mass-timber build is through the use of CLT floors, but this has other positive benefits too. Construction of a concrete suspended floor requires delivery and install of several individual elements. These include steel decks, timber formwork, steel reinforcing, and of course concrete. All this requires multiple truck deliveries arriving and moving on site. A typical CLT floor level at Clearwater Quays can be delivered to site and installed in less than one day.

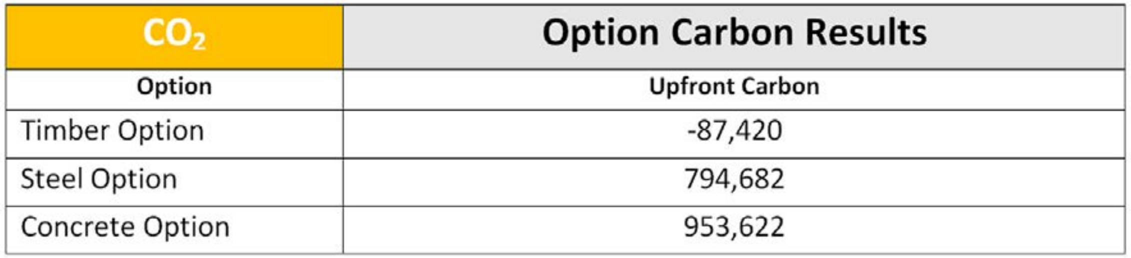
## CARBON CALCULATION

As discussed above, alternative design methodologies were completed for concrete and steel construction. Using BIM 5D Cost modelling technology, the QS team explored various build options and demonstrated some significant findings regarding carbon footprints. The metadata now stored in the 3D geometry is typically used for cost calculation, but also contains embodied carbon data. Carbon calculation is becoming a major consideration in building projects and can now be automated allowing for quicker and more flexible comparisons across build options. The results allow the client to understand the environmental impacts of their materials choices in conjunction with cost data allowing for more informed decision making.

This system has been refined in house and automated for completing carbon calculation assessment at feasibility/concept design stage. The models can be generated quickly by focusing on the variable core structures only, while the advanced parametric capability allows for quick conversion to the alternative material choice. Live data feedback with referenceable 3D-model information allows for in-depth analysis of different building and elemental options. which facilitates identifying and understanding the sweet spots between cost and carbon results in cost effective sustainable buildings.

For the Clearwater Quays project, the carbon calculation for the mass-timber building was nett negative 87,500 kilograms. If the building were to be built in traditional steel & concrete , it would have resulted in 800,000 kilograms of carbon being released into the atmosphere, and over 950,000 kilograms of carbon if concrete alone had been used.





| CO$_2$ | Option Carbon Results |
|---|---|
| **Option** | **Upfront Carbon** |
| Timber Option | -87,420 |
| Steel Option | 794,682 |
| Concrete Option | 953,622 |

***Fig. 22 -*** *Carbon released into the atmosphere for Timber, Steel and Concrete builds*

## 13. PROJECT LESSONS LEARNT

### Design & Architecture

Working closely with the structural engineer at the start of the project means that the design process becomes more holistic and symbiotic, whereby innovative structural solutions can help inform design. Ideally this collaboration would extend further with all design consultants, by engaging a contractor early on to facilitate a truly integrated design process.

Many mass-timber construction advocates promote the advantages of a shorter construction programme. This relates to actual construction time on site. However, time in the design process needs to account for the need to produce more detailed construction drawings. With earlier provision of more detailed design documents then the shop drawing process would be as per traditional contract procedures and be part of the contractor's tender.

The design and manufacture of this type of building and material at this stage of its development in the industry is too specialised to allow any subcontractor to just put their design around it. It needs to be designed using early contactor engagement and then tendered.

### Construction

There is no doubt that competitive supply options in the market place mean that mass-timber buildings have a place in today's construction environment and will become more and more popular as they become more main stream. This is the way of the future. There is  still a lot to learn, but good transparency and sharing of information will help.

Lessons Learnt:

- Put the team together from conception
- Design/Manufacture/Protection/Stacking/Transportation
- Site set out/handling on site/installation sequencing - The base plate connections to concrete floors are areas that need extra attention paid to.
- Gear/lightweight propping/specialised tooling and gear
- Correct Gear – Specific impact drivers, drills and batteries are required.
- Specialist fixing suppliers.

- Factory environment - More can be done in the factory environment to reduce time on site like intumescent paint, spring washers or lock nuts. All pre-torqued.
- Lifting plan for LVL ‘H frames’ - There should always be a lifting plan in place for all mass-timber projects. Although mass timber is relatively lightweight (20% the weight of concrete), the elements are still very heavy. When lifting frames, care must also be taken to have a lifting plan that avoids any twisting as the connections are generally weak in the out-of-plane orientation. The Clearwater Quays project team would always recommend an engineered solution for lifting elements on a building site.

LEARNINGS

## 14. RISK MANAGEMENT

Quality Risk – With a lower tolerance, the product is inherently better quality. In addition, if the product is designed well, as it is coming directly from a factory environment, the quality of the product should be extremely high. Therefore, the main risk is not being able to maintain the same tolerance and quality during the on-site erection. Another risk is not being able to protect the product properly once it arrives on site, which this could result in potential product damage.

- Dimensions – A high degree of accuracy is required from manufacturing to the site set out and foundations. The product is millimetres accurate, so the site team need to have a very high level of attention to detail.

- Construction site:
    - With this type of construction, it lends itself to “just in time” deliveries but there needs to be caution around this approach as there are industry supply issues for the foreseeable future.
    - The erection time is much quicker than for steel & concrete so all suppliers must be able to keep up with the faster speed of the build.
    - Health and safety requirements are less overall as there are fewer trades involved and minimum men required on install.
- Weather exposure – Better protection and temporary wrap needs to be sourced.

To move forward, the industry needs to invest in the protection of mass-timber materials as some fundamental challenges were identified during this project. Where mass timber members are tight-wrapped, a breathable wrap material that can be left on the product for long periods of time would be preferable, regardless of whether or not it is being stored under cover or erected on site. Plastic wraps sweat, and they have to be opened to allow air ventilation. For the Clearwater Quays project, the plastic wrapping was opened to form a rain protecting canopy and to allow the material to breath.

- Logistical Risks – With materials coming from between the North and South Islands, there is always a risk with transportation. Any hold ups can prove not only costly on site but the knock-on effects with other suppliers and storage can also be difficult and costly.

- Supplier capacity – SPAX screws need to be resourced very early on as there is only a limited supply in New Zealand and Australia. Storage and transportation of goods are very costly.

- Packaging order – As mentioned above, there is more work required from the industry around protection, packing and transportation.

- Financial Risk – There is potentially more cost and time required up front, however this is outweighed by shorter consenting and construction times. Comprehensively detailed documentation should result in more contractors not being intimidated by a different type of construction, which should be reflective in their pricing.

- Certification and approval – There are no differences between a mass-timber build and a traditional build.

- Delays and Variations – With comprehensive, detailed documentation, there will be fewer delays and variations. This type of construction lends itself to easier problem solving as the timber fabricators working with the construction team can come up with very effective solutions to put in front of the consultants.


SMITH

## 15. FREQUENTLY ASKED QUESTIONS

### How difficult is it to get building permission for mass-timber buildings?

The consenting process for the Clearwater Quays project was relatively straight forward. The design of CLT is out of scope of the verification method of NZS 3603:1992[1], so the CLT Handbook, prepared by FPInnovations[2], was used to provide support for the design and construction of CLT as an alternative solution, as well as to provide technical information and structural analysis methods for CLT. Long before the consenting application, a pre-application meeting was held between key designers and key council staff to set expectations and to open up communication channels. For this particular project, the council staff have been proactive in learning about the system, including by attending the open days.

To date, the Council inspections have been as per any other project.

### Can noise transfer risks be eliminated for multi-residential occupancies?

Yes, noise transfer risks can be mitigated for multi-residential occupancies by implementing the following:

**Wall linings:** Wall linings, such as plasterboard, over an air gap are required to reduce the direct sound transmission through walls. As this can clash with architectural desires to expose the natural beauty of timber, it is important to plan carefully, so that some direct exposure is still achievable.

**Resilient materials**: Close cooperation between the structural and acoustic designs is required to achieve optimal outcomes so that sound transmission paths are interrupted by resilient materials, or that such paths are shielded by wall or floor linings. Various types of wall/floor junctions can block or attenuate sound transmission.

**Floating floor**: A floating floor is required on top of the CLT floor plate to reduce both the impact sound to the apartment below, and the flanking sound to the adjacent apartment.

**Suspended ceiling**: A suspended ceiling also provides sound insulation not only in the vertical direction but also reduces flanking sound horizontally.

### How does the design tackle fire concerns?

It proved impossible to use timber cladding up the entire height of the tower due to fire/spread of flame restrictions. Instead, the Clearwater Quays project opted to use Vulcan timber cladding from Abodo within the deck/balcony areas with CLT floors acting as the fire separation, and for the ground-level garaging and separate garages. The remainder of the wall cladding was extruded aluminium Dualbord and Euro-suite Flashclad products from Flashman Flashing Systems installed in both vertical and horizontal orientations.

As required by NZBC and the Fire Engineering Report, the suspended CLT floors were required to be fire rated for 30 minutes for a fire-sprinklered apartment. The required fire resistance rating for the intertenancy floors was achieved by the fire-test data from the CLT manufacturer.

LVL beams and columns were designed for charring to support the floor during the fire load case. Bolts that were used to transfer the vertical shear from the beam into the column for the fire load case were countersunk up to steel internal gusset with a 30-mm ply plug and were therefore protected from charring of the timber. A 25-mm min plywood sacrificial layer was also provided around the bottom edges of the steel gusset to prevent heating during a fire. Where edges were exposed and not protected from charring, they were intumescent coated.

### How does the design tackle moisture concerns?

The external envelope for the Clearwater Quays project was designed to ensure a weathertight system keeping the internal space dry and free from external moisture.

The principle of the aluminium clad façade system was that of a sealed system with a drained cavity. The sealed system (Rigid Air Barrier and Adhesive Wrap) is a solar-sensitive product, so was overclad with an aluminium rain screen to provide protection to the Rigid Air Barrier and Adhesive Wrap. The aluminium rain screen also provides a cavity to the sealed system, that allows for wind-driven rain to get into the system, but also to let it safely drain out without compromising the sealed line. This is in line with good-practice principles used by the industry to prevent water from entering the internal spaces.

Aluminium is a product which is inherently durable and widely used in the industry. It includes bespoke jamb head and sill flashings around the windows to carry the principle of a drained cavity described above through the windows. These have been tested to AS/NZS4284 to ensure they are suitable for use in high-rise spaces.

The fixings of the façade elements were specified to be stainless steel to ensure that they are compatible with the timber substrate and are resistant to rust and corrosion so that the overall system meets load and structural capacity requirements.

### What does it cost compared to concrete and steel?

For the Clearwater Quays project, initial comparisons across the three construction methods (timber, steel & concrete, and concrete) examined showed that using a mass-timber method will cost 5% more than steel & concrete when the build cost is considered in isolation. However, this extra cost drops to 1.5%when programme and P&G savings are added. When realised development costs are added, mass timber construction offers a saving of 2.4% over steel & concrete or concrete methods alone.

### Is a mass-timber build faster than a traditional build?

For the Clearwater Quays project, the mass-timber build had a saving of 2.5 months compared with steel & concrete. These 2.5 months were saved during what would have been the critical frame-installation process where costs were close to $70k a month. Theoretically, savings during this period would have been $175k when compared with a traditional build.

### How does wood compare environmentally?

For the Clearwater Quays project, the carbon calculator for the mass-timber building was a nett negative 87,500 kilograms. If the building were to be built in traditional steel & concrete, it would have resulted in 800,000 kilograms of carbon being released into the atmosphere, and over 950,000 kilograms of carbon if concrete alone had been used.

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**Mid-Rise Wood Construction:** https://midrisewood.co.nz/ **WPMA:** https://www.wpma.org.nz/timber-design-guides.html

## 17. TECHNICAL CONTENT

### 1.1. Civil

There were no significant differences between civil engineering for the mass-timber build and the traditional steel & concrete build options modelled. However, had the ground quality not been as good as this particular site, piles would have been required for the traditional materials due to the heavier weight. As the water table was low here, this would have compounded the additional cost of the piles.

### 1.2. Structural Design/Seismic Performance

The ground floor consists of garages/service rooms, an access stairwell/lift and two apartments (separated by an intertenancy wall). The apartment layouts on the ground floor differ from the floors above due to the inclusion of access doorways/ corridors to the garages and the addition of another bedroom to the western apartment. Levels 2, 3, 4 and 5 consist two apartments each and the access stairwell/lift.

The rooftop services area is accessible through ceiling hatches. The floor area (including walls, excluding decks, common/service areas or garages) is approximately 297m$^2$ at the ground floor and 267m$^2$ for Levels 2 to 5.

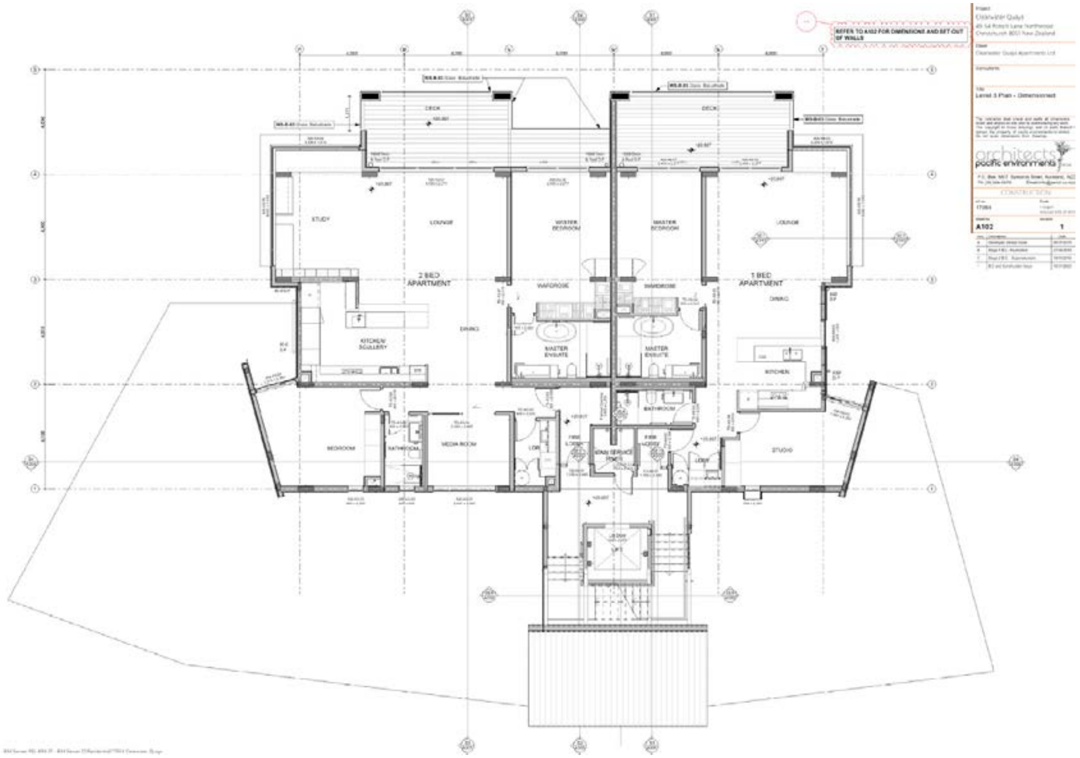


*Fig. 23 - Typical layout of apartments (Levels 2 to 5)*

## Design & Architecture

The Clearwater Quays Apartments have a structural system that works to dissipate seismic energy. Designed under the guidance of structural engineers from Enovate, the methodology of the structure is a system of seismic 'H-frame' LVL portals and beams, which provide bracing in the east–west direction whilst bracing is provided by the plywood-lined LTF bracing walls in the north–south direction.

The building sits on a raft foundation with a thick compacted gravel base that will help to limit any liquefaction. A CLT slab was considered for the roof structure but timber trusses were chosen (to reduce cost) with rafters over the stairwell to gain additional presence and height. Steel-splice joints were used to join the timber H-frames together and anchor them to the floor slab.

## ENGINEERING

### Site Foundations

The foundation system for the structure comprises of a grillage of shallow concrete foundation beams supported on a 1200mm and 600-mm thick reinforced gravel raft. These beams are 950 mm in depth and ranges in width from 800-mm to 1200-mm.

Due to close proximity of the building to the edge of the lake, protection of the lake edge against slope instability was required. This was to ensure that there is an acceptable factor of safety under static conditions and limited lateral movement under seismic conditions. The geotechnical engineer presented a couple of options for the protection of the lake edge. One option considered was to construct a 1.4-m thick reinforced gravel raft extending 10-m beyond the northern most foundation beam. However, this option would have required dewatering which would have likely been challenging for the highly permeable gravels with potential high dewatering costs. The second option was a buried timber retaining wall along the northern boundary. The latter option was adopted.

## Structural System

The structure consists of four levels of CLT floor, LTF trusses, prefabricated panelised LTF timber walls and LVL moment resisting and gravity frames and shallow reinforced concrete foundations. This project incorporates an innovative LVL moment-resisting frame system, which enables a relatively open floor plan and views of the lake to the north of the site. On the southern side of the building is an access stairwell and lift. Stair flights and landings were constructed using CLT with the lift shaft walls being constructed using LTF walls. Stair flights and landings are supported on LVL beams and columns. The roof of the single-level garages consists of LTF purlins supported on prefabricated LTF walls. Fixings between timber elements are predominantly with steel brackets/cleats and steel fasteners (nails, bolts, screws and dowels). A separate garage structural and bin room is also located at the south.

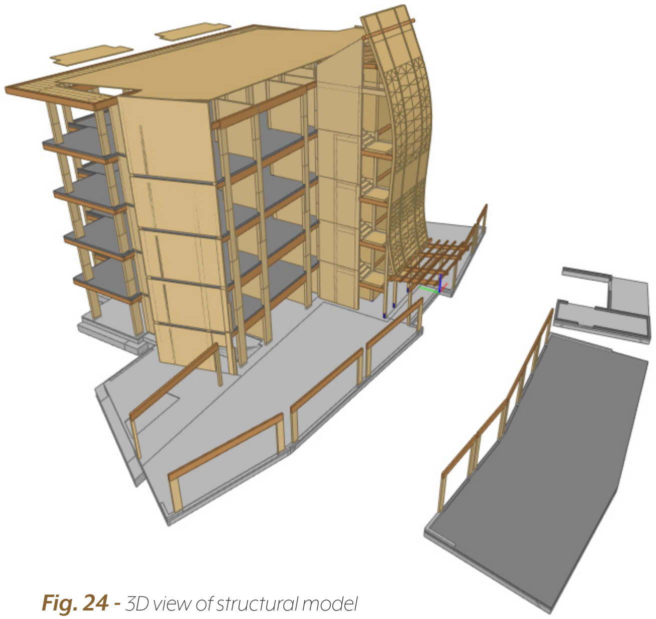


**Fig. 24 -** *3D view of structural model*

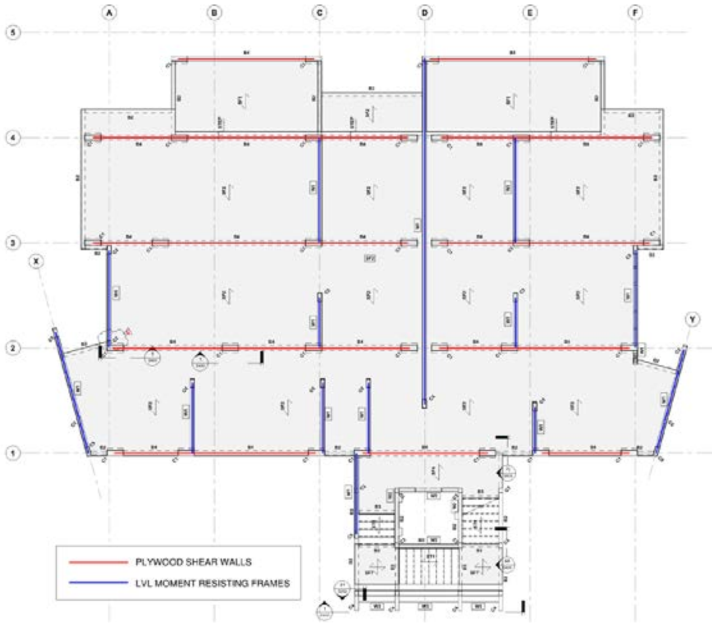


**Fig. 25 -** *Typical structural plan view showing structural system*

## LVL MOMENT RESISTING FRAMES

### Design Philosophy

In the east–west direction, the Lateral Load Resisting System (LLRS) are the LVL moment resisting portal frames. Tto enable a relatively open floor plan and views of the lake to the north of the site. As mentioned earlier, these also support the roof and floor of each level as gravity frames. 600 x 180 LVL11 beams and columns are adopted at the lower half of the building which transitions to 450 x180 LVL11 in the upper half of the building. The design of these moment resisting frames was governed by ULS (Ultimate Limit State) seismic loads.

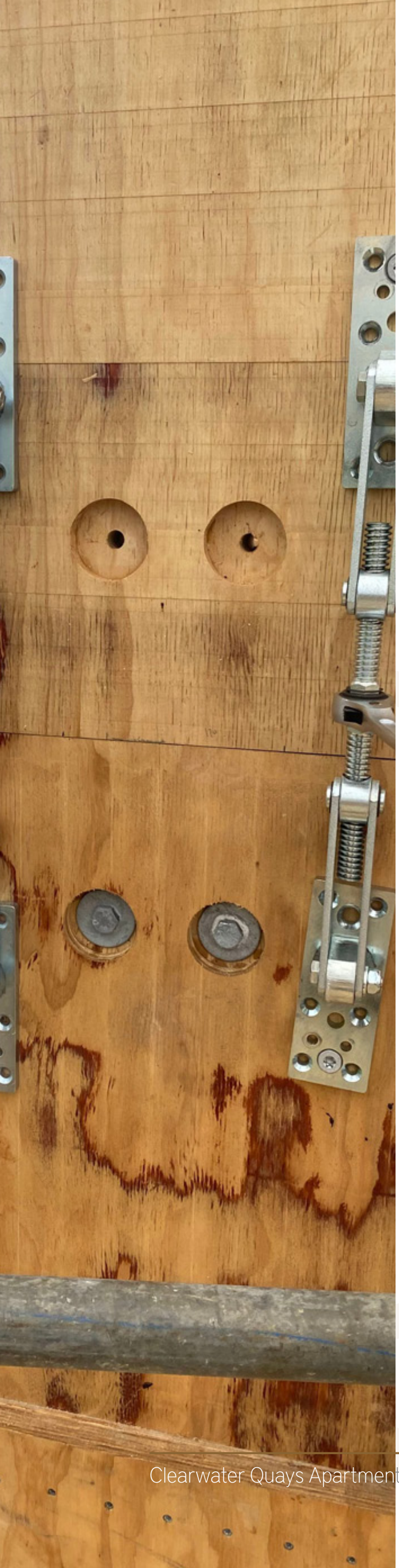
### DfMA

Designing for Manufacturing and Assembly (DfMA) is a process in which discrete sections of a building are fabricated in the factory before arriving on site[4]. It considers the optimisation of off-site manufacturing of elements and on-site assembly of elements.

Prefabricated structural systems are quick to assemble on site, which can significantly reduce the overall construction program and labour costs. In addition, health and safety risks can be greatly reduced with a cleaner site and fewer people and fewer hazardous trades on site.

From a design perspective, these moment resisting frames are designed as H frames in which the portal columns are spliced at every floor at mid height (with the exception of the ground floor being a full height column to the first floor). The size of the largest H frame is approximately 12 m in length and around 3.1 m in height, and were manufactured with computer numerical control (CNC) precision and assembled in the factory. These were lifted in place and

***Fig. 26 -*** *Photo showing first two levels of H frames*



propped at each level with the column splice connection constructed on site.

The splice connection detail at mid-height was originally designed as a pinned connection. This was later revised to a moment-resisting connection during the peer review process. This is due to the second order moments that are generated when the moment frames follow the deflected shape of the plywood shear walls in the north–south direction and the potential for axial load eccentricities. From a review by the main contractor, feedback has been very positive noting that the splice is quick to install, at a good working height to erect and screw making it simple and safe for the site team. However, this design/detailing did add significant cost to the frame system and should be carefully considered by future designers.

One potential lesson learnt, is that continuous columns with steel-to-steel beam-column joint connections may result in a more cost-effective solution.

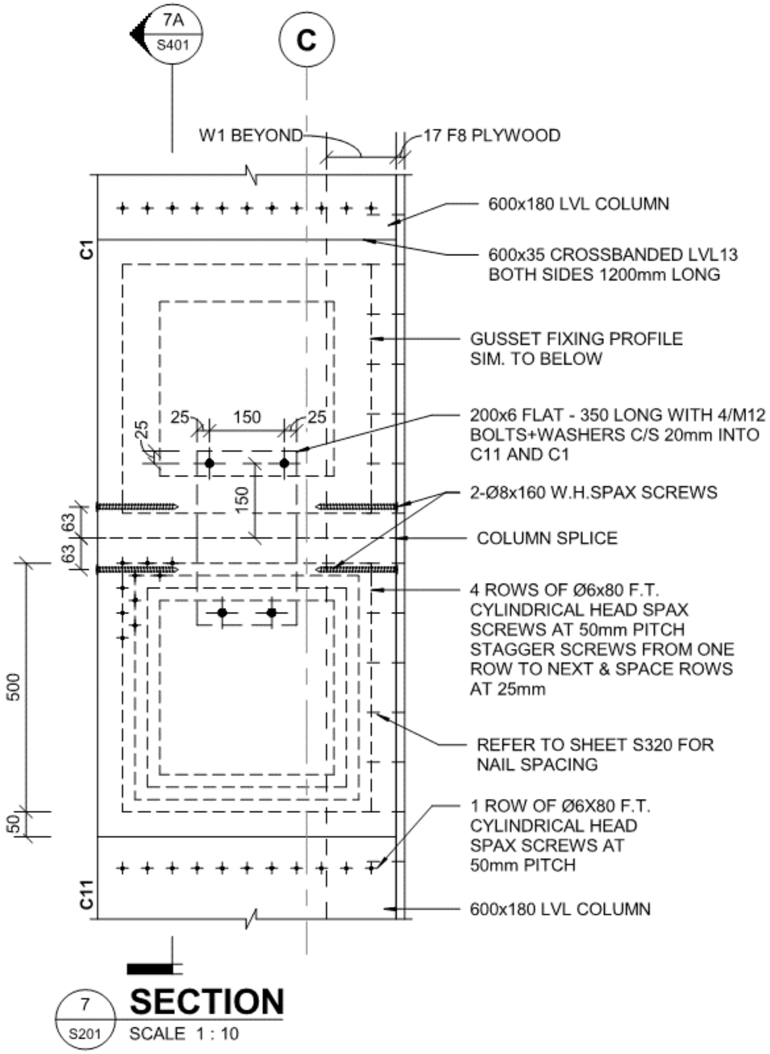


**Fig. 27 -** *Mid height splice connection detail for 600x270 portal column*

## Beam Column Joint

The beam-column joint consisted of two mild-steel 5mm gussets slotted inside the members connected by self-drilling SFS mild steel dowels. The use of self-drilling dowels allowed these to be installed without pre-drilling the steel gussets. Even though these dowels are fixed in the factory, more importantly they were selected due to their strength, stiffness and ductility capability[5]. These were designed to limited ductility (μ = 2) whilst all other components were designed to be capacity protected. Two rows of 7x173 SFS WS-T dowels were adopted with a pitch range of 100 to 150 centres. M16 and M20 bolts located within the gusset in the beam and column are primarily used to transfer the vertical shear from the beam to the column. Washer head SPAX screws are used to reinforce the joint to prevent splitting from tensile stresses perpendicular to the grain (in particular the corner dowels of the beam) when they are being mobilised.

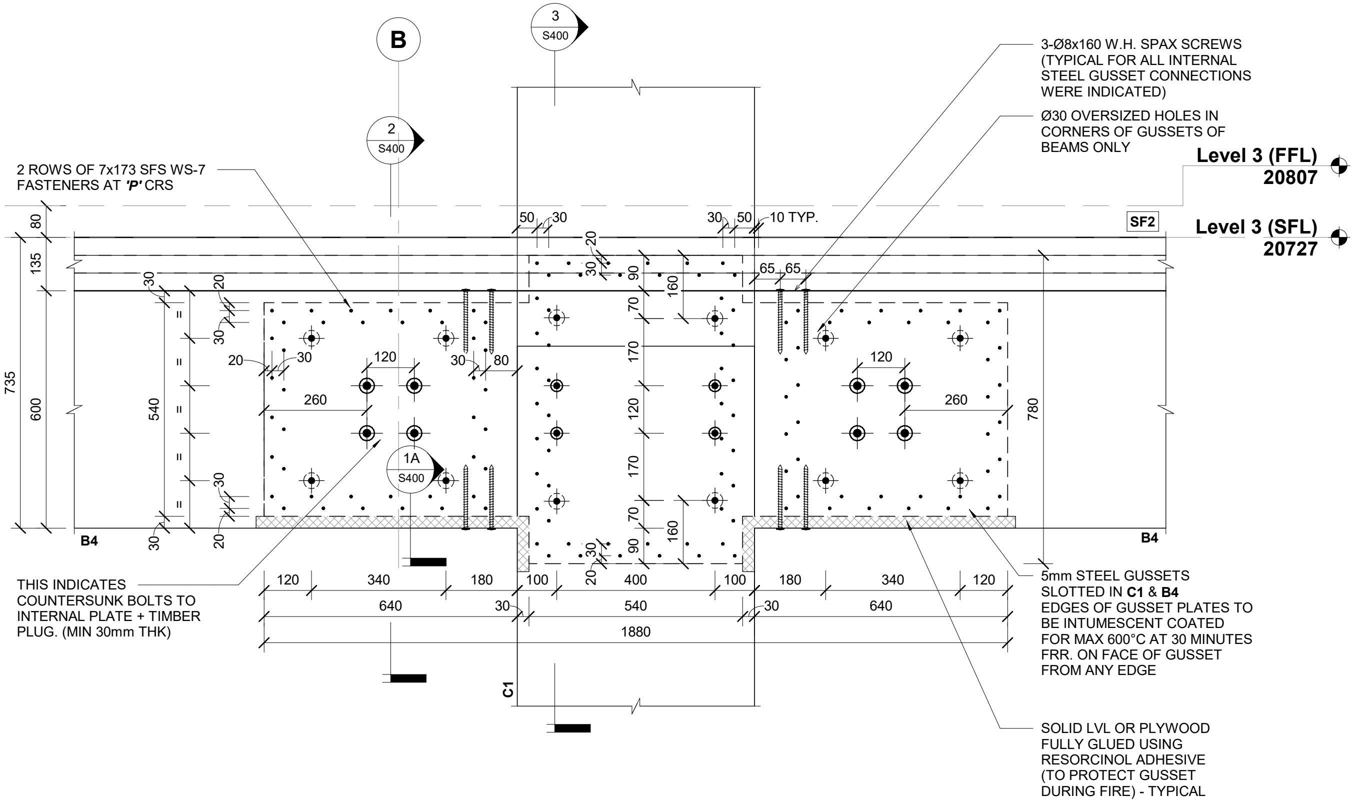


***Fig. 28*** *- Beam-column joint detail for 600x180 portal column*

Because there was no experimental test data to determine the over-strength factor for the self-drilling dowels for LVL moment resisting frames, an analytical derivation was used. The over-strength factor was derived analytically based on the ductile failure modes in the European yield model considering the variability of material properties and conservatism in semi- empirical embedment and dowel yield moment models[6]. Ultimately, it showed an over-strength factor of 1.6 was reasonable, which was then further verified by considering experimental testing [6] in similar connections. For design, an over-strength factor of 1.8

With the development of the post-tensioned timber buildings (Pres-Lam) being implemented in several buildings in New Zealand[7], the authors/designers felt such a system was not necessary for this project. This was because a damage avoidance design was not part of the client's brief. It was expected that the Pres-Lam system would result in higher costs and require specialist contractors. Further, the seismic performance/response of the frame system (as designed) is consistent with the ductile plywood shear walls in the other direction.

For future designers, it is recommended to avoid bolts where possible in this type of connection as the rebating is required to accommodate washers reduces the critical section of the timber significantly.

## 1.3. FLOOR AND WALL CONNECTIONS

### ENGINEERING

### Base Connection Detail

The base of the portal columns has been designed as fixed base to limit bending in the

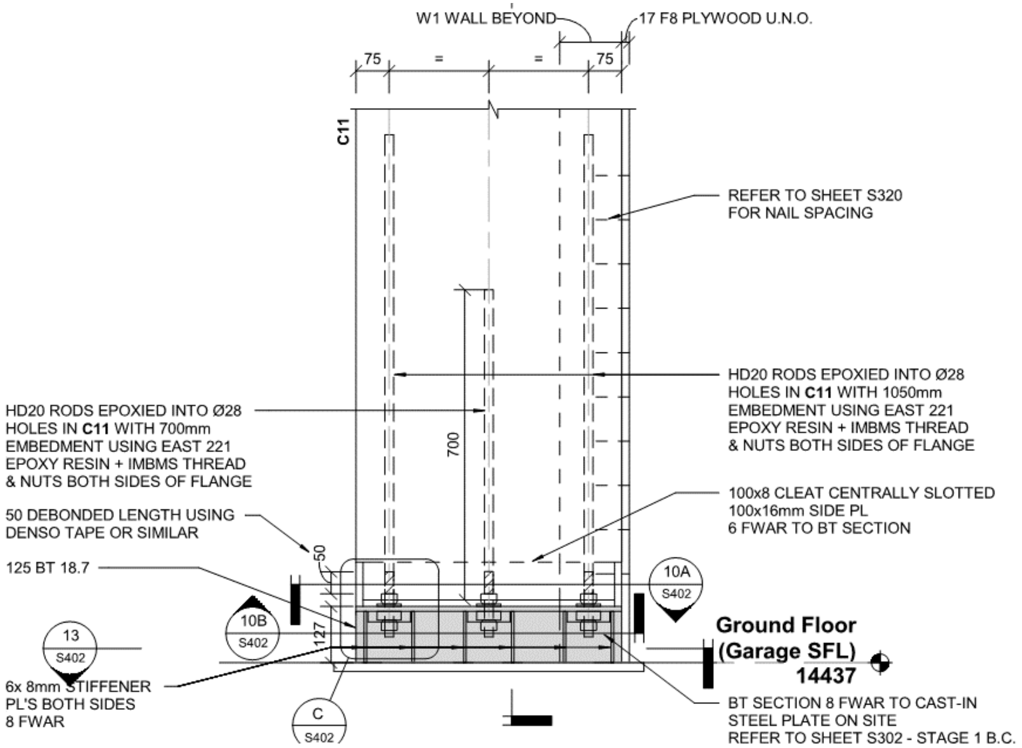


*Fig. 29- Portal column base connection detail*

***Fig. 30 -*** *Photo showing portal column base connection on site*

columns. The base connection consisted of deformed bars epoxied into the timber column, and bolted through the flange of a steel-hub T section at the base which are epoxied into the timber column. This connection is detailed as a two-part assembly in which the timber component (with epoxy rods) can be removed from the steel-hub. This allows the contractor to weld the steel-hub to the cast in plate before the timber is installed. Vertical tolerance is provided by steel shims being placed between the top flange of the steel-hub and bottom of the timber column. The horizontal tolerance is provided by welding the steel-hub on site onto the oversized cast in plate embedded into the foundation. These cast-in plates have 4/25mm Reidbars welded on with a flange nut at the bottom of each bar. The advice of using flange nuts as opposed to hooked bars was taken from lessons learnt from previous projects as it was difficult to install due to the heavy congestion of the reinforcement in the foundation beams. As the hold down bars are high strength grade 500, these were micro-alloy bars with welding done in the factory in accordance with AS/NZS 1554.3.

In future it may be simpler to use a column-base connection that is more consistent with the beam-column joint arrangement. This would limit out-of-plane deformation compatibility induced moments from developing.

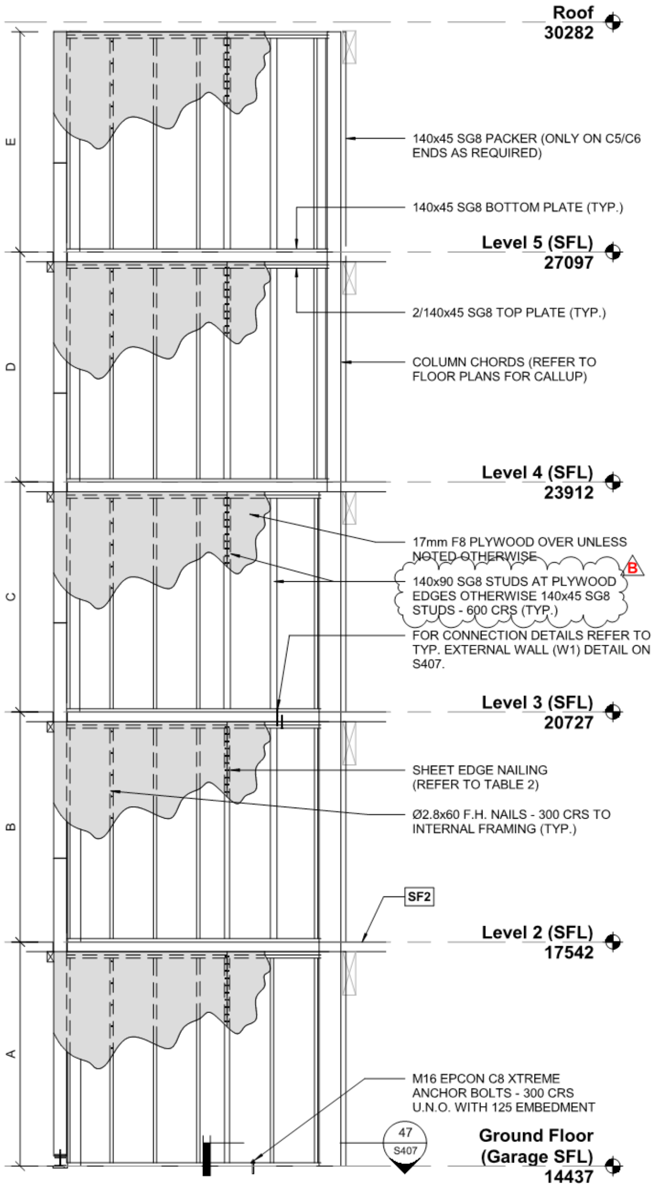


***Fig. 31-*** *Typical elevation of plywood shear wall*

## PLYWOOD SHEAR WALLS

### Design Philosophy

The LLRS in the north–south direction are the plywood shear walls. Plywood shear walls was selected as there was a considerable amount of walls available to be utilised in the north–south direction (IT and internal walls). They are designed for limited ductility (μ = 2) by considering the ductile yielding of nail connections between the plywood sheathing and LTF. All other components are capacity protected and designed for over-strength actions. An over-strength factor of 2.0 was considered in accordance with NZS 3603:19931. This design philosophy is consistent to the LVL moment resisting frames.

The chord members consist of 300x135 LVL13 at the lower 3 levels and 190x135 LVL11 at the upper two levels. These chords are spliced at each level on site using internal steel plates centrally slotted and fixed with self-drilling SFS dowels. The use of self-drilling dowels allowed the connection to be easily fixed on site whilst relaxing the required tolerance. All column chords bear onto one another at the splice location. This has been intentionally detailed to penetrate through the CLT floor to eliminate compression perpendicular to grain loading and effectively reducing the lateral displacements of the plywood shear walls. Some chords of the plywood shear walls also belong to the LVL portal frame columns. The hold downs for the chord members in the foundation beams are similar to that of the LVL portal columns.

***Fig. 32 -*** *Photo showing plywood shear wall in which the chords are the LVL portal columns*

It is noted that using a ductility any higher than 2.0 for these walls would have resulted in exceedance of the NZS1170.5 drift limits (even with very stiff chord details). Wider studs (90mm) are also adopted at plywood sheet joints, to achieve the edge/spacing requirements for the double row of nails.

## DfMA

The LTF walls have been pre-fabricated as panels by Concision. These panels consist of LVL and sawn timber wall framing and plywood sheathing plus additional finishes required for fire engineering, acoustic and architectural design (e.g. GIB Weatherline). These panels are constructed off site in the factory and assembled as panels on site. All non-structural partitions were also pre-fabricated in the factory.

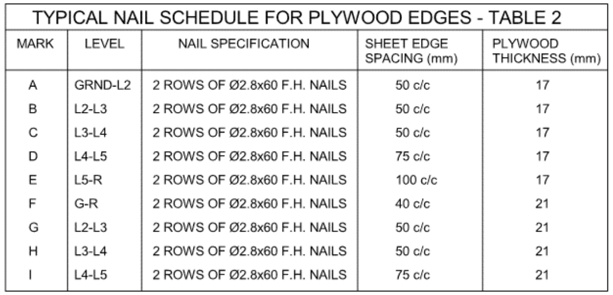
In regards to the plywood shear walls, the plywood sheathing is fixed in the factory with the plywood extending out onto the LVL chords to be nailed on site. The double rows of nails at the edges of the plywood sheets to the wall framing is nailed in the factory via CNC machining, guaranteeing accuracy and quality. This can reduce site time significantly as the double rows of nailing is quite labour intensive.

## CLT Stairs, Flights and Landings

The southern staircase and lift shaft is only connected to the main floor diaphragms on one side (Gridline 1). Typically, this form of structure would be braced using the CLT lift-shaft walls which would be tied into the main floor diaphragm. However, utilising CLT lift-shaft walls would result in a large stiffness/mass eccentricity in the east–west direction (due to the relative flexibility of the LVL moment-resisting frames and the CLT lift-shaft), which would result in a high torsional response. The diaphragm demand/detailing may also pose a challenge due to the limited amount of floor available to connect to the CLT lift-shaft walls.

An alternative approach would be to seismically isolate the CLT lift-shaft from the main structure. However, this would result in large differential

**Fig. 33 -** *Photo showing plywood sheet edge nailing*



TYPICAL NAIL SCHEDULE FOR PLYWOOD EDGES - TABLE 2

| MARK | LEVEL | NAIL SPECIFICATION | SHEET EDGE SPACING (mm) | PLYWOOD THICKNESS (mm) |
|---|---|---|---|---|
| A | GRND-L2 | 2 ROWS OF Ø2.8x60 F.H. NAILS | 50 c/c | 17 |
| B | L2-L3 | 2 ROWS OF Ø2.8x60 F.H. NAILS | 50 c/c | 17 |
| C | L3-L4 | 2 ROWS OF Ø2.8x60 F.H. NAILS | 50 c/c | 17 |
| D | L4-L5 | 2 ROWS OF Ø2.8x60 F.H. NAILS | 75 c/c | 17 |
| E | L5-R | 2 ROWS OF Ø2.8x60 F.H. NAILS | 100 c/c | 17 |
| F | G-R | 2 ROWS OF Ø2.8x60 F.H. NAILS | 40 c/c | 21 |
| G | L2-L3 | 2 ROWS OF Ø2.8x60 F.H. NAILS | 50 c/c | 21 |
| H | L3-L4 | 2 ROWS OF Ø2.8x60 F.H. NAILS | 50 c/c | 21 |
| I | L4-L5 | 2 ROWS OF Ø2.8x60 F.H. NAILS | 75 c/c | 21 |

**Fig. 34 -** *Nail schedule for plywood sheet edges*

deformations that need to be accommodated across seismic isolation joints and may compromise weathertightness (especially in the roof system).

A third option that could be considered would be to provide a LLRS on the southern external wall of the stairwell. However, detailing of the stair flights and landings to provide diaphragm action but avoid strutting of the stair flights would be highly complex to detail and would result in amplified drift demands.

Instead of the above approaches, the CLT stair flights and landings have been designed as a 3D lateral load resisting element (3D portal frame). Differential lateral displacements from one floor to the next result in in-plane bending of the stair flights and landings. Stair flight to landing connections are designed for limited ductility (μ = 2) by considering yielding of the ductile mild steel SFS dowels (to be compatible with the LVL moment resisting frames). All other components within the connection are designed for over-strength actions.

The joint between the CLT landing and the flight of the stairs has been designed as a beam-column joint providing moment, shear and axial capacity. The moment is resisted by a push-pull force generated by the dowels located at the outer ends of the stairs/landing panel. The shear and axial load is resisted by the dowels located within the middle of the stairs/landing panel. The flight leading to each of the main floor is designed/detailed as a pinned connection. Axial loads generated from the earthquake demands as well from the induced bending of the stairs/

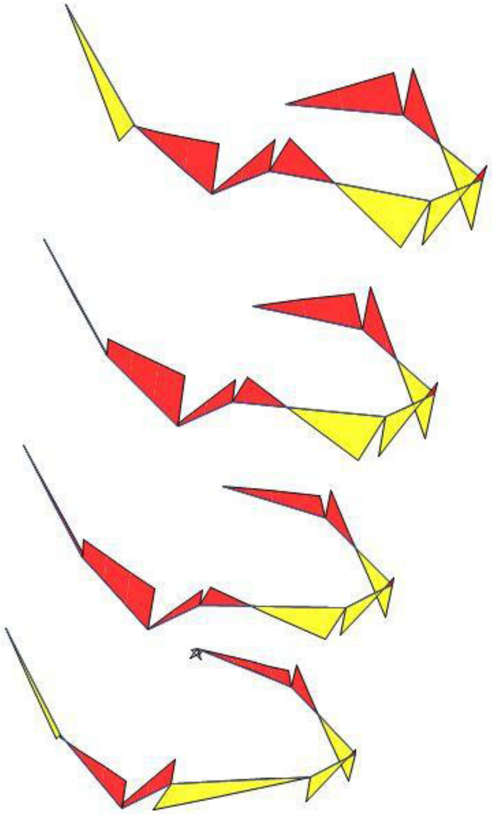


***Fig. 35 -*** *3D model of stairs and bending moment diagram profile of CLT stairs/landings at a typical level*

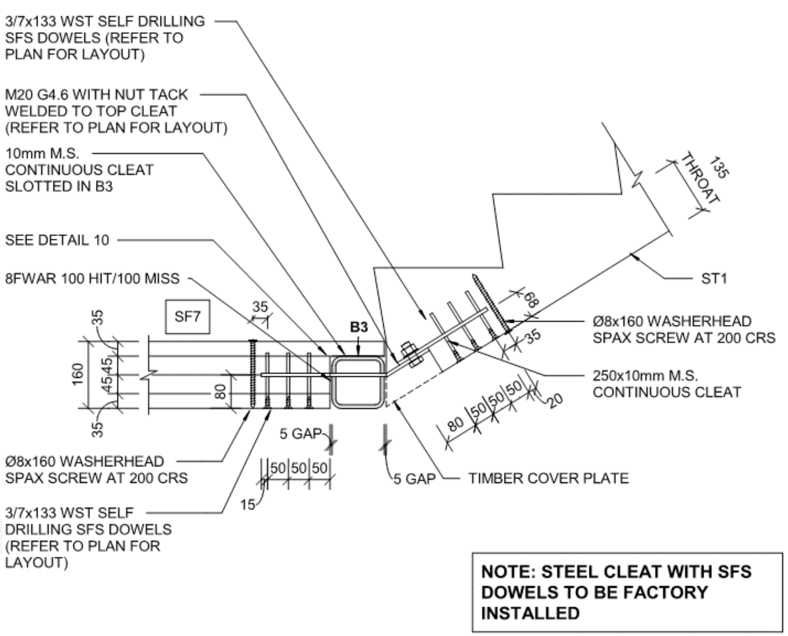
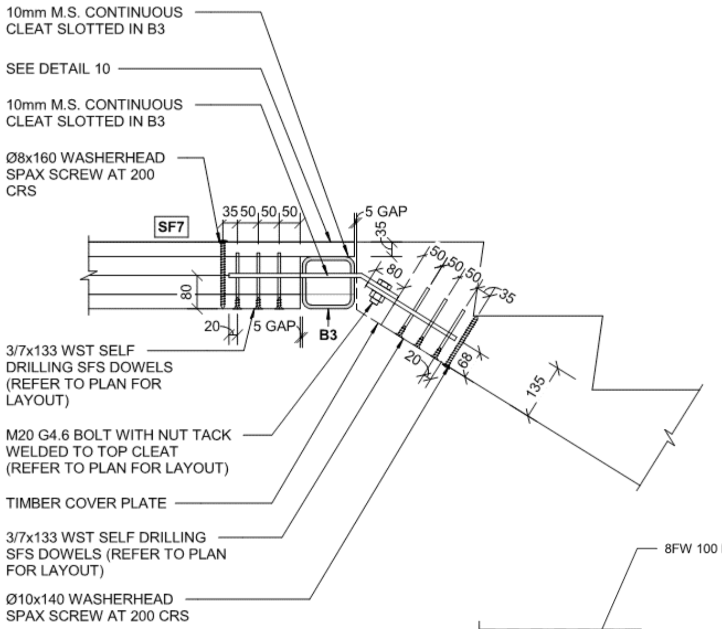


*Fig. 36 - CLT stairs/landing joint details*



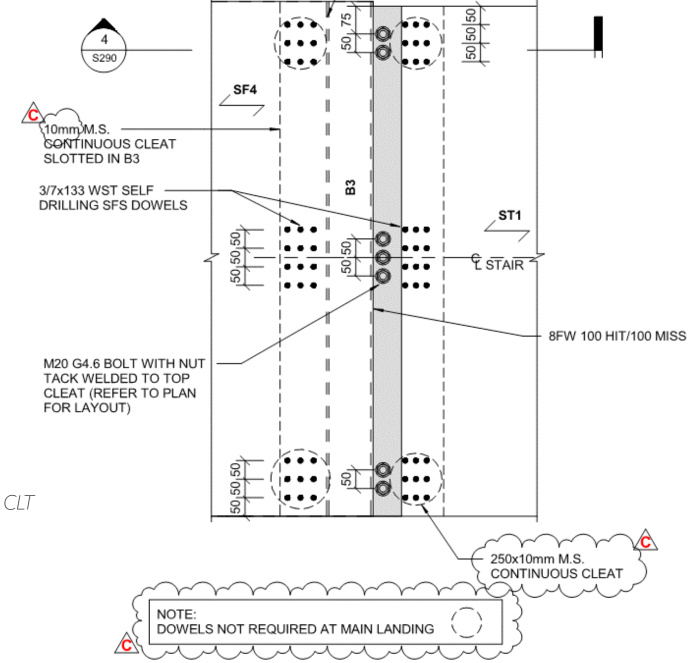


*Fig. 37 - Layout of SFS dowels for CLT stairs/landing joint*

landing create an upward/downward force. This is resisted by bending of the SHS beam supported by the LVL columns provided at the corners of the CLT landings. A 5-mm gap is provided between the CLT and the SHS beam to encourage the dowels to be mobilised in both directions (opening and closing) of the joint.

The lift-shaft is constructed using LTF walls. Due to its flexible nature, it is designed to go along for the ride with the CLT stairs/landings. The design approach adopted also eliminates the type of failure which was observed for the CCTV building in Christchurch[8].

## CLT Floor Diaphragm Design

The CLT floor diaphragm was designed using the equivalent truss method, similar to that of concrete diaphragms (strut and tie). It is based on the design procedures outlined in Daniel Moroder's thesis[9]. The CLT floor diaphragm was modelled using ETABS, with the CLT panel being modelled as an equivalent diagonal brace which has the same stiffness to that of the CLT panel being considered. The stiffness of the CLT panel considers the shear stiffness, fastener deformation (slip) and the additional required panel connections (splice) that make up the panel as these are the main sources of panel flexibility.

The tie beams that bound the diagonal braces consists of the main LVL portal beams as well as gravity beams. In the N-S direction, the tie provided at each panel end consists of a tie within the CLT panel (300 mm in width) at specified locations. Even though the CLT panel has

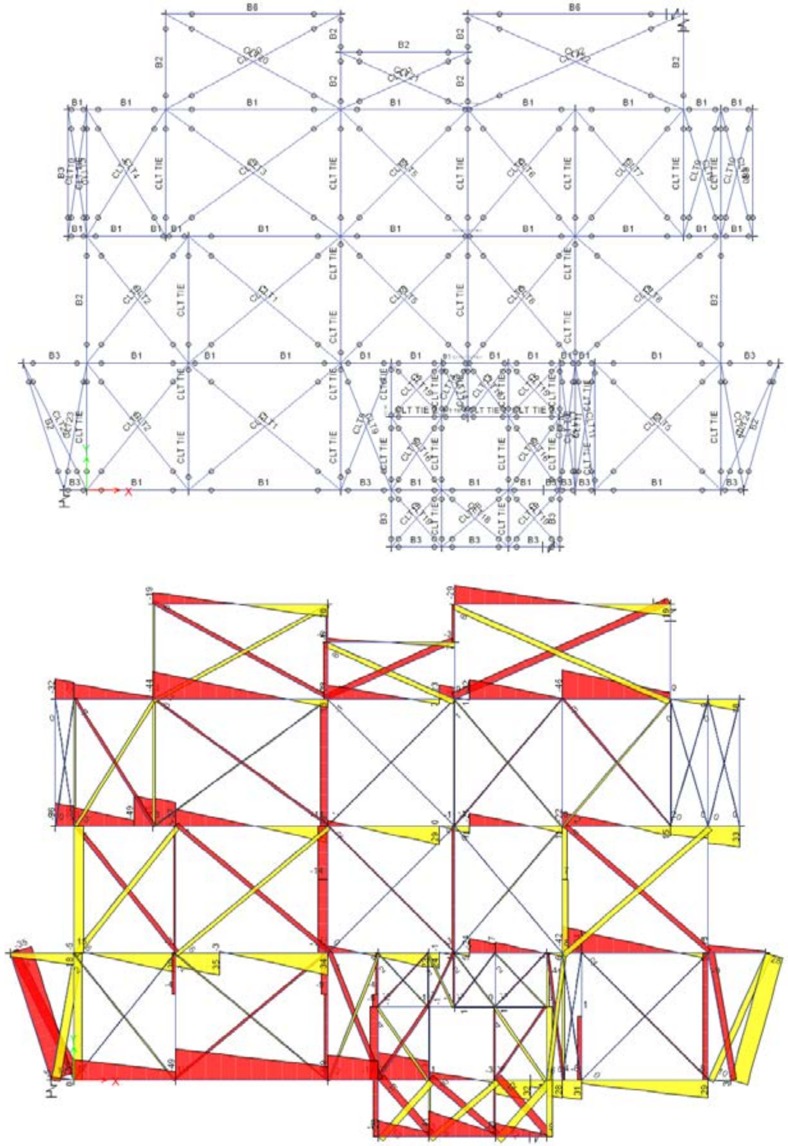


***Fig. 38-*** *CLT diaphragm ETABS model with axial load diagram*

axial stiffness, they are not being relied on to take any tension/compression forces. This was because the half lap joint for the CLT panel splice only has a 40 mm edge distance for the screw which may pull this joint apart. Therefore, the CLT panel is modelled and designed as a pure shear panel. The CLT panel is primarily used to take shear flow, with the shear flow being dragged by the defined tie beams acting in tension/compression. This is analogous to the design of a plywood shear wall in which the sheathing resists the shear flow and the end chords resists the tension/compression forces.

The pESA (pseudo Equivalent Static Analysis) method as outlined in NZS 1170.5:2004[10] was used to determine the seismic forces within the CLT diaphragm. As the structure has been designed to be ductile, the overall building over-strength factor was taken into account for each direction when determining the pESA loads. In the E-W direction (LVL moment resisting frames), this considered the average over-strength moment capacity of the beam-column joint over the average moment demand which gave an overall building over-strength factor of 2.7. In the N-S direction (plywood shear walls), this considered the average over-strength nailed capacity (in shear) over the average shear demand which gave an overall building over-strength factor of 2.3.

Rothoblaas perforated plates nailed onto the CLT floor were used for tension connections between ties where required. The CLT screw fixings for the half lap joint and to the tie beams were all 10 Diameter W.H. SPAX screws spaced at 200 mm. This showed that the CLT diaphragm was well distributed to the LLRS of the building.

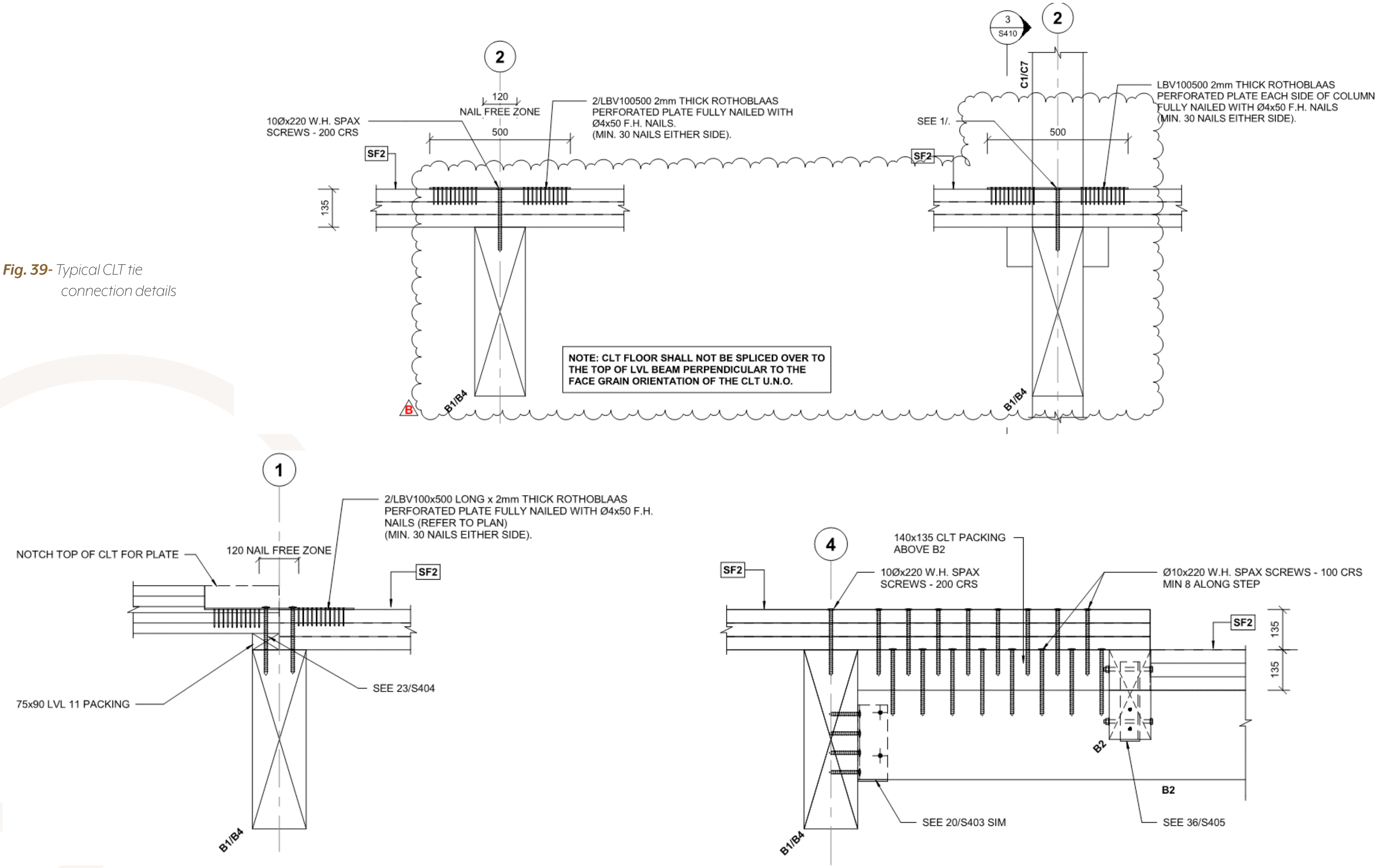


***Fig. 39-*** *Typical CLT tie connection details*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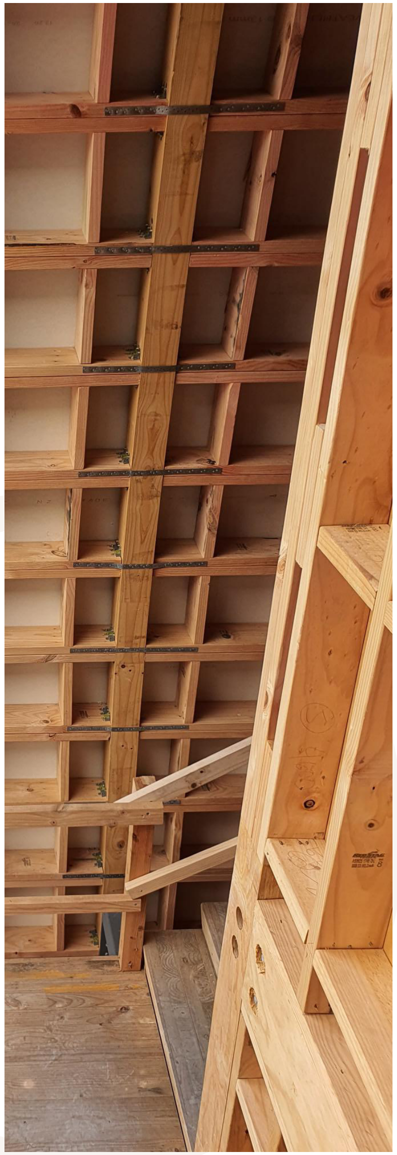

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## 19. PHOTO CREDITS

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