NEW APPLICATIONS AND CHALLENGES FOR ENGINEERED TIMBER STRUCTURES

P. Lavisci[1], A. Buchanan[2] & N. Burdon[3]

[1]WoodSolutions, Forest and Wood Products Australia. Email: paolo.lavisci@woodsolutions.com.au

[2]University of Canterbury (retired). PTL Structural Consultants. Email: a.buchanan@ptlnz.com

[3]AECOM, Associate Director-Building Structures Email: Nigel.Burdon@aecom.com

This paper was originally published for the 2018 Australian Structural Engineering Conference.

ABSTRACT

Engineered timber structures are moving into new grounds, thanks to significant interest from major developers and builders who see potential for reducing construction times and costs, while improving sustainability and comfort. With the ingenuity and pragmatism for which they have become known, Australian engineers are pushing the boundaries of standards and codes, prototyping and testing, and solving unconventional and creative structural problems to design timber structures and define applications that will shape the future of the way we build. This paper describes the main projects currently under development, with an insight into engineering challenges for design, code compliance, manufacturing and constructability.

KEYWORDS

Engineered timber products, timber structures, sustainability

1 INTRODUCTION

In the previous ASEC Conference [1] we reported on the increasing maturity of timber engineering, with an 18-storey building completed and projects up to 80 storeys being considered around the world. Most importantly, we reported about a significant shift in mindset for mid-rise construction, where the advantages of timber structures are already tangible and significant. Australia is part of this trend, with Deemed-To-Satisfy provisions introduced into the National Construction Code (NCC) in May 2016 for buildings up to 25m effective height (8-9 storeys) that belong to Class 2, 3 and 5, while no limits were set for the height of designs based on Performance Solutions. This paper describes the effects of the code change in Australia, outlining how some significant design challenges are being addressed. The state of the art and the design trends are discussed, with reference also to the Technical Design Guides which are free for download from www.WoodSolutions.com.au

2 AFTER THE CODE CHANGE

In 2016, soon after the NCC change, Forest & Wood Products Australia (FWPA) established the WoodSolutions Mid-rise Advisory Program (MAP) to promote Engineered Timber Products as the preferred solution to many building professionals and decision makers, supporting the application of both timber-framed and mass timber components. The MAP is run by 5 advisors, currently operating in Victoria and Queensland in a similar way to corresponding initiatives in the USA and Canada. The benefits of timber construction are demonstrated through a series of examples, using multiple tools such as public seminars, in-house presentations, site visits, a technical help desk, design guides and specific project-based meetings. This comprehensive approach has been much appreciated by the local building community and resulted, after 18 months of activity, in a total of 355 projects being identified as suitable for a timber structures, of which 21 have already been converted to timber and 56 have been influenced by the team to the point that they are very likely to adopt timber structures (Figure 1). Considering that the total number of mid-rise projects filed for planning permits in the test area, for the period, was about 630, the success rate (over 12%) is considerable. A few successful examples are described here, many of the remainder are still in the approval loop, monitored and supported throughout the whole process.

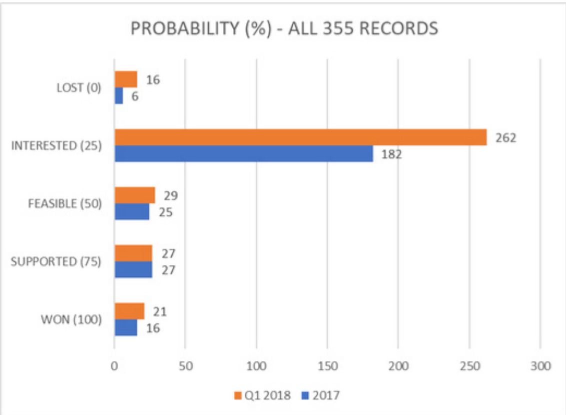

Figure 1: *Summary of the results from the first 18 months of the WoodSolutions Mid-rise Advisory Program. See Table 1 for descriptions.*

Table 1: Description of the probability levels of a mid-rise project being constructed in timber

%	Description
0	Lost: timber structures are not being used
25	Interested: at least 1 key consultant is considering the timber option
50	Feasible: the primary specifier and/or decision-maker is investing time in evaluating the timber option
75	Supported: the decision for timber is based on technical and economical evidence, or the timber design is filed for Planning Permit
100	Won: contracted to a timber supplier, filed for Building Permit or put to Tender

Perhaps the most notable Australian example in recent times is a 10-storey timber extension over an existing office building (Figure 2) in Melbourne's Southbank precinct. With the project destined for use as serviced apartments, the use of Cross Laminated Timber (CLT) has provided significant benefit to all stakeholders. Its light weight (approximately 20% of the equivalent in reinforced concrete) has permitted the building to extend far beyond the maximum 6 storeys of the initial design. In addition to this, the low levels of disruption afforded by timber-based prefabrication means that the existing building will remain in operation throughout the construction period. The MAP team has been supporting a number of parties involved in this project, from design resolution with both the architect (Bates Smart) and the builder (Atelier Projects) to the provision of specialist advice regarding code compliance, acoustics and fire rating of the building, including the procurement and logistic process and selection of material suppliers.

Figure 2: *Hume Partners Pty Ltd is developing 220 serviced apartments over an existing office building. Image: Bates Smart Architects.*

Representing the mid-rise mixed use building typology which is quickly growing in popularity as urban densification continues, the project shown in Figure 3 was initially designed for concrete but was costed by the Quantity Surveyors higher than budget. Value management and re-design processes were undertaken, with the resulting project now featuring 4 levels of offsite prefabricated timber frame walls and CLT floors over a concrete podium, boasting thirteen bespoke apartments, a large retail tenancy space, and car stackers at ground level. The MAP team have frequently provided support to Paul Gardiner architects, their Client and the selected builder (Sinjen) throughout the design and tender process, especially for the design of a brick-clad prefabricated facade, minimising the need for scaffolding and cranage on a narrow site.

Engineered Timber Products have also received interest from a number of institutional and University clients, as illustrated with the project identified in Figure 4. This project - a 6-storey, 150 room student accommodation building at Monash University's Peninsula campus -

is utilising the environmental properties and high construction speed of engineered timber to assist in achieving Passive House certification. The MAP team has regularly offered technical and logistical advice throughout the tender and detailed design processes to help facilitate the success of this project. The MAP team has extensively supported the Client and their tender-winning builder (Multiplex) throughout the whole design and procurement process, supporting the architect (JCB), engineers (Aecom) and building surveyor (SW&Partners) in their interactions for the progressive optimisation of a rather complex design and procurement process, with a very tight time frame for delivery.

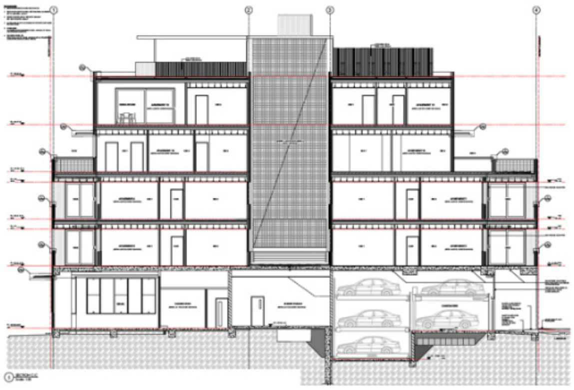

Figure 3: *A typical urban infill mixed used design, significantly optimised with timber structures on a concrete podium. Image: Paul Gardiner Architects.*

Figure 4: *Student accommodation for Monash University, being built by Multiplex in CLT. Image: JCB Architects.*

Such results, along with many similar ones (some of which are described later in this paper), set a base line for ongoing activities, in collaboration with a reactive supply chain which is significantly investing into offsite prefabrication. The daily interaction with building professionals has also generated useful feedback for starting other correlated FWPA initiatives, such as:

- A Mid-rise Structural Design Guide and a matching engineering software
- Laboratory tests and on-site measurements for better acoustic predictions
- Costing and programming analysis tools, case studies and video tutorials
- A 3-story mock-up with some operable components, to demonstrate safety and efficiency with "hands on" experiences.

The nature and variety of situations faced during the many meetings has resulted in an understanding of some structural engineering challenges which can be considered "typical" of urban infill design:

- Stiffer cores for slender and asymmetric structures, in relatively high wind conditions
- Floor depths optimising height restrictions with good acoustic and fire performances
- Open floor plans with grids up to 9x9m for offices or future flexibility.

The following paragraphs illustrate how these challenges are being dealt with in some cases.

3 STIFFER CORES

An adequate type and position of bracing walls is the most efficient structural system for lateral load design, but with complex architectural designs this is not always possible. Lateral bracing can be in the form of single walls, coupled walls in plane, or tubular wall structures such as service cores. Rather large and strong connections are needed for walls within tall timber structures, anyway spanning walls over multiple levels is also possible in some cases and it proves to be useful for an optimised design. Recently, the development of the XRAD (Figure 5) provided a single connector for transferring the shear and traction stresses, plus lifting, handling, positioning and fastening all thicknesses of CLT, thus making the most out of the distinctive mechanical properties of this type of panels.

Beyond this, the Pres-Lam system can be used to increase the efficiency of structural timber walls. Pres-Lam is a method of mass engineered timber construction that uses high strength unbonded steel cables or bars to create connections between timber beams and columns or columns and walls

Figure 5: *The XRAD connector optimises the use of CLT panels, also as cores. Image: Rothoblaas.*

and their foundations. As a prestressed structure the steel cables clamp members together creating connections which are stronger and more compact than traditional timber fastening systems [2]. In earthquake zones, the steel cables can be coupled with internal or external steel reinforcing which provide additional strength and energy dissipation, thus creating a damage-avoiding structural system [3]. Pres-Lam can be used in conjunction with any mass engineered timber product such as Glue Laminated Timber, Laminated Veneer Lumber or Cross Laminated Timber. As an example, it is being used by John Armsby Architects for a slender 10-storey mixed used building in Port Melbourne (Figure 6) where the design constraints required a lighter component and a quicker installation time with respect to concrete tilt-up panels. Two C-shaped core walls made from high strength LVL, anchored in the foundations with full-height vertical post-tensioning from the top of each wall, provide all the lateral load resistance for the building. The structural analysis is simple, because the core walls are vertical cantilevers springing from the base. The stress analysis of the base of each wall considered both flexural shear and torsional response. Other considerations were the connections between the wall elements, the diaphragm connections and the anchorage details at the top and bottom of the tendons, all addressed with standard carpentry details and connectors.

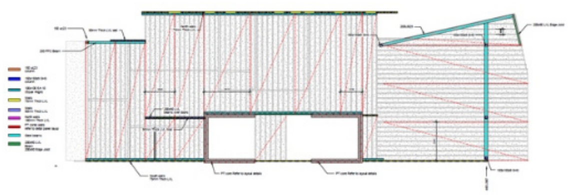

Figure 6: *Pres-Lam post-tensioned LVL core used for a slender 10-storey mixed-use building. Image: PTL Structural Consultants.*

4 FLOOR DEPTHS

Maintaining the floor depth within specified limits is a requirement in many projects and has different possible solutions:

- CLT slabs provide the best option for a diaphragm effect and individual panels can be efficiently connected to each other by diagonal screws or screwed splices
- LVL or GLT, having a much higher proportion of the wood fibre arranged in the same direction, provide a stiffer slab for a given depth and wood grade
- Cassette floor elements allow for an optimised weight/performance ratio and the possibility to run service conduits along the joists (and with trussed joists also across them), saving space.

All the above systems can be either used for a fully dry construction layup or combined with a concrete slab through shear connectors within a hybrid floor system that may bring some advantages for the control of impact sound and vibration.

Another solution that allows to run bigger service conduits is the elimination of beams using the SPIDER Connector (Figure 7) which offers a punctual support for CLT flat slabs with a span length up to 7 m. The system has two functions: reinforcement in the area of the support and suspension of the CLT slab by means of radial arms and fully threaded screws. Therefore it transmits 3-4 times higher vertical loads through the column with respect to a traditional design, without stressing the CLT perpendicular to the grain. The system can be easily installed from the top and immediately loaded. It is possible to integrate it within the floor structure because of its low construction height and it is thus protected from the exposure to fire from both below and above. The lower surface of the CLT can remain visible, thus providing a component which is both a structural slab and a decorative ceiling.

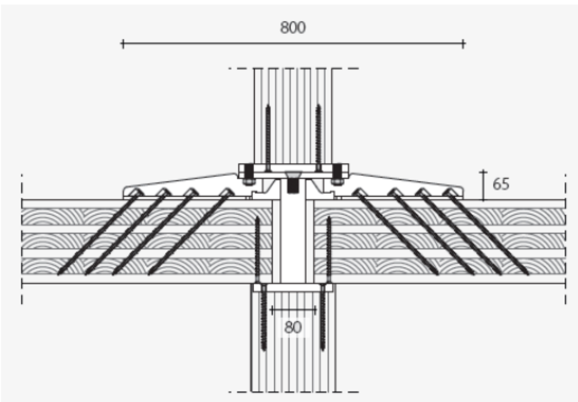

Figure 7: *The SPIDER Connector allows slab & column design up to 7m span. Image: Rothoblaas.*

5 OPEN FLOOR PLANS

5.1 General

Moment resisting timber frames can be used for both gravity and lateral loads, but they usually are not very efficient structures because of the high cost of moment connections and deformation flexibility, especially under lateral loads.

As an example, the development of a timber scheme for the Ballarat GovHub commercial office highlighted the importance of early engineering involvement and intelligent coordination between all disciplines to realise an economic and architecturally successful timber scheme. Some of the experiences of the process are shared below.

5.2 Frames

Commercial floorplates are commonly designed with grids spacings that lie somewhere between 9m and 12m apart. The future tenant expectations on this project meant that a 9m grid was the minimum that was considered acceptable. The use of a timber post and beam system made this possible, however the coordination between the downstand beams and particularly the mechanical services distribution put significant pressure on floor to floor heights, which in turn directly correlates to overall building cost.

Figure 8: *The 5-storey Ballarat GovHub by John Wardle Architects. Image: Development Victoria.*

Early engineering input into the development of the scheme also showed challenges with a comparatively long thin floor plate, and required significant coordination to achieve an efficient holistic solution (Figure 9).

Key factors that were coordinated in the early development of the project included review of implications associated with the selection of the services strategy, the issues associated with the aspect ratio and distance of the floorplate from riser locations, and the requirement for providing separate temperature-controlled zones are complicated by the constraints provided by downstand beams. Utilising chilled beam systems can significantly reduce mechanical air distribution requirements, but were found to come at a cost premium. Low temperature VAV systems were found to be the economic compromise, but required significantly larger duct areas. A number of structural engineering alternatives were investigated to facilitate the necessary mechanical services distribution, including early coordination of riser locations to mitigate service run lengths and individual duct sizes, use of shallower beams in key distribution zones, and implementation of penetrations in beam webs. Deep LVL beams were found to work well as they were developed to be a key part of the architectural response to the building, minimised material wastage by working to standard billet sizes, and facilitated comparatively large beam penetrations in a cost effective manner. These also opened up possibilities for simplified connections.

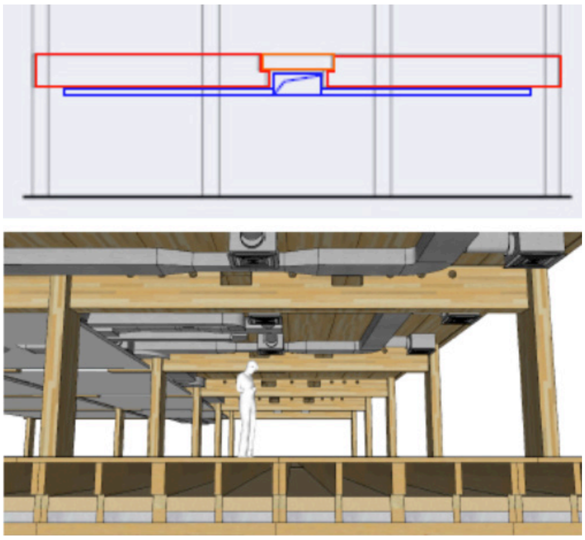

Figure 9: *Propped cantilever primary beams with penetrations, central HVAC channel, LVL/CLT cassette floors. Images: Aecom.*

5.3 Floor Systems

With the requirement for a 9m spans between primary beams there were various systems that were tested. While CLT or LVL plates can efficiently span up to around the 6m range, spans of up to 9m required different solutions. The use of a secondary beam system broke down the CLT floor plate spans in a simple and effective manner. Timber cassettes were also shown to work, providing the advantage of a flat soffit from an architectural perspective.

Meeting acoustics and vibration performance levels were also key considerations as part of the floor selection process. Mitigating or eliminating wet trades is possible, making use of components like a raised floor. A comparison was also made with composite hybrid solutions that make use of concrete toppings with flat plates, and use of timber downstand beams with a concrete plate over.

Similar projects, already built and in construction by Lendlease (Figure 10) use similar approaches.

Figure 10: *International House Sydney is a 7-storey timber office built by Lendlease with post&beam structures and CLT floors. Image: WoodSolutions.*

6 TALLER STRUCTURES

While mid-rise timber design and construction is being consolidated as described, there is also a trend towards using Engineered Wood Products for more challenging applications within taller timber structures.

A typical example is the combination of a steel diagrid with timber-based slabs, with the objective to decrease the weight and the construction times within projects where these aspects are critical, like for a slender residential tower over an active railway line (Figure 11) where timber is being considered by the developer SMA Projects and their consulting engineers (Bonacci) also for the external lift core. A similar approach is being followed by Multiplex for the extensions over existing heritage buildings in both Melbourne and Sydney.

Another very significant project, already with planning approval, is Collins Wharf in Melbourne (Figure 12) for which Lendlease is leveraging its experiences and using its prefabrication facilities to deliver a 26-storey residential complex over an existing wharf, where minimal foundation requirements and significant lateral stability are imperative.

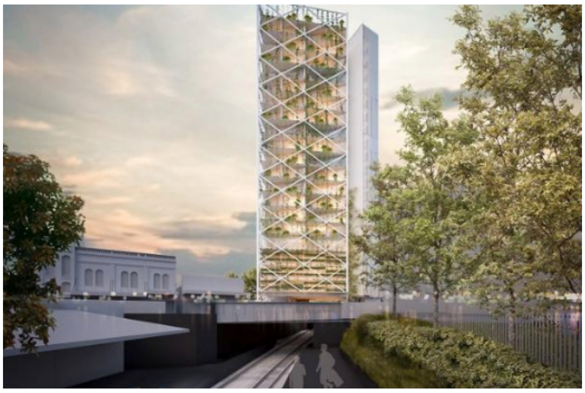

Figure 11: *Timber floor slabs are being considered for a residential tower above an active railway, a challenging design not rare nowadays in urban infill. Image: SMA Projects – JCB Architects.*

Figure 12: *Collins Wharf in Melbourne has received planning approval and is currently being detailed. Image: Lendlease.*

Last but not least, the University of Queensland has started a Centre for Future Timber Structures [4] for the education of the next generation of timber industry professionals and the creation of knowledge-based innovations that can drive the future development of timber in the built environment. Also other Universities are adding new research and teaching initiatives to their structural engineering and construction programs.

7 CONCLUSIONS

Pushing the boundaries of standards and codes, prototyping and testing, solving unconventional and creative structural forms are activities presently being undertaken by engineers in Australia with their typical ingenuity and pragmatism, to design timber structures and define applications that will shape the future of the way we build.

Engineered timber structures are moving into new grounds, thanks to significant interest from major developers and builders who see potential for reducing construction times and costs, while improving sustainability and comfort.

The paper described some of the projects currently under development in Australia, with more already in the approval loop.

Meanwhile, the Australian forest products industry is consolidating its efficiency and production capacity, thus defining a trend and a sustainable supply for the years to come. Australian softwood plantations, which cover over 1 million hectares, are sustainably managed and thriving. At the current production rate and industrial tranformation yields, this equates to a growth corresponding to 11-15 m3 of Engineered Wood Products per minute. As an example, the wood for the 4,300 m3 of CLT used for the 10-storey extension shown in Figure 2, would be regrown in only 5-6.5 hours.

REFERENCES

[1] Lavisci P., Iskra B., Woodard A., Gerber S.: The present and future of timber engineering. ASEC 2016, Nov 23-25, Brisbane.

[2] Below, K. and Sarti, F. (2016). "Cathedral Hill 2: the lateral design of a tall all-timber building". World Conference of Timber Engineering.

[3] Buchanan, A., Deam, B., Fragiacomo, M., Pampanin, S. and Palermo, A. (2008). "Multi-Storey Prestressed Timber Buildings in New Zealand". Structural Engineering Int. 18: 166-173.

[4] http://www.civil.uq.edu.au/timber