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# An introduction to mass timber: products and design considerations

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Boola Katitjin by Lyons with Silver Thomas Hanley, Aspect Studios, Officer Woods, and The Fulcrum Agency. Boola Katitjin has been built using approximately 30% concrete for foundations and ground floor slab and 70% timber for the structure above ground. (Image: John Gollings)

# Abstract

This note supports architects and designers with the specification of low carbon engineered and mass timber products, and considerations in their application and building process.

It provides an overview of the related terminology and the range of structural timber products available encompassing those drawn from sawn, peeled, and stranded timber, and those utilising adhesive and mechanical connection between the layers to achieve structural integrity.

# Introduction

Timber is a natural and sustainable resource, and the Australian design, development, engineering and construction industries have gained confidence in its use over the last decade.

The Australian industry has used timber stick framing for many decades, but now there are a range of engineered and mass timber products to utilise that use timber in solid and processed form.

A new generation of tall timber buildings have garnered international recognition and, at the same time, built the confidence of the Australian design community to utilise this natural resource for the key building component – the structure.

This renewed interest in timber is driven by a more carbon-conscious approach in development, design, engineering and construction. Environmental, social and governance (ESG) requirements and reporting are now the focus, especially in larger scale developments.

The use of timber and timber products has seen the introduction of new terminology with architects and designers describing structural timber systems in a more differentiated way – engineered timber or mass timber buildings. Due to the diversification of products available and emerging, it is essential to have a baseline understanding of the key terminology in this sector.

# Key terminology

It is essential to have a baseline understanding of the key terminology in this sector to understand the appropriate applications.

The term CLT (cross laminated timber) has been generically used to describe tall structural timber buildings, but it is just one of many mass and engineered timber products.

### Engineered timber

Engineered timber is created by binding together layers, fibres, or particles of wood using adhesives, pressure and, in some instances, heat. Some common types of engineered timber products (or engineered wood products) include plywood, non-structural multilayer panels (solid timber) and block glued boards, oriented strand boards (OSB), timber flooring, and structural timber products like bonded solid timber, veneer, and stranded products.

Engineered timber products are versatile, cost-effective and decorative, and can be used in a variety of construction applications. They are typically used in combination with other building materials and methodologies.

### Mass timber

Mass timber, or 'massive timber' as it was first defined in the National Construction Code 2019, is 'an element not less than 75 mm thick as measured in each direction formed from solid and laminated timber' (ABCB 2022). It refers to a more specific category of engineered timber which is used predominately for constructing entire buildings or large structures.

> Mass timber products are typically characterised by their size, length and structural properties enabling the products to form parts, or the entire load bearing structure, of a building, ie structural panels, beams and columns.

Currently mass timber products are made of processed timber fibre. The fibre is generally provided in three different forms: as sawn timber, as veneer, or as timber strands.

# Engineered/mass timber products

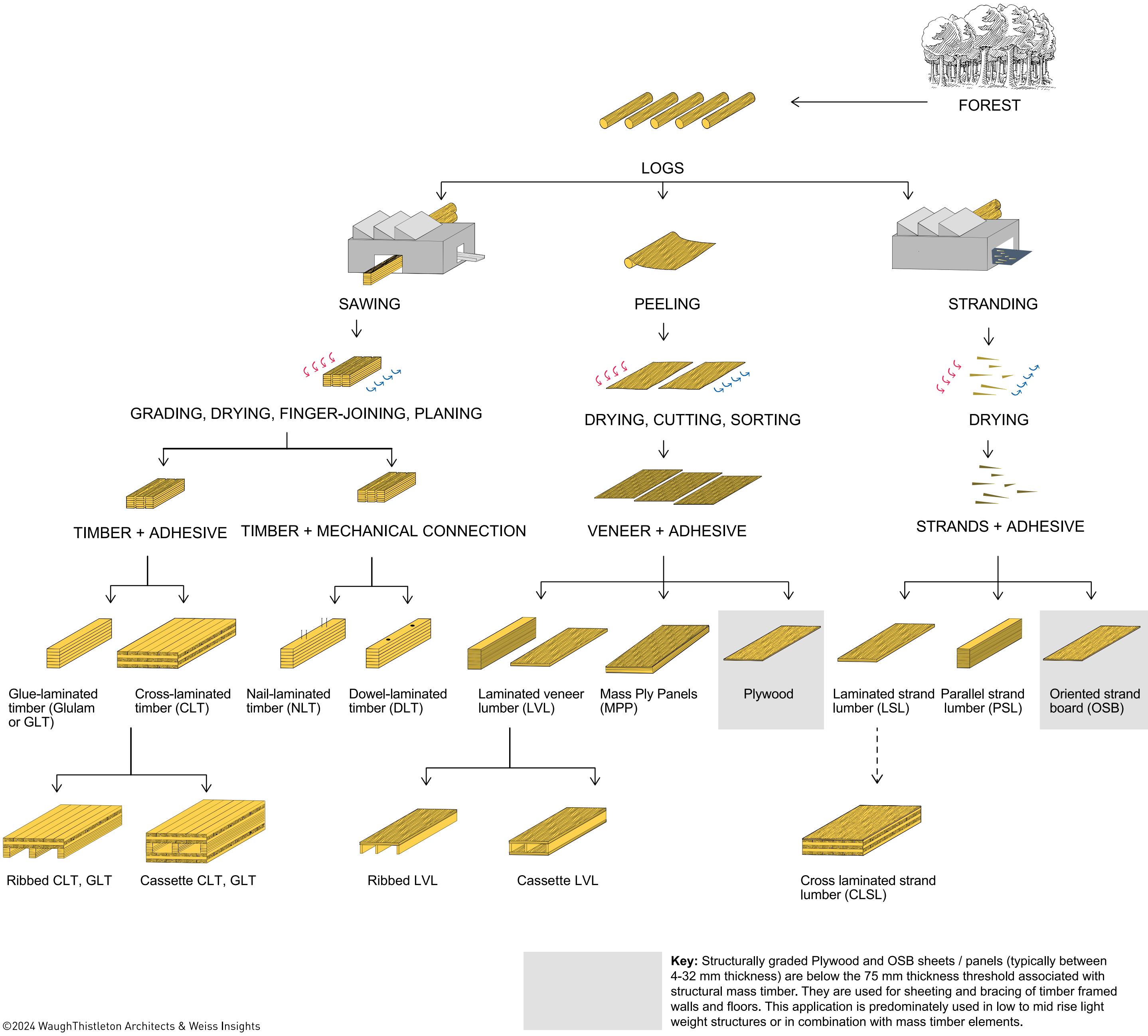


Figure 1. Engineered/mass timber product/process overview. (Image: Waugh Thistleton Architects, London; and Weiss Insights, Sydney)

# Engineered/mass timber products overview

## Sawn timber-based products

### Glue-laminated timber (glulam or GLT) Timber and adhesive

Glue-laminated timber is manufactured by bonding lamellae with parallel fibre orientation together under pressure. The solid timber lamella thicknesses and widths vary between the manufacturers and suppliers with the typical layer thickness for imported products being a multiple of 40 mm. However, thickness can vary between 6 to 45 mm whereas the width is predominately governed by the width of the stock. To achieve a wider GLT product, single planks are edge glued or multiple GLT elements are glued sideways; however, this may have cost implications.

The main sources are very similar to CLT, coming from sustainably-managed and certified (Forest Stewardship Council (FSC) or Programme for the Endorsement of Forest Certification (PEFC)) softwood plantation or forests. Australia, however, has been at the forefront in introducing hardwood into GLT manufacturing. The structural performance of hardwood is superior to softwood and allows for a different appearance which might be a design consideration.

Each plank in the manufacturing process is finger-jointed and stress graded. GLT products are available in different strength classes representing a range of strength and stiffness categories – specifically relevant for larger spans.

GLT can be manufactured to a length of 50 m and a height of 2 m – however, transportation will need to be considered from a cost and logistics aspect. Most manufacturers provide both standard sections sizes and lengths as well as customisation.

Both imported and locally manufactured GLT elements are available, manufactured to either EN or AS/NZS standards. GLT is widely available in Australia through local manufacturers in Qld, SA and Vic, and through importers of European GLT.

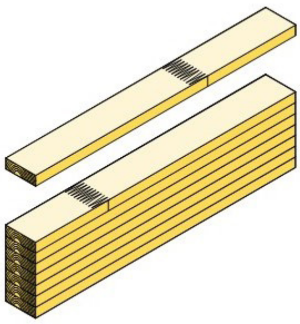

Figure 2. GLT product build up with finger-jointed solid timber planks. (Image: Waugh Thistleton Architects, London)

### Cross-laminated timber (CLT) Timber and adhesive

Cross-laminated timber consists of several (minimum three) layers of graded, kiln-dried solid timber planks, stacked perpendicular and symmetrical to each other, and glued together under pressure. The timber planks are predominately sourced from softwood resources and plantations, but lately hardwood has found its way into CLT panel production.

The resources used for Australian CLT products are Radiata pine (SA and Vic) and a smaller volume plantation hardwood (Tas). There are variations between local and imported CLT products. Imported CLT is often formed with certified spruce and pine, with other species available on request.

Planks might be longitudinal bonded finger-joints and edge glued before being glued and pressed into one solid billet, generally up to 16 m long, 3.5 m wide, and between 60 to 360 mm thick. The overall dimensions, layer build-ups and individual lamella thicknesses may vary between the different manufacturers and suppliers.

Once pressed and cured, the billets form a very dimensionally-stable, rigid and strong panel which then is processed using CNC (computer numerically controlled) technology to create highly accurate individual panels which can be used as structural walls, floors and roofs.

CLT is widely available in Australia through local manufacturers in SA, Tas and Vic, and through importers of European CLT.

Hardwood has recently been introduced into the CLT industry in small quantities by a Tasmanian producer. This product benefits from the superior properties of stiffness and strength in comparison to softwood, and it delivers a different aesthetic appearance.

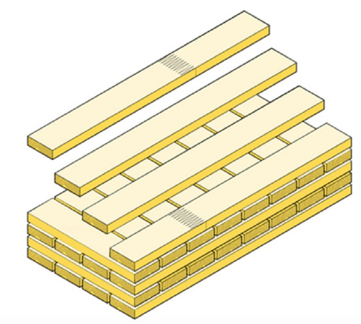

Figure 3. CLT product build up with finger-jointed solid timber planks. (Image: Waugh Thistleton Architects, London)

### Nail-laminated timber (NLT)
### Timber and mechanical connection

Nail-laminated timber, also called nail-lam, is manufactured in a similar way to DLT. Solid timber planks are nailed together face-on-face to create floor panels spanning between load-bearing walls. The same limitations as DLT apply to NLT. NLT can be manufactured from standard-sized planks without the need for a dedicated manufacturing facility. (NLT is not widely available in Australia.)

### Dowel-laminated timber (DLT)
### Timber and mechanical connection

Dowel-laminated timber is a type of mass timber made entirely from solid wood planks. All planks are kiln-dried, dressed, and planed multiple layers are connected face-on-face through friction-fit hardwood dowels to form a panel or billet. The panels are constructed from softwood boards. The avoidance of glue and easy machining makes DLT a more economic and faster way to produce floor panels. However, there are limitations in terms of span, and DLT panels are also more susceptible to moisture movement once applied in larger floor areas. (DLT is not widely available in Australia.)

## Veneer-based products

### Veneer and adhesive
### Laminated veneer lumber (LVL)

Laminated veneer lumber is a type of mass timber made from multiple layers of veneer glued together with most layers in the same direction and some in a perpendicular orientation. When the majority of layers are in one direction, this product is generally used for beams and lintels.

The veneer layers are typically approximately 3 mm thick — in some instances up to 6 mm — through a rotary peeling process of softwood logs, a very efficient way to extract as much fibre from a log as possible with hardly any waste. LVL is manufactured in a continuous process utilising phenolic resin, heat, and pressure, producing a billet which is then sliced into boards and beams.

LVL products are dimensionally-stable, suited to a variety of applications, and can be pressure-treated to respond to specific climate and biological conditions.

While the majority of LVL suppliers use softwood veneer, the use of hardwood veneer would improve overall structural performance further. Currently, there is only a limited number of manufacturers globally.

(Softwood LVL is manufactured in Australia and New Zealand and is also available through importers.)

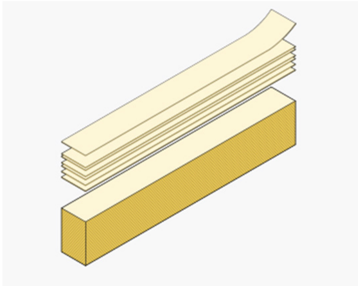

Figure 4. LVL product build up with layers of veneer.(Image: Waugh Thistleton Architects, London)

### Plywood

The development of plywood represented the beginning of engineered timber products. The first recorded patent was established in 1865 in the USA and by the early 1900s, an entire industry had been established around plywood.

It represented an increased conversion rate from tree trunk to finished product. In other words; deconstructing a tree and reconstituting the fibre into a better performing product and increasing the volume of useable fibre for structural and decorative purposes.

Plywood is manufactured similarly to laminated veneer lumber (LVL) where layers of veneer (peeled veneer) are glued together in a cross-laminated fashion using a thin layer of adhesive between each layer and applying heat and pressure.

Plywood utilises thinner veneers, between 0.9 to 2.0 mm, than both softwood and hardwood resources, and is manufactured as structural and non-structural plywood typically between 4 to 32 mm thick.

### Plywood panels

Structurally-graded plywood panels are typically between 4 to 32 mm thickness which means they are below the 75 mm thickness threshold associated with structural mass timber. However, they can be used for sheeting and bracing timber-framed walls and floors. This application is predominately used in low- to mid-rise light weight structures or in combination with mass timber elements.

### Mass plywood panels (MPP)

Recent years have seen an uptake of LVL and development of new LVL-based products such as mass plywood panels (MPP). MPP are manufactured by gluing LVL panels together in a very similar fashion to CLT to form large plywood billets and are showing superior properties and strength. However, supply is very limited with one American and one European manufacturer currently producing softwood MPP.

## Strand-based products

### Strands and adhesive

Laminated strand lumber (LSL): LSL is made from strands of wood bonded together with adhesive. It is used for beams and columns.

Parallel strand lumber (PSL): PSL is made from long, parallel wood strands bonded together. It is used for heavy structural components. The long thin strands of timber are glued under high pressure to create a high-strength material that is usually used for long-span beams or columns that need to carry heavy weight. The strands can be up to 3 mm thick, 15 mm wide and 2.6 m long, bundled together and laminated under high pressure in a continuous press.

Oriented strand boards (OSB): OSB are manufactured in a similar way to LSL where strands are oriented in a certain way and bonded together using a small amount of adhesive. OSB or panels are used in a similar way to plywood panels for bracing and flooring.

Structural composite lumber is the general name for a number of strand-based products. The most common strand-based product is the OSB, readily available in Australia and widely used as bracing board in the volume house-building market.

Strand lumber is based predominately on softwood strands like pine and fir. 'Stranding' a log provides one of the highest conversion rates from log to product as the process represents a re-constitution of the tree with improved performance characteristics.

There are three specific products in the market: LSL, PSL and OSB.

(LSL, PSL and OSB are not manufactured in Australia. There is limited availability through importers.)

## Emerging products and application

### Cross-laminated strand lumber (CLSL)

Cross-laminated strand lumber (CLSL) is made with laminated strand lumber panels which are cross-layered and glued together using an adhesive between the layers. This forms a CLT-panel of similar properties compared to the softwood timber-based CLT panels.

In recent years a hardwood strand-based LSL has been developed and the first approaches for turning this product into a CLT panel are showing superior performance in comparison to the softwood-based products in terms of stiffness and fire resistance.

CLSL has been developed in Australia and will be brought to market in the USA shortly. It is currently not available in Australia.

### Subassemblies

Beyond emerging products, subassemblies are now offered by most manufacturers of mass timber products, either as ribbed or cassette panels. They provide stiffer and longer-spanning floor and roof panels.

Subassemblies are manufactured/assembled in factory environments using a combination of mass timber products; either the same product or in combination with another timber product. They are connected either with adhesives or mechanically using screws, or a combination of screws and glue (see Figure 1).

Ribbed panels using CLT and glulam ribs or LVL cassette elements are the most common. LVL cassettes are predominately imported.

### Timber-concrete-composite and hybrid solutions

The development of so-called timber-concrete-composite elements has found its way into some project applications in Australia, where a CLT floor panel receives a concrete topping on site. Both materials are connected via so-called 'glued-in' shear connectors (glued into a CLT panel). The composite action of both combined materials can increase the stiffness of a floor panel significantly – after the concrete is cured. The concrete topping acts as compression while the CLT panel acts in tension, providing a timber finish on the soffit.

Another emerging application are so-called hybrid solutions or hybrid structures where a selection of materials from different material families are combined to enhance the overall structural performance of the building. In most cases a key driver can be either the structural limitations of a material or the ambition to decarbonise a building project overall.

A great example is the Atlassian Central building (under construction at time of writing). Designed by SHoP architects, New York, and BVN Architects, Sydney, the main structure (vertical and lateral) for the 140 m tall office building is steel with a concrete deck every 4th level and three-storey, mass timber-framed 'neighbourhoods' sitting in between. This hybrid solution of steel, concrete and mass timber provides an opportunity for a significant reduction in embodied carbon – expected to be approximately 50% of a conventional build.

The hybrid solution provides a compartmentalisation of the building into 'neighbourhoods' or material zones, allowing for adaptability of use and fire separation.

Figures 5 and 6. Atlassian Central, Sydney NSW by BVN SHoP Architects. Co-owned by Atlassian and Dexus. Sectional renders of the Atlassian Central building showing the mass timber-framed 'neighbourhoods' sitting in between the main steel structure. (Images courtesy of BVN SHoP Architects/Dexus)

## Mass timber summary

All mass timber products go through a manufacturing process that enhances the strength, stability and dimensional consistency of the original product.

The accuracy and the sophisticated level of milling, routing and sawing, combined with its suitability for prefabrication/pre-assembly, enables the opportunity for offsite manufacturing and onsite assembly process.

As such, mass timber provides the opportunity for innovation beyond the traditional construction process.

This fundamental 'process' shift enables vital flow-on benefits such as speed of install, less onsite labour, quieter building sites and many more encapsulated under modern methods of construction.

### File-to-factory

The majority of mass timber products are 'manufactured to order' on a project-by-project basis using industrial processes and manufacturing equipment. The equipment is primarily digitally driven, fully automated, uses CNC cutting and routing, and robotic machines.

This digital manufacturing process provides great opportunities for the designer and architect to benefit from a seamless file-to-factory approach (a seamless CAD CAM process).

A good understanding of material, production and equipment constraints are essential to fully benefit from a file-to-factory approach. Most manufacturers will provide the relevant technical support directly to the architect and the designers.

### Reporting considerations

As in any material consideration, beyond the performance and technical aspects of product and process, other factors need to be considered such as the material origin and the relevant sustainably-managed forest resources certifications, such as whether:

- the prominent global certificates are FSC or PEFC
- the Australian certificate AFS (Australian Forest Standard – Responsible Wood) is recognised by PEFC.

The ability to demonstrate the chain of custody compliance will be important for any Green Star-rated project (or other rating tools that require this demonstration) and ESG reporting.

As outlined in the product descriptions above, most mass timber products rely on a certain amount of adhesive/glue. While the amount of adhesive is in a single digit percentage area, it is important to consider if there may be any critical emission (VOC or off-gassing) from these adhesives once a building is occupied.

### Timber and carbon: environmental credentials

Wood is a natural, renewable material that has a uniquely low impact processing cycle. It is an excellent bio-based substitute for many mineral-based building materials with high carbon emissions intensity, provided it is sourced from a sustainably-managed forest. In addition, forests, forest soils, and wood products are integral parts of the global carbon cycle and function as key reservoirs for carbon, acting as 'carbon sinks'.

The conversation around, and recognition of, embodied carbon in the design process is still relatively new. However, it is rapidly evolving, and some clients have already clearly formulated carbon goals as individuals, enterprises and governments. Mass timber has a key role to play here.

### Embodied carbon

Embodied carbon is a measure of the greenhouse gas emissions associated with materials and construction processes throughout the whole life cycle of an asset (ie material extraction, transport, manufacture, construction, use (and replacement), demolition and end of life). Embodied carbon can be measured within different system boundaries (eg cradle to gate, cradle to site, cradle to practical completion, cradle to grave, or even cradle to cradle).

Refer *Acumen* note Embodied carbon in buildings.

#### Biogenic carbon/sequestration of carbon

Biogenic carbon is the carbon that is absorbed and stored (sequestration) by plants and trees through the process of photosynthesis. All timber products contain biogenic carbon that has been sequestered through the growth of the trees.

Carbon sequestration is a process of capturing and storing carbon dioxide from the atmosphere. Trees in forests, utilising the solar energy from the sun, photosynthesise and breakdown carbon dioxide, releasing the oxygen that we breathe and sequestering the carbon in the trees' woody mass.

After harvesting, this biogenic carbon remains stored in timber products for the life of the product.

At the end of the first service life, wood products may be:

- salvaged and reused as is
- recycled into new products (ie solid wood into particleboard)
- used as a biofuel to provide renewable energy
- landfilled, where if there is no oxygen (anaerobic conditions) the carbon will remain stored for life.

The storage of carbon in timber is an environmental attribute that doesn't currently exist in a comparable manner in competing structural products.

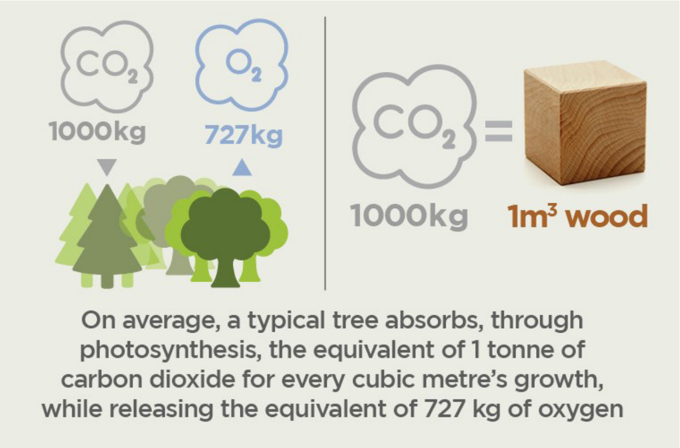


Figure 7. The role of wood products in zero carbon buildings. (Image: WoodSolutions Technical Guide)

## Design considerations for mass timber

Mass timber has, to date, been applied to all scales of construction, from small buildings through to larger and taller structures.

Designing with mass timber requires a robust understanding of material, material behaviour, material limitations, and manufacturing and install processes to ensure the best project outcome.

The drivers for the adoption of mass timber, now almost a decade ago, were the promises of faster and lighter builds:

- Forte in Melbourne's Docklands (Lendlease Design) in 2012 and 25 King Street in Brisbane (BatesSmart Architects) in 2018 were instrumental in demonstrating the technical capabilities of the 'new' timber materials and kick-started projects across all building typologies exploring the possibility of timber structures.
- While Forte (9-floor residential apartments on top of a concrete ground floor commercial unit) utilised CLT panels for both the vertical and horizontal structure, 25 King Street utilised GLT for the vertical structure and CLT for the horizontal floors. Both set new tall-timber benchmarks for building height in Australia when constructed.

### Today, mass timber is being applied across all building typologies and all regions in Australia.

One of today's key adoption motives is certainly the push towards a decarbonised build environment and construction industry. A natural, bio-based material from a renewable source is certainly very attractive as well as the biophilic properties of timber-based products.

#### Why choose mass timber?

This is a very relevant question to begin with. Does mass timber, as a material, respond well to a client brief and to context?

Two case studies have been provided to examine this question in contexts where the client consciously requested a mass timber design solution.

### Collaboration right from the start

Mass timber is still a relatively new material application for some or most design/project teams in architectural and design practices.

Engaging with all stakeholders right from the start is essential as collaboration and technical coordination across all disciplines is a key success factor. This also applies to stakeholders such as certifying authorities and even insurance providers. It is important to bring these wider stakeholders along on the journey to enable everyone to share the project learnings through to completion.

### Made to order

Structural mass timber components are not only made-to-order on a project-by-project basis, but they can also be cut, routed-to-order, and preassembled with connectors and other products if specified.

This represents an opportunity to leverage the precision and accuracy of a factory environment. However, it does require early design collaboration and coordination and timely decision making to benefit from this approach. This is a fundamentally different process to traditional design and procurement.

You must consider:

- technical clarification
- manufacturing time
- assembly time in the factory
- logistic time.

### Long lead times

Made-to-order structural products require a long lead time and are typically key to a project's critical path. Planning well ahead is even more crucial if the specified mass timber products are ordered from overseas. Lead time will need to be extended to take this into account. The most common delivery method is most likely to be in shipping containers and on ships as so-called 'break bulk' – goods of dimensions that do not fit into standard shipping containers.

### The manufacturing environment – collaboration is key

Mass timber products and building components are processed in a factory environment before being transported to site and assembled there. Therefore, before the machine can start, the process of selecting all dimensions and positions of holes and penetrations as well as the pre-install of all the connectors, must be coordinated and agreed by all the disciplines involved.

In this manufacturing environment it is essential to use a 'big room approach' – all disciplines come together in a big room (physically or virtually) to define and agree on all the interfaces on the 3D model – in real time.

Or, in simpler terms, close collaboration with all relevant subject matter experts at the very start of the design process will achieve the best outcome – and collaborative design and engineering teams realise the potential of the use of timber not only as a structural component but as a catalyst to a process change.

An example of successful knowledge transfer is the ongoing deep collaboration between the Japanese architect Shigeru Ban and the Swiss engineer Hermann Blumer. Hermann was involved in Shigeru Ban's first substantial timber building the Centre Pompidou in Metz, France, all the way to more recent structures like the Tamedia building in Zurich, Switzerland. They developed a key partnership, well documented by Shigeru Ban, which drove innovative outcomes such as the beam to column connection.

### Durability by design

There are critical details to consider for enhancing the durability of mass timber buildings, such as applying simple design rules from the design application of timber in the built environment.

Examples include ensuring the timber is clear off the ground, regular maintenance, and ensuring that water can always flow away from the timber. A good way to remember this is the phrase 'timber buildings should have strong boots and a big hat', which means the 'feet' of the building need to stay firm but off the ground and any water that falls will need to flow away from the timber structure ie roof overhangs.

## Building physics

### Fire

Mass timber, even in its processed form, is still classified as a combustible material. As such, it can ignite as a response to significantly increased heat caused by a fire within a compartment.

The National Construction Code 2022 has incorporated provisions and compliance pathways for 'massive timber' structures. Code compliance through a prescriptive 'Deemed-to-Satisfy Solution' requires full encapsulation of timber elements for buildings up to 25 m in height (measured at the height of the last habitable floor).

An alternative pathway is a performance-based solution which can be developed in collaboration with an accredited/registered fire safety engineer as part of a building solution. A Performance Solution pathway allows timber elements to be exposed to a certain extent.

It is always good practice to consult with authorities and a fire safety engineer early on in a project and include them as key parts of the wider design team. They will consider different measures for the fire resistance and fire safety of mass timber structures – always dependant on building type, scale, and height and code requirements.

There has been a significant amount of testing of components and assemblies completed internationally and in Australia. Most of the data is widely available through WoodSolutions (see Further information).

Typical safety measures are the introduction of sprinkler systems, considering encapsulation of timber with non-combustible material like plasterboard, or allowing for so-called char layers – a layer or sacrificial timber which will 'char' for a period of time without impacting the structural integrity of the building component. Consultation with the structural and fire engineer is recommended if you want to leave timber elements exposed.

### Water and moisture

Timber is a hygroscopic material which means it can absorb water and responds to increased humidity in the environment. This can result in a change in dimensions called swelling when moisture levels increase or shrinking when moisture levels drop. The timber end grains are the most receptive to water as the open fibre ends enable capillary action, literally sucking water towards the core, both horizontally and vertically.

The dimensional change can be problematic when tight tolerances are expected. Moisture levels within installed timber should not exceed 16 to 18% moisture content. Long term moisture levels above the 18% mark can cause long term issues like fungal growth and rot.

For this reason, there needs to be a specific focus on protection from water and weather events during construction where there is a risk that timber components may be exposed to the elements for even a short period of time. A moisture management plan should be requested from builders and installers. Manufacturers can offer coatings and end grain protection which is a good first line of defence. Taping and sealing of joints, especially on top of the floorplates, stops water being trapped in critical areas.

Water leakages during operation remain a concern. Regular maintenance and immediate attendance will be important as well as clear services distribution strategies in both the planning and execution stages. Moisture sensors in critical areas which are inaccessible are a good preventative warning system which can detect water ingress.

### Acoustics

While mass timber structures generally perform very well acoustically, attention to detail and collaboration with an acoustic engineer or a relevant specialist is key.

Consideration of airborne sound transmission from one room to another, both vertically and horizontally, and of so-called structure-borne footfall or impact sound transfer mostly through floors, is important.

You can achieve acoustic performance improvement by adopting a layered approach; floor build ups with separation and insulation layers of different density underneath the floor finish or as a suspended ceiling underneath.

Airborne sound insulation performance is typically measured as a D'nT,w value.  Footfall or impact sound insulation is measured as a L'nT,w value. As a rule of thumb the bigger the D'nT,w value and the smaller the L'nT,w value, the better the performance.

Special attention should be given to the possibility of flanking noise through directly adjacent and connected building components, ie the facade element bridging across from one apartment to the other without acoustic separation.

### Seismic

An earthquake – a seismic event – sends horizontal shock waves in short, rapid intervals. A building that behaves well in an earthquake is one that balances stiffness and lightness. The design and construction of mass timber buildings enable the absorption of high lateral impact forces by the higher degree of ductility of material and connections. Mass timber structures perform well under these conditions and have the advantage of being lighter. The lower mass leads to re duced inertial forces which can be created by seismic waves. In addition, timber and timber fibres allow a high degree of deformation – compression and tension – until the moment of its fracture.

Buildings typically support vertical load and lateral load to withstand strong horizontal forces like strong winds and storms. The National Construction Code 2022 requirements are very moderate as Australia hasn't typically experienced many or severe earthquakes, except for some recent seismic events in Victoria and the Blue Mountains in NSW. However, neighbouring countries like New Zealand have experienced catastrophic earthquakes like in Christchurch 2011.

Real 1:1 shake table tests in America, Europe and Japan have shown that mass timber buildings assembled with metal connectors are very adequate structures in response to these natural phenomena and can be repaired after such an event.

# Construction methodology and connectors

### Installation

Gaining an understanding of how the designed structure comes together is another essential control point for the design process. Mass timber components are typically of a bigger format and can weigh several tonnes. The install methodology should be considered at the start as it may drive other constraints like the size of crane and transport challenges in how to get a component to the site.

The install methodology will also define the install sequence and therefore the order of the components to be delivered – which then can influence the order of product manufacture.

### Connectors

One of the big advantages of mass timber structures is the level of prefabrication and preassembly of components in a factory environment. This allows control of tolerances and enables the preassembly of all the relevant connectors.

Connecting mass timber components like beams to columns, columns to columns, slabs to beams, connecting timber with timber, timber with concrete, and timber with steel, ensures vertical and horizontal loads are transferred and components form an adequate structural system.

Connections are not standardised, but performance requirements are defined. Most common are the so-called mechanical connections through brackets, bolts and screws.

Pure timber-to-timber connections are rare. They were achieved in Shigeru Ban's Tamedia building in Zurich. Beams bearing onto columns and CNC cutting and routing technologies allow precision milling of a timber-to-timber moment-connection.

Metal and steel connectors need to be concealed or embedded into the timber components for fire safety to avoid rapid heat transfer through steel components in the case of fire. This is only a requirement if structural mass timber components are left exposed. Connectors are a key component in influencing ease of assembly and potentially ease of disassembly.

There are a number of connector and fixing suppliers in Australia providing all the relevant products, solutions and expertise to the market.

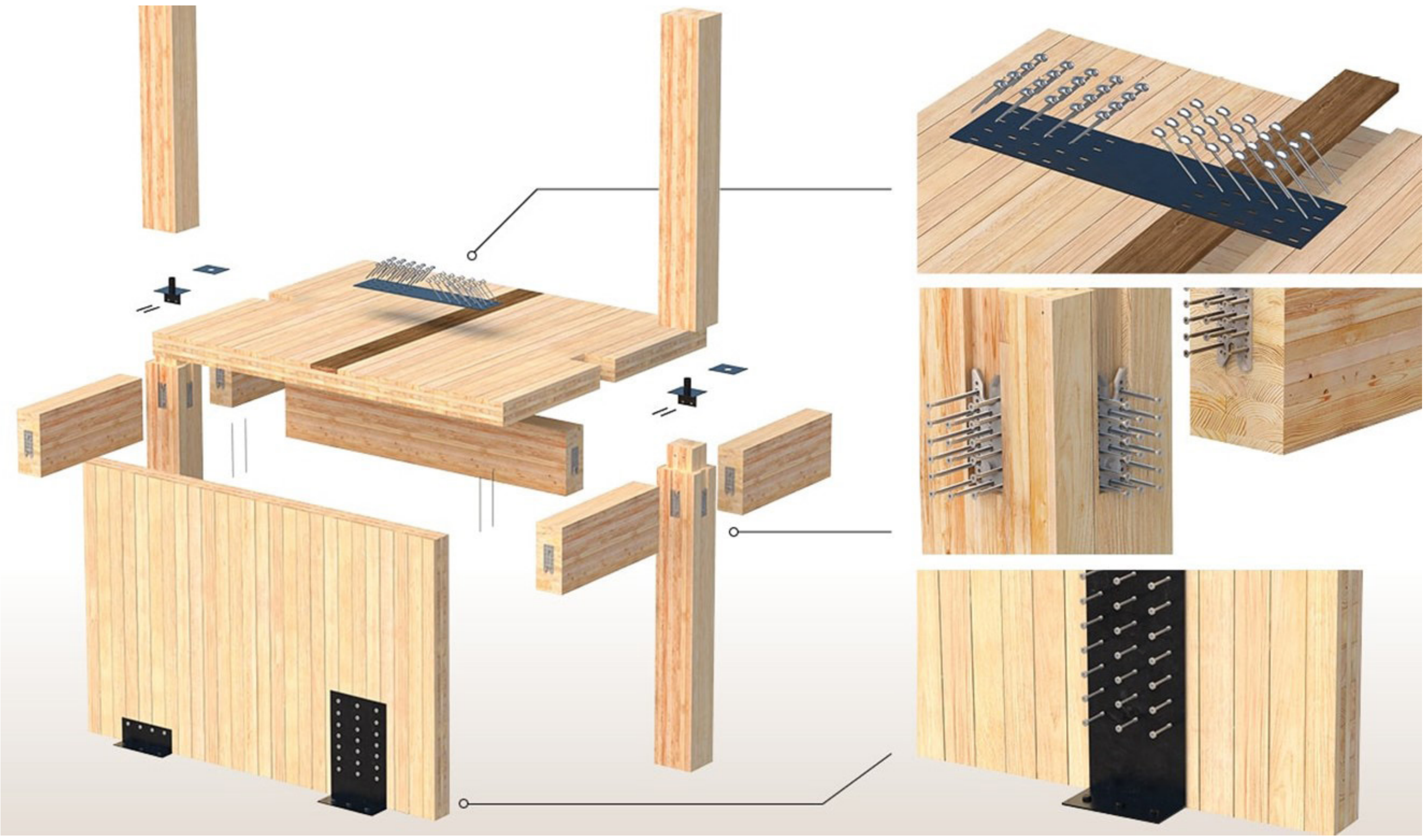

Figure 8. Mass timber connectors: screws, steel plates and brackets are most common. (Image: MTC Solutions Vancouver CA)

# Case studies

Figure 9. T3 Collingwood Southern elevation, nine levels of mass timber structure over six levels of traditional concrete structure and podium. (Image: Tom Blachford)

# Case study
# T3 Collingwood

Figure 10. Diagrammatic render, column beam and CLT slab with central concrete stability core. (Image: Hines)

**Country:** Land of the Wurundjeri Woi-wurrung people

**Location:** Collingwood, Victoria, Australia

**Client:** Hines, Australia (developer), UDNTT and Sumitomo Forestry, Australia (co-developer)

**Architects:** Jackson Clements Burrows Architects

**Consultants:** AECOM, Duo Projects, Openwork, Scientific Fire, Contour, McKenzie Group, du Chateau Chun, Phillip Chun, WRAP, Altitude, Rider Levett Bucknall

**Builder:** Icon Construction

**Mass timber:** Sourced locally within a 300 km radius. Hardwood GLT and CLT from Victoria, Australia

**Completion:** 2023

**Size:** 18,500 $m^2$

T3 stands for timber, transit and technology and, as such, represents the developer's core product and market differentiation strategy for this 15-level commercial building.

The surface quality of timber creates a warm internal environment while reducing the embodied carbon content of the building. Given the more stringent ESG requirements in the commercial building space, mass timber has been seen as a pathway to address these requirements and to contribute to a significant decarbonisation of the entire industry.

Clear client vison and ambition requires a corresponding architectural response. Jackson Clements Burrows Architects brought in a key team of design consultants to work with them from the start, bringing their unique experience and expertise to the project. This specific collaborative attention was required for the design challenge of the podium interfaces between concrete for the lower floors and timber for the upper floors. The design of T3 utilises mass timber as the main structural material from Level 6 onwards (Figure 9).

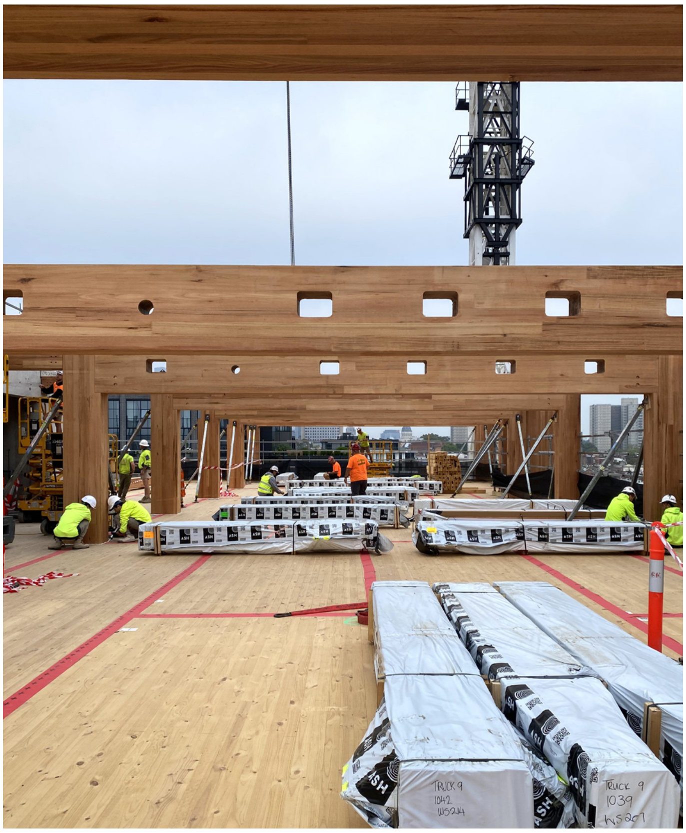

Figure 11. MASSLAM hardwood columns and beams positioned on live deck and lifted into position. Services penetration was coordinated up front and cut in factory prior to installation. (Image: Australian Sustainable Hardwoods)

Figure 12. CLT panels positioned on top of the MASSLAM GLT structure and connected. Vertical columns protected with temporary plywood covers. (Image: Australian Sustainable Hardwood)

Columns provide the vertical load transfer where the role of the CLT panels is to provide lateral stability by transferring the load back into the concrete core (Figure 10). Hardwood GLT columns and softwood CLT floor elements were both imaged in Victoria.

The combination of different structural materials requires good understanding of differential movement between the various materials as well an allowance for the relevant tolerances. Concrete was formed and poured in accordance with standards while timber was milled to the millimetre.

The other important learning was sequencing. Mass timber structures represent more of an 'assembly' process rather than a 'construction' process. The elements came fully processed to the building site where they were temporarily propped until all the elements were in position and connected (Figure 11).

A particularly relevant aspect of the install process was the protection of surfaces which can be exposed to the elements in their final stages (Figure 10 and 11). The protection included measures like the taping of all the joints and openings on the floor panels to avoid water penetrating and staining soffits, and the protection of the vertical elements during construction to avoid potential damages though material and or equipment movements.

Figure 13. Completed floor which internally exposed hardwood GLT columns and beams. (Image: John Gollings)T3's timber approach represented a 34% reduction in estimated upfront carbon emissions versus the same building when designed with a conventional concrete frame as calculated by the engineers, Aecom, using the Green Star upfront carbon emission calculation guide 2022. The estimated carbon reduction calculation is based on class A1- A5 EN15978, from raw material to construction on site.

# Case study
# Boola Katitjin

Figure 14. Boola Katitjin by Lyons with Silver Thomas Hanley, Aspect Studios, Officer Woods, and The Fulcrum Agency. Big open circulation spaces open to the environment allowing for an energy efficient mixed mode ventilation strategy. Hardwood GLT columns support softwood GLT beams and a CLT roof. Columns and beams are diagonally braced to ensure both free standing columns and support of substantial roof overhang. K-Braces delivered the majority of the lateral stability system and wide roof overhangs provide shading and protection of external timber elements. The hardwood columns sit on concrete plinths. This is good durability practice to elevate timber off the ground. (Image: John Gollings)

**Country:** Land of the Whadjuk and Binjareb Noongar peoples

**Location:** Perth, WA, Australia

**Client:** Murdoch University, Western Australia

**Architects:** Lyons Architects, OfficerWoods, Aspect Studios, Silver Thomas Hanley, The Fulcrum Agency

**Structural Engineer:** Aurecon, Services

**Engineer:** NDY Building,

**Surveyor:** Resolve

**Facade:** Inhabit

**Builder:** Multiplex

**Mass timber:** Approximately 1,800 mass timber elements. Sourced from Europe and Victoria

- Softwood CLT and GLT from Europe
- Hardwood GLT from Victoria, Australia

Completed: 2023

**Size:** 16,000 $m^2$

Boola Katitjin is the Whadjuk Noongar name meaning 'lots of learning' and, true to its name, the building has been fully embraced by students and staff. It has been globally recognised and awarded as an outstanding educational building.

Boola Katitjin is a new build on the existing Murdoch University campus in Western Australia. The university had a very clear vision and expectation on what they wanted the new building to deliver on. The provision of collaborative teaching and learning spaces in a building that would foster high quality learning experiences and fit into the landscape of the existing 'bush campus'. Even more, that the building would reflect the university's relationship and commitment to the Traditional land, to sustainability, and showcase their innovation focus. A building which would itself attract new talent and students.

As such, the university's brief, which mandated consideration of mass timber as one of the preferred design options, was a challenge to a standard design approach.

Mass timber is a material that represents a commitment to low carbon and environmental impact. In addition, it is a material which would drive innovation from all angles design and engineering, supply, manufacturing and construct perspectives.

The design team embarked on a deep research journey exploring locally available products and products manufactured some distance away which led not only to a strong collaboration within the design team, but an inclusion of the suppliers and manufacturers early in the design process.

This early collaboration allowed the integration of 'material' and 'process-specific' details as well as coordination between the different trades and disciplines. Softwood GLT columns and CLT panels had to be imported from Europe while the hardwood GLT elements at the perimeter of the building were sourced from Victoria, Australia.

Figure 15. Boola Katitjin by Lyons with Silver Thomas Hanley, Aspect Studios, Officer Woods, and The Fulcrum Agency. Exposed timber elements require a well-considered services reticulation strategy. Services are often surface mounted and penetration through structural elements should be coordinated during the design phase and integrated into manufacturing process prior to site assembly. For Boola Katitjin, the services reticulation was provided through an Under Floor Air Distribution system (UFAD) which required a 600mm access floor across the project. This allowed maximising the beautiful visual exposure of the CLT soffit. (Image: John Gollings)

To ensure the perfect coordination of all technical details across different regions and companies, a project-specific BIM coordinator was put in place across the design disciplines.

Prototypes of certain details were developed to test assumptions, manage client expectations from an appearance perspective, and upskill builders and installers before going into the construction phase.

Specific connection details were developed by the engineers to enable a column-free assembly and event space spanning 30 m; a testament of great collaboration.

This collaboration extended beyond the design team to the suppliers and even further, catalysing collaborations between universities and the industry at the same time:

- University of Queensland tested connections (destructively) designed by the engineers.
- University of Technology Sydney helped to develop a robotic screw application – reducing labour hours and reducing the risk of fatigue through repetitive work.

Figure 16. Boola Katitjin by Lyons with Silver Thomas Hanley, Aspect Studios, Officer Woods, and The Fulcrum Agency. Internal balconies and walkways suspended off cantilevering GLT beams. Balustrades and handrails supported from the beam edge with a very simple bolt on connection. The combination of different materials with timber elements requires a good understanding of the materials' behaviours and the required tolerances in the interfaces, ie timber to glass or timber to steel. Materials expand and shrink differently under different conditions. (Image: John Gollings)

# Conclusion

Timber is a natural material with compelling biophilic qualities and structural integrity and is one of the only true renewable building materials that can be applied at scale.

Mass timber is a contemporary productisation of this material which has opened up new possibilities and applications for design professionals.

Structural timber systems are an enabler of an assembly/disassembly driven building process while still offering the unique surface aesthetics of natural timber.

Scale and current environmental and resource constraints require deeper knowledge of material origin, material processes and properties, material hybridisation within a global imperative for durability and circularity. The limits and constraints of mass timber need to be understood and recognised in the design process.

The key take aways are:

- Mass timber structures perform very well – limits and characteristics should be included in the design process early on.
- Mass timber is still fairly new and collaboration across all disciplines and supply chain including manufacturers is a good pathway to develop a deep understanding of material properties and material constraints.
- Structural mass timber systems are an enabler of an assembly/disassembly driven design and construction process and can lead to greater levels of prefabrication.
- Developing the right set of details for timber structures is critical, both from a long term performance and from a manufacturing perspective.
- Timber buildings present a great opportunity to decarbonise the building industry.

# Further information

There are good resources available to the design community either through peak bodies such as Forest and Wood Products Australia or through manufacturers and suppliers:

- APA, the Engineered Wood Association
- Timber Development UK
- WoodSolutions, a division of Forest and Wood Products Australia

In addition, specialist podcasts provide research-backed insights which support the need for early collaboration in the design process:

- 2022 Highlights Timber Structural Fire Engineering
  - Episode 066 - Fire safe use of wood in buildings with Andy Buchanan, 7 September 2022.
  - Episode 111 - Experiments that will change fire science pt. 7 - CodeRed with Panos Kotsovinos, 26 July 2023.
- Fire Science Show:
  - Episode 018 - Engineered timber with Danny Hopkin, 15 September 2021
  - Episode 025 - Structural fire engineering with engineered timber with Felix Wiesner, 3 November 2021
- Timber Sustainable Future and Burning Issues:
  - Episode 035 - Fire safety as cornerstone of sustainability with Margaret McNamee, 26 January 2022

# Recommended reading:

Ferrer C, Hildebrand T and Martinez-Cañavate C (eds.) (2023) Touch Wood Material, Architecture, Future, Lars Muller Publishers, Zurich, Switzerland.

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## About the author


Karl-Heinz Weiss is founder and director of Weiss Insights and Professor of Practice, Architecture, Monash Arts, Design and Architecture. He has extensive knowledge and understanding of resources, processes, applications, assembly methodologies and technologies to drive continuous improvement and provide zero or low impact.

His professional career has encompassed technical, practice and management roles in United Kingdom and Australia. He has first-hand experience across the whole construction lifecycle, from design, manufacture and traditional construction and development, through to his pioneering work in the application of mass timber into the Australian and UK construction industry. He is a qualified master timber craftsman and an award-winning industrial designer.

He has been at the forefront of innovation from individual construction projects or related product development applications through to large scale, globally significant projects.


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