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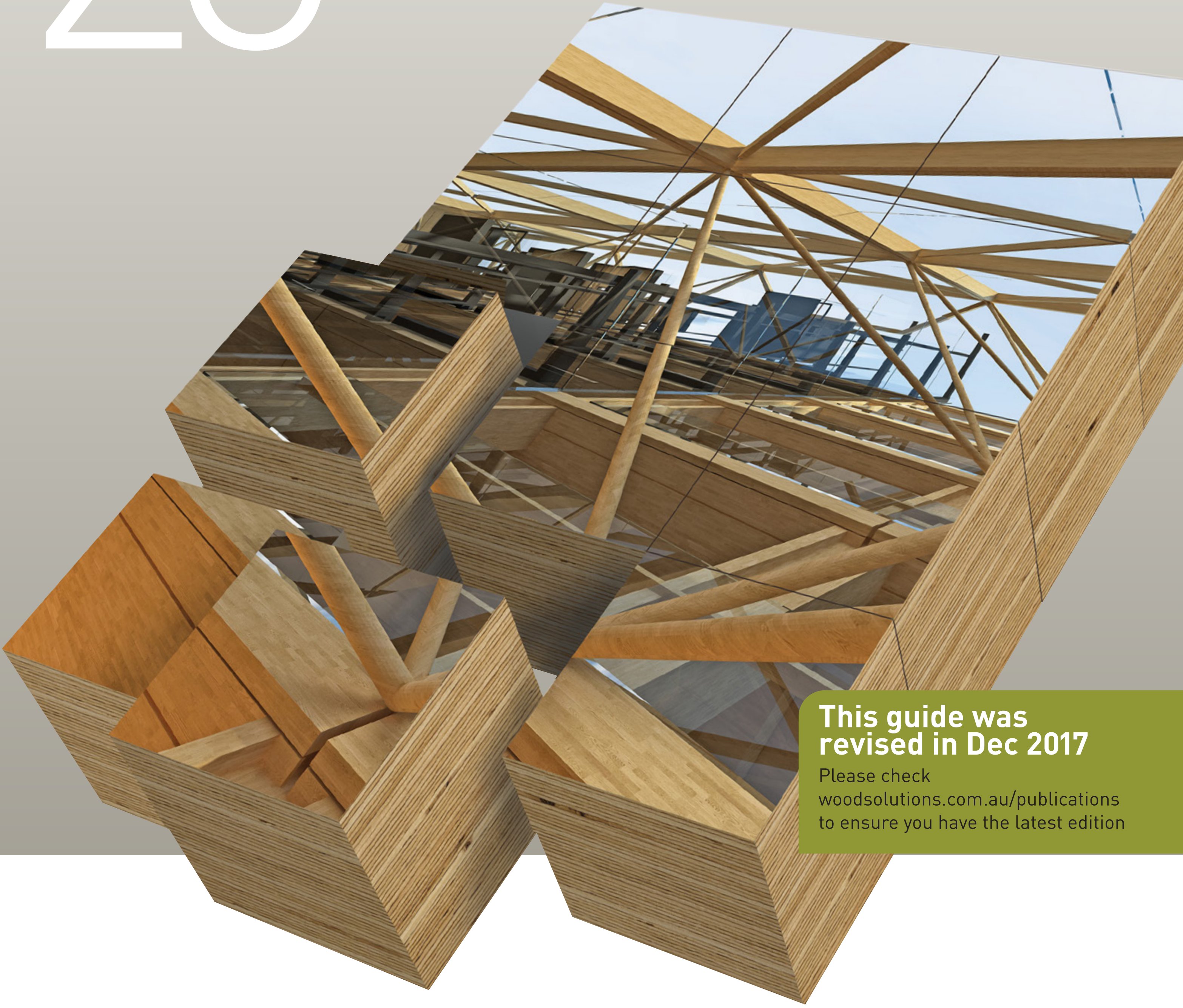

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Rethinking Office Construction - Consider Timber

Design Guide issued by Forest and Wood Products Australia

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Cover image: Render of proposed timber commercial building for Sussex Street Fitzpatrick + Partners Architects

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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 to 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 mid-rise office building projects.

The Guide is based on a research project that developed a model mid-rise office 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 provide guidance for compliance under the National Construction Code (NCC) for Class 5 office buildings. This Guide provides an explanatory understanding of decision making issues when developing timber solutions.

This Guide was updated in mid-2017 to bring the timber design inline with the 2016 changes to the Building Code of Australia for Fire-protected timber solutions. Pricing has also been revised to reflect current market conditions.

2

What Drives Decisions When Choosing an Office Construction System?

A key objective of the research project was to provide an understanding of the decision drivers along the full length of the customer/supply chain that influence the selection of office construction systems. Key areas of investigation included:

- Gathering information about customer needs and how construction affects things like the leasability of the floor space, how the structural configuration can affect the area that can be let, and the capacity to easily adapt the space for retrofit and upgrade.
- Benchmarking against existing office construction systems, especially conventional post-tensioned concrete slab construction. This was found to be the main method used for mid-rise office building construction and was consequently used as the basis for comparison to timber. A concrete solution for the model building is provided in Appendix A.
- Integrating understanding of technical design issues, including structure, HVAC and façade systems.
- 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.

3

Project Development

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

A team of experts worked 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 with 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, construction, cost and site productivity issues.
- **Fitzpatrick and Partners**: An architectural firm specialising in office design with significant experience in all the major cities in Australia. They provided feedback on client needs, helped design the model office building and the related timber solution.
- **Arup Ltd**: A global multi-disciplinary engineering firm with expertise spanning structural, acoustic, fire and services engineering. Arup provided design and engineering input into the timber solution and the corresponding concrete solution, as well as assisting in HVAC and acoustic decisions.
- **RBE Contracting**: A construction project management company with expertise in many forms of building construction and specific expertise in large-scale timber construction. They provided input into the timber solution and competing concrete solution, especially in terms of design management and site process–driven variables.
- **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.
- **MBM**: A national, indepentant construction consultancy specialising in quantity surveying. They provided quantity surveying, cost estimating and cost planning imput for both the timber and corresponding concrete solutions. MBM has recently developed experience in timber construction and costing.
- **Engineered timber manufacturers and suppliers (including Tilling Timber, Meyer Timber, Nelson Pine, Carter Holt Harvey Wood Products, MiTek)**: Their input included information on timber supply costs, practical viability, design properties, manufacturing processes and the availability of appropriate timber componentry (including supply of long span beam and panel products).

4

The Model Office Building - the Basis for Comparison and Solution Development

The model office building was created to provide a basis for defining and presenting a timber–based solution, as well as a corresponding concrete solution. Such an approach helps to model spatial, loading, fire and noise resistance conditions. Emphasis was placed on characterising a building that could apply to many suburban/urban office situations across Australia, approximating real world conditions.

A series of conceptual timber designs was developed by the research team revolving around different column and floor plate assemblies. In total, 30 initial designs were considered. Each was debated, tested for logic and then rationalised for functional performance, cost impact, construction flow, overall time efficiency, structural performance, services integration and value impact on the building owner. This informed the learning process for the research team in terms of understanding sensitive issues and key inter-relationships. From this, a refined set of options was distilled including a preferred option (as presented in the main body of this report) and three alternative options (described in a summarised format in Appendix D). Of note, this final set of options was primarily included for feedback to a broader cross-section of building owners, developers, designers and contractors.

Figures 1, 2 and 3 provide an overarching understanding of the model office building. The basic spatial characteristics and some of the detailed features of the model are provided in Table 1:

Item	What was used in the model	Relevance and Reasons
Height	• A 7-storey above-ground building, with two basement (car parking) levels. • A 26 m overall building height but with an NCC effective height of 22.2 m (referring to the upper most habitable floor but excluding the top storey, where used for items such water tanks, lifts, etc).	• This height is typical of many suburban and CBD office building situations. • The chosen height aims to maximise the floor-to-site ratio while staying below the 25 m effective building height used by the NCC as a limit for fire-protected timber soluions.
Area	• A floor plate area of 1,944 m^2 • Length 72 m x Width 27 m.	• Feedback from architects indicates that many suburban office buildings fit in a footprint range of 1,500 to 2,000 m^2. • Office buildings are often 24 to 32 m wide to allow natural light in the centre of the building and for car parking layout requirements.
Key set out criteria	• A column grid layout of 9.0 x 9.0 m has been applied repetitively across all floor levels. This negates the need for a transfer slab.	• Architectural practice emphasises large uninterrupted floor spaces, basement parking set out, flexibility of internal office layouts and freedom of worker movement. • Column spacing often uses an 8.4 x 8.4 m grid (based around parking layouts) or a larger 9.0 m x 9.0 m grid. The latter is used to show the spanning capabilities of timber.
Building ownership and fire compartment-alisation	• The building is assumed to be owned by a single entity (as is common in office building ownership).	• This avoids the need for certain fire resistant construction where large spaces are defined by multiple sole occupancy units (refer NCC for details).
Setbacks	• External walls are assumed to be at least 3.0 m away from the property boundaries and/or other buildings.	• The location of the building relative to other buildings impacts on façade fire resistance requirements.

Table 1: Spatial characteristics and features of the model office building.

4.1 Core Differences between the Timber and Concrete Solutions

Many aspects of the model design provide neutrality in terms of cost effectiveness between the timber and comparative concrete solutions.

The main difference is that the seven storeys above the ground are constructed using timber under one scenario and concrete under the other. This difference affected how each structure responded to building parameters such as fire, acoustics, ductwork and building services. These items are dealt with under dedicated headings below.

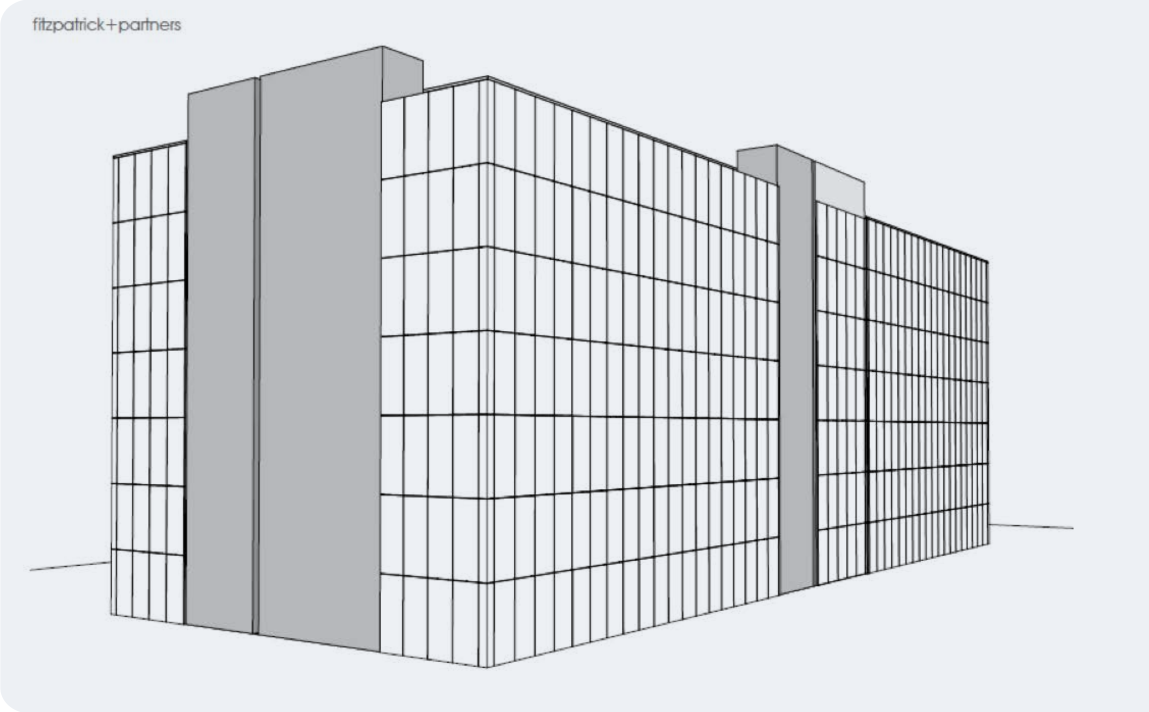


Figure 1: Model office building elevation view.

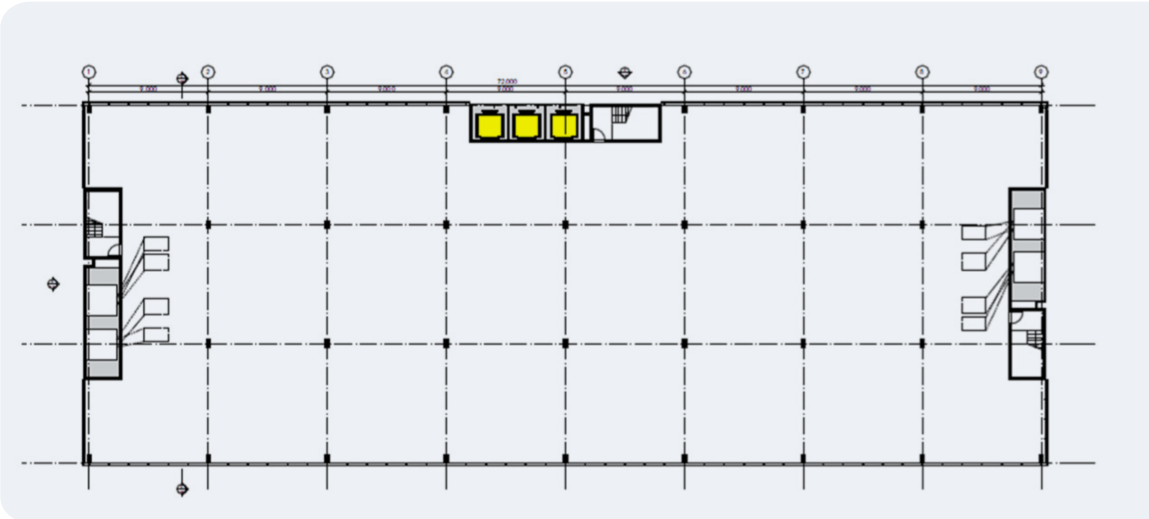


Figure 2: Model office building typical floor plate plan.

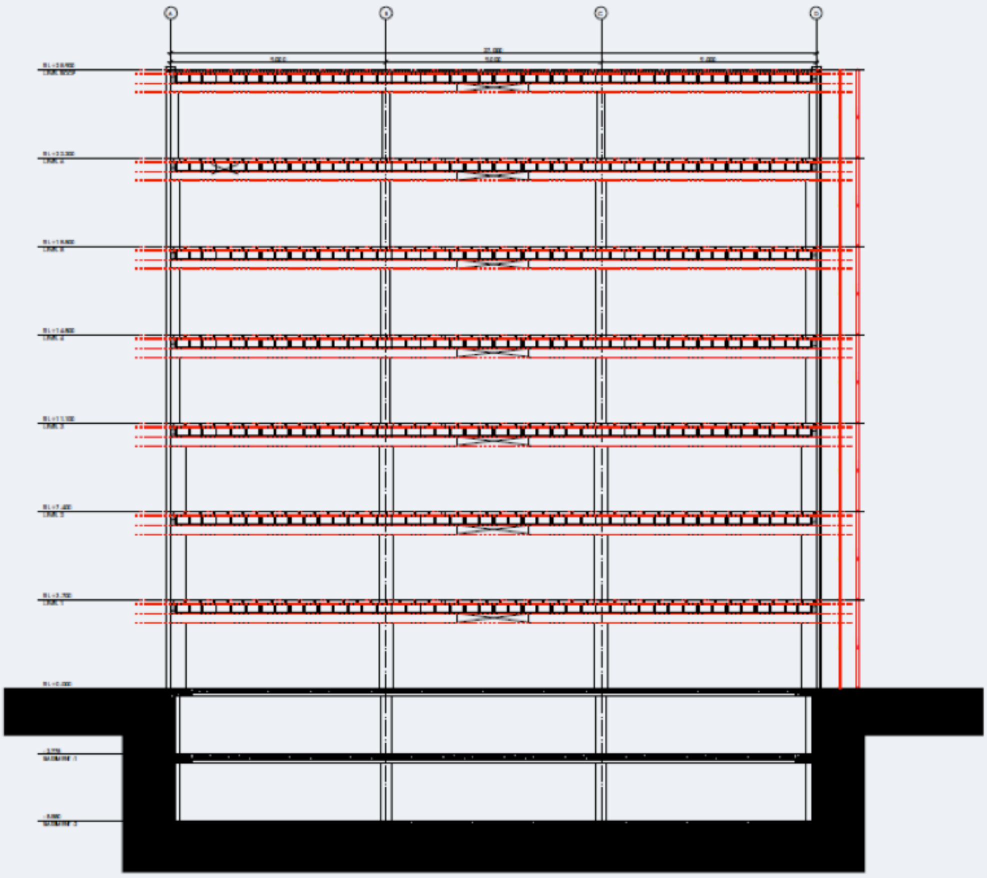


Figure 3: Section through model building.

4.2 Specific Parameters Below Ground

Parameters applied to the model:

- For the timber solution, timber starts at the ground floor level with concrete masonry construction applied to the two basement levels below.
- Weathered shale soil conditions were used in the structural analysis and cost planning exercises.

Reasons:

- While in technical terms, timber can be constructed below ground level, concrete and concrete masonry construction are less likely to attract concerns about moisture penetration and termite activity. The timber solution has a number of redundant strategies to prevent termite ingress, including the use of preservative-treated termite resistant timber for the ground floor columns, slab edge exposure around the building and a stainless steel mesh barrier at all hidden entry points between the concrete subfloor and timber structure.
- 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 and footing requirements.

4.3 Building Parameters Above Ground

Parameters applied to the model:

- A 3.7 m floor-to-floor height has been applied to all such levels including a 2.7 m habitable height and a 1,000 mm height for floor structure, mechanical/air conditioning ducts, the ceiling grid and the office tenant zone. Typical allowances incorporated into the 1.0 m height include:
  - Ceiling grid – 50 mm
  - Mechanical and air conditioning – 350 mm
  - Floor structure depth – 400 mm
  - Office tenant zone – 200 mm
- Standard loading from AS1170:
  - Permanent – 2.5 kPa
  - Applied – 3.0 kPa
  - Wind – N2

Reasons:

- The floor-to-floor height meets normal industry expectations and demonstrates that a timber solution can meet this requirement.
- Permanent loading includes the concrete screed inside the floor cassette, partitions, services and the ceiling.

4.4 Building Acoustics

Parameters applied to the model:

- Floors are designed to achieve a rating of at least Rw - 45 and a minimum $L_{n,w}$ (C_I) - 62 for impact sound (this assumes that carpets are added to the floor by tenants or landlords).
- Walls to the lift core are designed to achieve a rating of Rw 45.

Reasons:

- There is no requirement in the NCC for acoustic performance in office buildings but it is generally accepted that some level of performance will be required to meet end-user expectations. Feedback suggests floor design is normally dependent on impact noise and should achieve a rating better than $L_{n,w}$ (C_I) - 62 in order to meet industry expectations. For airborne noise, a range of Rw 45 to 50 has been applied to meet industry expectations.
- The timber solution provides simple provision for an upgrade in acoustic performance as required for sensitive areas, such as meeting rooms. This is achievable via the use of an access floor or acoustic designed ceilings.

4.5 Fire Resistance

Parameters applied to the model:

- The NCC defines the model building as a Class 5 (office building); involving a 7-storey rise and Type A construction. Collectively, these factors define measurable fire resistance requirements dealt with later in this section.
- A sprinkler system is incorporated at each floor level and at the roof level for both the timber and concrete solutions. Feedback from designers suggests that this has become a commonly expected requirement irrespective of minimum NCC requirements, because it can be used to avoid constraints in the façade design (concerning fire resistance at openings).
- Load-bearing internal walls are limited to lift and stair shafts and are designed for fire resistant construction by using the fire-protected timber solution within the NCC.

Reasons:

- For ease of implementation and standardisation, the parameters above allow the model building to largely use Deemed-to-Satisfy (DtS) provisions for fire resistance in the NCC.

Additional points of interest:

- While concrete construction can avoid sprinkler systems in buildings less than 25 m in effective height, it is still commonplace for such buildings to incorporate such systems for the reasons stated above.

4.5.1 Fire Resistance of External Walls including Vertical Separation of Openings in External Walls

Parameters applied to the model:

- A non-combustible and non-load bearing glass façade is used to prevent the spread of fire relating to the outer face of the building, thus providing a cost neutral façade for both timber and concrete solutions.

Reasons:

- NCC Specification C1.1, Table 3 for Type A Construction has no Fire Resistance Level (FRL) requirements for non-load bearing external walls that are 3 m or more from boundary or another building.
- Use of a non-combustible glass facade in combination with an internal sprinkler system effectively removes the need for fire protection on the outside of the building and the vertical separation of openings (as required under the NCC Deemed-to-Satisfy requirements), thus simplifying façade design constraints.

4.5.2 Fire Resistance of Internal Walls

Parameters applied to the model:

- Internal load bearing walls have been designed under the assumption that they only occur for the lift, stair and ventilation shafts in the model design.
  - For the timber solution: These walls have been designed to comply with the fire-protected timber solution within the NCC.
  - For the concrete solution, a Deemed-to-Satisfy solution already exists and applies an FRL of 120/120/120.
- Other fire resistant internal walls (including other load-bearing walls) do not exist in the model design and subsequently NCC-defined FRLs are not required (refer NCC Specification C1.1, Table 3 for Type A Construction).

Reasons:

- For fire-resisting lift, stair and ventilation shafts walls (and load bearing internal walls), the NCC requires an FRL of 120/120/120, as defined under Specification C1.1, Table 3 Type A Construction. These walls were designed to comply with the fire-protected timber provision in the NCC, specification C1.1, 3.1 (d) and (e) and NCC provision C1.13 Fire-Protected timber: concession.
- NCC provision C2.6 removes the need for a spandrel or horizontal projection where a complying sprinkler system is installed.

4.5.3 Fire Resistance of Internal Beams

Parameters applied to the model:

- Using the Deemed-to-Satisfy provisions of the NCC, the model requires beams to have an FRL of 90/90/90. This applies to both timber and concrete solutions.
- The timber solution can utilise 'charring' of the timber itself to meet Deemed-to-Satisfy provisions as calculated by Australian Standard AS1720 Part 4 (refer to Appendix E for details).

Reasons:

- NCC Specification C1.1, Table 3 Type A Construction – FRL of Building elements – requires beams to have an FRL of 120/120/120 but, by making use of Specification C1.1 Clause 3.3, there is the ability to apply a concession for 3.0 kPa loading situations, allowing floors and floor beams to be reduced to a FRL 90/90/90.
- NCC Specification A2.3 references Australian Standard AS 1720 Part 4 as a method to calculate FRL for structural beams and columns.

4.5.4 Fire Resistance of Columns

Parameters applied to the model:

- The ground floor to sixth floor of the model uses fire-rated columns with an FRL of 90/90/90. The seventh floor (the top floor) of the model requires a lesser FRL of 60/60/60.
- The timber solution can utilise 'charring' of the timber itself to meet Deemed to Satisfy Provisions under AS 1720 Part 4 (refer to Appendix E for details).

Reasons:

- NCC Specification C1.1, Table 3 Type A Construction – FRL of building elements – requires FRL 120/120/120 (but the concession used for floors and beams, Specification C1.1 Clause 3.3, is not applicable to columns). An Alternative Solution was required to reduce the FRL to 90/90/90.
- Reducing the FRL of columns to 90/90/90 instead of NCC DtS of 120/120/120 saves around $100,000. This saving is due to column size corresponding with more readily available laminated veneer lumber (LVL) sizes.
- The top-most storey of the buildings allows the ability to apply a concession concerning internal columns and walls whereby fire resistance can be reduced to FRL 60/60/60 for this level under Specification C1.1 Clause 3.7.

4.5.5 Fire Resistance of Floors

Parameters applied to the model:

- Using the Deemed-to-Satisfy provisions of the NCC, the model requires fire rated floors to have an FRL of 90/90/90. This applies to both timber and concrete solutions.
- The timber solution can utilise 'charring' of the timber itself to meet Deemed to Satisfy Provisions under AS1720 Part 4 (refer to Appendix E for details).

Reasons:

- Specification C1.1 Table 3 Type A Construction – FRL of Building elements – requires the floor to have an FRL of 120/120/120 but, by making use of Specification C1.1 Clause 3.3, there is the ability to apply a concession for 3.0 kPa loading situations, allowing floors to be reduced to a FRL 90/90/90.

4.5.6 Fire Resistance of the Roof

Parameters applied to the model:

- Using the Deemed-to-Satisfy provisions of the NCC, the model requires fire resistance for columns supporting the roof to have FRL 60/60/60. The roof framing itself (including related beams) requires no fire rating. Element sizes for the roof structure (including related beams and columns) can be reduced as there are no specific fire resistance requirements for the top-most storey of the building.
- This applies to both timber and concrete solutions, which have similar flat roof approaches above respective structural systems. Of note, this includes a waterproof membrane with a non-combustible covering (gravel) to protect the membrane.

Reasons:

- The roof need not comply with the NCC Specification C1.1, Table 3 for Type A Construction (i.e. FRL 120/60/30) as a complying sprinkler system is installed throughout the building, removing any fire resistance requirement for the roof, refer Specification C1.1 Clause 3.5.
- Floor cassettes and beam are similar to what has been used at each floor level, using existing trades already on site.

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 uses a number of themes:

- Prefabricated cassette floors to six levels of above-ground floors and roof.
- Cross-laminated timber walls for the building core in all seven above-ground floors.
- A propped cantilever beam system for primary beams, enabling strategic positioning of the main air conditioning ducting, within the primary beam alignment.

Details are provided below. In contrast, the concrete solution uses a more commonly used post tensioned, band beam design, which is detailed in Appendix A for comparative purposes.

5.1 Primary Beams

What was used in the timber solution:

- Paired LVL beams are used as primary beams, sized at 800 x 180 mm (each) using LVL13[1] grade (Figures 4, 5 and 6).
- The paired beams form a propped cantilever, whereby they span the outer bays on opposing sides of the building and then cantilever into the central bay. The paired beams are fixed to opposing sides of the column heads (Figure 6).
- Smaller infill beams, sized at 400 x 300 (LVL13) span the remaining part of the central bay and are simply supported by the main beam ends (Figure 5).
- Timber blocks are placed as spacers to reduce fire exposure between the paired beam, at the top and bottom (Figure 7).
- All timber blocks and ledgers secured to beams are screw fixed (Figure 7).
- Beams are fixed to columns with M16 bolts and timber washers (Figure 7).
- Fire protection to beam supports at columns is provided by notching the beam and column so that there is at least 100 mm of timber thickness protection, leaving around 40 mm of timber at the column support after charring from a potential fire event (Figure 8).

Reasons:

- LVL is commonly available and well suited to long-span construction situations. It is commonly manufactured in billets of 12 m x 1.2 m and thicknesses ranging from 28 mm to 105 mm. These sections can be paired (as above), laminated up to 300 mm thick or fabricated into box beam sections.
- The propped cantilever design makes it possible to make use of the full manufactured LVL billet length for use in the beams (e.g. 12 m long) without creating waste, consequently reducing costs. This also suits the maximum transportable size of the billets.
- The paired beam configuration is used to allow the beams to pass through the column joint (Figure 5), thus enabling the cantilever action to occur. A one piece beam arrangement could also be used but would likely create greater structural issues regarding load transfer to the column heads (as discussed below).
- As the width of the building is 27 m and the LVL billets are 12 m in length, the cantilever design maximises the structural efficiency of the primary beams allowing the mid bay to use reduced depth beams (400 mm deep).
- The reduced depth beams in the central bay create a ceiling void used for the main run of HVAC ducting which services the full length of the building (as discussed in Section 5.4).
- The paired beam arrangement also reduces the span of the floor system, providing further cost savings.

[1] LVL 13 is a general grade description of LVL that has a MOE of 13.2 Mpa

- The structural properties of LVL include a Modulus of Elasticity (MOE) that ranges from 9.5 to 18 MPa. The structural design used in the beams was conservatively chosen for MOE 13.2 MPa, although it would be possible to provide a more refined result if using LVL with a higher MOE in the primary beams.
- Higher compressive strength LVL (47 MPa) is used on the Ground to Level 1 columns.
- Timber blocks are placed between the top and bottom of the paired primary beam assembly (Figure 7) to reduce exposure of the inner faces of the beams to fire. This strategy ultimately reduces the amount of timber required in the paired beams because it reduces the need for a fire-resisting 'charring layer' on the inner faces on the primary beams as the blocks prevent these faces from being exposed (see Appendix E for details about charring).
- The primary beam configuration may remain visually exposed, but has been designed so the standard office grid ceiling could be used without affecting floor-to-floor heights.

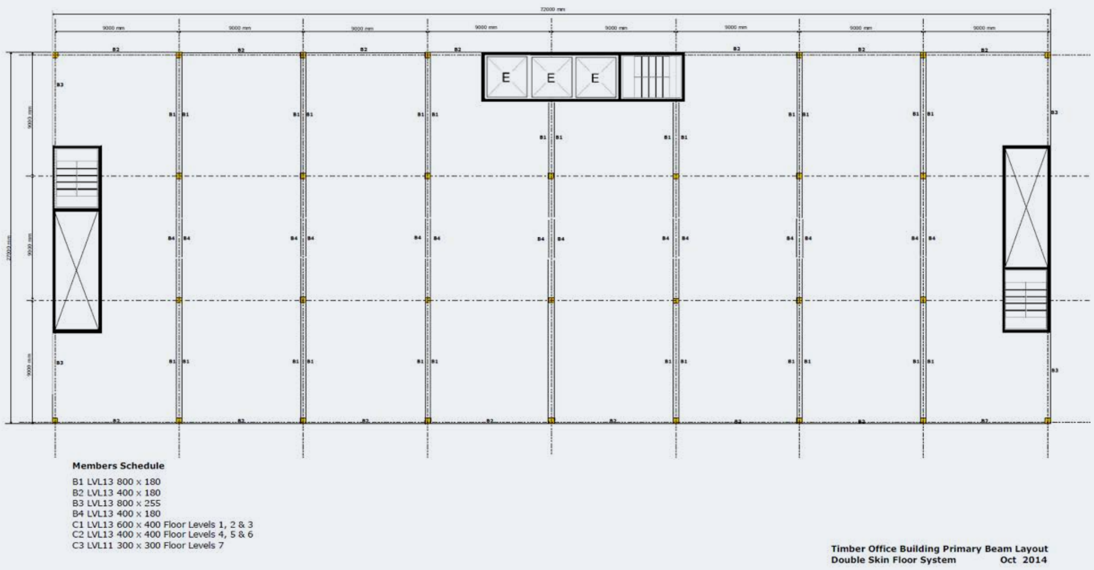


Figure 4: Primary beam layout plan.

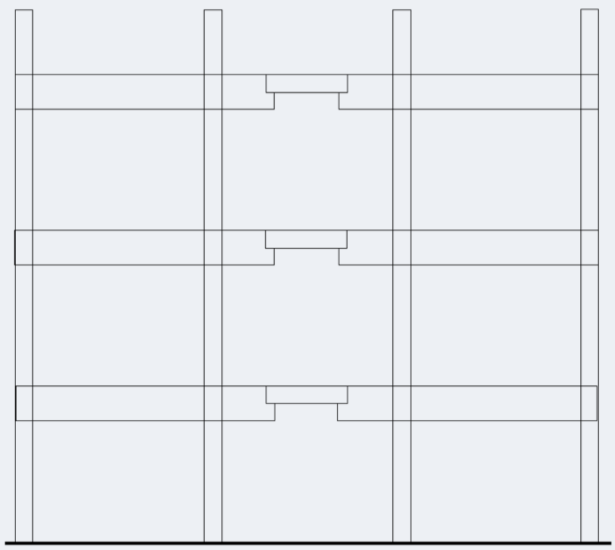


Figure 5: Propped cantilever primary beam.

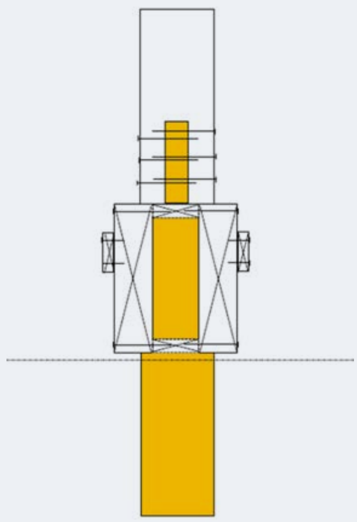


Figure 6: Primary beam support off column head and showing closed off paired beam.

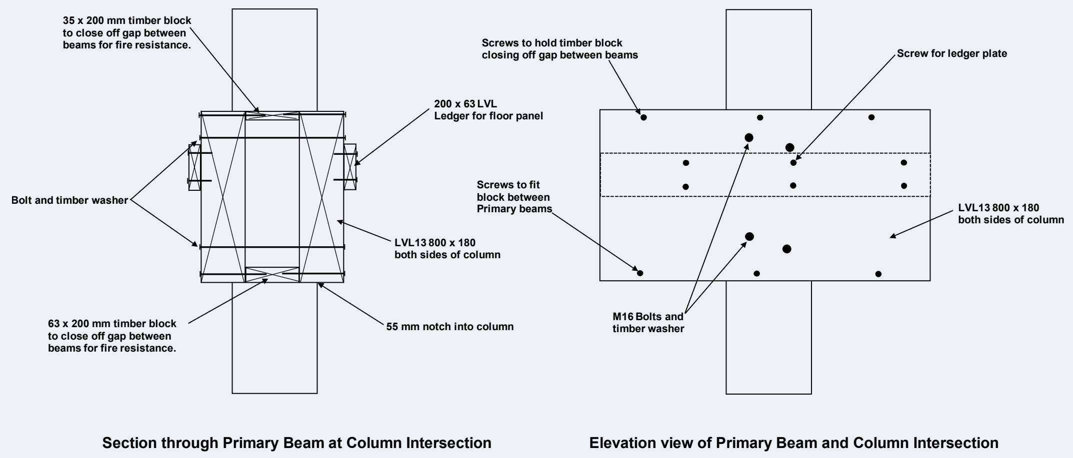


Figure 7: Screw and bolt fixing of beam to columns, Levels 2 to roof.

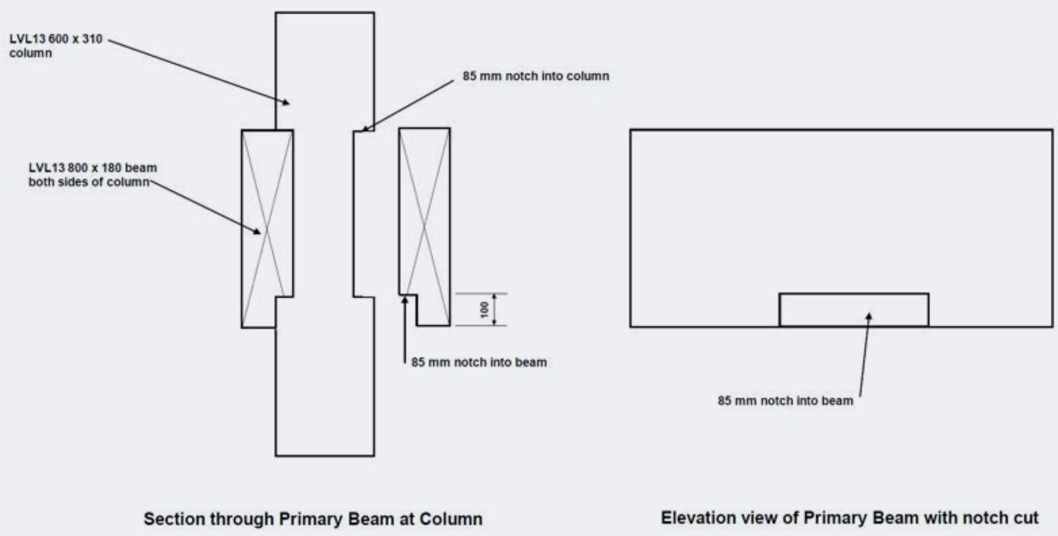


Figure 8: Notched column and beam to provide fire protection to beam support.

5.1.1 Alternative Primary Beam Options

A number of alternative options that could be used instead of the chosen primary beams are offered (below), where different design, construction and market environments exist.

The LVL box beam alternative:

- 800 x 400 mm LVL box beams instead of the paired beam configuration.
- Infill beams, consisting of 400 x 185 LVL13 beams.

Why consider this alternative:

- This alternative design is considered viable, where cost effective, to fabricate box beams and to manage the structural detailing of this beam configuration. This will vary from market to market and according to the availability of industrialised fabrication processes.
- The box beam is similar to the solution chosen for the model, except that the box beam relies on the structural capacity of the timber block while the solution used in the model design has timber blocks to reduce the char surface area and has no structural role.

The Glue Laminated Timber beam alternative (Glulam):

- A number of grades of Glulam can be used to replace the LVL paired beams, depending on the species of timber used in the base lamina. Typical options include:
  - GL10: White Cypress
  - GL17: Slash Pine or Radiata Pine
  - GL18: Tasmanian Oak or Victorian Ash

Why consider this alternative:

- Glulam has the advantage of being manufacturable in lengths greater than 12 m, 1.2 m deep and 300 mm wide.
- The selection of appropriate engineered wood products is principally dependent on the application and material specification, and as such there may be cost differences in respect to these products.

5.2 Flooring System and Perimeter Beams

What was used in the timber solution:

- Prefabricated cassette flooring elements and a perimeter beam system are used to work in a combined way in addressing structural and fabrication requirements.
- The floor cassettes use a double skin LVL assembly, which spans between the paired primary beams and measures 2,440 (W) x 8,500 (L) x 388 mm (D), see Figure 9 for details. The cassette assemblies include:
  – A bottom skin consisting of 2 x 1,220 mm (W) x 63 mm (D) LVL11 billets. The two billets are positioned side by side to make up the full 2,440 mm (W) cassette width.
  – A top skin consisting of 2 x 1,220 mm (W) x 25 mm cross-banded LVL sheets (again two panels are positioned side by side).
  – Web members separating the skins, consisting of 300 (D) x 35 mm (W) solid timber pieces at 600 mm maximum spacings and including a double laminar along the centre line of the 2,440 mm width (Figure 9).
  – Horizontal stiffeners between web members consisting of 300 (D) x 35 mm (W) solid timber packers (Figure 9).
  – 50 mm of polyfibre reinforced concrete is placed between the web members inside the cassette. Screws are placed to side of web members and in the LVL bottom skin for securing concrete in place in the event of a fire.
  – 75 mm glass wool insulation of at least 14 kg/m^3 is placed within cassette void to aid with reducing noise transfer.
  – Cassettes and primary beams contain interlocking haunches to assist seating during installation.
- The perimeter beams (secondary beams that occur in the same plane as the floor cassettes) use a 400 x 180 LVL13 and are designed to be selectively prefabricated into the edge of floor cassette assemblies, where required (as shown in Figure 10). The perimeter beams provide support for the façade system and tie the building together.

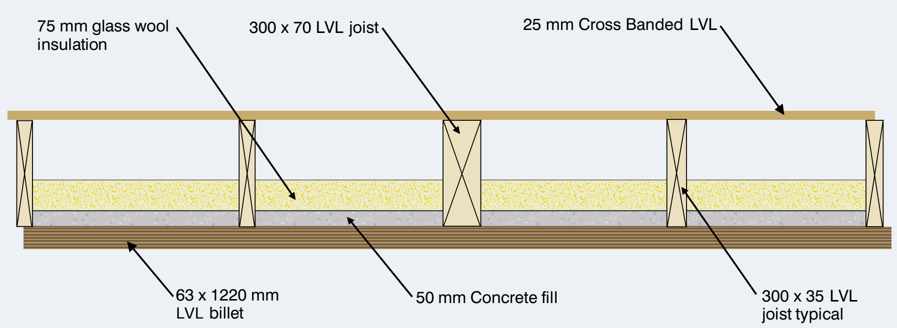


Figure 9: Cross-section of LVL floor cassette with concrete and insulation fill.

[2] Acoustic performance was assessed by PKA Acoustic Consulting

Reasons:

- The chosen cassette and perimeter beam system was found to provide the best mix of cost effectiveness, structural efficiency and speed onsite. It was chosen from an initial set of 30 floor systems (refer to Appendix D for details). Specific features include:
  – At 388 mm deep, the floor cassette system presented the shallowest floor plate depth which saved on floor-to-floor height and provided the necessary space for HVAC services. It is only marginally deeper than the 350 mm depth used for the concrete solution.
  – The floor cassette assemblies effectively span between primary beams instead of being supported by separate secondary beams. This saved erection time and provided structural efficiency.
  – The use of solid LVL as a structural skin on the underside of the assembly removed the need for additional fire resisting ceiling layers, such as plasterboard.
  – The 50 mm concrete and insulation inside the cassettes provide acoustic performance of approximately Rw 47 to 48[2] comparable to concrete solution.
  – Though structurally independent, the perimeter beams were incorporated into the floor cassette assemblies, thus simplifying and compressing onsite erection time.
  – The cassettes fully utilise the manufactured size of the LVL billets therefore removing wastage. The cassette size also minimises the number of craneage lift cycles for installation.

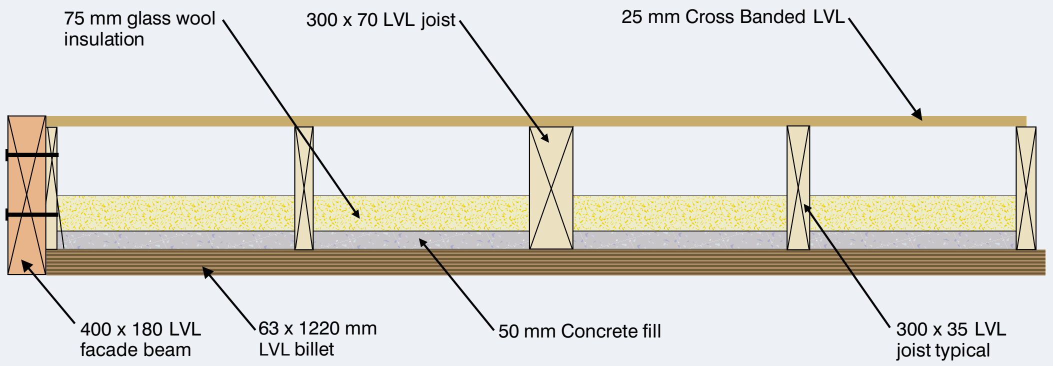


Figure 10: Cross-section of LVL floor cassette with perimeter beam attached.

5.3 Columns (including Column and Beam Junctions)

What was used in the timber solution:

- A number of different single storey column sections were used

– The cross-sectional sizes under this scenario include:

  - Ground to Level 1 – 600 x 310 LVL13 with higher compressive strength (47 MPa)
  - Level 2 and 3 – 600 x 310 LVL13
  - Level 4 and 5 – 3 off 400 x 310 LVL13
  - Level 6 – 300 x 310 LVL11

– The column heads can be nestled in between the paired primary beams, thus allowing a simplified assembly process.

– The rebate in the columns, to accept side mounting of the primary beams, is designed to allow the maximum wood fibre in the vertical direction for compressive loads and to facilitate the previously discussed propped cantilever of the primary beams.

– Erecting columns on a floor-by-floor basis allows the columns to be combined with the primary beams on the deck and lifted as one unit (refer Figure 11).

Reasons:

- Combining the column and beams into one unit removes multiple lifts required in dealing with individual columns and beam elements, speeding up the overall erection process.
- Storey high columns suit the use of a twin beam arrangement.
- Storey high columns require less work in terms of temporary support and smaller-scale materials handling equipment.

Figure 11: Column and primary beam in one lifting unit.

5.3.1 Alternative Column Options

A selective number of alternative column options are offered (below), where different design, construction and market environments exist.

What could be used as an alternative timber solution:

- Solid LVL columns spanning three floors (in each crane lift) (Figure 12) whereby the cross-sectional size of the columns decrease at each change point (see Figure 11 for details). Sizes included:
  - Ground, Level 1 and 2 – 600 x 310 LVL13
  - Level 3, 4 and 5 – 400 x 310 LVL13
  - Level 6 – 300 x 310 LVL11

Why consider this alternative:

- Three storey columns may reduce:
  - the number of crane lifts required onsite if lifted one piece at a time;
  - the number of column splices
  - material loss caused by the overlap required to produce the column splice and screws.
- This approach would require the need for more temporary support (props) during the construction process.
- The choice between single-storey and three-storey columns affects site fabrication preferences. It is worth checking with erectors and fabricators before committing to a design to ensure the most cost-effective option.

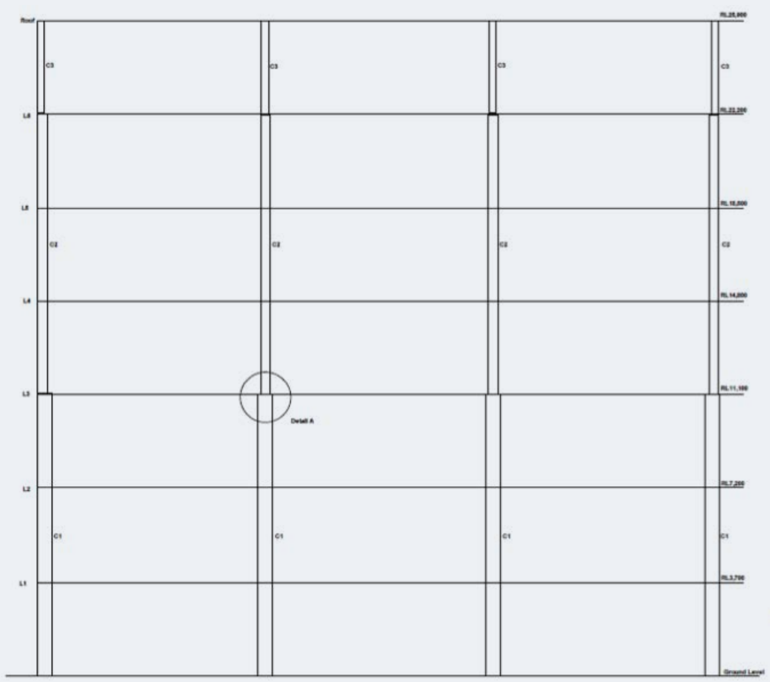


Figure 12: Elevation view of columns.

5.4 The Building Core - Providing Lateral Resistance in the Building

What was used in the timber solution:

- Cross-laminated timber (CLT) was chosen for constructing the core of the building (including lifts, stairs and MEP shafts). This subsequently provides lateral restraint for the building and includes the following features (Figure 13):
  - 185 mm thick CLT panels are used for the core walls running longitudinally over three storey sections (including structural continuity from one three-storey section to the next).
  - The floor cassettes, discussed previously, provide a diaphragm action that serves to transfer loads from the outer face of the building to the CLT core construction.
  - 16 mm fire-resistant plasterboard is used each side of the CLT walls.

Reasons:

- Use of the building core to manage lateral resistance is common to both timber and concrete building solutions. CLT provides a cost-effective material for constructing structurally efficient walls in this context.
- The use of CLT maintains the continuity of using timber as the dominant material and avoids the use of dissimilar materials, i.e. concrete. This circumvents introducing different material characteristics such as creep, settlement and shrinkage, and differential movement problems. It also reduces the need for dividing the work program into separate material-specific subcontracts.

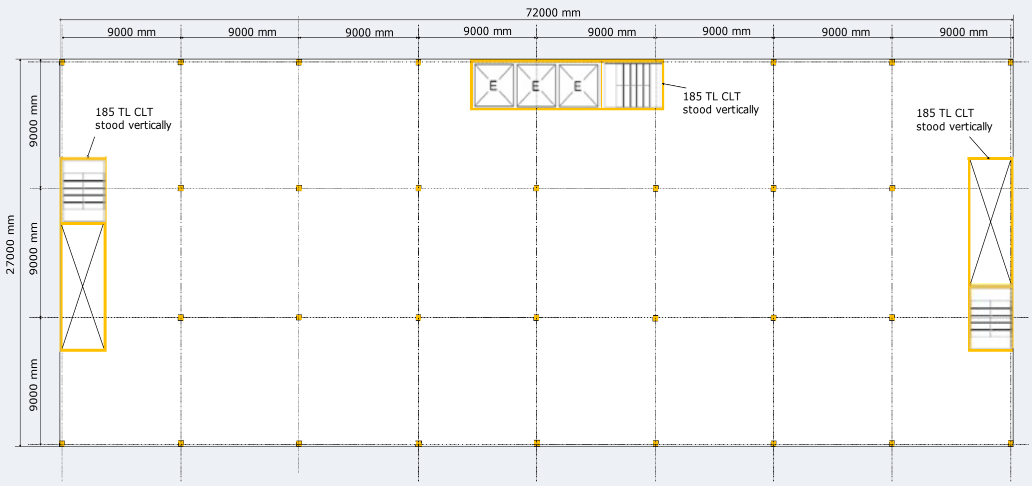


Figure 13: Plan of CLT cores.

6

Providing Noise Resistance

What was used in the timber solution:

- A 50 mm polyfibre reinforced concrete layer within the base of the floor cassette provides the main acoustic solution for impact sound (Figure 14).
- A 75 mm glass wool batt of at least 14 kg/m^3 placed within cassette void helps mainly with airborne sound.
- The floor cassette was estimated to have a base Rw of 47 to 48[3] without carpet or the addition of a ceiling.

Reasons:

- The concrete fill and insulation facilitates improves acoustic performance concerning airborne sound.
- The concrete and insulation are placed in the cassette during the offsite fabrication of the cassettes' construction to reduce on-site labour requirements and improve construction program time.
- Acoustic performance for sensitive areas such as meeting rooms can be easily upgraded by the addition of an access floor or acoustic ceiling.

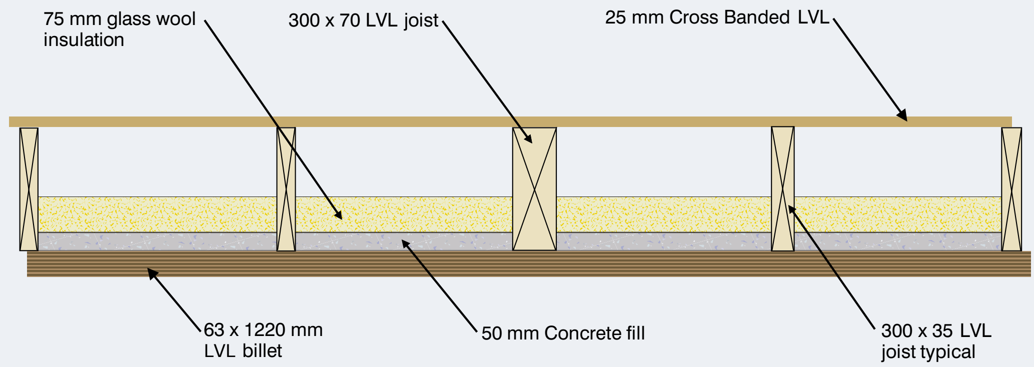


Figure 14: Floor cassette with concrete and polyester fill.

[3] Acoustic estimates provided by PKA.

7

Interface with the Façade

What was used in the timber solution:

- A standard glazed curtain wall façade was fixed to the timber structure (Figure 15).
- A timber perimeter beam (as discussed under perimeter beams and floor system) is used to connect the façade supports to the structure.
- The façade curtain wall framing is intended to be screw fixed to the perimeter beam.

Reason:

- The intention was that the façade system should be the same for both the timber and concrete solutions, making it cost neutral in terms of comparative imput.

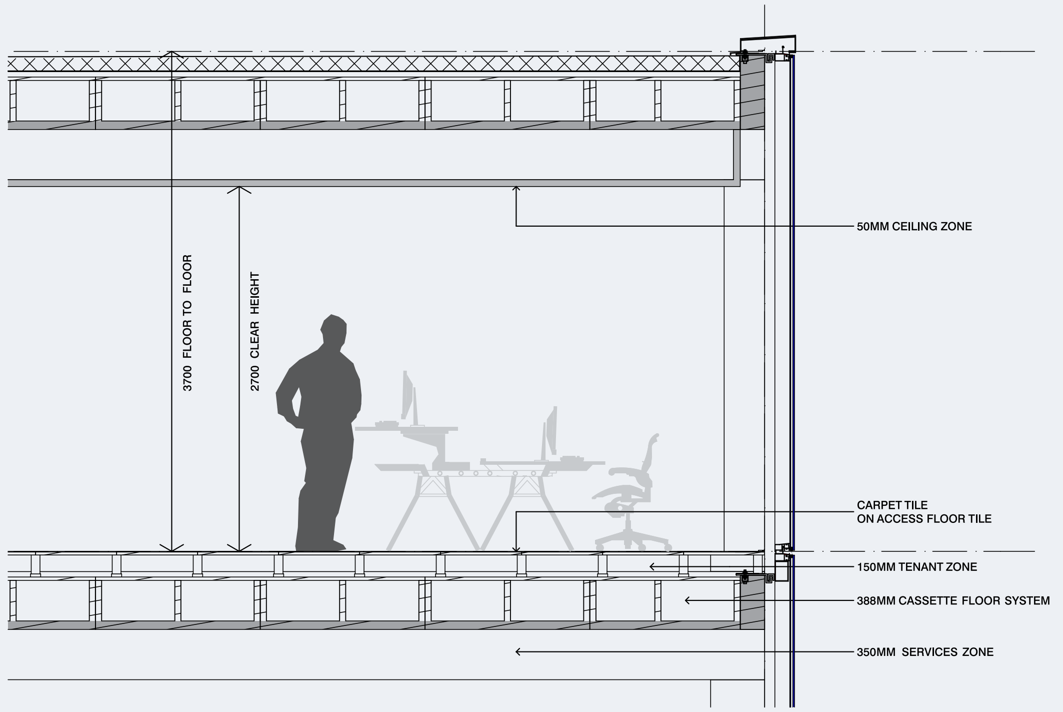


Figure 15: Illustration of standard façade screw fixed to timber perimeter beam.

8

Interface with HVAC and Other Services

What was used in the timber solution:

- Two main vertical shafts are provided at each end of the building to supply and return air to each floor level.
- On each floor level, three main ducts (2 x 600 x 250, 1 x 800 x 250) supply air along the central longitudinal axis of the floor, within a ceiling void made possible by the relatively shallow infill beams used in the primary beam arrangement (Figure 5).
- Return air is collected at two main vertical shafts.
- From the main ducts, perpendicular branch ducts supply and return air to individual bays defined by the column grid (see Figure 16 for details).
- The ducts are fixed directly to the underside of the floor cassette system.
- Any additional but minor cabling, piping or ducting services can potentially be dealt via small penetrations (up to 50 mm diameter) without affecting the primary beams. Larger holes require engineering design including reinforcement using plywood and an associated screw layout.

Reasons:

- The HVAC design has been driven by the need to maintain the targeted floor-to-floor height of 3.7 m, as would be achieved under a typical concrete-framed solution. The 250 mm deep centralised main ducts have been designed accordingly and effectively make this aspect cost neutral when compared to the competing concrete solution. Notwithstanding this, the timber solution should achieve better installation productivity due to the reduced work in fixing ducts to the timber structure.

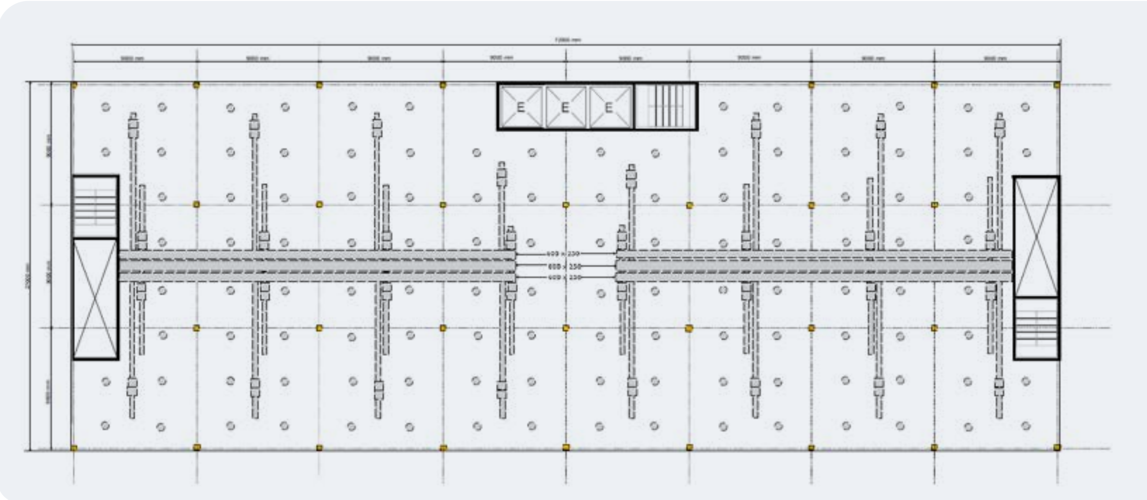


Figure 16: Plan of HVAC ducts.

8.1 Alternative HVAC Systems Options

A 'Displaced air' cavity system

- A 'Displaced air' cavity system requires a raised floor zone of between 300 to 400 mm. This system was not pursued as it required significant re-arrangement of the primary beam layout in trying to maintain the targeted floor-to-floor height. The viability of such a system may change according to project-specific requirements and with advances in the technology.

9

The Workflow and Speed Onsite of the Timber Solution

What was used in the model:

- A 78-day construction program (see Appendix C for further details) from the ground floor level to top storey (structure only) was found achievable and the program allows rough-in of MEP services to commence very early on Day 16 of the program found in Appendix C1.
- A crew of six (excluding crane driver, dogman, traffic control, etc) is assumed.
- All elements are designed so they sit on supports, i.e. beams sit on a halved column joint, or CLT core walls, and floor cassettes sit on a ledger at the side of the primary beam.
- Most joints use screw fixings inserted using commonly available power drill technology. Such fixings provide a countersunk head, which is expected to be aesthetically hidden in the final construction.
- Beam to column joints from Ground to Level 7 use standard through bolts and large washers.

Reasons:

- The project team reviewed more than 30 timber construction systems. Emphasis was placed on those systems capable of providing program savings compared to the targeted concrete system.
- Crane optimisation (i.e. minimising the number of crane lifts) dominated the ability to compress the chosen timber construction program and this especially revolved around the chosen cassette floor system. For instance, the floor system using 2,440 mm wide cassette panels spanning between the primary beams was found to deliver the least number of crane lifting cycles.
- Standard bolts and washers were used for the beam to column joints, which allowed the bolts to pull the joint together.

How does this compare to concrete:

- Post tension concrete structure was calculated to take 117 days.
- Rough-in of MEP services would commence at day 51.

Activity	Week	1					2					3					4					5				
	Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Survey & Set Out	2																									
Ground Floor Columns	3																									
1st Floor Primary Beams	2																									
Lift Shaft Panels 3 Storey High	5																									
1st Fl Floor Panels	4																									
2nd Floor Primary Beams	2																									
2nd Fl Internal Lift Wall Panels	2																									
2nd Fl Floor Panels	4																									

Table 2: Five-week construction program of timber frame and floor installation.

9.1 Other Time Savings

The timber model may have further construction program time savings as the follow-on trades would be able to access the first level 31 days earlier than with the concrete system. The work required for follow-on trades in timber structures is inherently easier, as fittings to the super structure do not require drilling into concrete. Though not calculated in this study, these savings would add further overall time savings.

Cost savings associated with the time saving are discussed in Section 10.

9.2 Time Savings in Other Timber Projects

A number of timber projects have been carried out around the world and most have indicated significant construction program time savings. Table 3 lists some of these projects and their associated construction program time savings.

Project Name	Location	Building Type	Storeys	Gross Floor Area (m^2)	Construction Type	Timber Superstructure Construction Program
Library at the Dock	Victoria Harbour, Melbourne, Australia	Institutional	3	3,500	Post and Beam CLT floor	10 weeks
LifeCycle Tower one	Dornbirn, Austria	Office	8	2,322	Post and Beam and Panel	8 days

Table 3: Real project time savings.

10 Cost Plan Results - Comparing the Timber Solution with Traditional Concrete Construction

Using the model 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 relative to the concrete solution.

The cost comparison was only undertaken for the parts of the building that were considered to have different costs under the two competing options. The elements of the building that are identical in costs for each model, such as the façade, and mechanical, electrical and plumbing items, were therefore excluded from the cost plan.

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

10.1 Process Taken to Obtain Comparison Design and Quotes

To ensure neutrality, the concrete design was independently developed by engineering firm Arup Ltd. The design was tested at a 2014 workshop of structural engineers where it was found to justly represent a typical concrete design. The timber design was developed through collaboration between the timber industry suppliers and the Timber Development Association and used a number of techniques discussed in Section 5 of this report.

The revised cost plan was developed by MBM who independently measured quantities off supplied drawings and obtained quotes from the market where needed. An important element to the cost plan was the saving brought about by construction program time saving. An independent erector with experience in timber and concrete construction developed a construction program for both models. These programs are found in Appendix C.

As concrete construction is widely used, MBM utilised current data within their database to develop a price for this model. As the timber design is relatively new, a price from the marketplace was found. Meyer Timber provided this price as they operate in the Sydney region, and have experience among fabricators and suppliers, allowing a full price to be developed for all costs up to the point of delivery to the building site.

10.2 Cost Plan Results

The basic differences in the cost plans for each model are shown in Table 4. Detailed results can be found in Appendix B.

Element	Timber	Concrete	Variance
Columns	$450,218	$307,224	+$142,994
Staircases	$319,700	$305,865	-$13,835
Upper floors	$4,491,903	$4,736,195	-$244,292
Roof	$593,105	$792,480	-$199,375
Shafts External Walls	$345,825	$522,000	-$176,175
Shafts Internal Walls	$521,268	$717,600	-$196,332
Ceiling Finishes	$997,740	$997,740	$0
Preliminary Adjustments	-$482,500	-	-$482,500
Total	**$7,237,259**	**$8,379,104**	**-$1,141,845**

Table 4: Cost comparison between each building considered.

In analysing the differences between the two plans, the timber building provides a saving of $1,141,845 being 13.6% cheaper than the concrete solution. Specific savings under the timber solution are as follows:

- Floor: $244,292 (4.7% less)
- Lift, Stair and Air shafts: $356,342 (23% less)
- Roof: $199,375 (25.1% less)
- Preliminary costs: $482,500 less.

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

- Stairs: $13,835 (3% more)
- Columns: $142,994 (31.8% more)
- Connections: $59,769 more
- Termite & Fire Engineering: $35,000 more.

10.3 Qualifications and Hidden Costs

Some detailed qualifications are required to clarify certain costs that are not necessarily apparent at first glance. Of note:

- Suspended versus exposed ceiling: The suspended ceiling, common in the concrete construction model, could be deleted from the timber model, exposing the solid timber underfloor. Though there would be some additional cost to provide a neater HVAC and suspended lights (estimated to be $266,064) the overall saving for the timber solution would be $1,873,521 (being 22.3% less than the concrete solution).
- Preliminary cost savings: the emphasis on pre-fabricated construction creates savings in site infrastructure costs such as labour costs, scaffolding, site accommodation, hoist and crane. Prefabrication also provides the ability to compress the construction program, which further reduces preliminary costs. Relative to concrete, the 39-day saving on the main structure (nine working weeks) is estimated to save $157,500 per week compared to concrete (equating to a $517,500 saving across the entire project). As mentioned previously (Section 9), there is potential to leverage this situation to also compress the internal works by a further 34 days. If this is taken into account, further savings are achievable.

D1.2 Floor system discussion

Of the 30 floor systems reviewed, four floor systems were investigated further. These were:

10.4 Further Cost Saving not included in Calculations

Other cost savings are also possible for the timber model and they are discussed below, but for this cost exercise they have not been included. These are:

10.4.1 Scaffolding

The timber structures can be constructed with safety hand rails already attached to floor cassettes. This removes the need for traditional scaffolding to the outside of the building.

10.4.2 Screens

Timber structures can also be constructed without the need of temporary screens to the outside face of the scaffolding.

10.4.3 Time before First Fix can Occur

The time to carry out first fix of MEP services in timber structures is generally less, as there is less time needed to fix brackets and supports onto the superstructure. Timber structures use cordless screw guns, which are light, and quick and easy to use. Concrete structures require drilling into concrete, which is slow, noisy and dirty work.

Overseas experience has shown that with the introduction of massive timber structures, the internal building trades do not initially recognise the significant time savings possible, and quote the job as if it was concrete. With time, internal building trades will learn to recognise the savings that are possible with timber and pass a portion of this back.

10.4.4 Footing Consideration

The timber model is estimated to be 50% lighter in weight than the concrete model, as timber is 20% of the weight of concrete for the same spanning conditions. Though not taken into account, this would allow lighter footings for the timber model, potentially providing greater savings. The cost plan assumes the footing design is the same for both models.

10.4.5 Columns

The timber columns come with a weather protection sealer. No additional surface treatment is required. The concrete model normally requires all columns to have frames or furring channels and plasterboard sheets.

10.4.6 Crane Size and Type

The cost comparison assumes that the same tower crane is used for both building models. The crane savings included in the timber cost plan result from less hire time required. The timber model's largest element is 4.0 tonnes, being a standard floor cassette. It is conceivable that a light electrical and remote crane could be used in lieu of a standard tower crane, offering further savings not taken into account in the cost plan.

10.5 Cost Neutral Items

Many of the items in the cost plan have not been included as they are cost neutral between each model building. These include:

- Mechanical, electrical and plumbing: both model buildings use the same layout and assumptions.
- Façade cost: both model buildings are the same height and use identical cladding that is fixed in a similar manner.
- Floor finishes: floor finishes are not included in either model building.
- Crane cost: it is assumed the same crane has been used in both model buildings.
- Scaffold: it is assumed the same scaffold has been used in both model buildings.

10.6 Additional Costs

The timber model has additional costs. These include:

10.6.1 Additional Engineering Costs

The timber model would need additional fees for fire engineers to provide Performance Solutions for a 30-minute reduction to the fire resistance level to the columns. The fire engineering fees were estimated to be $20,000, based on quotes from Sydney-based fire engineers. These have been included in the timber model's costs.

10.6.2 Termite Protection

Both models sit over a two-level concrete basement garage. The timber structure has considered termite protection by:

- Glue line preservative treatment to the LVL columns from ground to level one.
- Concrete slab edge exposure at the ground level.
- Stainless mesh steel protection to all hidden entry points to the structure.

This protection resulted in a conservative additional cost to the timber model of $35,000 and this has been included in the timber model's costs.

11

Conclusion

A model seven-storey office building was designed, engineered, planned for construction, and costed using an optimised structural timber solution and a more conventional structural concrete solution. The costing exercise focused on areas where significant cost differences would occur and excluded common aspects of the building that are predominantly cost neutral.

The timber solution was found to be $1,141,845 more cost effective, which equates to a 13.6% saving compared to the concrete solution, even when additional costs such as fire engineering and termite protection are included. The timber model was more cost effective in all structural aspects except for the columns, which were 31.8% more expensive.

The cost plan also investigated the effect of removing the suspended ceiling, as the timber model may not require it. If the suspended ceiling was removed, the timber model would be $1,973,521 more cost effective, equating to a 23.3% saving on the concrete model, even after taking additional costs of neater HVAC ducts and suspended lights into account.

The cost plan exercise showed that timber can be a cost-effective option for medium rise office building construction compared to more conventional construction methods. Further areas for cost savings are also identified, particular in terms of preliminary costs that have not been fully taken into account in this comparison.

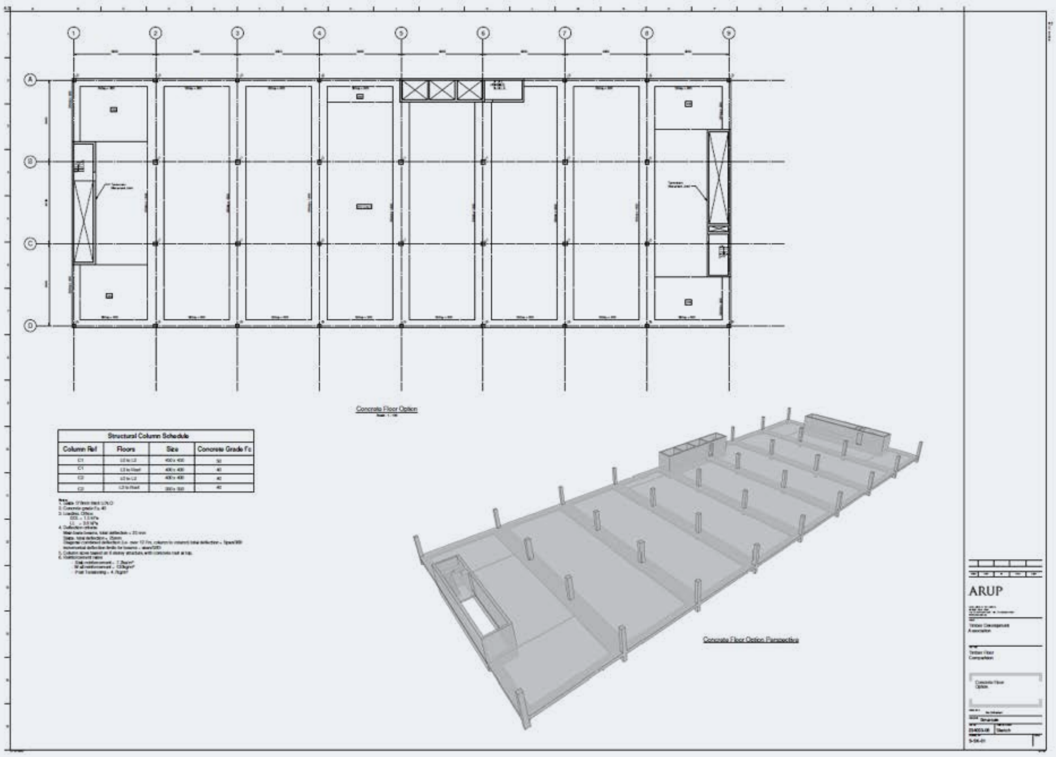
This Guide shows that timber office buildings should be considered as a viable alternative to conventional concrete construction. This is particularly borne out when there are restrictions on the site such as poor ground conditions that need a lightweight structure solution, such as extensions to the top of existing buildings or air right locations (vertical space above a property), short construction programs or sites with highly restrictive access issues.

The area where significant cost savings can be made with a timber construction system is in the area of preliminary costs. Therefore, when considering a cost plan for a timber structure, it is recommended that a detailed investigation of the preliminary costs is required. Considering only installed material costs ignores significant savings that can be made with timber construction systems.

A

Appendix A: Comparison Design: Concrete Construction

Assumptions about post-tensioned concrete slab construction (used for competitive benchmarking purposes)



Appendix B: Detailed Cost Plan

Project Name: **Office Building - Timber-Framed (LVL)**

Client Name: Timber Development Association for Forest and Wood Products Australia **Date of Estimate**: 17/07/2017

Element		Qty	Unit	Unit Rate ($)	Cost ($)
1	**Timber Framed (LVL)**				
1.1	**Columns**				
1.1.1	600 x 300 Laminated Veneered Lumber (LVL13) 3 storey column, 3700 storey height, 75 notch on two sides at storey levels to receive 800 deep timber beams, 450 extension tongue at head to receive upper column; including protective treatment.	18	No.	6,786	122,148
1.1.2	600 x 300 Laminated Veneered Lumber (LVL13) 3 storey column, 3700 storey height, 75 notch on three sides at storey levels to receive 800 deep timber beams, 450 extension tongue at head to receive upper column; including protective treatment.	12	No.	6,786	81,432
1.1.3	400 x 300 Laminated Veneered Lumber (LVL13) 3 storey column, 3700 storey height, 75 notch on two sides at storey levels to receive 800 deep timber beams, holed at base to receive lower tongue column section, 450 extension tongue at head to receive upper column; including protective treatment.	18	No.	6,609	118,962
1.1.4	400 x 300 Laminated Veneered Lumber (LVL13) 3 storey column, 3700 storey height, 75 notch on three sides at storey levels to receive 800 deep timber beams, holed at base to receive lower tongue column section, 450 extension tongue at head to receive upper column; including protective treatment.	12	No.	6,609	79,308
1.1.5	400 x 300 Laminated Veneered Lumber (LVL13) single storey column, 3700 storey height, 75 notch on two sides at storey level to receive 800 deep timber beams, holed at base to receive lower tongue column section; including protective treatment.	18	No.	1,157	20,826
1.1.6	300 x 300 Laminated Veneered Lumber (LVL13) single storey column, 3700 storey height, 75 notch on three sides at storey levels to receive 800 deep timber beams, holed at base to receive lower tongue column section; including protective treatment.	12	No.	1,157	13,884
1.1.7	Add for screw-connections	1	Item	13,658	13,658
					450,218
1.2	**Staircases**				
1.2.1	Stairs 'AirStair' - supply cost - 2 x 9 levels	18	level	6,500	117,000
1.2.2	Stairs 'AirStair' - supply cost - 1 x 10 levels	10	level	6,500	65,000
1.2.3	Installation	81	m/rise	1,250	101,250
1.2.4	Extra over above for fixings and handrails	81	m/rise	450	36,450
					319,700
1.3	**Upper Floors**				
1.3.1	Composite beam 8750 long, comprising 2No 800 x 180 LVL13 members, 240 x 63 hySPAN blocking piece top and and 240x35 hySPAN blocking piece on bottom; 200 x 63 hySPAN ledger pieces each side to take floor edges; including protective treatment.	72	No.	10,358	771,878
1.3.2	Composite beam 2810 long, comprising 2No 800 x 180 LVL13 members, 240 x 63 hySPAN blocking piece top and 240 x 35 hySPAN blocking piece on bottom, 200 x 63 hySPAN ledger pieces each side to take floor edges; including protective treatment.	84	No.	3,308	287,598
1.3.3	Composite beam 5400 long, comprising 2No 800 x 180 LVL13 members, 240x63 hySPAN blocking piece top and 240 x 35 hySPAN blocking piece on bottom, 200x63 hySPAN ledger pieces each side to take floor edges; including protective treatment.	12	No.	6,295	78,184
1.3.4	Beam 6500 long; 600 x 180 LVL13, 200x63 hySPAN ledger to one long edge; including protective treatment.	24	No.	3,221	80,010
1.3.5	Beam 8750 long; 400 x 180 LVL13; including protective treatment.	78	No.	3,105	250,667
1.3.6	Beam 3800 long; 400 x 180 LVL13; including protective treatment.	6	No.	1,398	8,682

Client Name: Timber Development Association for Forest and Wood Products Australia **Date of Estimate**: 17/07/2017

Element		Qty	Unit	Unit Rate ($)	Cost ($)
1.3.7	Beam 8200 long; 400 x 180 LVL13; including protective treatment.	6	No.	2,905	18,040
1.3.8	Beam 3860 long; 400 x 300 LVL13; including protective treatment.	42	No.	1,697	73,769
1.3.9	LVL double skin floor panel 8500 x 2300 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 63 LVL lower skin, softwood solid blocking, 50 concrete fill to void, 75 insulation, 200 x 50 ledger each short side.	36	No.	5,302	197,553
1.3.10	LVL double skin floor panel 8500 x 2440 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 63 LVL lower skin, softwood solid blocking, 50 concrete fill to void, 75 insulation, 200 x 50 ledger each short side.	372	No.	5,621	2,164,197
1.3.11	LVL double skin floor panel 8500 x 2440, checked around core, comprising 300 x 35 LVL joists, 25 Xband LVL upper skin, 63 LVL lower skin, softwood solid blocking, 50 concrete fill to void, 75 insulation, 200 x 50 ledger each short side.	36	No.	5,621	209,438
1.3.12	LVL double skin floor panel 4650 x 2440 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 63 LVL lower skin, softwood solid blocking, 50 concrete fill to void, 75 insulation, 200 x 50 ledger each short side.	48	No.	3,121	155,051
1.3.13	LVL double skin floor panel 5150 x 2300 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 63 LVL lower skin, softwood solid blocking, 50 concrete fill to void, 75 insulation, 200 x 50 ledger each short side.	12	No.	3,209	39,856
1.3.14	LVL double skin floor panel 4200 x 2440 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 63 LVL lower skin, softwood solid blocking, 50 concrete fill to void, 75 insulation, 200 x 50 ledger each short side.	6	No.	2,725	16,922
1.3.15	LVL double skin floor panel 8500 x 2300 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 63 LVL lower skin, softwood solid blocking, 50 concrete fill to void, 75 insulation, 200 x 50 ledger each short side.	6	No.	5,302	32,925
1.3.16	LVL double skin floor panel 8000 x 2440 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 63 LVL lower skin, softwood solid blocking, 50 concrete fill to void, 75 insulation, 200 x 50 ledger each short side.	6	No.	5,998	37,248
1.3.17	Add for screw-connections	1	Item	67,523.00	69,886
					4,491,903
1.4	**Roof**				
1.4.1	Composite beam 8750 long, comprising 2No 800 x 135 LVL13 members, 240x63 hySPAN blocking piece top and 240 x 35 hySPAN blocking piece on bottom, 200x63 hySPAN ledger pieces each side to take floor edges; including protective treatment.	12	No.	8,587	105,105
1.4.2	Composite beam 2810 long, comprising 2No 800 x 135 LVL13 members, 240x63 hySPAN blocking piece top and 240x35 hySPAN blocking piece on bottom, 200 x 63 hySPAN ledger pieces each side to take floor edges; including protective treatment.	14	No.	2,850	40,698
1.4.3	Composite beam 5400 long, comprising 2No 800 x 135 LVL13 members, 240x63 hySPAN blocking piece top and 240 x 35 hySPAN blocking piece on bottom, 200x63 hySPAN ledger pieces each side to take floor edges; including protective treatment.	2	No.	5,321	10,855
1.4.4	Beam 6500 long; 600 x 135 LVL13, 200x63 hySPAN ledger to one long edge; including protective treatment.	4	No.	2,845	11,608
1.4.5	Beam 8750 long; 400 x 180 LVL13; including protective treatment.	13	No.	3,105	41,172
1.4.6	Beam 3800 long; 400 x 180 LVL13; including protective treatment.	1	No.	1,398	1,426
1.4.7	Beam 8200 long; 400 x 180 LVL13; including protective treatment.	1	No.	2,905	2,963
1.4.8	Beam 3860 long; 400 x 300 LVL13; including protective treatment.	7	No.	1,697	12,117

Element		**Qty**	**Unit**	**Unit Rate ($)**	**Cost ($)**
1.4.9	LVL double skin floor panel 8500 x 2300 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 25 LVL lower skin, softwood solid blocking, 150 x 50 ledger each short side; all as Dwg OBF 22A	6	No.	4,152	25,410
1.4.10	LVL double skin floor panel 8500 x 2440 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 25 LVL lower skin, softwood solid blocking, 150 x 50 ledger each short side; all as Dwg OBF 22A	62	No.	4,410	278,888
1.4.11	LVL double skin floor panel 8500 x 2440, checked around core, comprising 300 x 35 LVL joists, 25 Xband LVL upper skin, 25 LVL lower skin, softwood solid blocking, 150 x 50 ledger each short side; all as Dwg OBF 22A	6	No.	4,410	26,989
1.4.12	LVL double skin floor panel 4650 x 2440 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 25 LVL lower skin, softwood solid blocking, 150 x 50 ledger each short side; all as Dwg OBF 22A	8	No.	2,440	19,910
1.4.13	LVL double skin floor panel 5150 x 2300 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 25 LVL lower skin, softwood solid blocking, 150 x 50 ledger each short side; all as Dwg OBF 22A	2	No.	2,536	5,173
1.4.14	LVL double skin floor panel 4200 x 2440 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 25 LVL lower skin, softwood solid blocking, 150 x 50 ledger each short side; all as Dwg OBF 22A	1	No.	2,241	2,286
1.4.15	LVL double skin floor panel 8500 x 2300 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 25 LVL lower skin, softwood solid blocking, 150 x 50 ledger each short side; all as Dwg OBF 22A	1	No.	4,152	4,235
1.4.16	LVL double skin floor panel 8000 x 2440 comprising 300 x 35 LVL joists 25 Xband LVL upper skin, 25 LVL lower skin, softwood solid blocking, 150 x 50 ledger each short side; all as Dwg OBF 22A	1	No.	4,185	4,269
					593,105
1.5	**External Walls**				
1.5.1	External walls; 185TL CLT set vertically	1,305	m^2	265	345,825
1.5.2	Add for screw-connections	1	Item		Incl.
					345,825
1.6	**Internal Walls**				
1.6.1	Internal walls; 185TL CLT set vertically	1,794	m^2	280	502,320
1.6.2	Add for screw-connections		Item	18,948	18,948
					521,268
1.7	**Ceiling Finishes**				
1.7.1	Suspended ceiling with 300 mm suspension	11,086	m^2	90	997,740
					997,740
1.8	**Preliminaries Adjustment**				
1.8.1	Provision of time related preliminaries based on the duration of structure construction time.				0
1.8.2	Preliminaries based on reduced Construction duration of:	9	Weeks	-$57,500	-517,500
1.8.3	Termite Protection Allowance	1	Item	35,000	35,000
					-482,500
Total Cost					**7,237,259**

Client Name: Timber Development Association for Forest and Wood Products Australia **Date of Estimate**: 17/07/2017

Element		Qty	Unit	Unit Rate ($)	Cost ($)
1.1	**Columns**				
1.1.1	450 x 450 reinforced concrete columns; 50MPa; Formwork; Reinforcement 240kg/m^3; 42No.	141	m	505	71,205
1.1.2	400 x 400 reinforced concrete columns; 40MPa; Formwork; Reinforcement 240kg/m^3; 104No.	349	m	440	153,560
1.1.3	350 x 350 reinforced concrete columns; 40MPa; Formwork; Reinforcement 240kg/m^3; 64No.	217	m	380	82,460
					307,224
1.2	**Staircases**				
1.2.1	Concrete fire stairs inclusive of handrails and associated works	63	m/rise	3,150	198,450
1.2.2	Concrete fire stairs inclusive of handrails & associated works incl.overrun to roof	34	m/rise	3,150	107,415
					305,865
1.3	**Upper Floors**				
1.3.1	Reinforced in situ concrete suspended slab, 200 thick; 40MPa Concrete; Formwork; Reinforcement 7.2kg/m^2; Post Tensioning 4.7kg/m^2	1,150	m^2	275	316,248
1.3.2	Reinforced in situ concrete suspended slab, 170 thick; 40MPa Concrete; Formwork; Reinforcement 7.2kg/m^2; Post Tensioning 4.7kg/m^2	9,936	m^2	270	2,682,768
1.3.3	Reinforced in situ concrete attached beam, 1,800 wide x 350 deep; 40MPa Concrete; Formwork; Reinforcement 180kg/m^3	1,098	m	885	971,730
1.3.4	Reinforced in situ concrete edge beam, 900 wide x 350 deep; 40MPa Concrete; Formwork; Reinforcement 180kg/m^3	1,458	m	525	765,450
					4,736,195
1.4	**Roof**				
1.4.1	Reinforced in situ concrete suspended slab, 200 thick; 40MPa Concrete; Formwork; Reinforcement 7.2kg/m2; Post Tensioning 4.7kg/m^2	178	m^2	278	49,484
1.4.2	Reinforced in situ concrete suspended slab, 170 thick; 40MPa Concrete; Formwork; Reinforcement 7.2kg/m2; Post Tensioning 4.7kg/m^2	1,767	m^2	270	477,090
1.4.3	Reinforced in situ concrete attached beam, 1,800 wide x 350 deep; 40MPa Concrete; Formwork; Reinforcement 180kg/m^3	183	m	885	161,955
1.4.4	Reinforced in situ concrete edge beam, 900 wide x 350 deep; 40MPa Concrete; Formwork; Reinforcement 180kg/m^3	198	m	525	103,950
					792,480
1.5	**External Walls**				
1.5.1	Reinforced in situ concrete external walls, 200 thick; 40MPa Concrete; Formwork; Reinforcement 130kg/m^3; Post Tensioning 4.7kg/m^2	1,305	m^2	400	522,000
					522,000
1.6	**Internal Walls**				
1.6.1	Reinforced in situ concrete internal walls, 200 thick; 40MPa Concrete; Formwork; Reinforcement 130kg/m^3; Post Tensioning 4.7kg/m^2	1,794	m^2	400	717,600
					717,600

Client Name: Timber Development Association for Forest and Wood Products Australia **Date of Estimate**: 17/07/2017

Element		Qty	Unit	Unit Rate ($)	Cost ($)
1.7	**Ceiling FInishes**				
1.7.1	Suspended ceiling with 300mm suspension	11,086	m^2	90	997,740
					997,740
1.8	**Preliminaries Adjustment**				
1.8.1	Provision of time related preliminaries based on the duration of structure construction time.				
1.8.2	Preliminaries based on reduced Construction duration of:	0	Weeks		0
					0
Total Cost					**8,379,104**

Notes

1. The cost estimates are priced at September 2014 prices and based on construction in the Sydney Region.

2. RC concrete frame is traditionally a slower construction than both steel frame and timber frame that have prefabricated components produced off-site. The longer construction period of RC Frame will therefore have higher time-related preliminaries costs incurred by both the sub-contractors and Head Contractor. The comparison makes provision for the time-related preliminaries associated with the RC frame construction portion of the Building Construction.

3. The cost comparison of RC, Steel and Timber Frames uses the RC Frame program duration as the base; and subsequently there is no adjustment to the preliminaries above.

4. RC frame concrete rates are inclusive of the concrete pumping costs. When compared to steel or timber frame all lifting costs would incur craneage cost.

5. The RC Frame construction detailed above includes traditional timber soffit formwork. An option to reduce program duration by the substitution of Bondek soffit formwork in lieu of timber formwork. The impact is to increase formwork soffit rates by $10 to $15/m2. It is often found that the savings to time-related preliminaries outweighs the construction rate cost premium.

6. Traditional timber formwork is site labour intensive and the costs for formwork can vary up to 30% depending on the current market's supply and demand of formwork labour in the region.

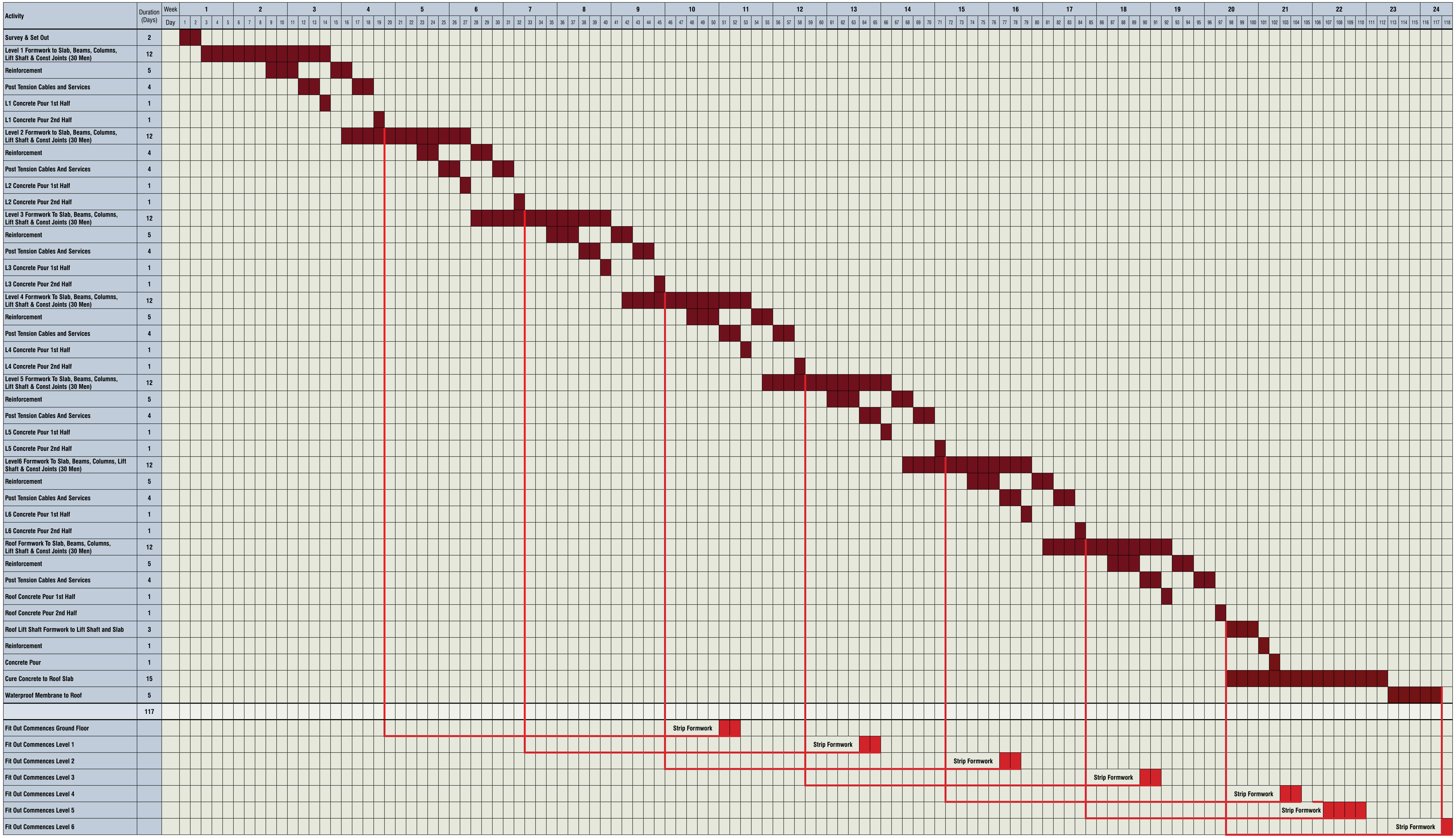
Appendix C: Construction Programs

C1 Timber Model Program

Example: 7 Story Building
Construction: Timber Beam, Columns and Floor Cassettes
Program Length: 78 Days

Activity	Duration (Days)
Survey & Set Out	2
Ground Floor Columns (3 Storey)	3
1st Floor Primary Beams	2
Lift Shaft Panels 3 Storey High	5
1st Fl Floor Panels	4
2nd Fl Primary Beams	2
2nd Fl Internal Lift Wall Panels	2
2nd Fl Floor Panels	4
3rd Fl Primary Beams	2
3rd Fl Internal Lift Wall Panels	2
3rd Fl Floor Panels	4
3rd Fl - Columns (3 Storey)	3
4th Floor Primary Beams	2
4 Fl to Roof Lift Shaft Panels Int & Ext	5
4 Fl Floor Panels	4
5 Fl Primary Beams	2
5 Fl Internal Lift Wall Panels	2
5 Fl Floor Panels	4
6 Fl Primary Beams	2
6 Fl Internal Lift Wall Panels	2
6 Fl Floor Panels	4
6Th Floor - Roof Columns	2
Roof Primary Beams	2
Lvl 6- Roof Lift Panels	2
Roof Slab Panels	4
Roof Lift Shaft Panels	2
Roof Of Lift Shaft	1
Waterproof Membrane To Roof	5
	80
Fit Out Commences Ground Floor	
Fit Out Commences Level 1	
Fit Out Commences Level 2	
Fit Out Commences Level 3	
Fit Out Commences Level 4	
Fit Out Commences Level 5	
Fit Out Commences Level 6	

Example: 6 Story Building
Option 6: Reinforced Concrete Frame and Slab in Post Tension
Program Length: 117 Days



D

Appendix D: Other Timber Floor Solutions

While the previous discussion has focused on a single specific timber solution, the full breadth of the study investigated multiple options (30 separate floor systems were investigated). Some of the competitive alternatives are presented in this Appendix. The main drivers of this selection process focused on the floor construction system and the spatial requirements of MEP services, which dominated costing issues.

D1 Floor Design between Primary Beams

D1.1 Floor Design Key Considerations

1. Structural depth to allow HVAC and other services
2. Fire protection
3. Acoustic design
4. Floor vibrations/dynamics

D1.1.1 Structural Depth to Allow HVAC and Other Services

A key aspect of the floor selection was the ability to fit the mechanical air supply, floor structure, office tenant zone, lighting and ceiling construction within a 1,000 mm floor height. This was crucial in order to compete with traditional concrete construction.

D1.1.2 Fire Protection

There were two approaches used to provide fire resistance in timber construction, including:

- install a fire-resisting plasterboard ceiling, or
- utilise the char capacity of solid timber elements.

The decision to use either approach is dependent on the char capacity and size of the timber element. Solid thick elements like CLT and LVL can be designed first for structural requirements under fire load conditions, and then the cross-sectional size of the timber components can be upsized to provide a charring layer to meet targeted fire resistance levels. This method was chosen for the cassette system using 63 mm thick LVL panel to achieve this requirement on the underside of the cassettes.

This approach is less effective for thinner frame flooring options, as the timber frame components would be more easily consumed by the fire. In this case, a fire rated ceiling can be achieved by using layered plasterboard sheeting. Alternatively, a mix of the two solutions can also be provided where appropriate to do so.

What drove the use of ‘massive timber’ as a preferred fire resistance barrier in the chosen option was the fact that the timber itself could be used for a number of other purposes such as deflection and vibration control, decorative surfaces (removing the need of additional cost from ceiling or linings), sound reduction, diaphragm action and reduced construction program time (removes the installation of a number of layers or coverings) and site labour. All of these add to cost savings relative to the concrete model.

D1.1.3 Acoustic Design

The acoustic design dominated the floor system selection including time and cost. The use of the concrete fill and insulation within the cassette – installed off-site – helped resolve this issue by providing noise resistant construction without adding additional construction effort onsite or introducing an extra wet trade to a relatively dry trade site.

D1.1.4 Floor Vibrations

Another key criterion was the response factor (measure of intermittent footfall vibration). For a typical commercial building, a target design value of a response factor (RF) <8 for intermittent footfall vibration was aimed for. The inclusion of concrete fill within the cassette void helped to control this vibration issue.

D1.2 Floor system discussion

Of the 30 floor systems reviewed, four floor systems were investigated further. These were:

1. Timber concrete composite
2. Mass timber panels supported by secondary beams
3. I-beam cassette floor
4. Double skin massive timber cassettes

The four floor systems investigated are discussed below in terms of their advantages and disadvantages.

D1.2.1 Timber Concrete Composite

The timber concrete composite floor consisted of two 400 x 63 mm LVL11 joists at 800 mm centres, and a 100 mm concrete topping slab (Figures D1 and D2). Shear keying is provided by notches into joists and coach bolts. Fire resistance provided by concrete thickness and the char capacity of the timber joists.

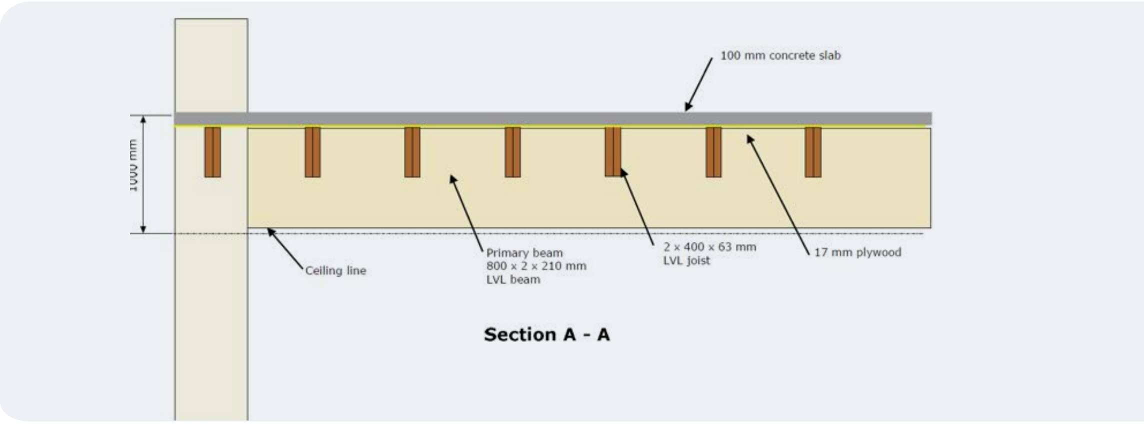


Figure D1: Timber concrete composite floor.

Figure D2: Timber concrete composite floor – Merits Office Building Christchurch. (Photo: TDA)

Advantages:

- Depth of floor system is 500 mm
- Panel width is around 2.7 m
- Overall floor cavity depth <1000 mm required
- Improved acoustics
- Top surface is concrete being similar to traditional office floors
- Joist are spaced widely allowing HVAC access

Disadvantages:

- Re-introduction of wet trades on to the building site
- May require back propping
- LVL joists can't be notched for services

D1.2.2 Massive Timber Panels supported by Secondary Beams

This system utilised the fire resistance capacity of massive timber panels of either CLT or LVL (refer to Figure D3). Two secondary beam spacing options were considered, the first at 4.5 m centres and the second at 3.0 m centres. The 3.0 m centres allow a thinner floor panel and consequently a more cost-effective solution.

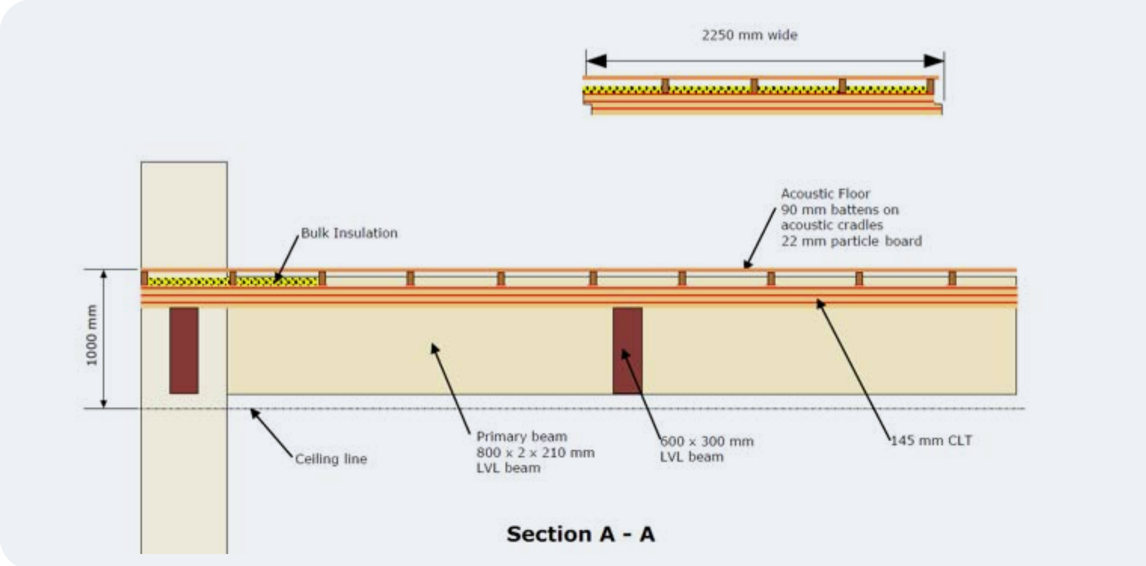


Figure D3: Massive timber panels supported on primary and secondary beams.

Advantages:

- Simple beam layout and floor panel concept
- No fire rated ceiling required
- Overall floor cavity depth <1000 mm
- Improved acoustics
- Conventional HVAC can be used

Disadvantages:

- Depth of floor system is 800 mm but has space for HVAC
- Secondary beams interfere with secondary HVAC ducts but could be notched to overcome this issue
- Tennant zone can occur in access floor

D1.2.3 I-beam Cassette Floor

This 2.7 m wide floor cassette consists of joists made from 400 mm deep I-beams at 600 centres, 21 mm plywood top and bottom (refer Figure D4).

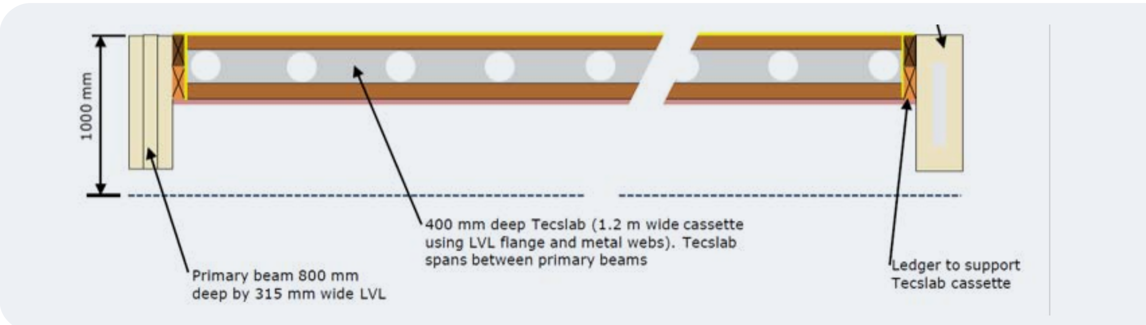


Figure D4: Tecbeam floor cassette.

Advantages:

- Enables competitive cassette depth
- Cassette 2.7 m wide require less crane lifts
- Could be built by Frame and Truss operation
- Overall floor cavity depth <1000 mm

Disadvantages:

- Requires fire-resisting ceiling

D2 Floor System Adopted in Model

This system uses a double skin LVL cassette. It offered potential reduction in construction program, price and the fact that there are fabricators with the capacity to make these panels in major city centres (Figure D5).

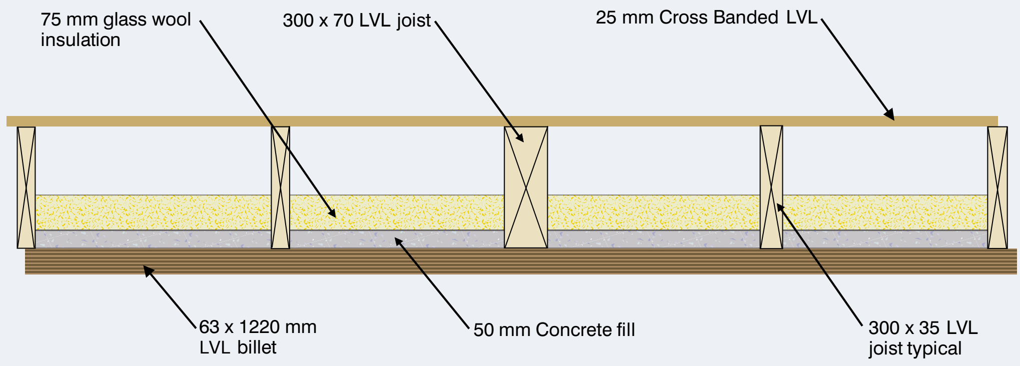


Figure D5: Section through LVL double skin cassette with concrete and insulation.

D2.1 Construction Program

Construction programs were investigated for all the floor systems short listed. The time taken is compared against a post tension slab and the results are provided in Table D1.

Floor System	Programmed Days	Days saved
LVL Double Skin Cassettes (used)	78	39
I-Beam Cassette	78	39
Timber Concrete Composite	119	-2
Secondary Beam CLT plate	105	12
Secondary Beam LVL plate	126	-7
Post Tensioned Concrete	117	0

Table D1: Construction time for various floor systems.

The construction program difference between secondary beam supported LVL and CLT floor planes is due to more crane lifts required for LVL as they are narrower panels.

E

Appendix E: Boosting the Fire Rating of Timber Elements using Timber Charring or Plasterboard

The previous discussion defined fire resistance requirements for wall, floor and roof elements; the following section more specifically determines how to address this as part of a timber-based solution.

Put simply, fire resistance in timber element (such as beams and columns) is typically achieved in two separate ways:

- Encapsulating the elements in fire protective coverings (such as plasterboard) (Figure E1).
- Designing a sacrificial charring layer in the timber element, which serves to protect the structural part of the elements. This is because the charring layer serves to insulate against fire penetration into the inner timber.

E1 Encapsulating Structural Timber Elements in Fire Protective Coverings

What was considered:

- Floor: FRL 90/90/90 - 2 x 16 mm fire-resisting plasterboard ceiling under floor
- Beam: FRL 90/90/90 - 2 x 16 mm fire-resisting plasterboard round all exposed sides of the beam
- Columns: FRL 120/120/120[3] - 3 x 16 mm fire-resisting plasterboard round all exposed sides of the column

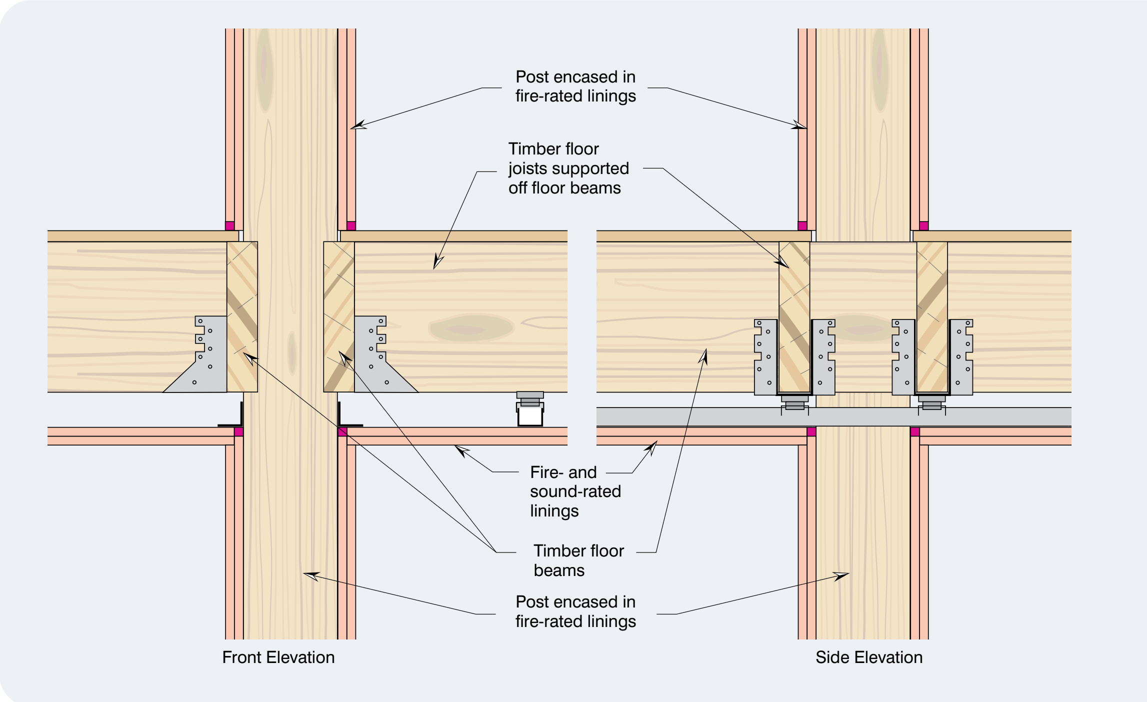


Figure E1: Plasterboard protecting timber elements.

[3]CSR Gyprock Red Book, System CSR 496

What was used:

- Floor: FRL 90/90/90 - 67 mm thickness of timber
- Beam: FRL 90/90/90 - 67 mm thickness of timber
- Columns: FRL 120/120/120 - 87 mm thickness of timber

Reason:

- A protective layer of timber can be used and can be calculated from Standard *AS 1720.4 Timber Structures – Fire-Resistance of Structural Timber Members*

Notional Charring Rate

$C = 0.4 + (280/D)^2$

Where

C = notional charring rate in mm/min
D = timber density at a moisture content of 12% in kg/m^3

Density and species of timber

The density of plywood and LVL is approximately equivalent to the density of the timber species used to manufacture the product. The density of pine plywood is in the range 500-650 kg/m^3.

Use 600 kg/m^3.

$C = 0.4 + (280/600)^2$
$= 0.61$ mm/min

Effective Depth of Charring

de = C.t + 7.5

Where

de = calculated effective depth of charring in mm (refer to Figure B2)

C = notional charring rate in mm/min, calculated above

T = period of time, in minutes 90 mins

de = C.t + 7.5
= 0.61 x 90 + 7.5 mm
= 62.8 mm > 63 mm

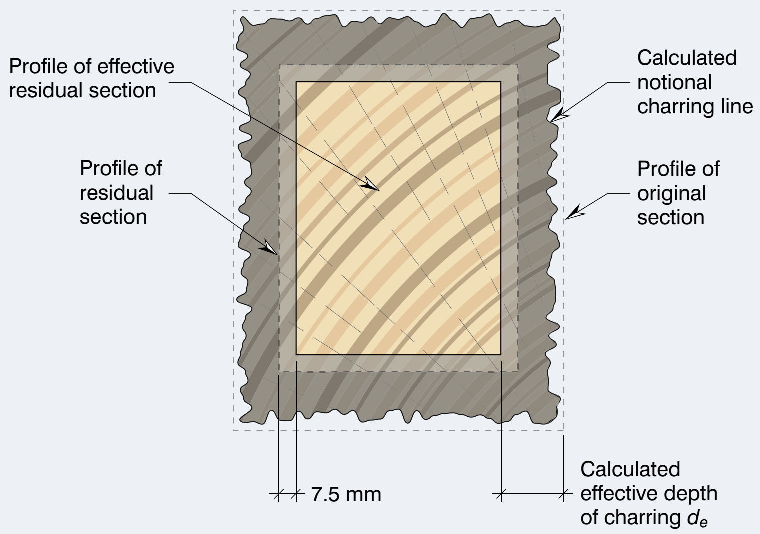


Figure E2: Char to timber element.

E3 Beam Discussion

The fire rating required for a beam is an FRL of 90/90/90. This is to be provided by char layer on the beam. Using the paired beam arrangement in the timber model would mean that the charring would occur on three sides of each beam (Figure E3). A more efficient solution would be to use a 63 mm timber block fitted in the gap top and bottom between the paired beams sealing and protecting the two internal faces of the beams from the fire (Figure E4).

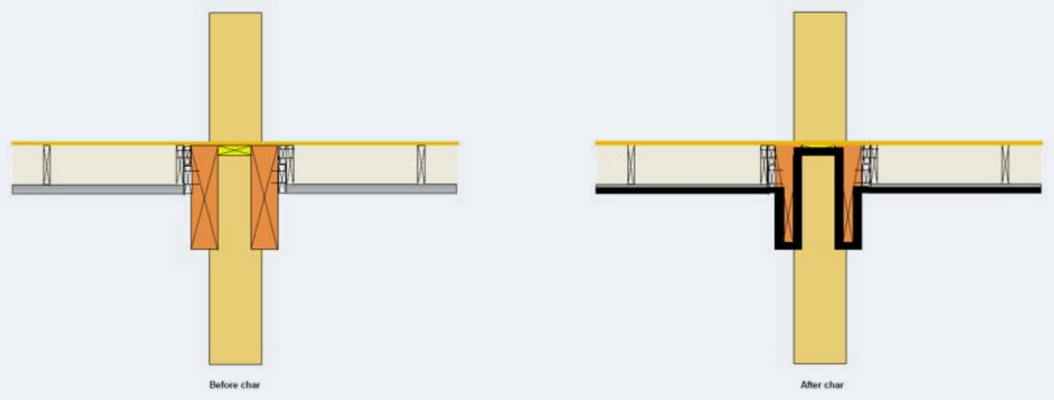


Figure E3: Char difference between blocked and unblocked paired beams.

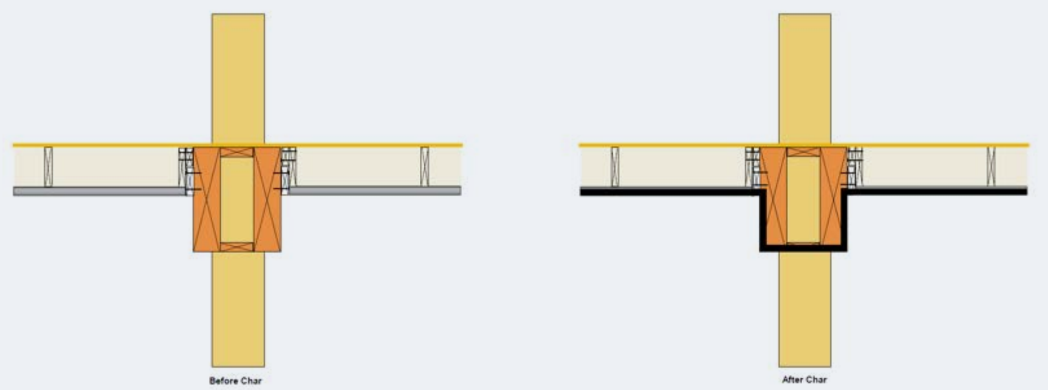


Figure E4: Char difference between blocked and unblocked paired.

E4 Char Capacity of CLT

CLT is not recognised in AS1720.4 as the product char rate is dependent on production methods. Consequently, manufacturers' information is required to be used.

F

Appendix F: Boosting the Acoustic Performance of Timber Elements

F1 Acoustic Design

There are three methods generally employed

1. Suspended ceiling
2. Concrete screed
3. Access floor

F1.1 Suspended Ceiling

Which acoustic solution is used depends on the floor system. A lightweight timber cassette system could utilise the fire-resisting plasterboard ceiling and suspend it using noise-isolating supports to provide the acoustic separation (Figure F1). Massive timber floors that use char capacity for fire protection generally don't use suspended ceilings as the addition of another layer of construction interferes with the visual appearance. A suspended ceiling is sometimes seen in areas where there are higher noise issues, such as corridors. This zone may also include services.

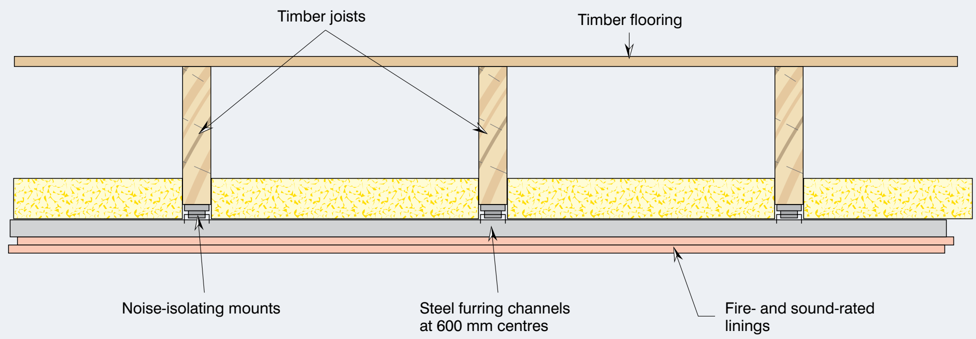


Figure F1: Suspended ceiling.

F1.2 Concrete Screed

Using a concrete screed is a common method to improve acoustic performance. Normally, a resilient mat is included between the screed and the structural floor. The depth of the screed depends on the acoustic performance required. Generally, 40 mm is the minimum (Figure F2). Issues such as cracking and curling of the screed may result in other depths. If a concrete screed is to be used for acoustic reasons, it should also be used (if needed) to help provide some composite structural action. For this reason, a Timber Concrete Composite has been considered in the cost plan.

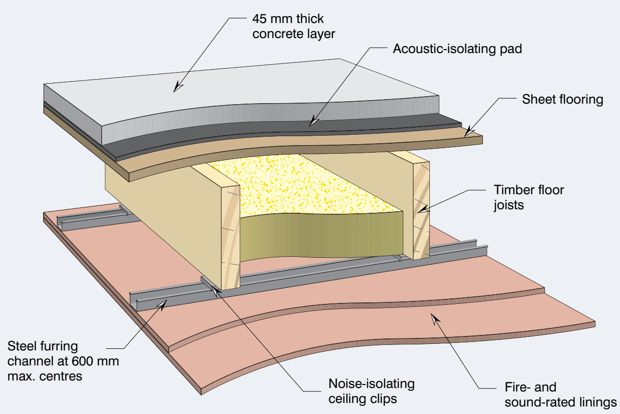


Figure F2: Concrete screed on rubber mat.

F1.3 Access Floor

Where a screed or suspended ceiling is not possible, an access floor is an option. Access floors give opportunity for services and further improvements to acoustic performance when required (Figure F3).

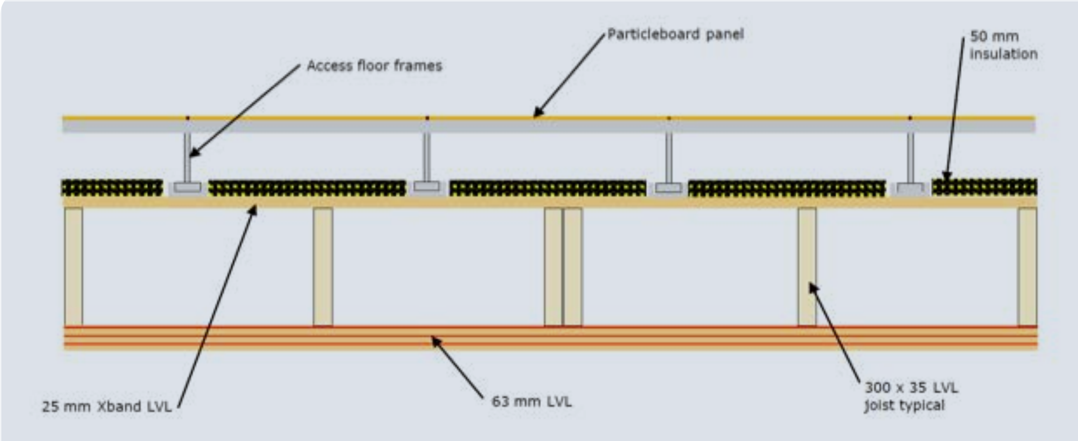


Figure F3: Access floor in combination with timber model floor cassette.

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