27

Rethinking Apartment Building Construction - Consider Timber

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Contents

1

Introduction

Timber's sustainability credentials are attracting world-wide interest and advances in timber engineering have made timber an increasingly cost-competitive proposition.

Encouraging the construction industry to adopt innovative approaches needs information and evidence. Attention to technical design, construction costs and site processes is critical to show the value proposition of timber construction to customers and optimise its use.

This Guide aims to help those involved in the decision chain (such as cost managers, estimators, design professionals, building developers and project managers) gain a better understanding of the value that timber construction systems offer apartment building projects.

The Guide is based on a research project that developed a model apartment building and a corresponding timber solution, and compared it with conventional concrete construction. The timber solution was designed to optimise functional performance, constructability and cost effectiveness and provides guidance for compliance under the National Construction Code (NCC). This Guide provides an explanatory understanding of decision making issues when developing timber solutions.

2

What Drives Decisions When Choosing Apartment Construction Systems?

A key objective of the research project was to understand the decision drivers along the customer/supply chain for the selection of apartment construction systems. Key areas of investigation included:

- Gathering information about customer needs and how construction affects things like the spatial requirements and liveability issues, especially when designing for high-end apartment living.
- Benchmarking against existing apartment construction systems, especially conventional post-tensioned concrete slab construction. This was found to be the main method used for apartment construction and was consequently used as the basis for comparison to timber.
- Understanding the nature of the overall delivery supply chain and related work flows, especially construction scheduling, productivity and prefabrication issues.
- Optimising the regulatory framework where it affects the viability of timber solutions, including fire and acoustic issues.

3

Project Development

The research project was developed by a series of expert/stakeholder meetings, interviews, concept development sessions, design charrettes, cost planning studies, construction programming studies and design detailing studies aimed at developing the model apartment building and a cost-effective timber solution for it.

A team of experts worked together to provide input to the development process. Core collaborators included:

- **The Timber Development Association (TDA**) – A market development association for the timber industry and the project leader for this work, on behalf of the timber industry.
- **The University of Technology Sydney:** A technology-driven university with an integrated understanding of the building industry and specific expertise in timber construction. The university co-developed the research method and mediated the strategic direction of the timber solutions in terms of detailed design, cost and site productivity issues.
- **studio505:** An architectural firm with a strong understanding of design and the effects of material and system selection. They prepared and led the design of the model apartment building with case specific input into the related timber solution.
- **Taylor Thompson Whitting Consulting Engineers:** An engineering firm with specialised services in structural, civil and facade engineering that provided the structural concrete design for the concrete solution.
- **AECOM**: A global multi-disciplinary engineering firm with expertise spanning structural, acoustic, fire and services engineering. They provided specialist advice on the design of the timber solution.
- **BCIS**: A global subsidiary of the Royal Institute of Chartered Surveyors who specialise in gathering building cost data used for reporting on cost trends for a variety building forms. BCIS provided quantity surveying, cost estimating and cost planning input for both the timber solution and the corresponding concrete solution.
- **Engineered timber manufacturers, suppliers and industry associations** (including Tilling Timber, Hyne Timber, Meyer Timber, Nelson Pine Industries, Carter Holt Harvey Wood Products, MiTek): Their input helped ensure the practical viability, design properties and availability of appropriate timber componentry.

Cross-laminated timber (CLT) was chosen as the main element used in the timber solution (Figure 1). Based on this, a preferred timber solution was derived and tested on a cross-section of building owners, developers, designers and contractors to provide critical feedback. This design was then compared against a typical post-tension concrete design using band beams and columns (as detailed in Appendix A).

Figure 1: Cross-Laminated Timber construction

Architect: Waugh Thistleton
Engineer: Techniker
Contractor: Telford Homes
CLT Supply and Installation: KLH UK
Photography: KLH UK

[1]For more information on Cross Laminated Timber refer to WoodSolutions Guide No 16; Massive Timber Construction Systems - Cross-laminated Timber (CLT)

4

The Model Apartment Building – the Basis for Comparison and Solution Development

The model apartment building was created to provide a basis for defining and presenting a timber-based solution, as well as a corresponding concrete solution. It provides a prototypical situation for modelling spatial, loading, fire and noise resistance conditions, enabling a neutral base for creating both the timber and competing concrete solutions.

The model building aimed to meet high-end consumer needs, including large and open room layouts. An emphasis was placed on characterising a building that could apply to many suburban/urban apartment situations across Australia.

The model apartment building is shown Figure 2. The building is divided into three distinct parts: car parking in the basement, retail space on the ground floor and seven stories of apartments. This mix of spaces mimics real world situations and creates a mix of different building classifications under the National Construction Code (NCC).

Figures 3 to 6 provide an overarching understanding of the model building, including the sawtooth style façade, which creates an interesting yet complex aesthetic for the building. The basic spatial characteristics of the model are provided in Table 1.

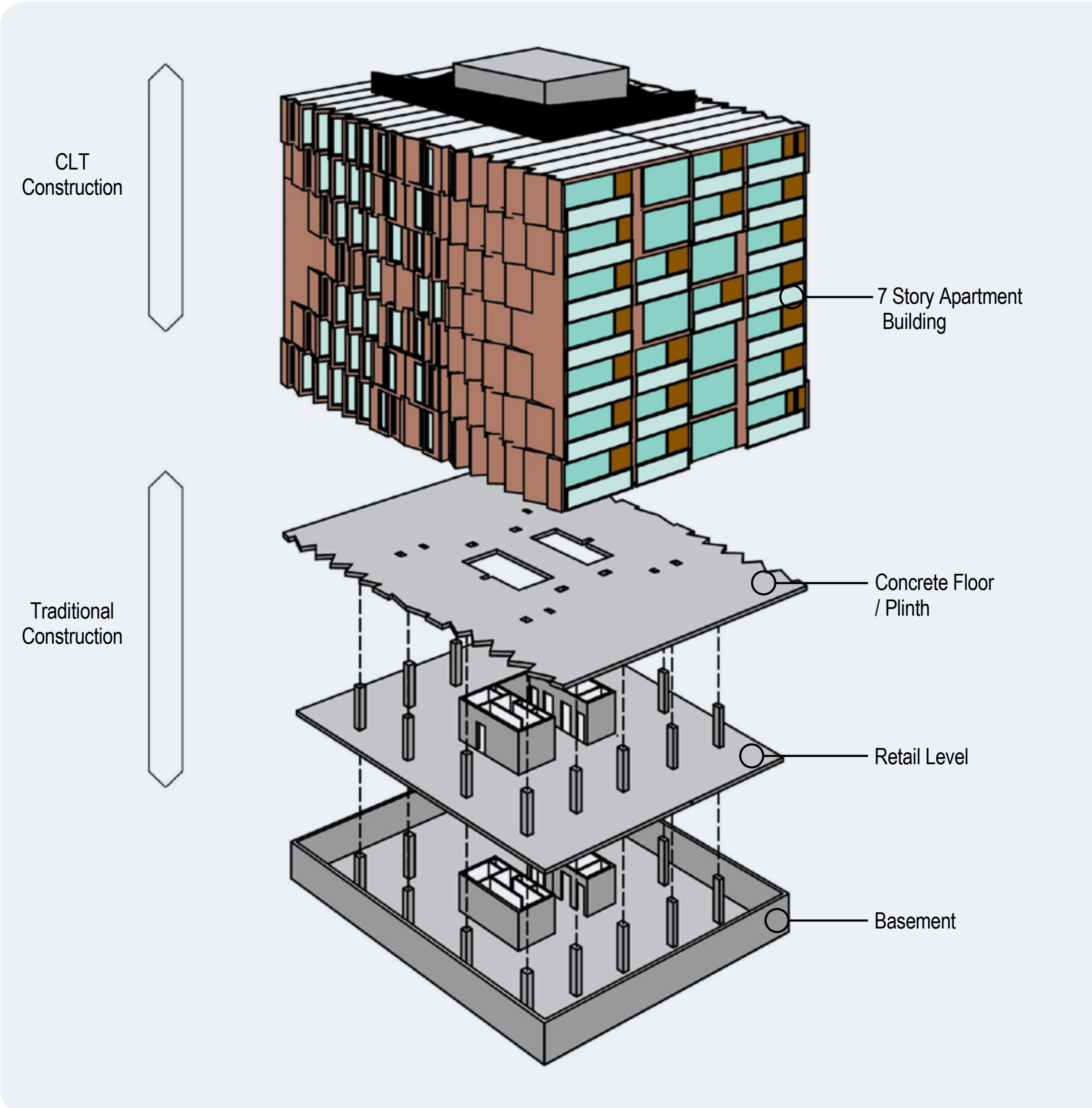


Figure 2: The building broken into three distinct zones. *Design and image: studio505*

Figure 3: 3D exterior views. *Design and image: studio505*

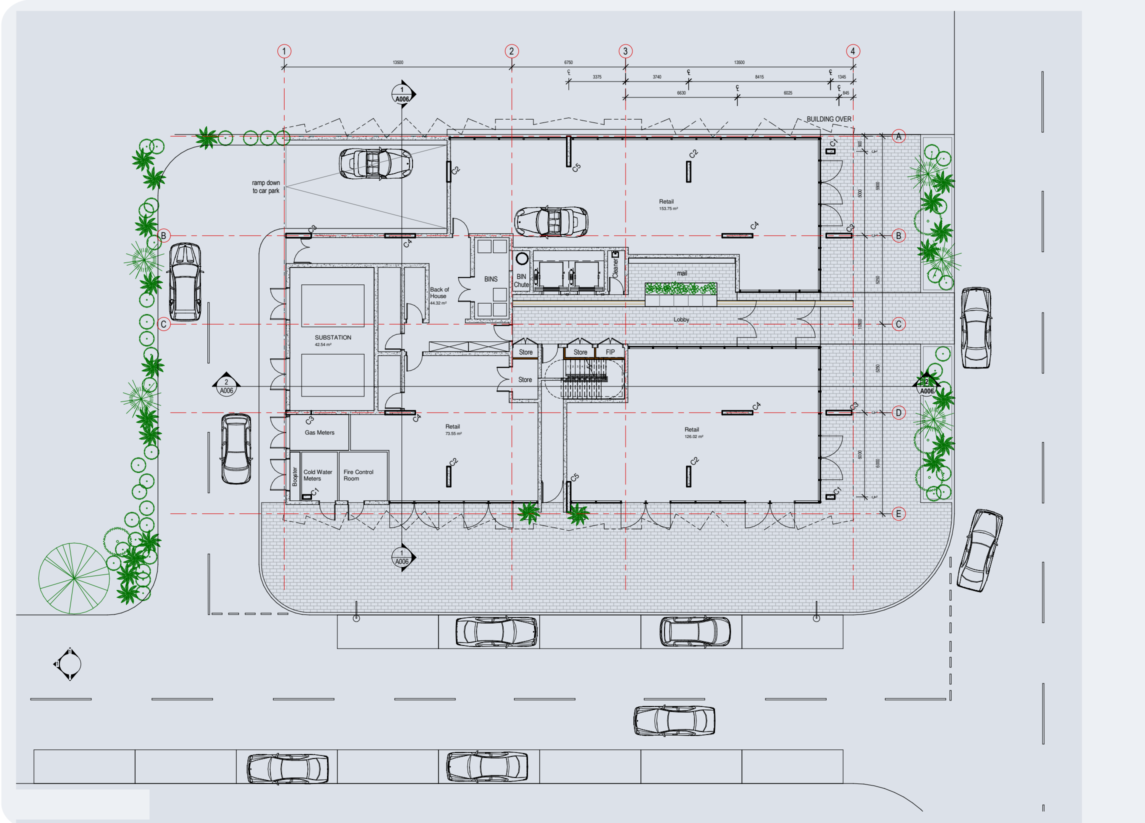


Figure 4: Plan view of retail level (ground floor). *Design and image: studio505*

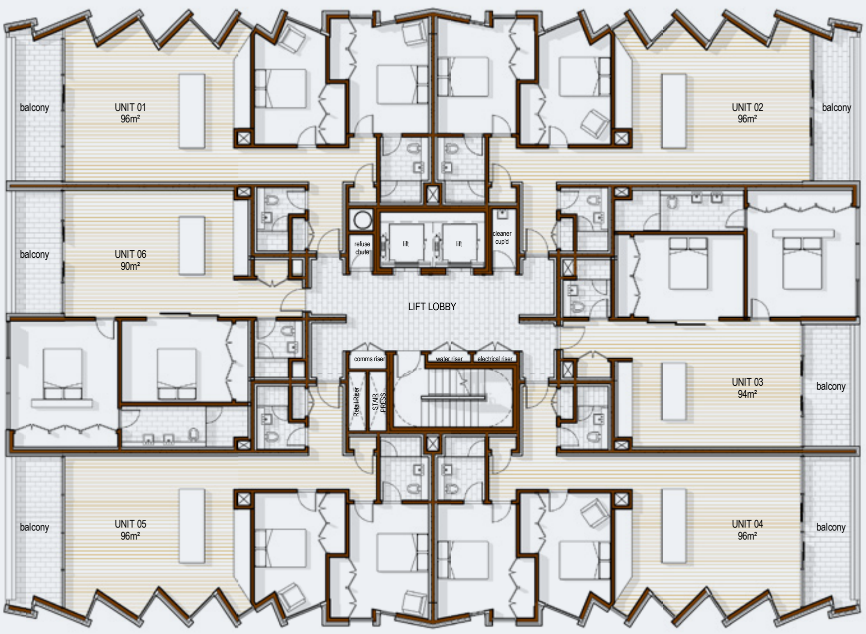


Figure 5: Typical floor plan for apartment levels. *Design and image: studio505*

Figure 6A: Section view - short section. *Design and image: studio505*

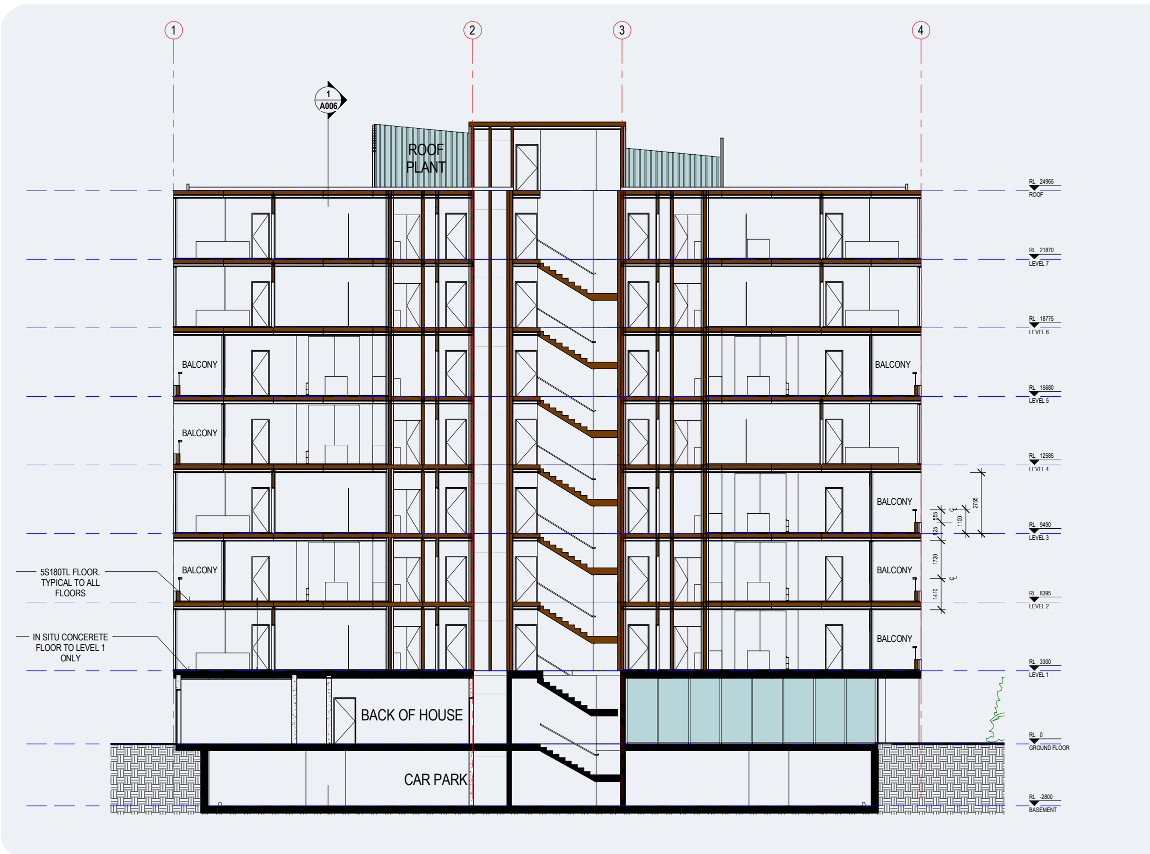


Figure 6B: Section view - long section. *Design and image: studio505*

Item	What was used in the model	Relevance and Reasons
Height	• An 8-storey design height above ground level, including 7 apartment levels and 1 retail level. • A 25.9 m overall building height but with an NCC effective height of 22.8 m (referring to the upper most habitable floor but excluding the top most storey where used for items such water tanks, lifts, etc). • A 3.130 m floor to floor height for the apartment levels and 4.0 m for the retail level.	• The apartment levels provide a 2.7 m habitable height plus room for the structure and services. Lower ceiling heights may also be possible in accordance with the NCC. • The retail level provides for a maximum depth of 650 mm thick transfer slab above, i.e. as used to transition loads from the timber to concrete parts of the building.
Area	• A floor plate area of 760 m2. The apartment levels include 42 apartments (94–96 m2 each). • The retail level assumes three shops varying in area from 77–150 m2. It also includes a foyer area, an entrance to basement car parking, utility meter rooms, an electrical substation and a waste area.	• Feedback and analysis indicates that many suburban mid-rise apartment buildings fit the scenario provided
Key set out criteria	• Length 33.75 m x Width 22.5m (edge to edge of floor plates). • An 8.2 x 8.2 m column grid used on the retail level (Level 1) and the basement level below.	• The width of the building accommodates the size and set-out of the large, high-end apartments. • The grid layout accommodates car parking in the basement.
Building ownership and fire compartment-alisation	• The building is considered to be strata titled including the retail area on the ground floor.	• Strata title creates the need for each title to be defined as a separate Sole Occupancy Unit under the NCC which creates fire and noise performance requirements.
Setbacks	• External wall distances are (at minimum) less than 1.5 m from the property boundary.	• The location of the building relative to other buildings or properties affects façade fire resistance requirements.

Table 1: Key spatial characteristics of the model apartment building

4.1 North and South Façade

The building's multifaceted north and south façades model boxes stacked on top of each other and, at each level, each box is slightly rotated about its axis (Figure 7). The façade is divided into four zones and they are repeated four times (Figure 8).

The intricate façade design is a consequence of the design team wanting the building to have more interesting architecture, while adding a degree of difficulty to the project's design. The façade's twisted design means the boxes in the external wall do not line up on top of each other (Figure 9). The façade design drove the need to fully protect the buildings with sprinklers, as it removed the need for spandrel projection or panels.

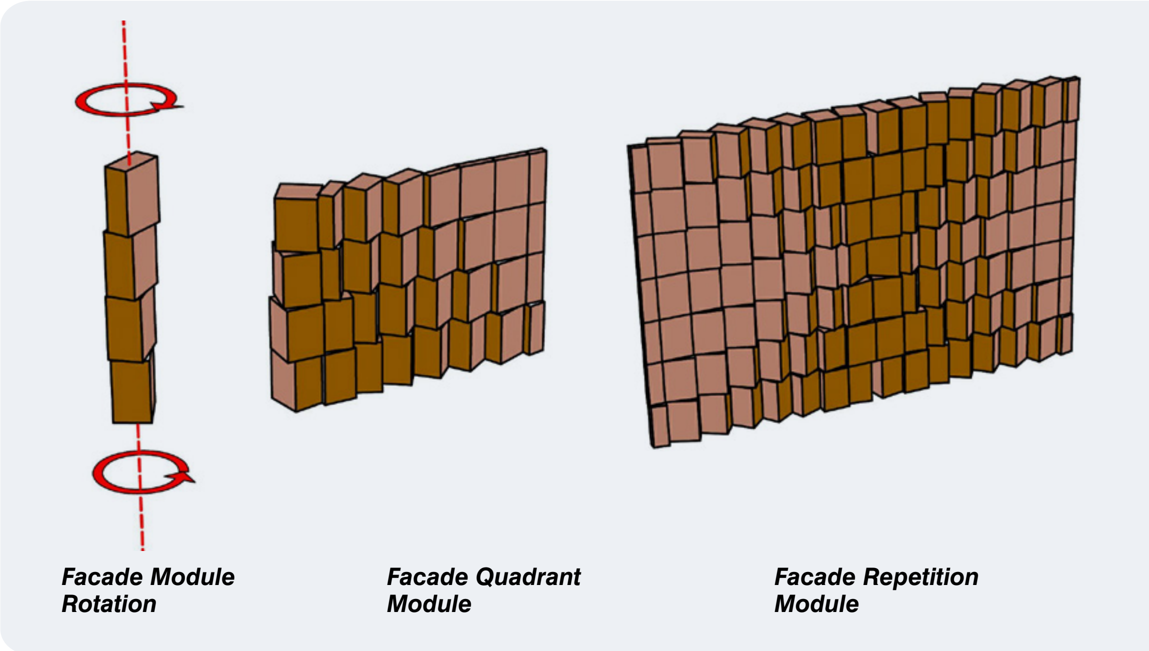


Figure 7: Model of the north and south façade. *Design and image: studio505*

Figure 8: Façade repetition. *Design and image: studio505*

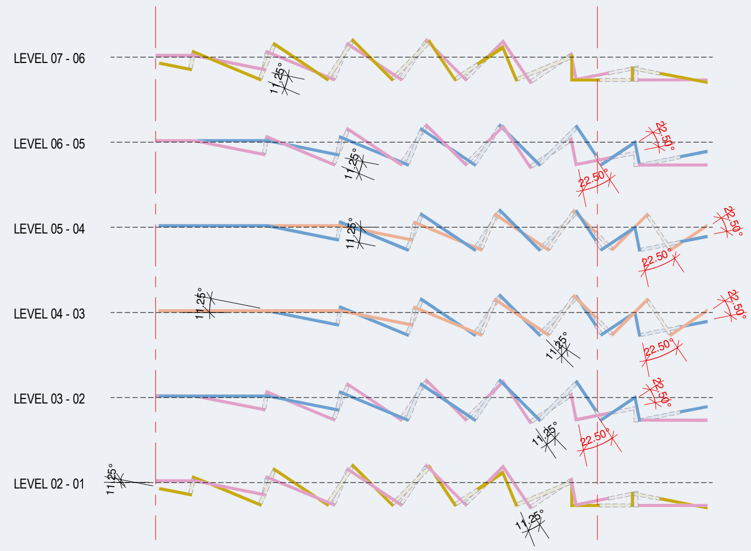


Figure 9: Difference in external wall location on various floor levels. *Design and image: studio505*

4.2 Core Differences between the Timber and Concrete Solutions

The only difference between the timber solution and competing concrete solution concerns the wall and floor structure throughout the apartment levels of the building (i.e. the seven levels above the ground floor retail level).

Parameters pertaining to fire, acoustic and building services requirements (which affect both the timber and concrete solutions) are provided under dedicated headings below.

Other aspects are essentially the same and provide relative neutrality when comparing the two competing solutions. Consequently, discussion of the solution below Level 1 (retail level and basement car parking) has been excluded from this Guide.

4.3 Structural Themes

Parameters applied to the model:

- Deemed-to-Satisfy loading was taken from AS 1170, e.g. applied, imposed wind loads.
- Load paths are managed in the apartment levels via cellular timber construction which converts to a concrete slab and column (grid) structure for the retail and basement levels below. The transition between the two is managed by a 500 mm deep concrete transfer slab for the timber solution (650 mm deep for the concrete solution).
- Weathered shale soil conditions have been applied in the structural design.

Reasons:

- While in technical terms, timber can be constructed below ground level, concrete construction is less likely to attract concerns about moisture penetration and termite activity. To allay such concerns, the timber solution uses a stainless steel mesh barrier at all hidden entry points between the concrete levels and the timber levels above.
- Concrete construction is used for the retail and basement levels because:
  - These levels pertain to Class 7b (car parking) and Class 6 (retail) under the NCC, and subsequently have higher fire resistance requirements than the main Class 2 apartment levels of the building. It was found more cost effective to use concrete construction on these lower levels.
  - The transfer slab was found to be the most cost-effective means of transferring loads, especially at the change between timber and concrete construction (Figure 10).
- Weathered shale is a moderate foundation condition common in many parts of Australia and is relatively neutral for both timber and concrete solutions.

Additional points of interest:

- The lightweight nature of timber is particularly advantageous in poor foundation conditions. Though not dealt with specifically in this study, its lightweight nature contributes to reduced piling or smaller footing sizes.

4.4 Building Acoustics

Parameters applied to the model were designed to achieve above NCC Deemed-to-Satisfy requirements including:

Floors:

- Rw + Ctr (airborne) between 50 and 55
- Ln,w + CI (impact) between 40 and 50.

Walls:

- Walls between neighbouring units: Rw + Ctr (airborne) of 55 to 60 and is discontinuous construction.
- Walls to plant room, lift shafts, stair shafts and corridors: between Rw 50 - 55. These walls must also be discontinuous construction, i.e. separate wall leaves.
- Service shafts; Rw + Ctr (airborne) of 40.
- Doors to apartments: Rw 30.

Reasons:

- Since the apartments aim to meet high-end consumer standards, the nominated acoustic requirements have been selected to surpass minimum NCC Deemed to Satisfy requirements.

4.5 Fire Resistance

Parameters applied to the model:

- The NCC defines the model building as being mixed use including Class 7a – car parking; Class 6 – retail; and Class 2 – residential. It involves a rise of 8 storeys which subsequently requires Type A fire resistant construction. For the apartment levels, this determines the Fire Resistance Levels required of individual building elements further dealt with below. Here, Deemed-to-Satisfy (DtS) provisions were applied to all of the concrete solution and the majority of the timber solution. An Alternative Solution (as detailed in the NCC) was required for some parts of the timber solution, mainly around loadbearing and fire-resisting walls.
- A sprinkler system was applied to the building at each floor level as well as the under-roof area for both the timber and concrete solutions to reduce spread of fire requirements that would otherwise limit design options for the external face of the building (as discussed in Section 4.1).

Reasons:

- An Alternative Solution was required for some parts of the timber solution because the NCC's Deemed-to-Satisfy provisions require concrete or masonry construction or non-combustible materials.
- The use of a sprinkler system removed the need for fire protection of openings in the exterior façade, therefore avoiding usage of spandrel panels and similar facade treatments. (NCC provision C2.6 removes the need for spandrel panels or horizontal projections where complying sprinklers are installed.) While this choice benefited the timber solution and was less necessary for the concrete solution, feedback from architects suggests that this potential economy associated with concrete (and similar) spandrel panels is rarely used because of the unwanted design limitations it places on the appearance of the building.

4.5.1 External Walls

Parameters applied to the model:

- The NCC (Table 3 Specification C1.1. Clause 3) Deemed-to-Satisfy Fire Resistance Level (FRL) has been applied to external wall elements for the concrete and timber solution. As the external walls are considered to be less than 1.5 m away from adjoining property boundaries, the FRLs used are:

  - Loadbearing walls 90/90/90, and
  - Non-loadbearing walls - /90/90.

- For the timber solution, an Alternative Solution was developed for the external walls.

Reasons:

- For the timber solution, the NCC (Table 3 Specification C1.1. Clause 3 solution) was followed, but the requirement for non-combustible materials could not be met. An Alternative Solution[2] provided by a fire engineer was developed that showed the inclusion of sprinklers resulted with the same or improved fire safety for the building's occupants.

4.5.1.1 Vertical separation of openings in external walls

Parameters applied to the model:

- There are no spandrel or horizontal projections used.

Reasons:

- The use of spandrel or horizontal projections interfered with the facade appearance (Section 4.1) and are not necessary when complying sprinklers are installed (NCC Provision C2.6).

4.5.2 Internal Walls

Parameters applied to the model:

- The NCC (Table 3 Specification C1.1. Clause 3) Deemed-to-Satisfy Fire Resistance Level (FRL) has been applied to fire-resisting lift and stair shaft walls; walls bounding public corridors and lobbies; walls between or bounding apartments; and walls relating to service shafts. The FRLs used are:
  - fire-resisting lift and stair shafts – loadbearing walls: 90/90/90 and non-loadbearing walls: -/90/90
  - walls bounding public corridors and lobbies – loadbearing: 90/90/90 and non-loadbearing: -/60/60
  - between or bounding apartments – loadbearing walls: 90/90/90 and non-loadbearing walls: -/60/60
  - service shafts – loadbearing walls: 90/90/90 and non-loadbearing walls: -/90/90
- For the timber solution, an Alternative Solution was developed for the loadbearing internal walls and non-loadbearing fire-resisting walls.

Reasons:

- For the timber solution, the NCC (Table 3 Specification C1.1. Clause 3) requirement for loadbearing internal walls to be concrete or masonry and non-loadbearing fire-resisting walls to be non-combustible, could not be met by the timber solution. Here an Alternative Solution provided by a fire engineer was developed that showed the inclusion of sprinklers resulted with the same or improved fire safety for the building's occupants.

4.5.3 Floor Structure

Parameters applied to the model:

- The NCC (Table 3 Specification C1.1. Clause 3) Deemed-to-Satisfy Fire Resistance Level (FRL) has been applied to floor structure. The FRL used is 90/90/90.
- For the timber solution an Alternative Solution was developed for the floor structure.

Reasons:

- For the timber solution, the NCC (Specification C1.1. Clause 2.2 Fire Protection for a support of another part) requires that where the floor structure supports a fire-rated element that is required to be non-combustible, the floor structure must also be non-combustible. For the timber solution this cannot be met. An Alternative Solution provided by a fire engineer showed the inclusion of sprinklers resulted with the same or improved fire safety for the building's occupants.

4.5.4 Roof Structure:

Parameters applied to the model:

- A non-combustible roof covering is used.
- There is no fire resistance requirement for roof elements.
- Fire-rated walls extend to the underside of the non-combustible roof coverings.

Reasons:

- NCC (Spec C1.1 Clause 3.5) provides a concession for roofs in Class 2 buildings, requiring no fire resistance as long as a non-combustible roof covering is used.

[2] Further information on Alternative Solutions can be found in WoodSolutions' Guide No 17 *Alternative Solutions Fire Compliance – Timber Structures*

5 The Timber Solution

In response to the model building (including fire, acoustic, building services and structural loading requirements), this section presents a timber solution that aims to optimise cost, time and constructability requirements. It focuses on the seven levels constituting the Class 2 apartment section of the building (levels 1 to 8) and uses a number of themes:

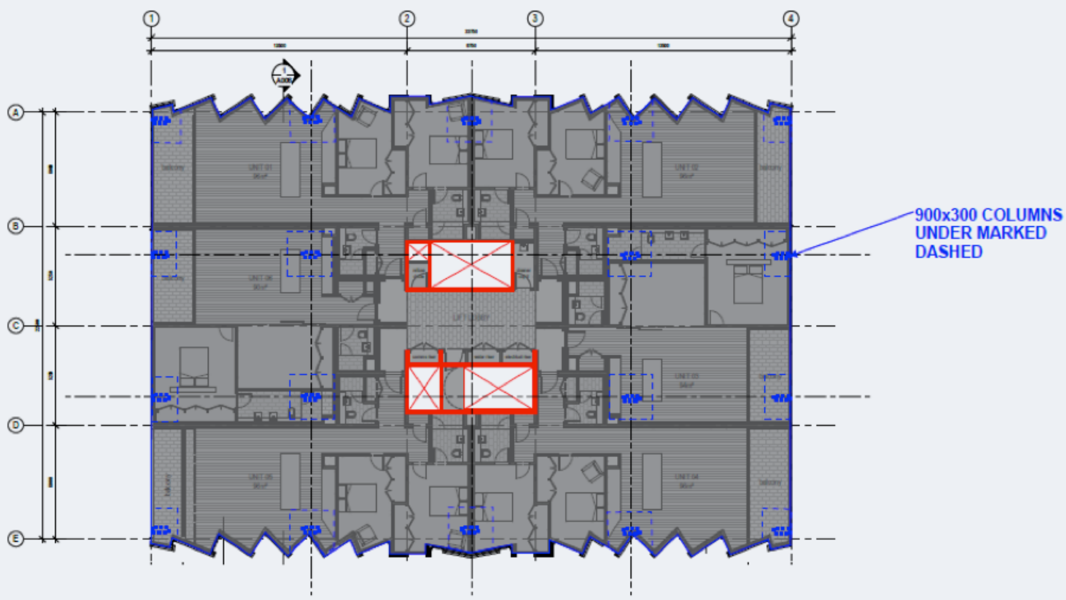
- Use of cross-laminated timber (CLT) for loadbearing walls, fire-rated walls, lift shaft, stair shaft, floor and roof elements (Figure 10 for details of concrete transfer slab).
- Use of stud partition walls for non-loadbearing and non-fire resistant internal walls.

Details are provided below.

In contrast, the concrete solution uses a more commonly used post tensioned flat plate design, which is detailed in Appendix A for comparative purposes.

Many other aspects of the overall construction are common to both the timber and concrete solutions and have subsequently been excluded from the ongoing discussion. This includes the:

- Basement construction
- Retail level construction.



LEVEL 1

Notes:
1. Slab to be 500mm thick U.N.O
2. Drop Panels to be 1800 x 1800 x 650mm deep U.N.O
3. Slab:
   - PT rate = 6.0 kg/m^2
   - Reinforcement rate = 45 kg/m^3
4. All concrete f_c = 40 Mpa
5. Column sizes denoted on plan with a reinforcement rate of 240 kg/m^3
6. Core walls to be 200mm (W) with a reinforcement rate of 140 kg/m^3

Figure 10: Details of concrete transfer slab at Level 1. *Design and image: TTW*

5.1 External and Internal Walls

What was used in the timber solution:

- Cross-laminated timber has been used for all external and internal walls (including stair and lift shafts) that are loadbearing and/or require fire resistance levels (see Figure 11 for details). Specific element sizes vary according to application (Table 2) and include:
  - External walls: 125 mm thick 5-ply CLT,
  - Interior walls:
    - Loadbearing: 95 mm thick 5-ply CLT
    - Non-loadbearing and fire-resisting: 95 mm thick 5-ply CLT
  - Stair and lift shaft: 125 mm thick 5 ply CLT.
- Fire protecting to CLT varies on the load being applied to the walls. CLT on the top floor requires no protection as the CLT provides fire resistance through its own char capacity[3]. The middle storeys have one layer of fire-resisting plasterboard and the lower storeys have two layers of plasterboard. By increasing the layers of fire-resisting plasterboard, the amount of charring that occurs on the CLT is reduced or removed. This, in turn, provides more structural timber to support higher loads that generally occur towards the base of the building.
- Where required for acoustic reasons, CLT wall panels have additional stud construction to improve sound performance (Table 2).
- The stair and lift shaft are twin wall CLT systems, separated by a 20 mm cavity.
- Service shafts are constructed from metal stud with 13 mm plasterboard and 25 mm shaft wall system.
- Non-loadbearing and/or non-fire-resisting partition walls within apartments are constructed from 70 x 35 mm timber-framed studs at 600 mm centres walls with plasterboard or fibre cement linings.

What was assumed in terms of planning construction of the model:

Key

- Wall Type 1
- Wall Type 2
- Wall Type 3
- Wall Type 4
- Wall Type 5
- Wall Type 6
- Wall Type 7

Figure 11: Plan indicating location of various wall types. *Design and image: studio505*

[3] Further information on Timber char capacity can be found in WoodSolutions Guide No 3: Timber-framed Construction for Commercial Buildings Class 5, 6, 9a & 9b - Design & construction guide for BCA compliant fire-rated construction

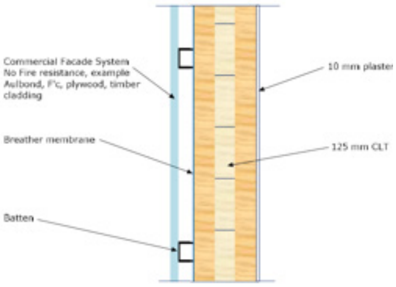
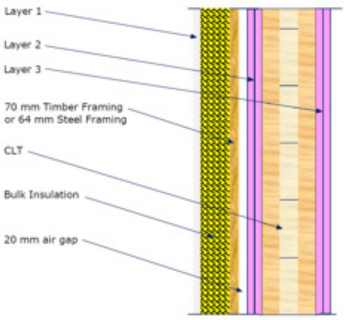
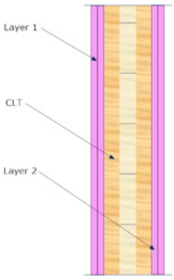
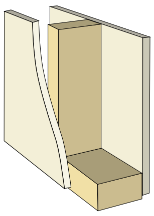
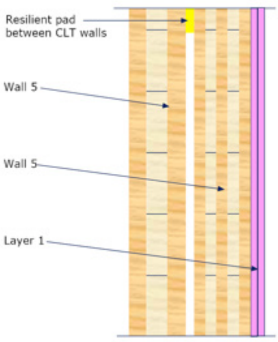
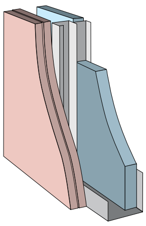
Wall Type	Diagram of Wall System	Description		Acoustic Rw + Ctr	Fire rating
		Structural	**Linings & Insulation**		
1		125 mm thick 5-layer longitudinal-faced CLT panel.	10 mm plasterboard internal coverings and aluminium composite commercial facade exterior coverings on battens. Vapour permeable paper direct fixed to CLT. Insulation installed in cavity.	No rating required	90/90/90
2		95 mm thick 5-layer transverse-face CLT panel with 70 mm timber studs with 20 mm gap between CLT and studs for maintaining discontinuous construction.	• Layer 1 – 1 x 13 mm plasterboard • Layer 2 & 3 - varies: - Level 1 & 2 – 2 x 13 mm fire resisting plasterboard - Level 3, 4 & 5 – 1 x 13 mm fire- resisting plasterboard - Level 6 - 1 x 10 mm plasterboard • 75 mm insulation installed in the timber-framed wall	54	90/90/90
3		95 mm thick 5-layer transverse faced CLT panel.	Fire-resisting plasterboard is direct fixed to both sides of CLT: • Level 1 & 2 – 2 x 13 mm fire resisting plasterboard • Level 3, 4 & 5 – 1 x 13 mm fire resisting plasterboard • Level 6 – 1 x 10 mm plasterboard	No rating required	90/90/90
4		70 x 35 mm studs at 600 mm crs	1 x 10 mm plasterboard or 6 mm fibre cement (wet areas) direct fixed,	No rating required	No rating required
5&6		Wall 5 – 125 mm thick 5-layer longitudinal-face CLT panel Wall 6 – 95 mm thick 5-layer transverse-face CLT panel	Layer 1 – 2 x 13 mm fire rated plasterboard	54[4] Resilient strip placed between CLT to maintain 20 mm gap and discontinuous construction	90/90/90
7		102 mm metal studs	Layer 1 – 2 x 13 mm fire-resisting plasterboard Layer 2 – 25 mm plasterboard shaft liner	40[5]	- /90/90

Table 2 – Wall Systems

[4] CLT's acoustic performance is based on SmartStruct (Tilling Group) assessments

[5] CSR RedBook System CSR 977

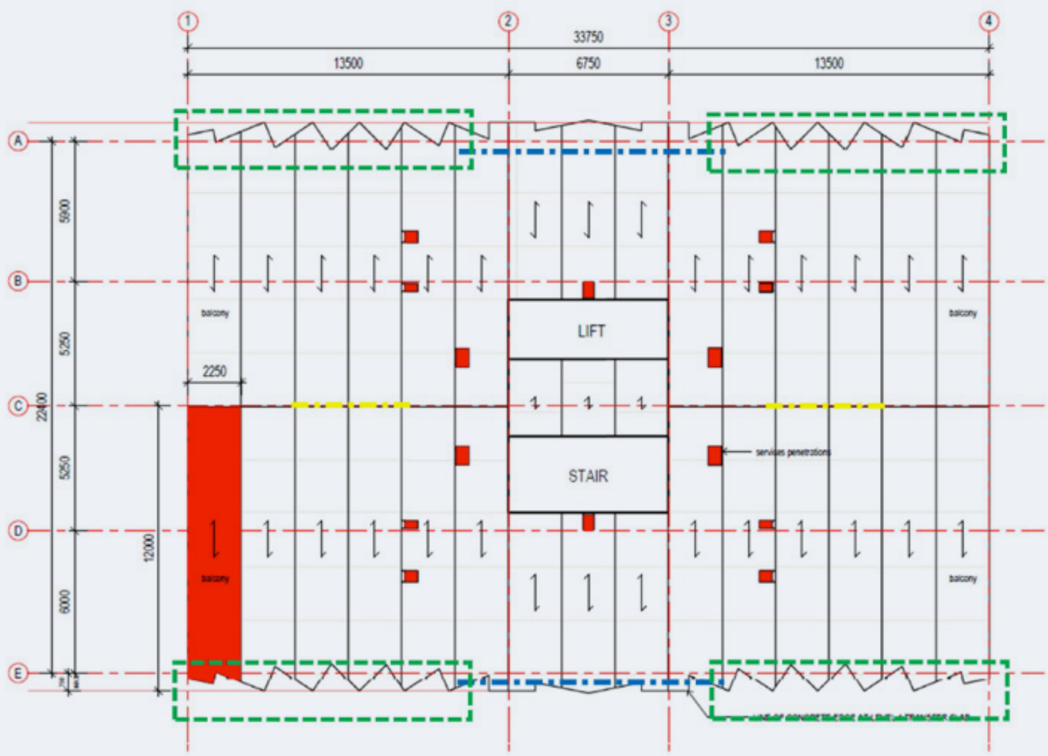
5.2 Floor Structure

What was used in the timber solution:

- 180 mm thick 5-ply longitudinal-faced CLT panel spanning over three supports with a maximum span of 6 m (Figure 12 and Table 3).
- Beams under CLT panels reinforce areas over openings:
  - Two 2 x 200 x 63 LVL13 beams located near external sawtoothed walls to assist in transferring loads from cantilevered sawtoothed floor overhang and related external wall panels.
  - Two 240 x 90 LVL13 beams under the floor in opening in wall in Units 3 and 6.
- Where the floor sits on the external wall to the north and south façade, some supporting walls do not line up over each other (Figures 9 and 13). To provide higher shear capacity to the CLT, screw reinforcement is used in these regions (Figures 13 and 14).

Reasons:

- The CLT panel thickness provides the best spanning capacity and vibration control relative to the other timber options available.
- The layout and CLT panel arrangement minimises waste material and transportation costs.
- Compared to increasing the thickness of CLT floor elements in area of high shear, screw reinforcing is more cost effective.



Material Key

5S180TL CLT Panel

Indicate zone of screw reinforcement.
See Sketch CLT Screw reinforcement sawtooth wall

2 x 200 x 63 LVL13

2 x 240 x 90 LVL13

Figure 12: Floor system plan. *Design and image: studio505*

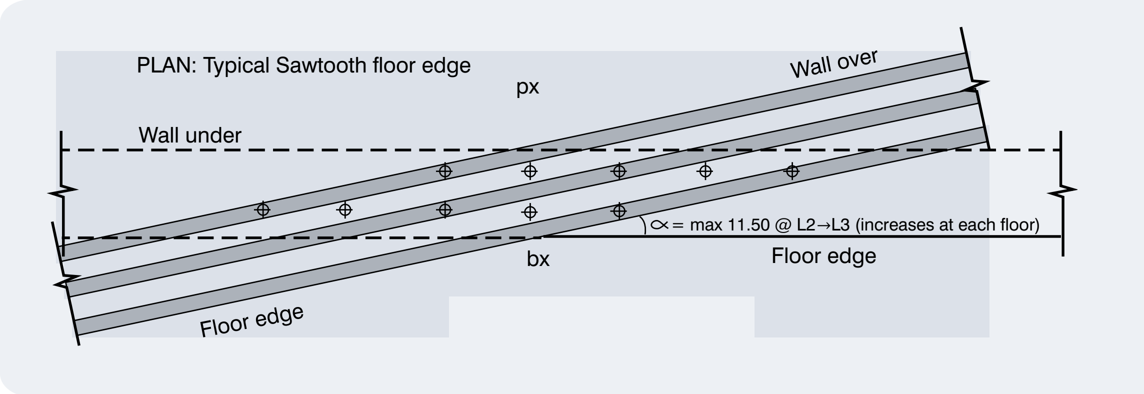


Figure 13: Plane view of external wall element and screw reinforcing location. *Design: AECOM*

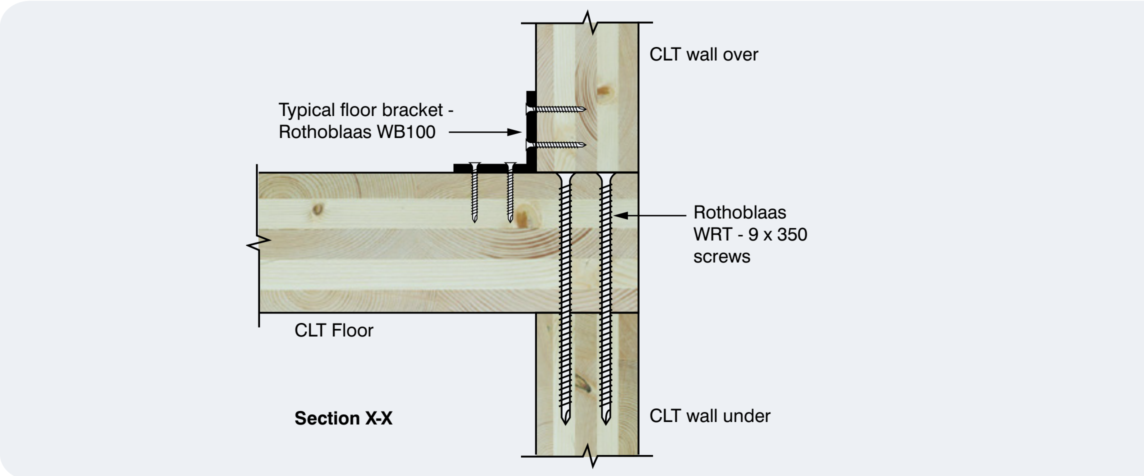


Figure 14: Screw reinforcement details to floor. *Design: AECOM*

5.3 Roof Structure

What was used in the timber solution:

- 140 mm thick 5-ply longitudinal-faced CLT panels (Table 3).

Reasons:

- The CLT panel thickness was reduced in the roof structure as the loads are less and there is no fire resistance requirement.

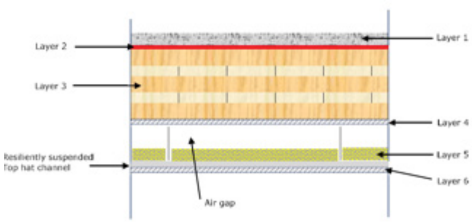
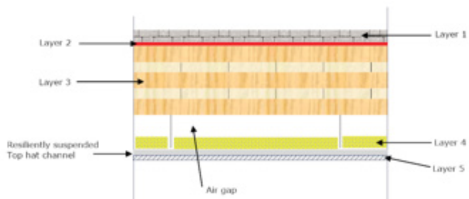
Type	Diagram of Floor System	Description	Acoustic		Fire rating
			Rw + Ctr	Ln,w (Ci)	
Floor		Layer 1 - 40 mm screed Layer 2 - 10 mm recycled rubber mat. Layer 3 - 185 CLT Layer 4 - 2 x 16 mm fire-resisting plasterboard Layer 5 - 75 mm insulation Layer 6 - resiliently mounted 13 mm plasterboard	53	47	90/90/90
Roof		Layer 1 - Gravel Layer 2 - waterproof membrane Layer 3 - 140 CLT Layer 4 - 75 mm insulation Layer 5 - resiliently mounted 13 mm plasterboard	Not required	Not required	Not required

Table 3: Floor and roof systems

5.4 Lateral Resistance

What was used in the model:

- The lateral forces were resisted by the CLT lift and stair core.
- CLT twin wall system was used. The inner core walls being panels placed vertically, in three storey high sections; the outer layer placed horizontally in single storey sections.
- The floor was designed to act as a diaphragm transferring lateral loads to the CLT cores.

Reasons:

- CLT is a cost-effective material for cores in buildings.
- The use of CLT avoided the use of dissimilar materials and hence avoids differential creep, settlement, shrinkage, cracking and misaligning of various elements.
- Lateral resistance is treated in the same generic way as used in the concrete solution, i.e. loads are transferred to the core of the building.

5.5 Façade: Timber Solution

What was used in the model:

- North and south face (Figure 7)
  - Short CLT panels that aligned with the sawtooth shape of the façade were used.
  - The CLT panel were clad on the exterior face with an aluminium composite panels on battens.
  - Vapour permeable membrane was direct fixed to the outer CLT face.
  - Thermal insulation was placed in the cavity formed in the external wall.
  - The interior face of the CLT was lined with 10 mm plasterboard
- East and west face
  - Simple glazed elements were used.

Reasons:

- CLT was easiest to handle as the floor panels could be precisely cut in the factory to the sawtooth shape without any cost difference.

How does this compare to concrete?

- The same construction was used except aerated concrete wall elements were used instead of CLT.
- The concrete flat plate was more costly in the detailing of the form work at building's edge, requiring additional work to position post tensioning anchoring points and accurate laying out of the sawtooth profile.

6

The Workflow and Speed Onsite of the Timber Solution

- A crew of six site workers were used for the installation of the timber solution (excluding crane driver, dogman, traffic control, site management staff etc.).
- All connection of CLT elements used brackets and/or screw fixings.
- The construction program associated with the installation of the core structural elements above the Level 1 transfer slab until completion of the façade only, was considered. From experience obtained from similar buildings construction (Table 4) and the UK experience of BCIS, the concrete solution was estimated to take 18 weeks while the timber solution was estimated at only 12 weeks.
- The installation time for the façade, MEP, interior coverings, and so on, was assumed to be similar for both solutions.

Reasons:

- Each solution is identical until the Level 1 transfer slab commences and the model has assumed that they take the same length of time until this point. Above this level, the time taken to install the superstructure to roof level for the concrete solution was estimated at 18 weeks while the timber solution was estimated at only 12 weeks.
- Construction time beyond the installation of the superstructure was assumed to be identical.
- Refer to Section 7.7 for other potential cost savings

Project Name	Location	Apartments	Floors	Super Structure Construction Program Time
Murray Grove	Hackney, London, UK	29	9	17 week[6]
Bridport House	Hackney, London, UK	42	8	12 week[7] (superstructure construction program)
Forte	Victoria Harbour, Melbourne Australia	27	10	3-4 month[8]

Table 4: Examples of time schedules on three timber apartment projects

[6] KLH UK PowerPoint presentation
[7] Stora Enso case study Bridport House ttp://www.clt.info/en/projekte/detail/?slideId=2507&category=
[8] Lend Lease PowerPoint presentation

7

Cost Plan Results - Comparing the Timber and Concrete Solutions

Using the model apartment building described in Section 4, the timber solution described in Section 5 and the corresponding concrete solution described in Appendix A, a cost estimate and cost planning comparison was undertaken to help determine the potential benefits of the timber solution. The cost comparison was only undertaken for the parts of the building that were considered to have different costs. The elements of the building that are identical in costs for each model, such as the façade, and mechanical, electrical and plumbing items, were excluded from the cost plan.

To create stable costing conditions, it was assumed that the building would be constructed in suburban Sydney.

7.1 Process Taken to Obtain Comparison Design and Quotes

From the parameters of the model apartment building discussed in Section 5, two designs were developed: one in the conventional material (concrete in this case) with timber as the comparison.

The cost plan was developed by the Building Cost Information Service (BCIS), a subsidiary of the Royal Institute Cost Surveyors (see Appendix B for full cost plan results). BCIS independently measured quantities off supplied drawings and obtained quotes from the market where needed. As concrete construction is widely used, BCIS utilised current data within their database to develop a price for this model.

As the timber solution is a relatively new construction system, a price from the marketplace was obtained. A quote was attained from SmartStruct (Tillling Group), an agent for KLH CLT both in Australia and New Zealand.

SmartStruct (Tilling Group) worked closely with the design team to assist in the optimisation and modelling of the most cost-effective CLT solution for the project. They also generated a detailed 3D CLT model, which was used to accurately price the supply of the CLT component. The 3D CLT model illustrates how the CLT elements were optimised (Figure 16).

An all-inclusive price for the optimisation of design, shop detailing, fabrication, freight and supply considerations (off-site storage, wharfage, etc), fixtures and fittings and just-in-time delivery to site was made and used in the study.

7.2 Cost Plan Results

The basic differences in the cost plans for each model are shown in Table 5. Detailed results can be found in Appendix B.

Element	Timber	Concrete	Variance
Columns	28,305	306,130	-277,825
Level 1 Transfer Slab	312,660	480,340	-167,680
Upper Floors	1,132,287	1,180,395	-48,108
Roof	147,135	205,530	-58,395
External Walls	1,087,910	1,098,327	-10,417
Internal Walls	939,037	954,955	-15,916
Wall Finishes	867,998	414,416	+453,582
Ceiling Finishes	792,373	486,090	+306,288
Termite & Fire Engineering	35,000	0	+35,000
Preliminaries	-312,000	Base	-312,000
Total	$5,015,705	$5,126,705	-$110,478

Table 5: Cost comparison between each building considered

In analysing the differences between the two plans, it can be seen that the timber building provides a saving of $110,478, 2.2% cheaper than the concrete solution.

Significant savings under the timber solution are found in:

- the concrete transfer slab at Level 1
- the loadbearing structure including walls, floors, columns and roof
- the preliminary costs for the project (including crane, site sheds, supervision, scaffolding, and traffic control costs)

Additional costs under the timber solution (relative to the concrete solution) are in:

- the fire protection of the CLT elements
- the termite protection of the timber elements
- the fire engineering costs for the Alternative Solutions required for the loadbearing and fire-resisting walls.

Each is discussed in more detail below.

7.3 Savings in the Concrete Transfer Slab

As the timber solution is lighter in weight (20% of the mass of concrete) than the concrete solution, a thinner and cheaper concrete transfer slab is possible.

Timber	$312,660
Concrete	$430,340
Difference	-$167,680 (39% cheaper)

7.4 Savings in the Loadbearing Structure

Savings are possible due to reduction of material required for the roof and core walls and also the removal of columns throughout the building by the use of loadbearing walls.

Timber	$2,055,252
Concrete	$2,359,412
Difference	-$304,160 (13% cheaper)

7.5 Preliminary Cost Savings

The timber solution includes an estimated saving in preliminaries of $312,000, based on a construction program saving six weeks over the concrete solution (refer to Section 6). Here, each week was estimated to save $52,000, based on labour cost savings for site management, site sheds and plant such as crane, hoist, and scaffolding hire, compared to the concrete solution.

7.6 Additional Fire Protection Costs

Extra costs for the timber solution relate to the additional linings required for fire protection of timber loadbearing walls and floors ($734,940)

7.7 Additional Fire Engineering Costs

The timber solution includes additional consultancy fees (relative to the concrete solution) as a Deemed-to-Satisfy solution is not possible for the external and/or loadbearing fire resistant walls, and so an Alternative Solution is required. Based on quotes from Sydney-based fire engineers, the fire engineering fees for this under normal project-based scenarios would be $20,000.

7.8 Additional Termite Protection Costs

The timber solution sits atop a concrete basement (car park) and concrete retail level. As an additional precaution, the timber structure has termite protection by way of stainless mesh steel protection to all hidden entry points from the ground to the concrete structure. This protection was estimated to add $15,000 to the timber solution.

7.9 Other Potential Cost Saving for the Timber Solution

The following items include areas where cost saving potential exists in the timber solution, but for this cost exercise they have not been included.

- **Smarter Scaffold Erection Potential:** The timber structure only requires the use of scaffolding for the installation of the façade panels. The installation of aluminium cladding to the CLT panels, before erecting, could remove the need for scaffold and be replaced with hand rails already attached to floor panels. Joints in aluminium cladding could be completed by the use of mobile elevated platform.
- **Earlier start time on internal works:** Additional time savings are possible due to the earlier start time for internal work, as achieved by the earlier completion for the main structure (as discussed previously). Activities such as services rough-ins and internal wet area construction could all begin earlier compared to the concrete solution.
- **Easier substrate for linings and finishes:** The time to carry out fit-out activities is generally less than for concrete structures. For instance, cordless screw guns and nailing can be used, which is light, quick and easy to use. CLT inherently provides 'anywhere' fixing points. Concrete structures require drilling into concrete, which is slow, noisy and dirty, and requires anchor or friction-style fixings.
- **Footing Costs:** The timber solution is calculated to be 50% lighter than the concrete solution which potentially provides lighter and cheaper footings.
- **Crane size and type**: Crane savings discussed previously focus on the reduced hire period required for the timber solution, but there is also potential to use a lighter, remotely controlled crane (i.e. operated from the floor deck under construction). For instance, the timber solution's maximum panel weight is only 2,500 kg.
- **Truck Deliveries:** Deliveries for the timber solution are significantly reduced, saving supervision, handling at the road level and traffic management. Just-in-time delivery of timber can avoid panel storage on site.

8

Conclusion

A model eight-storey, high-end 42-apartment building was designed and costed using a timber (CLT) option and a conventional concrete-framed solution for a theoretical location in suburban Sydney. The site was assumed to have no significant cost implications concerning site access, ground conditions or neighbouring properties.

The timber solution was found to be $110,478 more cost effective, which equates to a 2.2% saving compared to the concrete solution. The main structural component costs were found to be lower in the timber model, but the fire protection requirements to some of these elements and the cost of termite protection largely offset this advantage.

Savings also existed in the preliminary costs for the project, an area not fully recognised when comparing costs. Further, it is concluded that the sawtooth style façade is more readily constructed using timber floor plates (which can be factory cut and cantilevered over beams), as distinct from the effort involved in formwork for the sawtooth protrusions in each floor plate under the concrete construction solution.

This Guide recommends that timber apartment building be considered as a viable alternative to traditional post tensioned concrete frame construction, particularly where:

- a lightweight structure provides structural benefits (including in poor foundations)
- prefabricated construction offers advantages
- the timber solution can be optimised for a given design
- the need for a short construction program is apparent
- there is a genuine intent to reduce preliminary costs.

Importantly, the level of cost comparison with concrete must go beyond a basic comparison of material costs and should instead weigh up a holistic spectrum of cost-sensitive issues affecting the construction process.

A

Appendix A: Comparison Design: The Concrete Solution

A1 Floor and Roof

Generally, a 200 mm flat plate concrete slab reinforced using conventional steel reinforcement and post tensioning cables, refer to Figures A1 and A2 on reinforced concrete columns.

Table A1 details the acoustic performance.

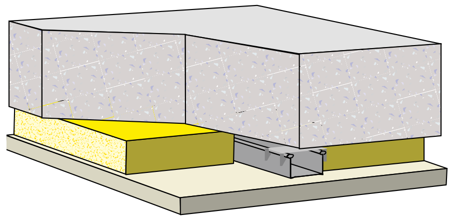
Type	Diagram of Floor System	Description	Acoustic		Fire rating
			Rw + Ctr	Ln,w (Ci)	
Floor		200 mm concrete slab, with furring channel at 600 crs, supporting 10 mm plasterboard. 50 mm polyester insulation is placed between furring channel	53[9]	35 to 40 with carpet and underlay	90/90/90

Table A1: Acoustic and Fire performance of Concrete Floor

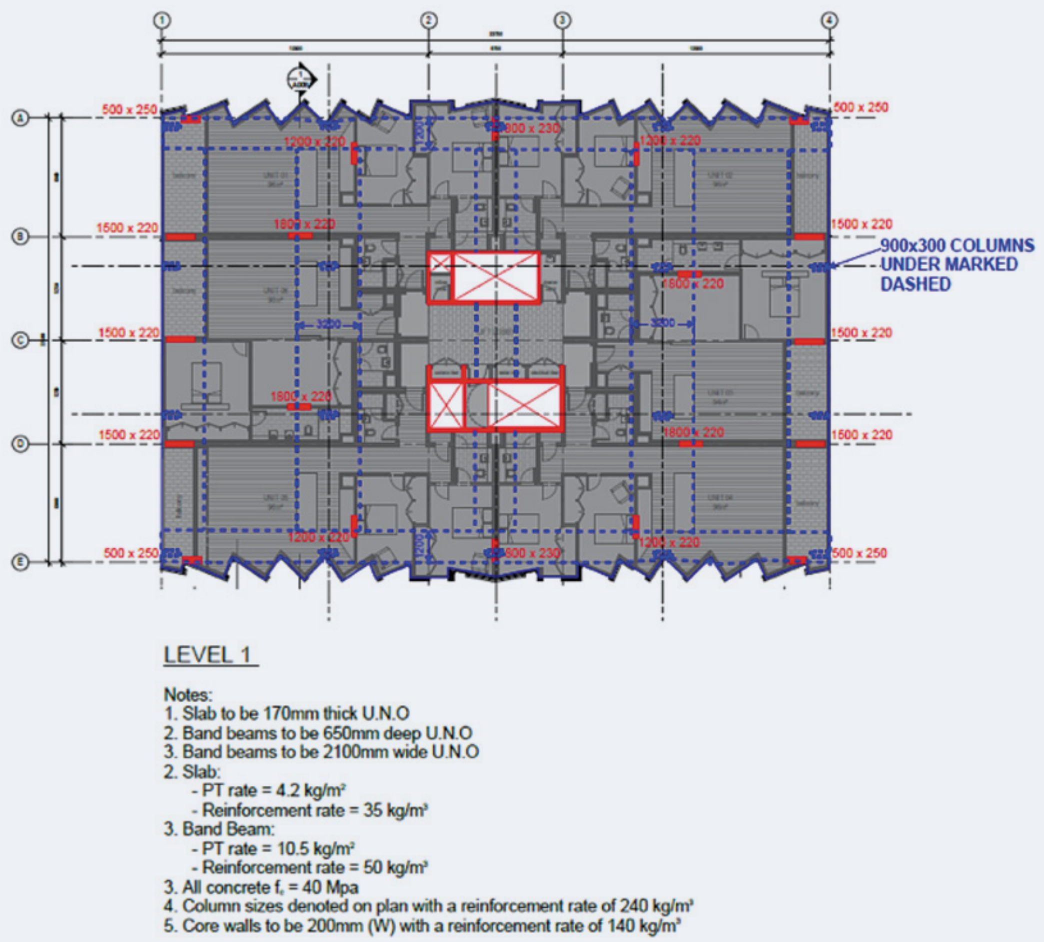


Figure A1: Level 1 concrete slab *Design and image: TTW*

[9] Boral Plasterboard System CFA10U

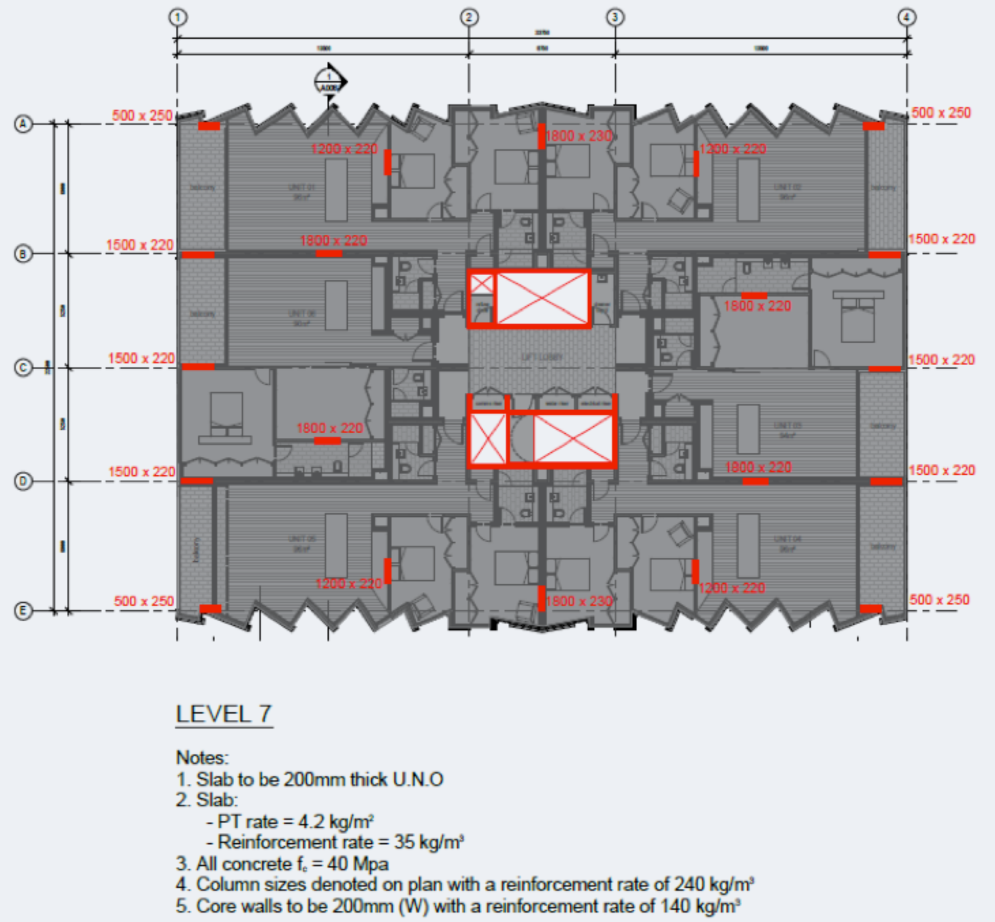


Figure A2: Level 2 to 7 and Roof Concrete Slab. *Design and image: TTW*

A2 Wall Systems

What was used in the timber solution:

- An aerated concrete wall system with metal studs, refer to Table A2.

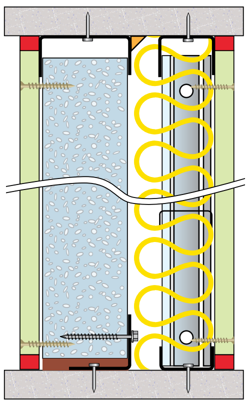
Wall Type	Diagram of Wall System	Description		Acoustic Rw + Ctr	Fire rating
		Structural	Linings & Insulation		
Internal		75 mm aerated lightweight concrete panel, with 64 mm steel stud with 20 mm air gap between aerated concrete and steel stud	13 mm fire-resisting plasterboard linings both side of wall (moisture-resistant used in wet areas). 75 mm glass wool in air gap	53[10]	90/90/90

Table A2: Acoustic and Fire performance of Concrete Solution Walls.

[10] High Rise Multi-Residential Intertenancy and Service Walls Design and Installation Guide, Hebel, 2014

Appendix B: Detailed Cost Plan

Project Name: **Residential Building – Timber (CLT)**

Client Name: Timber Development Association for Forest and Wood Products Australia

Element		$/m² GFA	Quantity	Unit	Unit Rate ($)	Cost ($)
Office Timber (With Ceiling)			**5,401**	**m²**	**$928.66**	**$5,015,705**
Columns		**$5.24**				**$28,305**
1	900 x 300 Reinforced concrete columns; 40MPa Concrete; Formwork; Reinforcement 240kg/m³, Post Tensioning 6kg/m²; 18No.	$5.24	51	m	$555	$28,305
Upper Floors		**$326.92**				**$4,254,500**
1	Reinforced in situ concrete suspended floor slab 500 thick; 40MPa Concrete; Formwork; Reinforcement 45kg/m³; Post Tensioning 6kg/m².	$57.89	772	m²	$405	$312,660
1a	Reinforced in situ concrete drop slab to underside of transfer slab; 1,800 x 1,800 x 650 thick; 40MPa Concrete; Formwork; Reinforcement 45kg/m³	$5.17	18	No.	$1,550	$27,900
2	5S180TL CLT floor panel approximate size 2,250 x 12,000 overall; sawtooth detail to one short edge.	$110.11	96	No.	$6,195	$594,720
3	5S180TL CLT floor panel approximate size 2,250 x 12,000 overall; sawtooth detail to one short edge; 2No. Services penetrations.	$27.53	24	No.	$6,195	$148,680
4	5S180TL CLT floor panel approximate size 2,250 x 12,000 overall; sawtooth detail to one short edge; 1No. Services penetration.	$27.53	24	No.	$6,195	$148,680
5	5S180TL CLT floor panel approximate size 2,250 x 7,520 overall; sawtooth detail to one short edge.	$17.62	24	No.	$3,965	$95,160
6	5S180TL CLT floor panel approximate size 2,250 x 7,520 overall; sawtooth detail to one short edge; 1No. Services penetration.	$8.81	12	No.	$3,965	$47,580
7	5S180TL CLT floor panel approximate size 2,250 x 3,260 overall.	$6.75	18	No.	$2,025	$36,450
8	2/200 x 63 LVL13 beams 11,250 mm long	$3.59	14	No.	$1,383.75	$19,373
9	2/240 x 90 LVL13 beams 5,250 mm long	$2.54	14	No.	$981.75	$13,745
Roof		**$27.24**				**$147,135**
1	5TL140 CLT roof panel approximate size 2,250 x 12,000 overall; sawtooth detail to one short edge.	$15.15	16	No.	$5,115	$81,840
2	5TL140 CLT roof panel approximate size 2,250 x 12,000 overall; sawtooth detail to one short edge; 2No. Services penetrations.	$3.79	4	No.	$5,115	$20,460
3	5TL140 CLT roof panel approximate size 2,250 x 12,000 overall; sawtooth detail to one short edge; 1No. Services penetration.	$3.79	4	No.	$5,115	$20,460
4	5TL140 CLT roof panel approximate size 2,250 x 7,520 overall; sawtooth detail to one short edge.	$2.43	4	No.	$3,285	$13,140
5	5TL140 CLT roof panel approximate size 2,250 x 7,520 overall; sawtooth detail to one short edge; 1No. Services penetration.	$1.22	2	No.	$3,285	$6,570
6	5TL140 CLT roof panel approximate size 2,250 x 3,260 overall.	$0.86	3	No.	$1,555	$4,665

Client Name: Timber Development Association for Forest and Wood Products Australia

Element		$/m² GFA	Quantity	Unit	Unit Rate ($)	Cost ($)
External Walls		**$201.43**				**$1,087,910**
1	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 1,290 wide x 2,950 high	$4.82	28	No.	$930	$26,040
2	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 2,590 wide x 2,950 high	$13.14	42	No.	$1,690	$70,980
3	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 2,230 wide x 2950 high	$11.51	42	No.	$1,480	$62,160
4	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 2,120 wide x 2,950 high	$7.36	28	No.	$1,420	$39,760
5	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 1,650 wide x 2,950 high	$5.91	28	No.	$1,140	$31,920
6	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 4,590 wide x 2,950 high	$5.34	28	No.	$1,030	$28,840
7	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 2,470 wide x 2,950 high	$4.72	28	No.	$910	$25,480
8	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 2,350 wide x 2,950 high	$4.67	28	No.	$900	$25,200
9	5S125TL CLT panel fixed to CLT floor panel; Wall Type 1; 2,940 wide x 2,950 high	$2.44	14	No.	$940	$13,160
10	Alucobond on and including timber framing to CLT external wall panels (Measured separately); Wall Type 1.	$136.51	2048	m²	$360	$737,280
11	5S125TL CLT panelling fixed to CLT floor panel; Wall Type 1	$5.02	129	m²	$210	$27,090
Internal Walls		**$173.86**				**$939,037**
1	5S95TT CLT panel fixed to CLT floor panel; Wall Type 2; 2,950 high	$55.14	1,584	m²	$188	$297,792
2	5S95TT CLT panel fixed to CLT floor panel; Wall Type 2; at door openings	$3.27	94	m²	$188	$17,672
3	5S95TT CLT panel fixed to CLT floor panel; Wall Type 3; 2,950 high	$27.92	802	m²	$188	$150,776
4	5S95TT CLT panel fixed to CLT floor panel; Wall Type 3; at door openings	$11	316	m²	$188	$59,408
5	70 x 35 untreated softwood stud members	$21.94	1,823	m²	$65	$118,495
6	70 x 35 untreated softwood stud members	$2.70	224	m²	$65	$14,560
7	5S125TL CLT panel fixed to CLT floor panel; Wall Type 5; 2,950 high	$21.27	555	m²	$207	$114,885
8	5S125TL CLT panel fixed to CLT floor panel; Wall Type 6; 2,950 high	$25.91	676	m²	$207	$139,932
9	90 mm timber stud framed wall, lined one side with 10 mm plasterboard; Wall Type "8".	$4.72	323	m²	$79	$25,517

Client Name: Timber Development Association for Forest and Wood Products Australia

Element		$/m² GFA	Quantity	Unit	Unit Rate ($)	Cost ($)
Wall Finishes		**$160.71**				**$867,998**
1	2/13 mm FR Plasterboard direct fixed to one side of CLT wall panel (Measured separately), 70 mm timber framing with 75mm bulk insulation between members, 10 mm plasterboard finish; Wall Type 2.	$19.66	685	m^2	$155	$106,175
1a	1/13 mm FR Plasterboard direct fixed to one side of CLT wall panel (Measured separately), 70 mm timber framing with 75mm bulk insulation between members, 10 mm plasterboard finish; Wall Type 2a.	$16.87	685	m^2	$133	$91,105
1b	70 mm timber framing with 75 mm bulk insulation between members, 10 mm plasterboard finish	$4.34	230	m^2	$102	$23,460
2	2/13 mm FR Plasterboard direct fixed to one side of CLT wall panel (Measured separately); Wall Type 2.	$6.72	685	m^2	$53	$36,305
2a	1/13 mm FR Plasterboard direct fixed to one side of CLT wall panel (Measured separately); Wall Type 2a.	$3.93	685	m^2	$31	$21,235
2b	1/10 mm Plasterboard direct fixed to one side of CLT wall panel (Measured separately); Wall Type 2b.	$1.11	230	m^3	$26	$5,980
3	2/13 mm FR Plasterboard direct fixed to both sides of CLT wall panel (Measured separately); Wall Type 3.	$15.01	765	m^2	$106	$81,090
3a	1/13 mm FR Plasterboard direct fixed to both sides of CLT wall panel (Measured separately); Wall Type 3a.	$8.78	765	m^2	$62	$47,430
3b	1/10 mm Plasterboard direct fixed to both sides of CLT wall panel (Measured separately); Wall Type 3b.	$2.64	255	m^2	$56	$14,280
4	10 mm Plasterboard direct fixed to both sides of CLT wall panel (Measured separately); Wall Type 4.	$32.79	3162	m^2	$56	$177,072
5	6 mm Fibre Cement board direct fixed to both sides of stud wall (Measured separately); Wall Type 4.	$14.91	610	m^2	$132	$80,520
6	2/13 mm FR Plasterboard direct fixed to one side of CLT wall panel (Measured separately); Wall Type 6.	$2.14	218	m^2	$53	$11,554
6a	1/13 mm FR Plasterboard direct fixed to one side of CLT wall panel (Measured separately); Wall Type 6a.	$1.25	218	m^2	$31	$6,758
6b	1/10 mm Plasterboard direct fixed to one side of CLT wall panel (Measured separately); Wall Type 6b.	$0.38	74	m^2	$28	$2,072
7	102 mm C-H metal stud framed wall, lined between studs with 25 mm Fire-Resistant Plasterboard, 2/13 mm Fire Resistant Plasterboard finish; Wall Type 7.	$19.56	607	m^2	$174	$105,618
8	10mm Plasterboard direct fixed to CLT external wall panel (Measured separately); Wall Type 1.	$10.62	2048	m^2	$28	$57,344
Ceiling Finishes		**$146.71**				**$792,373**
1	2/16 mm FR Plasterboard direct-fixed to underside of CLT panels (Measured separately).	$61.71	4629	m^2	$72	$333,288
2	Standard suspended ceiling grid, 150 mm drop; 10 mm Plasterboard to and including top hat channels; 50 insulation.	$85.00	5401	m^2	$85	$459,085
Preliminaries Adjustment		**-$54.06**				**-$292,000**
Provision of time related preliminaries based on the duration of structure construction time.						
Preliminaries based on reduced Construction duration of:		-$57.77	6	Weeks	-$52,000	-$312,000
Termite Protection Allowance				Item		$20,000
						$5,015,705

Notes:
1. The cost estimates are priced at September 2014 prices and based on construction in the Sydney Region.
2. The adjustment made to Preliminaries reflects the program savings compared to RC Frame construction.
3. Timber Frame construction will have a significantly faster construction program than RC Frame.
4. CLT internal partitions measured over door openings, which are shown taken separately.
5. CLT price is based upon an exchange rate of 1 AUD to 0.69 Euros.

Client Name: Timber Development Association for Forest and Wood Products Australia

	Element	$/m² GFA	Quantity	Unit	Unit Rate ($)	Cost ($)
Residential Reinforced Concrete Framed Building			**5,401**	**m²**	**$949.12**	**$5,126,183**
Columns		**$56.68**				**$306,130**
1	Reinforced Concrete columns 500 x 250; 40MPa Concrete; Reinforcement 240kg/m³; 28No.	$4.40	82	m	$290	$23,780
2	Reinforced Concrete columns 1,500 x 220; 40MPa Concrete; Reinforcement 240kg/m³; 42No.	$16.97	123	m	$745	$91,635
3	Reinforced Concrete columns 1,200 x 220; 40MPa Concrete; Reinforcement 240kg/m³; 28No.	$9.26	82	m	$610	$50,020
4	Reinforced Concrete columns 1,800 x 220; 40MPa Concrete; Reinforcement 240kg/m³; 28No.	$13.36	82	m	$880	$72,160
5	Reinforced Concrete columns 1,800 x 230; 40MPa Concrete; Reinforcement 240kg/m³; 14No.	$6.83	41	m	$900	$36,900
6	900 x 300 Reinforced concrete columns; 40MPa Concrete; Formwork; Reinforcement 240kg/m³, Post Tensioning 6kg/m²; 18No.	$5.86	57	m	$555	$31,635
Upper Floors		**$307.49**				**$1,660,735**
1	Reinforced in situ concrete suspended transfer floor slab 170 thick; 40MPa Concrete; Formwork; Reinforcement 40kg/m³; Post Tensioning 4.2kg/m².	$35.02	772	m²	$245	$189,140
2	Reinforced in situ concrete suspended floor slab 200 thick; 40MPa Concrete; Formwork; Reinforcement 35kg/m³; Post Tensioning 4.2kg/m².	$218.55	4629	m²	$255	$1,180,395
3	Reinforced in situ concrete attached beam, 2,100 wide x 650 deep; 40MPa Concrete; Formwork; Reinforcement 40kg/m³; 19No.	$53.92	280	m	$1,040	$291,200
Roof		**$38.05**				**$205,530**
1	Reinforced in situ concrete suspended floor slab 200 thick; 40MPa Concrete; Formwork; Reinforcement 35kg/m³; Post Tensioning 4.2kg/m².	$11.00	316	m²	$188	$59,408
External Walls		**$203.36**				**$1,098,327**
1	75 mm Hebel external wall panel; Wall Type 1; 1,290 wide x 2,950 high	$3.16	28	No.	$609.00	$17,052
2	75 mm Hebel external wall panel; Wall Type 1; 2,590 wide x 2,950 high	$9.50	42	No.	$1,222.00	$51,324
3	75 mm Hebel external wall panel; Wall Type 1; 2,230 wide x 2,950 high	$8.19	42	No.	$1,053.00	$44,226
4	75 mm Hebel external wall panel; Wall Type 1; 2,120 wide x 2,950 high	$5.19	28	No.	$1,001.00	$28,028
5	75 mm Hebel external wall panel; Wall Type 1; 1,650 wide x 2,950 high	$4.04	28	No.	$779.00	$21,812
6	75 mm Hebel external wall panel; Wall Type 1; 4,590 wide x 2,950 high	$11.23	28	No.	$2,166.00	$60,648
7	75 mm Hebel external wall panel; Wall Type 1; 2,470 wide x 2,950 high	$6.04	28	No.	$1,166.00	$32,648
8	75 mm Hebel external wall panel; Wall Type 1; 2,350 wide x 2,950 high	$5.75	28	No.	$1,109.00	$31,052
9	75 mm Hebel external wall panel; Wall Type 1; 2,940 wide x 2,950 high	$3.60	14	No.	$1,388.00	$19,432
10	Alucobond on and including timber framing to Hebel external wall panels (measured separately); Wall Type 1.	$136.51	2048	m²	$360.00	$737,280
11	Reinforced Concrete walls 200 thick; Formwork; 40MPa Concrete; reinforcement 140kg/m³	$10.15	129	m²	$425.00	$54,825

Project Name: **Residential Building - RC Frame**

Client Name: Timber Development Association for Forest and Wood Products Australia

Element		$/m² GFA	Quantity	Unit	Unit Rate ($)	Cost ($)
Internal Walls		**$176.81**				**$954,955**
1	Reinforced Concrete walls 200 thick; Formwork; 40MPa Concrete; reinforcement 140kg/m³	$70.74	899	m²	$425	$382,075
2	75 mm Hebel; Wall Type 2.	$47.72	1611	m²	$160	$257,760
3	64 mm Steel stud partitioning, built alongside Hebel internal partition, 50 bulk insulation; Wall Type 2.	$23.86	1611	m²	$80	$128,880
4	64 mm Steel stud partitioning	$34.48	3104	m²	$60	$186,240
Wall Finishes		**$76.73**				**$414,416**
1	10 mm Plasterboard to steel stud partitioning; Wall Type 2.	$7.76	1611	m²	$26	$41,886
2	10 mm Plasterboard direct fixed to Hebel; Wall Type 2.	$7.76	1611	m²	$26	$41,886
3	10 mm Plasterboard to steel stud partitioning	$26.95	5598	m²	$26	$145,548
4	6 mm Fibre Cement board direct fixed to steel stud partitioning.	$4.86	610	m²	$43	$26,230
5	102 mm C-H metal stud framed wall, lined between studs with 25 mm Fire Resistant Plasterboard, 2/13 mm Fire-Resistant Plasterboard finish; Wall Type 7.	$19.56	607	m²	$174	$105,618
6	10 mm Plasterboard direct fixed to Hebel external wall panel (measured separately); Wall Type 1.	$9.86	2048	m²	$26	$53,248
Ceiling Finishes		**$90**				**$486,090**
1	Standard suspended ceiling grid, 150 mm drop; 10 mm Plasterboard to and including top hat channels; 75 insulation.	$90	5401	m²	$90	$486,090
Preliminaries Adjustment		**$0**				**$0**
Provision of time related preliminaries based on the duration of structure construction time.						
Preliminaries based on reduced Construction duration of:		$0	0	Weeks	$0	$0
						$5,126,183

Notes:

1. The cost estimates are priced at September 2014 prices and based on construction in the Sydney Region.
2. The cost comparison of RC and Timber Frames uses the RC Frame program duration as the base; and subsequently there is no adjustment to the preliminaries above.
3. Timber Frame construction will have a significantly faster construction program than RC Frame.
4. The timber frame rates are based on feedback from the Sydney market.

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