J. W. Gottstein Memorial Trust Fund

The National Educational Trust of the Australian Forest Products Industries

Lessons from North American Experience. A review of lessons learnt and future directions for EWP construction systems in Australia.

By

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Joseph William Gottstein Memorial Trust Fund

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Glossary

Building Envelope
The 'external skin' of a building which controls the transfer of air, moisture, and other elements between the inside and outside environments. The building envelope may include elements such as walls, windows, doors, and the roof, and 'envelope layers' such as plasterboard (internal lining), framing, structural elements, air and moisture control membranes, ventilated cavities, and external cladding.

Mid-rise building
A medium-rise or mid-rise building is loosely defined as a structure that has between four and 8 storeys and is equipped with a lift.

Large-scale Construction
Construction of buildings at a large scale, with a project budget typically exceeding $3m. For example, both construction of a precinct of detached houses or a single mid-rise office building would be considered to be large-scale.

EWP or Engineered Wood Product
A general term for a manufactured product made from sections of solid timber, veneer or wood strands, particles or fibres arranged and usually bonded together with an adhesive under heat and pressure to form a structurally reliable material that avoids or minimises the natural variability found in logs or sawn timber. Glulam, plywood, LVL and oriented strand board are engineered wood products (WoodSolutions, 2020).

MGP10
Machine Graded Pine '10' – referring to sawn structural softwood which has been graded to a stiffness class of 10,000 MPa (Modulus of Elasticity) by a grading machine. Machine grading is distinct from visual grading (easily identified through the use of 'F' grades).

CLT
Cross laminated timber (CLT) is engineered wood panels made by joining layers of timber together with the grain direction of alternating layers at right angles (WoodSolutions, 2020).

Core
The structural 'spine' of a building which assists in the transfer of all loads, but particularly shear loading, to the ground foundation. Buildings may not require a structural core if lateral loads are transferred in another way (e.g., through bracing elements), however a structural core is the most common solution for achieving this outcome. The core is typically (but not always) located in a central position of the building, and often contains the project's lift shaft, fire stairs and services risers.

ECI
Early Contractor Involvement, referring to a procurement model which sees the engagement of a contractor in an advisory role at a very early stage of a project – sometimes as early as concept design. This format of procurement allows the contractor to coordinate the design, provide advice on buildability, and even facilitate early purchasing of materials and systems for the project (as may be useful for prefabricated systems).

End-grain
The grain shown on a cross cut surface of wood (WoodSolutions, 2020).

Glulam or Glued Laminated Timber
Sections of sawn timber glued together to form larger, more structurally reliable timber elements. The sections are often joined along their length into laminates, then glue together on their wide face or on their edges (WoodSolutions, 2020).

LVL or Laminated Veneer Lumber
An engineered wood product made from peeled veneers bonded together with an adhesive under heat and pressure into panels with the grain of most veneers running parallel to each other along the board. The panel is then resawn into market sizes (WoodSolutions, 2020).

Point load
A point load is a load that is applied at a specific, concentrated point, sometimes referred to as equivalent concentrated load (ECL). This is in contrast to loads such as uniformly distributed loads (UDL), where the load is distributed across a region of an element such as a beam or slab (Designing Buildings, 2023).

Prefabrication
The design and off-site manufacture of a project specific component, assembly or system that is utilised, in part or as a whole, to build a structure (WoodSolutions, 2020).

Executive Summary

Recent years have seen a surge in interest in the use of Engineered Wood Products (EWPs) in Australia and around the world. A relatively new class of building product to commercial construction, EWPs are produced through the lamination smaller timber elements into a larger beam or panel. Lamination can be achieved through either gluing or mechanical fixing (e.g., with nails or dowels), with timber elements ranging in format from 3-4mm veneers (as is typically used for Laminated Veneer Lumber) through to solid rough sawn timber sections, commonly used in Glue Laminated Timber and Cross Laminated Timber Elements. The great strength of this approach lies in the distribution of natural timber defects such as knots and checks throughout an element, meaning that the final product is much stronger than the sum of its parts.

While it seems a month cannot pass without the announcement of a new 'World's Tallest Timber Tower' there is general consensus that the sweet spot for projects which predominantly utilise EWPs falls in the mid-rise range of 4-12 storeys (WoodSolutions, 2019). There are hundreds of EWP-based precedent projects meeting this criterion around the world, with clients ranging from state governments, institutions, and major tech brands lining up to label them as safe, low-risk, and beneficial for the environment.

However, as adoption of EWP systems in the Australian mid-rise market continues a transition is likely to occur. A relatively new and exciting construction system, until now large-scale timber construction has primarily been the forte of top tier design and construction firms. Driven by their larger, institutional and governmental clients (as well as a smattering of forward-thinking private clients), these designers and builders have been tasked with the design and delivery of smaller buildings than they may typically tender for. Large in size and with resources to invest in both research and learning, it has been possible for these firms to visit the established timber construction markets in Europe and North America to identify best practice approaches and avoid potentially disastrous mistakes in their own buildings. To date this has been highly effective, with dozens of high-quality mid-rise timber buildings now dotted around the country.

With award winning and influential precedent timber projects now delivered by high budget project teams, the rest of the market is paying attention. The smaller developers and designers who are more at home with mid-rise projects are aspiring to build their first timber building, but now with significantly less time and money to learn before doing so.

This poses a risk to Australia's timber industry. Past construction quality issues such as the structural cracking at Sydney's Opal Tower (2019) have experienced widespread media coverage, leading to the collapse of businesses, state government intervention, and the loss of public trust. Such an event in a mid-rise timber building would likely cause as much if not more reputational damage for the timber industry, and could slow or even halt the growth in EWP uptake.

With this in mind, in September 2022 the Author was supported by the Gottstein Trust to undertake a tour of North America's timber construction industry to meet with designers, suppliers, and builders, visit mid-rise timber buildings, and collect lessons learnt and experiences for communication with the Australian market. These key lessons learnt were recorded and have been summarised in this report under seven topic areas including supplier procurement, structural design, acoustic design, fire, finishes, moisture and ventilation, and installation.

As detailed in this report, design and construction complexities associated with timber projects are rarely unique to any single project. This report highlights a variety of useful considerations which – while observed and collected through visits and discussions in North America – are just as applicable in the Australian market.

These valuable observations will be communicated with the Australian market through both this report, and ongoing initiatives supported by the 'WoodSolutions' brand.

Introduction

Australia's urban population is growing. Driven through international and to a lesser extent domestic migration, beyond the blip of COVID our cities are growing at a significant rate. For example, at the time of writing in 2023 the region of Greater Melbourne is home to roughly 5.1m residents. By 2032 this population is projected to reach 6.1m – an increase of 16% - and by 2056, exceed 9m (Centre for Population, 2022; Victoria State Government Department of Environment, Land, Water and Planning, 2019). As our urban population grows, Australians are increasingly experiencing the carry-on impacts of this – longer commuting times, increased costs of living, and by some observations a reduction in quality of life.

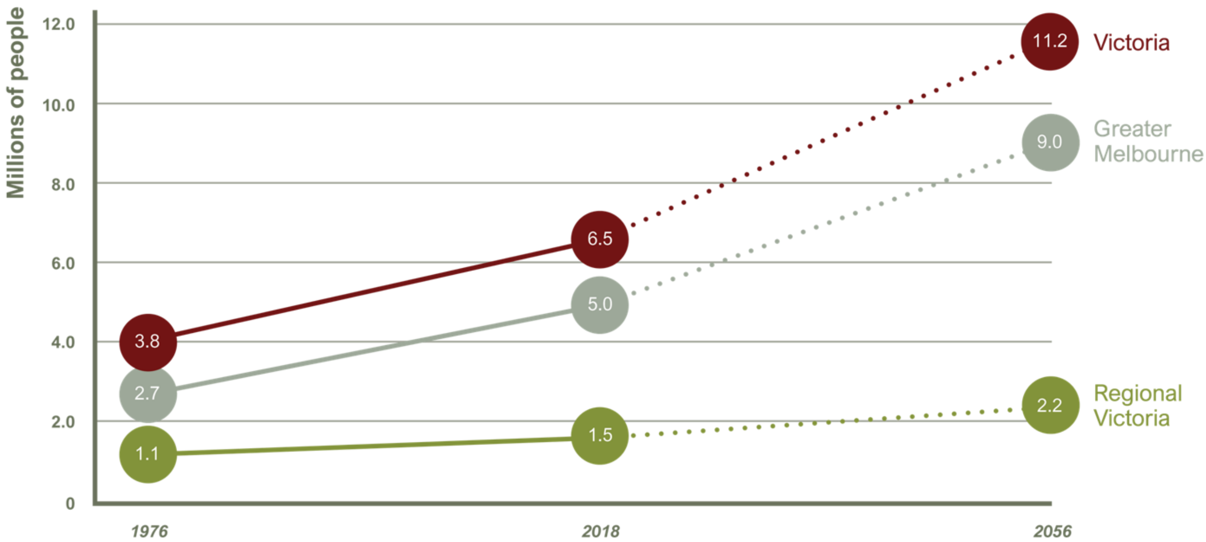

Chart 1: Victoria's population growth to 2056 (Victorian DELWP, 2019)

As Australia's urban population grows, the way we plan, design, and build our urban environment becomes increasingly important. Urban and city planning examples from around the world show that increasing a city's footprint ahead of density can lead to increased pollution, higher economic stress, and reduced quality of life (Hankey, S. & Marshall, J. 2017). Meanwhile, prioritising density and instead incentivising tall tower based apartment living has been linked to increases in mental health issues and a less safe society.

While both of these extremes may offer benefits to certain subsectors of the population, research in city planning and demography suggests that the most sustainable and successful model for urban growth lies in mid-rise development, typically defined as buildings between 4 and 8 storeys. This height range is purported to provide enough density for improved amenity associated with high-density tower living, while supporting and reinforcing residents' connection with the street. Where successfully managed, this balance has been shown to deliver safer, happier, healthier, and more sustainable communities, even as populations grow (Montgomery, 2013).

Meanwhile, as our construction industry booms attention is increasingly turning to greenhouse gas emissions and embodied energy associated with construction and demolition activities. Driven by both growth and the changing needs of an aging population, this increased construction activity ranges from standard infrastructure upgrades to the construction of new residential structures, as well as the relocation and upgrade of industrial precincts (Australian Construction Industry Forum, 2022). Approaching this growth in a traditional lens involves the production and placement of vast quantities of structural steel and cement, both of which are core ingredients of reinforced concrete.

Reinforced concrete is a staple of modern construction, and at a minimum is typically utilised in the ground slabs and footings of structures. In Australia however, it is common to see entire structures built from reinforced concrete, even where alternative construction systems are available. At the time of writing (and for the foreseeable future) however, global cement production accounts for roughly 8% of all carbon emissions, while the global steel industry is also responsible for approximately 8% of all CO_2 emitted (Unknown, 2021; OECD, 2022).

As building activity increases, these already frightening statistics could understandably be expected to increase. This fact alone has regulators and more forward-thinking developers and investors looking to alternative structural solutions, however this practice is yet to become widespread.

Finally, chronic local skills shortages have combined with recent supply chain disruptions and increased worldwide demand for building products and services to create a perfect storm of higher construction costs. While structural timber pricing spikes have attracted much media attention around the world, locally we are seeing significantly higher costs associated with all stages of building construction, from excavation through to structure and fit-out (CoreLogic, 2022).

Price increases and difficulties in securing subcontractors and workers have seen many builders considering prefabricated solutions for the first time. Prefabrication, also referred to as off-site construction or "modern methods of construction" is a term used to describe the partial construction of a structure in an off-site location. In many ways closer to manufacturing than construction, prefabrication sees components prepared and assembled into either elements, panels, or large format 'modules', which are then transported to site for assembly into the main structure.

Prefabrication is often touted as the future of construction, as off-site facilities offer subcontractors the ability to complete their work in a better lit, safer, more controllable environment. What's more, prefabrication facilities are typically located in industrial locations and as such can be permitted to operate on a three-shift, 24-hour work schedule in which a facility need never close. While this fine-tuned scale of prefabrication is yet to reach Australian shores, when implemented at scale it has been shown to achieve significant efficiencies in both labour and material usage, offering cost benefits for both the builder and client while providing workers with a safer and more enjoyable work environment.

Collectively, these pressures are driving Australia's construction industry toward a future of mid-rise timber construction; and indeed, to date our timber industry has risen to meet the challenge. Since Australia's first mid-rise project incorporating EWPs was completed in 2013 (Forte Living, 2013) we have seen the exponential growth in number of mid-rise timber buildings around the country.

Supported by the hard work of Forest and Wood Products Australia (FWPA) and their joint funded Mid-rise Advisory Program which ran from 2016 to 2021, many Australian architects, engineers, and developers now consider timber construction as a plausible alternative for mid-rise buildings. With reliable resources and positive reinforcement freely provided through FWPA's 'WoodSolutions' brand through several initiatives, mid-rise timber buildings now take centre stage in several Australian universities, not to mentioned local and state government precincts, and is now even growing into the mainstream private development market.

Problem Statement and Research Question

While the adoption of timber construction systems is rapidly growing, this uptake is still fragile. As demonstrated by the Grenfell fire tragedy in the UK in 2019, it only takes one major event for law makers to tarnish an entire industry (in this example, even though there were no structural timber products involved in the Grenfell fire, knee-jerk reaction legislation limited the use of timber in buildings over 6 stories). In fact, this has already happened with high-rise concrete apartments in Australia, as demonstrated by the structural cracking of Sydney's Opal tower in 2019, and again at Sydney's Mascot apartments in 2020. These structural disasters are symptoms of broader industry issues and have already affected confidence in the construction industry. As timber construction systems continue to see rapid adoption in in larger and larger buildings, it is vital that the professionals involved in their design, procurement, and installation do their job right the first time.

Figure 1 (Top): Opal Tower (left) in Sydney
Figures 2 and 3 (Bottom): Cracking in the slabs and columns at Opal Tower

Fortunately, to date the majority of Australia's mid-rise timber buildings have been delivered by top-tier firms such as Lendlease, Multiplex, and Besix Watpac. The large size and high sophistication of these companies has allowed their project teams to visit established timber construction markets in Europe and North America, learning from the experiences of designers and builders who have been working with these systems for years. By the time these projects have started on site their project managers and other senior staff are familiar with mid-rise timber construction, and the tried and tested approaches required to deliver high quality, durable, and successful timber buildings.

However, as mid-rise timber construction continues to grow in popularity it is likely that projects will start to be designed and built by smaller companies. These firms – in construction categorised as 'Tier 3' and 'Tier 4' – lack the resources of the larger 'Tier 1' firms, and as such may not have the opportunity to visit international mid-rise timber construction markets prior to involvement in their first project. This poses a risk to the increase uptake of timber construction systems, as poor designs or site management could lead to structural concerns in the mid to long term.

With this in mind the Author was awarded a fellowship of the Gottstein Trust in 2020, which provided funding for a three week tour of North America's mid-rise timber construction industry. This study tour involved several site visits to structures of different scales and type – both under construction and complete – as well as multiple interviews with builders, designers, suppliers, and those with extensive experience in delivering successful mid-rise timber buildings.

The purpose of this tour was to collect as many insights and lessons learned as possible from experienced timber construction professionals and communicate these to the market of smaller designers and builders through this report, and through ongoing work with WoodSolutions and Forest and Wood Products Australia.

Methodology

This Fellowship to the Gottstein Trust was awarded in 2019, with the study tour intended to take place in 2020. Four days before the Author was booked to leave Australia our borders were closed to international air travel as a new and poorly understood Novel Coronavirus quickly spread around the world. This halted all air travel for an extended duration and delayed the commencement of this study tour until 2022. The author would like to extend their great thanks and appreciation to the board of the Gottstein Trust for their understanding and support at this time, and their willingness to delay the commencement of the tour until it was deemed safe and possible to do so.

After much delay, on the 26th of September 2022 the Author left Melbourne for three weeks in the USA and Canada. Given the purpose of this tour was to collect lessons learnt from designers and builders with experience in delivering mid-rise timber buildings, it was logical that the author should visit the most active centres of mid-rise timber construction in the region. With this in mind, the tour commenced in San Jose, California before continuing up the West coast of the USA and crossing the border into Vancouver, British Columbia, Canada. After approximately one week in Vancouver the Author flew to Milwaukee to meet with the architect of the World's tallest multi-residential tower build from timber, before continuing to Montreal. A full itinerary with all project visits and meetings has been provided below:

Country	City	Projects Visited	Meetings Held with
U.S.A.	San Jose, California	- Java Building (Office) - 1 De Haro (Office) - Boulevard Community (Multi-residential) - Edgeview (Multi-residential)	- XL Construction - Entekra - Brookfield Residential
U.S.A.	Portland, Oregon	- Albina Yard (Offices) - Carbon12 (Multi-residential) - Hidden Creek Community Centre (Public) - Unknown timber frame building (Multi-residential) - Wingspan Event Centre (Events) - World Forestry Centre (Education)	- Timberlab - World Forestry Centre
U.S.A.	Moscow, Idaho	- ICCU Arena (Sports)	- University of Idaho
U.S.A.	Spokane, Washington	- Catalyst Building	- Mercer International
U.S.A.	Seattle, Washington	- Heartwood (Multi-residential)	
Canada	Vancouver, British Columbia	- Brock Commons Tallwood House, University of British Columbia (Accommodation)	- Naikoon Contracting

		- Centre for Interactive Research on Sustainability, University of British Columbia (Education) - Forest Sciences Centre, University of British Columbia (Education) - On5 (Offices) - PH1 (Offices) - Pura Condos (Multi-residential) - Surrey Memorial Hospital Critical Care Tower (Healthcare)	- Equilibrium Consulting Inc. - University of British Columbia - Hemsworth Architecture - Adera Development - WoodWorks - SCIUS Advisory
U.S.A.	Milwaukee, Wisconsin	- Ascent MKE (Multi-residential)	- Korb + Associates Architects
Canada	Montreal, Quebec	- Arbora (Multi-residential) - SMEC Soccer Stadium	- Nordic Structures
U.S.A.	New York, New York	- Wythe 1 (Mixed use)	

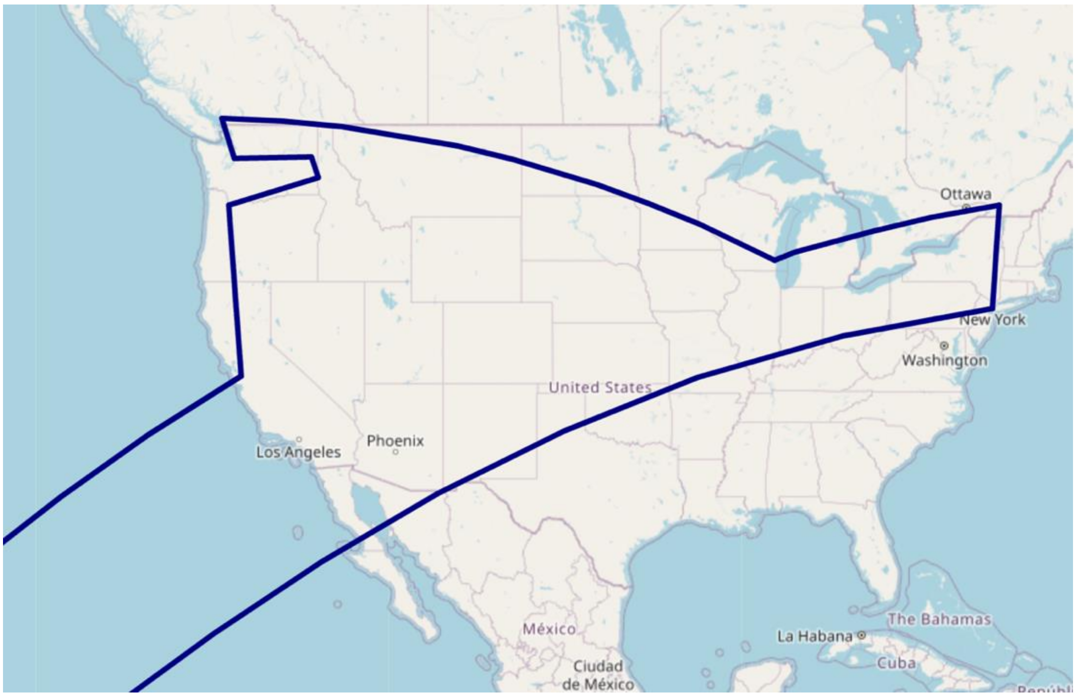

Figure 4: Schematic diagram showing the route taken.

Findings

Much like Australia, mid-rise mass timber construction is quickly growing in popularity in many of the areas of North America visited during this study tour. However, unlike Australia lightweight timber framing is well established as the construction system of choice for 3-5 storey multi-residential structures.

It is clear that the North American construction market is well primed for adoption of timber construction systems – both mass and lightweight – in tall building construction. Through years of exposure the market of buyers and tenants has come to identify lightweight timber construction as *normal* in low-to-mid-rise buildings, supporting the ready uptake of both systems in taller structures.

Indeed, this uptake has been rapid. While mass timber construction is still relatively new to the United States of America, the sheer size and density of the population has supported the delivery of over 800 mass timber projects at the same time it has taken the Australian market to build fewer than 100 (WoodWorks, 2023; WoodSolutions, 2023). This significant experience has supported accelerated learning in the North American market, presenting an opportunity for us to learn from their experiences.

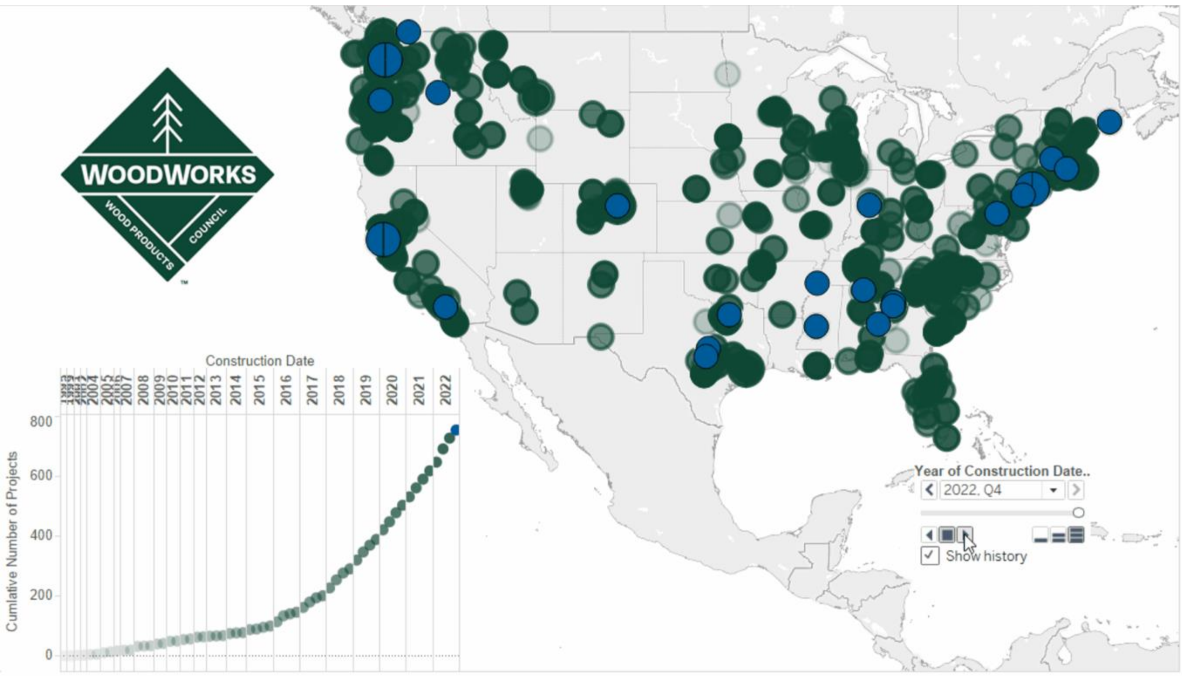

Figure 5: Mass timber projects constructed in the United States of America to 2022

Through multiple site visits and interviews across five American and two Canadian states the Author has identified a wide range of valuable tips and experience-based lessons learnt which may be useful for designers and builders involved in the delivery of mid-rise timber buildings in Australia. In this section we take a closer look at these lessons, which have been divided into seven broad categories, namely:

1. Supplier Procurement,
2. Structural Design,
3. Acoustic Design,
4. Fire (during construction and post completion),
5. Finishes,
6. Moisture and Ventilation, and
7. Installation.

1. Supplier Procurement

The term 'Supplier Procurement' is often used to refer the sourcing, specification, and purchasing of products and materials, but in reality, it's so much more than this. Supplier procurement represents an interaction between the designer or builder and the supply chain, and as such can be seen as an opportunity for the supply chain to provide value in the form of advice, or product or system information which the designer or builder may not already have.

For example, a mass timber supplier may be able to offer advice which improves efficiencies and ultimately saves cost in a project – this could involve finding an optimised, standardised element thickness or size which is efficient to both produce and install, or identifying a surface finish which is cheaper and faster to produce than a default option.

It's important to note that while the above also holds true for prefabricated lightweight frame and truss suppliers in Australia, the majority of America's buildings built with lightweight systems are actually not prefabricated. An exception to this can be seen in the projects supplied by Entekra, a technology forward lightweight prefabricator based in California. Entekra are well known for supplying projects ranging in size from single detached dwellings to five storey apartment buildings with their efficiently prefabricated wall frames and floor cassettes. Site visits with Entekra client and global builder developer Brookfield Residential revealed that the adoption of the prefabricated lightweight framing systems supplied by Entekra reduced project program by almost 50% while delivering the same quality product.


Figure 6: A 5-storey multi-residential building under construction utilising a prefabricated stud framing solution.

With this in mind, it is logical that the earlier a supplier is engaged in the design process, the more value they might be able to create for the project. However, while this option offers many potential benefits, it is common of designers, builders, and developers to be concerned about locking themselves into a single supplier at an early stage, thereby allowing the supplier to limit design freedom or take advantage of the relationship. This can also be an issue in government projects, where all projects must be supplied through open tender.

A potential answer to this problem can be seen in the use of an ‘Expression of Interest’ (EOI) process. This is a process in which the customer – designer, builder, or developer – prepares a 10–20-page document describing the project, its intentions, and the requirements and scope of a potential supplier. At an early stage of the project this document is then issued to a selection of suitable suppliers who can provide a formal response, in addition to product specific advice and design support.

While the EOI is particularly valuable for project teams with relatively little timber experience, it can also be beneficial to more experienced project teams as it gives suppliers an opportunity to understand the limitations and goals of a project at an early stage and provide advice which may result in a shorter build time or lower construction cost.

While Brookfield Residential didn’t engage with Entekra through an EOI specifically, an open and non-transactional relationship-based contracting approach allowed Entekra to provide expert support and advice to the builder, resulting in innovations such as five storey lightweight timber lift cores and pre-lined elements (generating further program savings).

As demonstrated in this example, relationship-based contracting creates value beyond simple budget and program savings. Consulting early with suppliers allows them to consider their capacity to supply the project given their forecast workload and advise based on this. This can effectively be considered a form of risk management, offering benefit to the broader project for relatively little effort.

Figure 7: Precinct of completed multi-residential buildings built utilising prefabricated lightweight framing solutions.

2. Structural Design

Engineered Wood Products are primarily utilised to perform as structural elements within a building’s structural system, and as such the design of this system directly impacts the amount and type of timber products specified. This in turn directly impacts project buildability, program, and ultimately cost.

With hundreds (if not thousands) of mid to high rise timber buildings now completed throughout North America, the market now has many examples of different approaches to structural design. Interestingly, while the fundamentals of structural engineering don’t differ between construction materials or structural systems, there are several important considerations that need to be made by a project’s structural engineer when designing a timber building. These include:

Stacking vertical load bearing elements

Vertical load bearing elements such as columns and load bearing walls preform the key function of transferring loads from higher floors down through to the floor below. At ground level these load bearing elements typically sit over the building’s ground-foundations (e.g., concrete piles), which are often founded on bedrock – sometimes extending 30m below ground surface level.

This is important, as in mid- and high-rise buildings it is common to provide differing building uses on different floors, for example foyer on ground level, carpark either underneath or over this, a recreation centre – sometimes with gym and swimming pool – above this, and then multiple floors of apartments. Each of these building uses may require different floor spans and column locations, and therefore it isn't always possible to maintain a direct vertical load path in which vertical load bearing elements are 'stacked' upon each other.

In these cases – where a column may terminate on a suspended floor element – vertical loads must be transferred laterally through this floor element, a requirement that requires extreme stiffness in order to avoid severe deflection. Unfortunately, even the slower growth and higher strength Spruce and Douglas Fir common in North America don't exhibit stiffness levels high enough to efficiently transfer these loads, and as such these circumstances of load transfer either require significant floor panel thickening, extra secondary beams, or additional diagonal bracing to assist with the load transfer to the next floor.

None of these solutions is ideal, particularly as column load transfer is considered somewhat normal in reinforced concrete construction.

For this reason, wherever possible it is recommended that a vertical load path is maintained as far it can be throughout a tall timber structure. Fortunately, this doesn't necessarily always make a design more difficult, but the designer might need to be flexible and open in their thinking in order to achieve the best outcome.

For example, as shown in Figure 8 the Java office construction site toured in San Jose delivers a beautiful aesthetic and with a functional, spacious interior, and still manages to 'stack' vertical load bearing columns from floor to floor. This is a great precedent of a successful design which can be replicated in a variety of contexts.

Figure 8: Vertical loads are directly transferred to the foundation by 'stacking' them from floor to floor, as shown in this mid-rise office project.

There are some cases where it is impossible to continue a vertical load path from column to column, in which circumstance the designer should consider a composite solution. Depending on the location and number of these transfers it might be best to simply convert the structure up to that slab into a reinforced concrete design, with timber structure extending above. As seen in many mid-rise lightweight framed apartment buildings and again at Ascent MKE (Figure 9)– the World's tallest timber apartment tower (at time of writing) at 25 storeys – this can be a highly effective solution. In these cases, the designers chose to utilise a concrete podium structure to provide large open spaces on the ground floor entry and foyer, loadbearing capacity, fire and spill resistance, and longer spans to above ground multi storey carparks, and moisture resistance and performance under impact and tension in recreation centres. With all of these building uses housed within the concrete podium structure, the timber structure above could be designed for maximum efficiency.

Figure 9: Ascent MKE in Milwaukee effectively uses materials where they are best suited. Here the first 6 storeys – with house the foyer, pool, and other amenities - are constructed from traditional reinforced concrete, with a 19-storey timber tour rising above.

Avoiding crushing floor elements

In addition to improving structural efficiency, it’s important to minimise lateral load transfer through floor elements to minimised crushing.

While EWPs are capable of transferring significant loads parallel to their fibre (for example Douglas Fir has a compressive strength of 49-51MPa parallel to the grain, similar to LVL produced in Australia, and roughly the same strength as high strength concrete), their compressive strength perpendicular to the grain is significantly lower than this (Matweb, 2023; Wesbeam, 2021). For example, the Douglas Fir mentioned above exhibits a compressive strength perpendicular to the grain of just 6MPa – almost 90% lower than compressive strength parallel to the grain.

This is important, as significant long-term point loads applied directly to a flooring element with grain running laterally (meaning the load will be extending perpendicular to the grain) will cause this grain to crush, decimating its load bearing capacity and 'shortening' the building. Where this occurs on multiple floor a building can 'shorten' by centimetres, causing defects in structural connections and faults in rigid connections used in plumbing and gas fitting.

As observed on all multi-story projects visited during this tour (and shown in Figure 10) this design approach forms a fundamental consideration in a timber-experienced structural engineer. Typical design measures employed to mitigate this 'crushing' phenomenon include allowing EWPs bearing vertical loads to terminate end-grain to end-grain so vertical loads can be transferred directly along the strongest axis of a timber element, or utilising a proprietary structural steel connector which connects to both the end-grain at the bottom of the upper column and the end-grain at the top of the below column.

Figure 10: The Java offices utilised a proprietary steel connector to transfer vertical loads from column to column without crushing floor panels.

Finally, it appears the issue of crushing is most relevant where columns are used to transfer vertical loads, concentrating a significant amount of vertical load in a relatively small cross-sectional area. Depending on their length and thickness, load bearing wall elements may be less exposed to this issue. Designers and builders should confirm any requirement for ‘crush-avoidance’ measures with their project’s structural engineer.

Use materials to their strength

First time designers of timber buildings are often motivated to maximise the usage of EWPs throughout a project. However, while driven by the best intentions, this homogenous approach can result in an inefficient design, and difficulties achieving budget targets (amongst other things).

As revealed through multiple discussions, including with the highly experienced Nick Milestone, a more mature and realistic approach to successful timber construction involves the use of a variety of structural products and systems, with each product or system utilised where it provides most value.

While this combination may include a range of timber-based systems such as CLT floors, lightweight timber framed walls, and glulam or LVL columns and beams, but more often it will also include cement-based products in the form of in-ground concrete footings, a concrete podium slab, or a cementitious screed applied on top of timber floor elements for acoustic and construction program (to be discussed in later chapters). Successful construction projects utilising EWPs may also include structural steel elements where the unique benefits of a steel beam cannot be provided by an EWP – for example to transfer a column load to another element, or where a significant open span is required for a relatively small structural depth.

However, when combining structural products it is important to consider the difference in construction tolerances of each material, as the often loose fabrication tolerances associated with structural steel (+/- 6mm as per AS4100) and broad tolerances associated with in-situ concrete (L/200 or +/- 10mm – whichever is larger - as per AS3600) rarely meet the very tight production tolerances experienced with CNC-cut EWPs (+/- .5mm).

For this reason, throughout this tour it was generally agreed that the use of structural systems and products should be carefully considered during the design process to minimise the likelihood of construction program delays resulting from structural clashes.

Figure 11: This four-storey apartment building in Portland Oregon effectively uses a structural steel frame to create large open spaces on the ground floor, with timber frame apartments above.

Don't discount a timber-concrete hybrid

Despite the complexities associated with combining structural systems, it's clear that this can offer significant benefits to a project, from feasibility to constructability and regulator signoffs, and perhaps most importantly the indoor environment of the completed structure. As demonstrated in a wide range of successful projects, the strategic utilisation of building products and systems which offer more comfort and familiarity to designers, builders, and regulators, which can also provide unique structural benefits to a project, can be highly advantageous.

For example, the large concrete lift and fire stair core utilised at the 25 storey Ascent MKE in Milwaukee not only gave comfort to the building's designers and approval bodies, but also performs as a stiff 'spine' to the building, reducing the structural demands on the timber superstructure. This functional performance is important, as it allows for less external bracing of the timber frame, allowing flexible floor plans which support residential leasing and sales – a vital factor to consider in multi-residential development.

Beyond use in the building core, concrete has also been successfully utilised in composite form with timber structural elements to create open floorplates with large spans between columns, as seen in the office site visit with XL Constructions in San Jose. In this use-case the reinforced concrete is utilised not only for its structural capacity, but also to reduce any 'bounce' under foot, and importantly to improve acoustic separation between floors.

This acoustic separation, why it matters, and how it can be approached to maximise positive outcomes is the topic of the next report section.

3. Acoustic Design

Acoustic design is an often-overlooked field of engineering which has a disproportionately large impact on the ultimate success of a project – whether residential, offices, or another use. While acoustic engineers perform a wide range of valuable services – ranging from environmental noise monitoring (for example measuring the impact of the addition of wind turbines to a regional environment) to designing auditoriums and theatres, to acoustic testing of specific wall and floor build ups for suppliers – in the design and construction of large habitable buildings they may be engaged to assist with the design of walls and floors intended to provide acoustic separation between either sole occupancy units or workspaces.

While this does occur in complex projects, it is common for designers and builders on more straight-forward projects to instead rely on pre-tested, standardised wall build ups offered by building product suppliers such as CSR Gyprock and Knauf. This is important, as while the use of timber in a project doesn't necessarily correlate with lower acoustic ratings, timber's properties are different to those of the more commonly used concrete and steel, and as such the acoustic design of buildings utilising timber structural systems must consider this.

The acoustic separation of spaces is typically measured with two variables: airborne sound transfer (referred to as 'Rw'), and impact sound transfer (referred to as 'L_nw'). Airborne sound refers to sound which travels through the air – for example a person's speech, the noise produced by a television, or the sound of a kettle boiling. Impact sound refers to sound which is produced through an impact which sends vibrations spreading through one of the surfaces involved in the impact.

Airborne sound travels most effectively through air and can generally be effectively attenuated through the use of multiple layers of medium-to-high mass matter, for example an apartment party wall which comprises multiple layers of fire rated plasterboard (which is typically thicker and has a higher density than general purpose plasterboard), a wall frame, a gap, then another wall frame, and again multiple layers of fire rated plasterboard. This example wall build up is actually a wall build up typically found in multi-residential design around Australia.

Impact sound travels through vibration, which means it easily spreads through rigid mediums such as reinforced concrete but can be simply attenuated through the use of non-rigid layers such as carpet, underlay, or other impact isolation products. Similarly, to airborne sound, impact sound can be somewhat dissipated through the use of multiple treatment layers, as some energy is lost each time the vibration transfers from one element to another.

Mass Adding Systems

While impact sound attenuated can generally be achieved by following traditional approaches (e.g., carpet and underlay), the natural light weight of wood (compared to reinforced concrete) means that airborne sound attenuation requires more attention. Reinforced concrete typically weighs approximately 2,400kg per cubic meter, compared to ~500kg per cubic meter for the structural softwood commonly utilised in Australian EWPs.

Understanding that airborne sound is effectively attenuated by high-mass elements, in order to deliver quiet and pleasant indoor spaces it is necessary to add mass to timber-based walls and floors, where required to provide sound attenuation.

In Australian projects to date builders have elected to utilise a number of different systems, ranging from wet, pumpable screeds to the installation of multiple layers of cement sheet, or other high-mass panel products (e.g., magnesium oxide board).

Interestingly, during this tour I didn't observe any dry mass additions, instead finding that most sites utilised either a pumpable cement-based screed, or notably in a residential setting a pumpable gypsum-based product named "Gypcrete".

As revealed by the Superintendent of a mid-rise residential precinct which utilised prefabricated lightweight framing, a highly pumpable mass adding solution such as Gypcrete offered a number of benefits to a project, ranging from simple and fast floor levelling to fire rating, plus of course the all-important mass addition for acoustic performance. Other reasons for utilising the gypsum based product on this project included the fact it is much easier to spread and self level than a cement based product, and once dried you can nail through gypcrete without damaging the surrounding area (it doesn't chip or splinter).

Figure 12: This 5 storey prefabricated lightweight framed apartment building utilised a pourable Gypcrete floor topping to counter airborne noise transfer.

During other site visits the Author observed that a cement based screed was preferred. While in one circumstance this was because the structure was a timber-concrete composite, in other cases when questioned it appeared that the choice of cement based over gypsum based was purely due to local availability and the previous experience of the site team (e.g. where they were familiar with cement based screeds, but had little experience with gypsum based screeds).

The observed use of wet screeds to address acoustic rating requirements was an interesting contrast to experience in the Australian market, where many projects have utilised dry mass adding systems instead. For example, in their market-leading office projects in Barangaroo (Sydney) Lendlease laid a magnesium oxide board product named “Brioboard” over their CLT floor panels, and at the Student Accommodation building (“Gillies Hall”) built at Monash University’s Peninsula Campus Multiplex applied multiple layers of fibre cement sheet to achieve the same outcome.

Notably, the Author is not aware of a Gypcrete-style product in the Australian market, or even one with a lower embodied energy. This represents a great market opportunity for suppliers looking to provide an effective and environmentally conscious alternative to cement-based screeds.

Impact Sound Attenuation

While the addition of mass to a floor element can significantly reduce the transfer of airborne noise between two spaces, a designer still needs to consider the attenuation of impact sound in their design. As noted above this can effectively be achieved through the addition of resilient layers to a floor build up – a simple task where carpet is specified, but much more difficult with tiles, vinyl, or floorboards. As identified during multiple site visits, impact sound is typically treated differently depending on the structural system being utilised.

In prefabricated lightweight framed buildings it is quite normal for the underside of the floor structure to be fully lined with plasterboard, and as such it is relatively simple to add acoustic isolation mounts to this system, ultimately reducing the transfer of vibration between the top floor surface and the lower ceiling lining. In this case it is important to also consider the use of acoustic insulation batts in the ceiling cavity, as some impact sound may be projected from the surface of the floor structure into the floor cavity. Where this occurs, the reverberation of this relatively small space can amplify the noise, negating any value of acoustic isolation mounts. However, where designed and built appropriately a suspended ceiling system can be highly effective in attenuating both airborne and impact sounds.

Where a mass-timber structure is used, the design measures targeted at attenuating impact sound are often shifted to the upper-side of the floor element, as in many cases the client and/or designer wishes to expose the aesthetically appealing finish of a mass timber structure in the ceiling. In multi-residential projects utilising mass timber floors (with exposed ceilings) this acoustic system typically comprises several layers including a mass-adding element in addition to a resilient underlay. For offices, perhaps the simplest approach could be seen in the use of an access floor on top of the structural floor element. This access floor typically produces a cavity of 100-150mm in which an office tenant's cabling can be run, reducing the amount of cabling infrastructure installed in the ceiling space which providing effective acoustic separation between floors.

Figure 13: The Hidden Creek Leisure Centre in Hillsboro (Oregon) utilises an access floor and isolation mounts to minimise the transfer of vibration from the first floor gym.

4. Fire

Fire is often the first concern raised by those unfamiliar with timber construction systems. After millennia of making fires for warmth and heat humans are almost intuitively aware of the combustibility of wood fibre, so it's natural that our first concern when building timber buildings should be fire safety.

Indeed, while countless fire tests of different scales have repeatedly shown properly built timber buildings to be safe, major construction site fires – resulting from hot works, arson, or other reasons in an environment where fire suppression systems are incomplete or not active - still occur in traditionally stick-built lightweight framing projects around North America with shocking regularity.

It's important to note here that while mid-rise timber construction has become the default of mid-rise construction in North America, the term 'timber construction' can refer to three main types of construction:

1. Stick-built construction, where packs of timber (or “lumber”) are delivered to the site, and are measured, cut, and nailed together on site.
2. Prefabricated lightweight construction (Figure 14), where wall and floor panels are built in a highly controlled off-site location (often with the use of digital models, robots, and manufacturing-syle production lines). These elements are then assembled on site like a Meccano set, with very little (if any) cutting required.
3. Mass-timber construction, where panel and beam/column elements are produced and cut to exact, predetermined sizes and shapes in a highly controlled off-site facility (utilising digital models, computer controlled cutting machines, etc.). These elements are then typically screwed and/or glued together on site.

Of these three types, stick-built construction is by far the most common form of timber construction, however recent years have seen an explosion of mass timber and prefabricated lightweight system, initially in the North West and more recently in the Southern states. This is important, as to date it appears that all major loss events associated with timber-building fires in North America have occurred on sites utilising stick-built construction, where practically all construction work takes place on site.

It's important to consider this, as this study tour and report primarily focus on the latter two types of construction. Despite this focus, the stigma of building fires created by large-scale stick-built construction continues to impact all timber buildings and as such it is important that this topic is discussed.

Figure 14: Prefabricated lightweight construction is a quickly growing form of timber construction in the USA. Unlike ‘stick built’ construction, this approach sees wall frames and floor cassettes prefabricated off site and delivered to site on the back of a truck as seen here in Portland, Oregon.

Fire During Construction

Construction fires are an important consideration when planning and managing construction projects utilising a timber structure. Ultimately, timber products are combustible and as such it is important to have procedures in place that reduce the likelihood of a fire event occurring, and reduce the consequence of this occurrence should it happen.

As highlighted with XL Constructions and Nordic Structures, major benefits of utilising massive timber construction systems (also shared by prefabricated lightweight framed systems) lie in the speed of construction and lack of curing times or back-propping requirements which limit subcontractor access to the site. The short on-site construction time frame associated with prefabricated systems not only represents a reduced duration of risk exposure to construction fires, but also results in fewer opportunities for a fire ignition event to occur.

Unlike a traditional construction environment where high risk works such as welding, steel reinforcement cutting, and torch-applied roofing membranes are common, the on-site construction process associated with prefabricated systems is more ‘assembly-focussed’. With the many works completed in a safe, well lit, controlled indoor factory environment, on-site structural process involve the lifting and of prefabricated elements from the bed of a delivery truck, and fixing in place through the use of battery powered hand tools, screws, and steel brackets. This construction environment presents significantly fewer opportunities for fire ignition.

What’s more, the off-site step in prefabricated timber construction supports extra value adding steps such as the lining of elements with fire rated linings prior to their delivery to site, both reducing on-site labour and fire risk exposure in one step.

Finally, as observed on site with XL Constructions, the minimal back-propping required for prefabricated timber construction systems means that fire services trades are able to commence the rough in and install of the fire riser, hydrants, and sprinkler systems practically within hours of a level of structure being completed.

Figure 15: A fire extinguisher presents a simple, mobile form of fire safety. While useless against established fires, this might be used to address a small fire in its early stages.

Figure 16: A temporary fire hydrants is installed in a mid-rise mass timber project, and will be removed once the building's permanent fire hydrant is installed and operational. While this hydrant isn't required by local authorities, the builder believes it is a simple risk mitigation strategy to avoid potential significant consequences of a loss event occurring.

5. Finishes

During this tour the Author was fortunate to visit both prefabricated lightweight framed mid-rise apartments, and mass timber apartments and offices which featured a variety of finishes, from plasterboard (known in North America as "Drywall") to exposed structural timber, plus an interesting wall finish locally known as 'Orange Peel' or 'Knock Down'.

While there is little new knowledge to share regarding plasterboard finishing, the use of spray on gypsum-based compounds to create an 'Orange Peel' or when lightly trowelled 'Knock Down' textured surface was interesting. This finish was fast to apply using a spray gun, and effectively hid any minor defects in wall construction.

Where a designer had elected to expose structural mass timber elements, there was consensus that no matter how hard the builder tried to protect a visual grade finish during the building process, parts of it (at a minimum) would need to be re-sanded prior to completion in order to remove scuff marks, stains, and UV discolouration.

Figure 17: While this Glulam was being pre-sanded in the shop before leaving for installation, the supplier (Timberlab) advised that it would likely still need to be spot-sanded on site.

An important takeaway for visual grade mass timber elements was to be careful of positioning in relation to steel elements which might rust over the course of construction, causing rust stains to spread when it rains. Reportedly these stains are amongst the most difficult to remove from a visual grade finish, and should be avoided wherever possible.

6. Moisture and Ventilation

Perhaps one of the most significant risks to the enduring success for a large-scale timber project is that of moisture accumulation in the structure, leading to potential mould growth, discolouration, and in the worst cases, structural damage.

While even the typical softwoods used in EWPs have shown effective resilience when exposed to rain events during construction, it is important that the moisture content of structural elements is managed appropriately in order to:

1. Minimise the likelihood that EWPs will be exposed to moisture, and
2. Where EWPs are exposed to moisture, provide simple and effective ways for the moisture to leave the structural envelope.

The observed solutions to achieve these outcomes will be discussed further below.

Reducing exposure to moisture

The risk level associated with exposing EWPs to moisture is influenced by the duration of the exposure, and to a lesser extent the intensity of the exposure. For example, a relatively short but extreme exposure such as a rainstorm during construction of an EWP project constitutes a relatively small risk. In this case, the builder is aware of the moisture exposure, and is able to implement moisture management strategies that remove any areas of 'pooling' water, and allow the structure to dry out relatively quickly.

In contrast to this, a moderate exposure which impacts a timber element for a long duration could present a much higher risk level.

It's important to note that it typically requires a very long period of un-addressed moisture exposure before negative outcomes are incurred. EWPs normally feature a moisture content of 10-12% at the time of their installation, and depending on their location in a project this might reduce further (to 7-8%) once the structure is completed and air-conditioning installed. With this in mind, mould will not grow on the surface of a timber element until it reaches a moisture content of approximately 18%, and rot (which could impact the structural performance of an element) doesn't occur until the element reaches a moisture content of 40%.

Timber elements may be protected from moisture ingress via a number of methods depending on the stage of a project. These methods include:

Prior to installation: EWP suppliers are able to pre-coat the end-grain of an element (where moisture is most rapidly absorbed) with a non-permeable coating

During construction: Depending on the seasonal climate of the construction site, the builder may choose to protect the entire site under a 'tent'. Alternatively, the builder may choose to cover or wrap visual grade timber elements in a waterproof, vapour permeable membrane, effectively protecting the most valuable surfaces.

Once completed: Moisture exposure control in an operational structure needs to be considered at the design stage, where the highest risk locations for moisture creation are identified and these are treated appropriately. For example, the façade of a structure represents its interface with the outdoor environment, and as such requires a suitable build up featuring a rainscreen, ventilated cavity, and non-combustible vapour permeable (but moisture resistant) barrier over the timber structure. Internal areas where long term moisture exposure is possible also need to be treated carefully, with multiple levels of redundancy provided.

Figure 18: This 4 storey prefabricated timber frame apartment building utilised Super Jumbo Tex – a vapour permeable, water resistant membrane used in the building envelope.

Opportunities for timber elements to dry out

Where EWPs are exposure to moisture it's important that there are no impediments to their drying out naturally. For example, if a builder were to cover a wet EWP with a waterproof tarpaulin after a rain event, this would prevent the timber element from drying out. In this circumstance it could be expected that the timber element would absorb moisture, and would likely start to grow surface mould. In the event that a sufficient quantity of water was captured in this area (e.g. in a CNC-cut recess for a bracket) that was then covered for a long duration, this may lead to the localised increase in moisture content to over 40%, leading to rot.

Enabling a timber structure to dry out may look different at different stages of a project. For example:

Prior to installation: prior to installation, EWPs should be stored off the ground and where possible under a roof. Elements should not be wrapped in a non-breathable product (e.g. non-permeable plastic) – many suppliers instead choose to just cover the top and sides of their product with a UV resistant plastic (leaving the bottom open), or alternatively wholly wrap it in a water resistant but vapour permeable plastic membrane.

During construction: Projects utilising EWPs should be equipped with a well-thought-through moisture management plan which considers different moisture exposure events and their response. While short-term moisture exposure is not a problem, a moisture management plan should identify key response tasks which support the rapid drying of the structure. These tasks may including dewatering construction decks, removing any water which has pooled in recesses in panels (sometimes cut to house brackets), and ensuring that no wet surfaces are covered with impermeable coverings (e.g. tarpaulins, plastic sheeting, or other). In addition to these activities, a construction site superintendent or manager should have access to a professional-grade moisture meter, allowing them to test the moisture content of the structural EWPs. When selecting a moisture meter one should seek a penetrative tool rather than a surface tool, as the moisture content of the surface may be quite different to that of the fibre 1-2cm from the surface.

Once completed: The operational stage is normally the longest period out of the three identified in this section, and as such experiences the maximum risk exposure. With this in mind, it’s important that the designer implements resilient and pragmatic solutions to identifying when a structure has been exposed to moisture, and where this has occurred, removing moisture and allowing the elements to dry out.

Design measures achieving these outcomes may vary throughout a structure, however as identified during a site visit with Brookfield Residential, the strategic use of wall-mounted vents present a fool-proof and affordable solution to supporting airflow in otherwise enclosed structural envelopes. In a similar approach to this, the use of a vapour permeable membrane and ventilated cavity façade system is effective at supporting the drying out of any timber structure in a façade build up. Internally, the risk posed by moisture exposure may be easiest to address by simply exposing the structural timber. This allows occupants to identify any changes in timber surface colour while also supporting the release of moisture into the air as required.

Figure 19: The Superintendent of this Brookfield Residential site points to the permanent vents installed in external wall build ups to ensure they are able to dry out in the event of moisture ingress.

Finally, a common approach to risk mitigation is the separation of balcony structure from the rest of the building. For example, a building’s balconies can be installed as superficial elements, externally to its envelope system. Balconies are often identified as high risk areas, so this total separation not only allows them to be treated specially from a design perspective, but also limits the spread of moisture into the main structure should a leak occur.

7. Installation

With structural elements typically prefabricated in an off-site location, the construction tasks associated with timber buildings primarily represents an assembly process. With much of a project’s ‘buildability’ determined before EWPs are even delivered to site, it’s important for designers and others involved in pre-construction planning to understand the impact of their decisions, and make decisions that support a streamlined design and construction process. Key takeaways collected throughout this tour include:

Use Virtual Design and Construction (VDC) wherever possible.

VDC refers to the use of Building Information Modelling (BIM) to visualise and interrogate construction plans which are more usually prepared in tabular format. For example, a contractor may choose to utilise Navisworks (a 4D simulation program) which takes in the building model, as well as the project’s program. The Navisworks interface then allows the user to visualise each step in the program, essentially building the structure virtually as a way to identify the most efficient construction methodology and program. Performing this simulation process early in the project is valuable, however its utility extends to the construction site, where it can be used to communicate a day's sequence of works to the site team.

This approach has been used on multiple sites in Vancouver, Canada, and has led to great success.

Choose your species of timber carefully

When meeting with Timberlab in Portland, Oregon we discussed the variety of species utilised in engineered timber construction, and whether certain species are easier to work with than others. Engineered Wood Products in North America are typically manufactured out of SPF (Spruce Pine Fir – a collective name which represents all three species), however some designers specifically request other species such as Southern Yellow Pine.

While fabrication and installation of EWPs utilising SPF is considered to be quite straight forward, specific mention was made of using Southern Yellow Pine, as while this is lower density (and therefore lighter) than SPF, it has a very high Janka rating of 870 (by comparison the Janka rating for Sitka Spruce is 510). Where this is specified for use on projects, installers find they need to pre-drill more often, and even replace drill bits and saw blades with a higher frequency than typical.

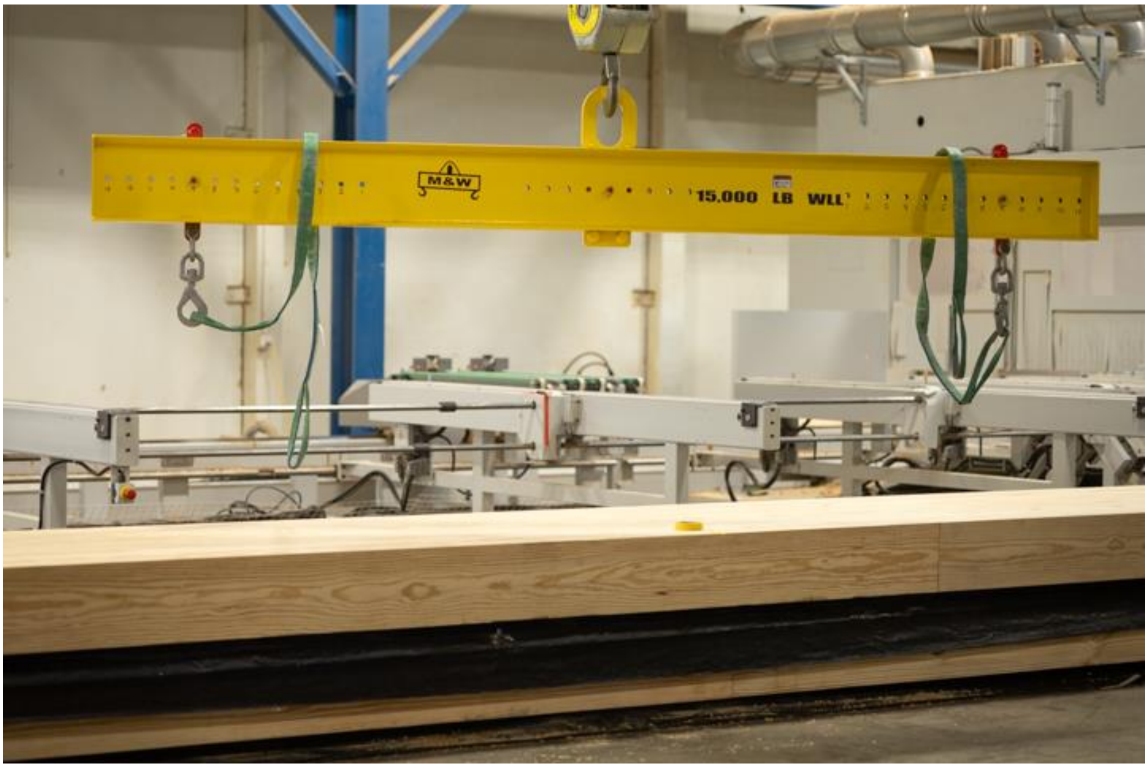

Figure 20: A large Southern Yellow Pine glulam element awaits processing.

In Australia, Engineered Wood Products are typically produced from plantation softwoods which offer little resistance to nailing and screwing, however other harder species such as Mountain Ash (Eucalyptus regnans) and Larch (Larix decidua) are also available. Harder timber species can often make for more durable and aesthetically appealing EWPs, however the impact of using these species should be considered during design.

Avoid thick concrete toppings on EWP floors

As identified in the section on acoustics above, it is common for floor systems to feature a thin layer of dense material such as gypcrete or concrete. While this topping plays an important role in the acoustic separation of internal spaces, the designer must consider the extra load that this topping presents.

In most cases this topping layer is less than 50mm thick, adding a uniformly distributed load of up to 120kg per square meter, or 1.18kN. While this depends on the design, this loading rarely results in deflection of the timber flooring panel, and as such doesn't require extra propping while the floor topping hardens.

However, where a thicker floor topping layer is applied – as sometimes can be the case in timber-concrete-composites – the designer should consider whether this will result in the requirement for back propping, essentially negating many of the program and safety benefits associated with prefabricated timber construction.

Small teams and fast installation

It is common for first-time timber builders to underestimate the speed of construction, and overestimate the amount of labour required to install a timber project. Installation teams typically consist of between 5 and 8 workers (including the crane team) per crane, with installation typically proceeding at about 500sqm of floor space per week.

This speed is important to consider, as with no back-propping it is possible for follow on trades (e.g. services contractors) to commence the rough in of services within the first week of timber installation. By contrast, this work task may not occur for months after the commencement of structure works on a traditional concrete site.

This opportunity for early access has perhaps the most impact on overall project program savings, so it's important for builders and subcontractors to be prepared for it.

Carefully consider surface protection where required

Where building with visual grade mass timber elements it is highly recommended that these elements are covered with a UV-resistant product – typically a vapour permeable membrane, but sometimes even mechanical protection such as MDF boards. Importantly, as identified on site in California the builder and installer should make sure that either the tape being used to secure this protection is UV-resistant, or that there are no gaps in protection underneath the tape, as otherwise you can be left with small and seemingly random areas of UV discolouration.

Where possible, install brackets before lifting

Wherever possible the builder and/or installer should pre-install steel bracketry on the ‘lower’ timber element before it is lifted into place on site. Completing this step in a safe, easily accessible location will allow highly accurate installation, as well as a faster, smoother installation on site.

While this pre-installation would be risky with less precise structural elements (e.g. a steel beam or precast column), the extreme precision of the CNC provides confidence that elements will fit together on site.

Discussion & Conclusion

This three week tour across North America identified and highlighted a variety of valuable considerations for designers and builders planning to deliver a successful commercial timber building. While some of the points noted in this report (e.g. the consistent requirement to re-sand visual grade finishes on site) have been observed in Australian projects, their continued importance in the more mature North American timber construction market indicates that they are not confined to a single project or circumstance, and instead can be applicable to every project.

As noted, lightweight timber construction systems (i.e. those utilising studs and plates to build wall frames, and floor joists to build floor systems) are very familiar to the North American market. Almost a default option for most buildings less than 6 storeys, the market's comfort with these structures has supported its rapid uptake of mass timber products and systems in a range of contexts.

While Australia is home to an established and active lightweight framing prefabrication industry, these systems are typically only found in structures of up to three storeys, and very rarely in multi-residential or commercial contexts. Noting the current local uptake of mass timber systems in the mid-rise space perhaps this process could be reflected here, with commercial scale mass timber construction supporting the uptake of lightweight systems.

Whether mass timber or lightweight systems, many of the observed projects experienced and effectively dealt with issues which are also common on timber projects in Australia such as exposure to moisture, structural, fire, and acoustic design concerns, complexity in procurement, and unpreparedness in installation. However, unlike the local market, methods used to manage these difficulties have been tested at scale across dozens if not hundreds of projects, ensuring both efficiency and practicality in application.

North American timber construction continues to grow in popularity and uptake, with support from both codes and standards bodies and all levels of government. Perhaps, like the design and construction techniques and considerations identified in this report, this governmental support could be documented and presented to Australia's leaders as a proven path for successful and sustainable growth.

As timber construction continues to grow in popularity in Australia and around the world it is important that the designers and builders involved in delivering these sustainable buildings are aware of both the strengths and weaknesses of timber. If our buildings are to be robust, durable, and conducive of further uptake we need to identify where projects can go wrong, and implement design and management approaches to deal with this appropriately.

This report has presented the observations and key takeaways collected through a three week tour of North America's timber industry. While it would be impossible to collect and summarise all of an industry's experience in this time, it is the author's strong belief that the areas addressed in this report represent some of the most important lessons learnt.

Readers seeking further information and support are encouraged to contact the Author, or alternatively approach WoodSolutions – a free and reliable Australian resource for designers and builders working with timber.

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Figure Credits

Figure 1: Opal Tower. Sourced from: https://www.smh.com.au/national/nsw/opal-tower-builder-icon-has-court-win-against-insurers-over-damage-bill-20201019-p566gk.html

Figure 2: Opal Tower Cracking. Sourced from: https://www.9news.com.au/national/opal-mascot-tower-cracks-cracked-australia-faces-6-billion-bill-for-unit-defects/cac9df62-2138-4d84-b51a-49b247f5ffaf

Figure 3: Opal Tower Cracking. Sourced from: https://www.news.com.au/finance/business/blame-game-over-crumbling-building-begins-as-experts-claim-its-part-of-a-much-wider-problem/news-story/5df0832490ec2d1d3401d6756ecd95bf

Figure 4: Schematic map showing route of tour

Figure 5: Mass timber projects constructed in the USA. Sourced from: https://www.woodworks.org/resources/mapping-mass-timber/#:~:text=Mapping%20Mass%20Timber,in%20design%20with%2C%20mass%20timber.

Figure 6-20: Various photos taken by the author.