Building and Construction Authority

Design for Manufacturing and Assembly (DfMA)

Mass Engineered Timber

Version 1.0 - September 2018

DISCLAIMER

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4. Design Considerations

(Photo courtesy of Rubner Holzbau)

(Photo courtesy of DERIX-group, Germany)

FOREWORD

Dear readers,

With the advent of digital revolution, rapid urbanisation and increasing environmental awareness, the Construction Industry Transformation Map (ITM) has identified Design for Manufacturing and Assembly (DfMA), green buildings and Integrated Digital Delivery (IDD) as the strategic areas to transform Singapore's built environment sector.

Mass Engineered Timber (MET) construction embraces all three strategic areas. It involves the prefabrication of sustainable material to building components for easy assembly at the worksite. It is best facilitated by smart advanced technologies that integrates the building processes and project stakeholders. In Singapore, more projects are adopting MET construction and reaping significant savings in time and manpower. The rising demand for smart, green and high quality buildings has positioned MET as a valuable solution for productive and sustainable construction.

To support the increasing use of MET, this guidebook serves to provide guidance to practitioners on MET construction in Singapore from design considerations to technical co-ordination and project delivery. Developed collaboratively by experienced industry professionals, technical associations and government agencies, this guidebook is a showcase of best practices drawn largely from actual project implementation in Singapore and overseas. It highlights key areas where MET construction is most impactful and beneficial.

I hope that with this publication, industry stakeholders are inspired and equipped with the necessary knowledge to adopt MET construction for your projects. As the built environment sector innovates and transforms, we welcome any feedback on this guide for improvements in subsequent editions. Let us work together on this journey towards a better and future-ready built environment.

Neo Choon Keong
Deputy Chief Executive Officer
Industry Development
Building and Construction Authority

ACKNOWLEDGEMENT

This Mass Engineered Timber (MET) Guidebook is developed by the working committee and reviewed by the technical committee. It is the result of a collaborative effort by key technical agencies and industry representatives comprising architects, engineers, builders and specialist contractors.

BCA acknowledges the valuable contributions from the committee members and technical agencies to this MET Guidebook.

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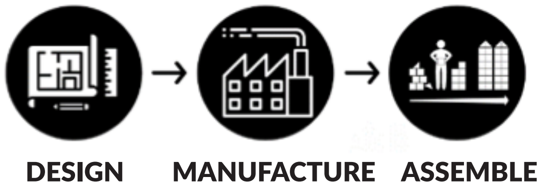
INTRODUCTION

In the past, Singapore's construction industry relied heavily on cheap and low-skilled foreign manpower. However, there is an increasing focus on reducing the dependency on foreign manpower and moving towards a productive industry by fundamentally changing the way we design and construct.

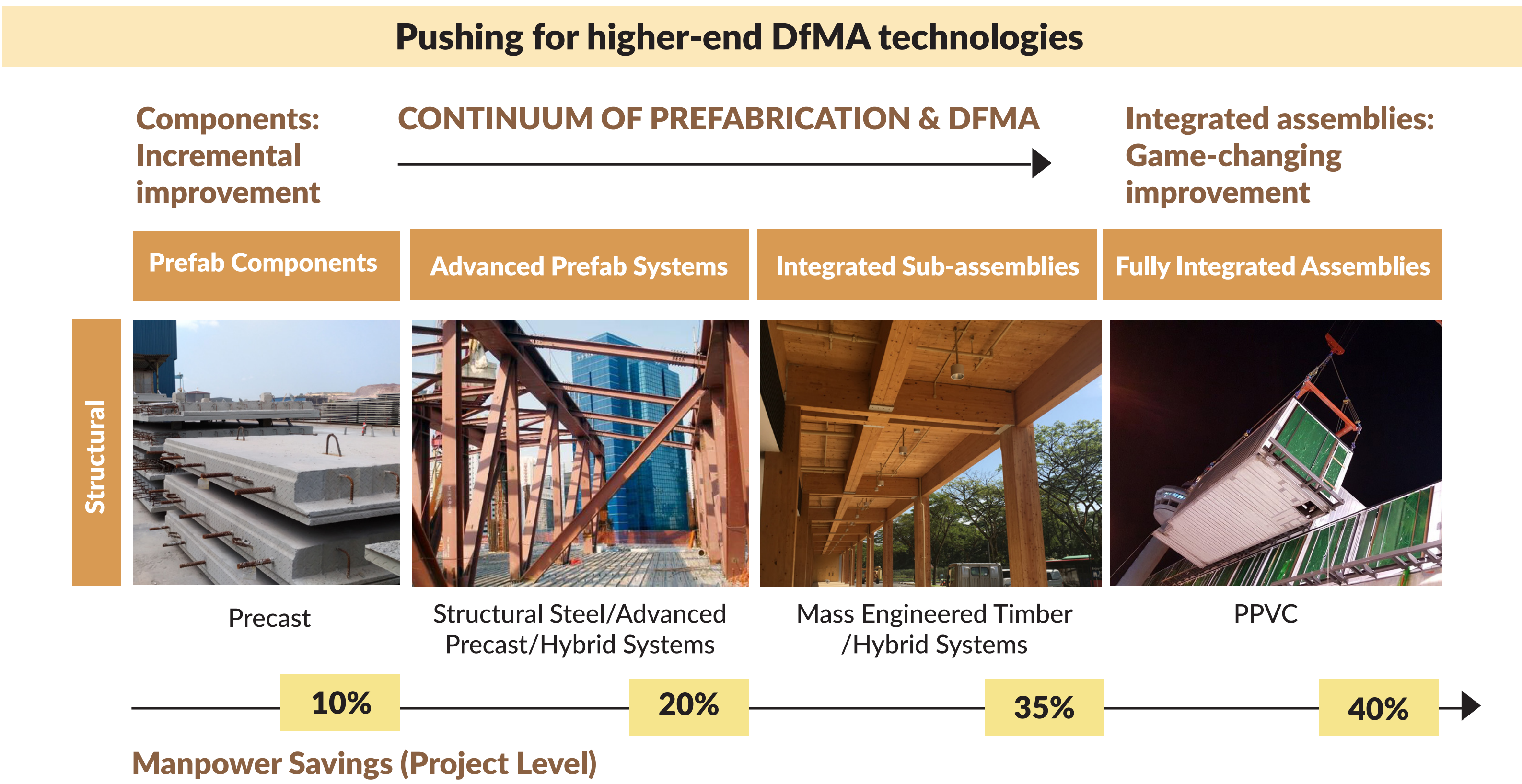
A Construction Industry Transformation Map was developed to steer the construction industry towards adopting Design for Manufacturing and Assembly (DfMA), where construction processes are designed to enable most work to be completed offsite in a controlled environment, for easier assembly on site.

By doing so, higher productivity can be achieved as manpower and time needed to construct buildings are reduced. As fewer activities are carried out on site, work sites are also safer and more conducive, and there is minimal impact on the surroundings and residents in the construction vicinity.



Mass Engineered Timber (MET) is an example of a DfMA technology. It is predominantly manufactured in Europe from sustainable softwood species and has been adopted in many countries including Singapore due to its significant benefits in construction productivity, sustainability and more.

This guidebook helps industry professionals understand the considerations, good industry practices and benefits of adopting MET, and in so doing, build the industry's knowledge and capability for MET construction in Singapore. Examples of MET projects in Singapore and overseas can also be found in the appendix of this guidebook.



2. TYPES AND BENEFITS OF MASS ENGINEERED TIMBER

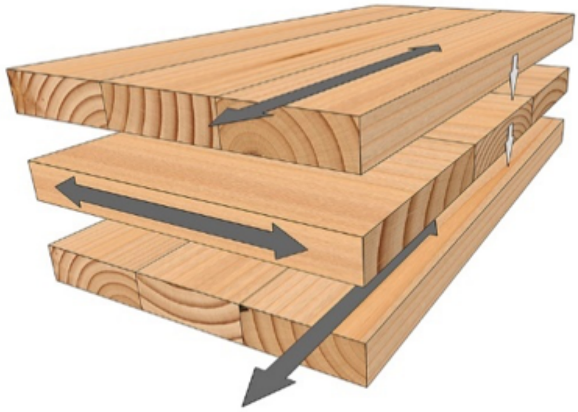
MET refers to engineered wood products with improved structural integrity. It can be used for the construction of various types of developments such as infrastructure, commercial, residential and institutional buildings.

Although MET is a relatively new structural material, it has been gaining acceptance worldwide as a sustainable construction material for low and medium-rise buildings. MET construction is also a productive construction method adopting the DfMA concept as building components are prefabricated offsite in factories to precise dimensions before assembly on site.

Examples of MET include Cross Laminated Timber (CLT), glued laminated timber (glulam) and Laminated Veneer Lumber (LVL). Details of these MET products are covered in sections 2.1 to 2.3.

2.1. Cross Laminated Timber (CLT)

CLT is an engineered structural material comprising layers of laminated timber softwood stacked perpendicularly to each other and bonded with structural adhesives. A cross-section of a CLT element has at least three to seven glued layers of boards placed orthogonally to neighbouring layers.



The benefits CLT offers to structural applications include:

DESIGN FLEXIBILITY
The computer numerical control (CNC) cutting process used during the manufacturing of CLT panels enables the panels to be cut or routed according to the client's requirements.

STRENGTH
CLT is stronger in two directions than solid timber as it has a wider distribution of natural defects due to the cross-lamination process and high standard of board strength grading.

STRUCTURAL CAPABILITY
CLT is typically used for floor, roof and wall elements of building structures with spanning capabilities of up to 6m or longer (refer to Section 6.3 and 7.2 for more information). As CLT has high in-plane strength and stiffness, it can be used effectively as shear walls, diaphragm plates and deep beams.

QUALITY
CLT is manufactured to strict quality assurance requirements from stress-graded timber of known structural capacity.

CONSISTENCY
CLT is manufactured from kiln-dried timber (12%- 14% moisture content) and the cross-lamination process makes it less prone to movement caused by changes in moisture content.

There are various types of CLT panels available and their sizes vary according to the manufacturers, suppliers and other limitations such as transportation. For further information, refer to the manufacturer's technical guidance.

2.1.1. CLT Applications

FLOORS AND ROOFS

Figure 1:
CLT floor construction

WALLS

Figure 2:
CLT wall construction

STAIRS AND STAIR CORES

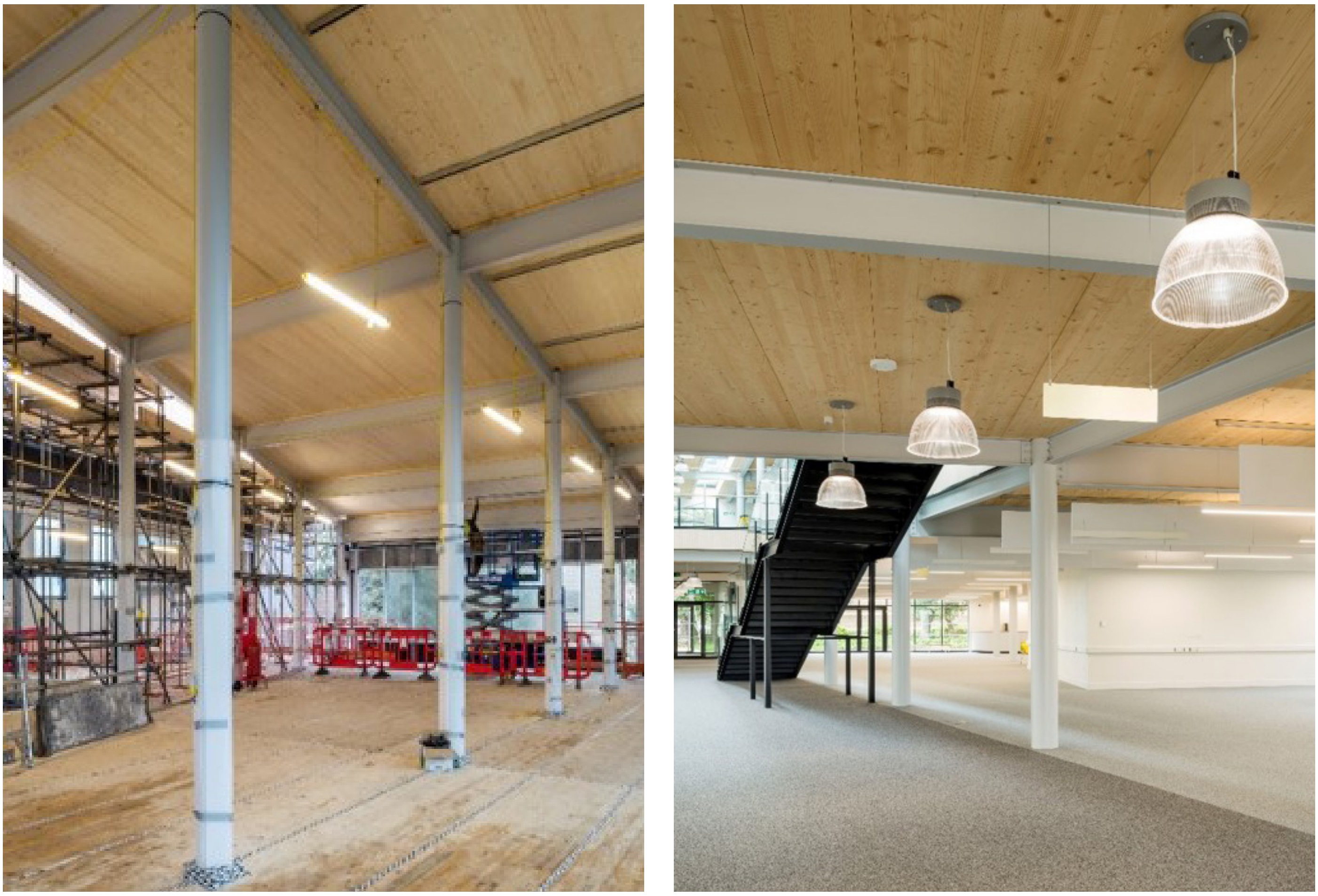
Figure 3: *Example of CLT stairs and stair cores (Sky TV Campus, London, UK)*

SERVICE RISERS

Figure 4: *Service risers in CLT (Burlington Gate, London, UK) (Photo courtesy of B&K Structures)*

PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION (PPVC)

Figure 5: *Modular MET Construction (Hotel Jakarta, Amsterdam) (Photo courtesy of DERIX-group, Germany)*

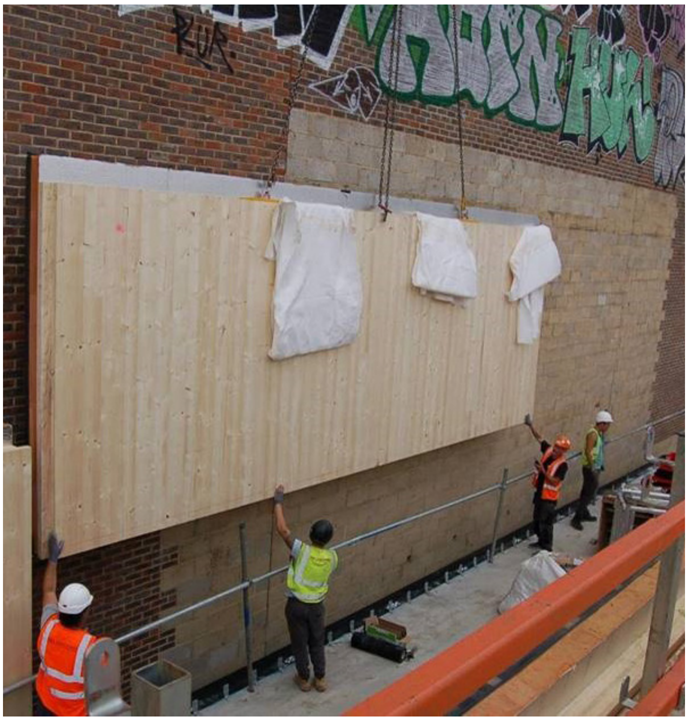


HYBRID CONSTRUCTION - STEEL & CLT

Figure 6: *Steel frame with CLT floors (Famborough University Technical College, UK)*
(Photo courtesy of B&K Structures)

HYBRID CONSTRUCTION - CONCRETE & CLT

Figure 7: *Hybrid structure using concrete beams/ columns, glulam beams and CLT floors*
(Pei Hwa Secondary School, Singapore)

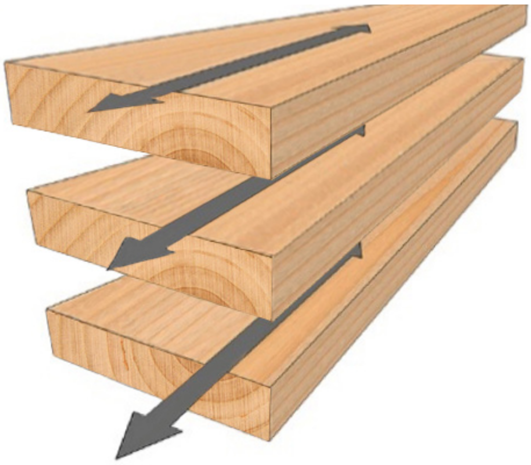


THRU-WALL SYSTEM

Figure 8: *Load-bearing thru-wall system using CLT (Dalston Lane, UK)*

2.2. Glued Laminated Timber (Glulam)

Glulam is manufactured from small sections of plane timber boards or lamella bonded together with structural adhesives. Hence, it is able to form larger members with mechanical properties that are stronger than normal timber boards. It is produced in a similar method as CLT, but with the grain aligned in the same direction.



Glulam can be used for structural beams, columns or truss elements and offers many advantages. These include:

DESIGN FLEXIBILITY
Glulam can be manufactured in a wide variety of shapes, sizes and configurations. It is ideal as a structural beam and can be manufactured curved or straight. Curved glulam can take the form of a simple curved beam, a pitched and tapered curved beam, or a complex arch configuration.

The material can either have a 'homogeneous' layup, where all the laminations are of the same class of strength, or 'combined', where the outer laminations (one-sixth of the depth on both sides of the neutral axis of a beam) are of a higher strength class.

For those with a combined layup, the position of the lamination grades within the overall beam layup is determined by referencing the BS EN 14080. Besides using different layup combinations for the engineering properties of the material including bending strength and stiffness, some manufacturers may advise to use specific classes of laminations for certain parts of a structure to ensure practicality of supply.

GOOD STRENGTH-TO-WEIGHT RATIO
Glulam beams are able to carry loads similar to steel or concrete beams, while being lighter due to their high strength-to-weight ratio. The section size of the glulam beams generally tends to be bigger than those of steel and concrete.

Glulam elements are available in various sizes and shops (refer to the manufacturer's technical guidance). However, their sizes may be limited due to transportation restrictions or the supplier.

Common sizes can exceed (i.e. block glue) on a case-by-case basis depending on the structural requirements. However, the customisation of sizes may increase cost.

2.2.1. Glulam Applications

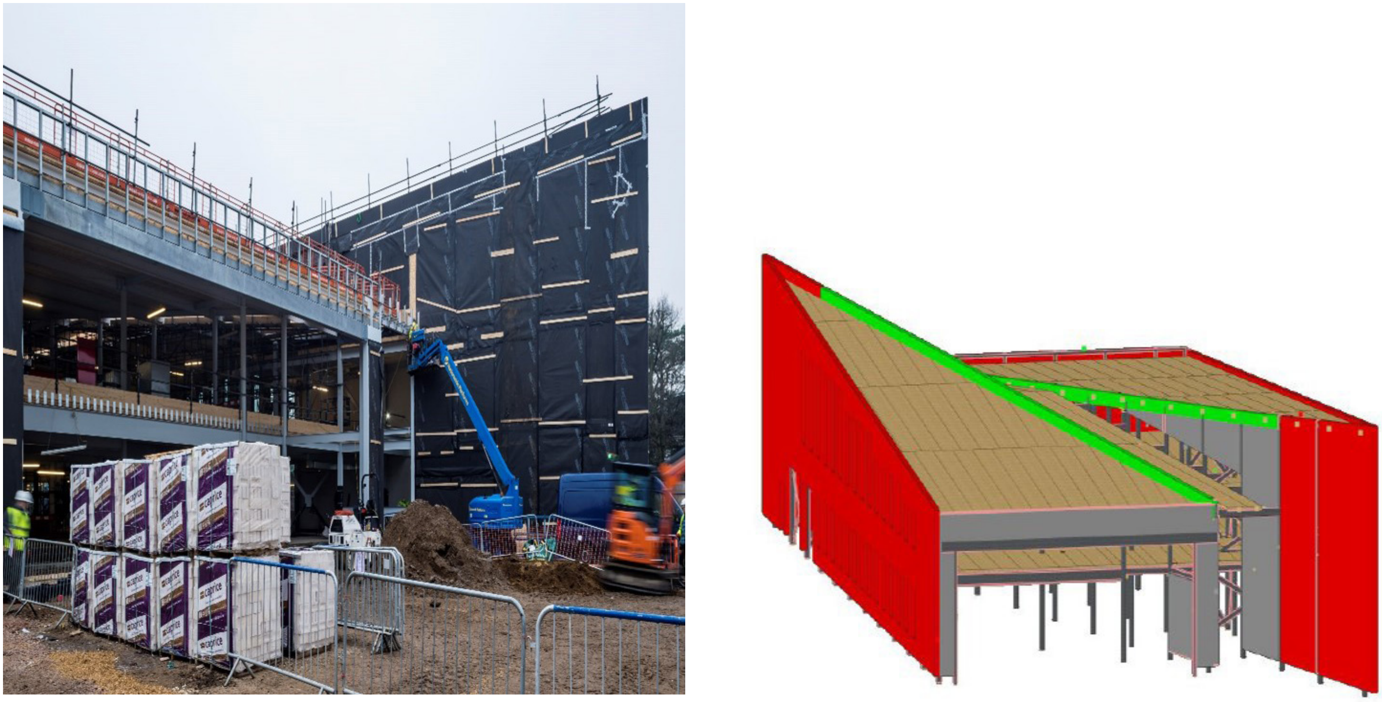
BEAMS & COLUMNS
Figure 9: *Example of glulam beams and column (Sky Believe in Better, UK)*

LONG SPAN BEAMS
Figure 10: *Example of a long span curve glulam beam (Pei Hwa Secondary School, Singapore)*

LONG SPAN BEAMS
Figure 11: *Example of arched glulam beams (Mactan Cebu Airport, Cebu)*

GRIDSHELL SYSTEMS

Figure 12: *Example of a gridshell system using glulam beams (Canary Wharf Crossrail station)*



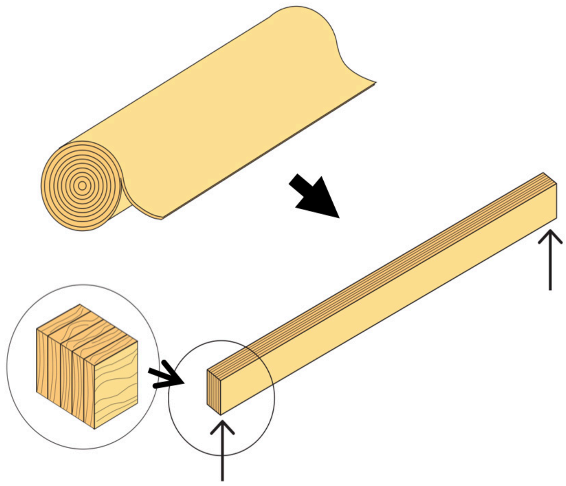
THRU-WALL SYSTEM

Figure 13: *Example of non load-bearing thru-wall solution using mass engineered timber framing (Farnborough University Technical College, UK) (Photo courtesy of B&K Structures)*

2.3. Laminated Veneer Lumber (LVL)

Laminated Veneer Lumber (LVL) is an engineered wood manufactured by laminating thin veneers similar to those in most plywood, using structural adhesives. During production, veneers measuring 3mm to 4 mm in thickness are peeled off good quality logs and vertically laminated with structural adhesives under heat and pressure. Veneers are generally orientated in a common grain direction for beams and studs, and cross-laminated for panels.

There are fewer LVL manufacturers compared to CLT and glulam.



Grades
- S grade – Beams
- T grade – Studs
- X grade – Panels (cross-laminated)

2.3.1. LVL Applications

LVL can be used for beams, lintels, purlins, truss chords, columns, floor decking, doors and window frames, formwork systems and flanges of I-joists.

Figure 14: *Example of LVL flooring deck (M&S Cheshire Oaks, UK) (Photo courtesy of B&K Structures)*

2.4. Building Process

1. Manufacturers source timber from sustainably managed forests to produce MET. (Refer to Section 2.5)

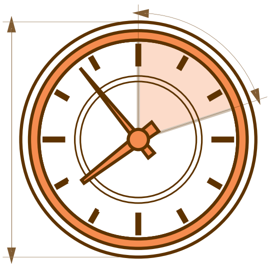
2. MET components are prefabricated in factories to precision to reduce wastage. (Refer to Section 6)

3. MET components are delivered flat-packed which reduces transportation costs. (Refer to Section 7.2)

4. MET components can be delivered directly to the site for just-in-time installation, or stored away temporarily. (Refer to Section 7.5)

5. Dry installation of MET components improves productivity. (Refer to Section 7)

2.5. Benefits of Mass Engineered Timber



INCREASES CONSTRUCTION PRODUCTIVITY

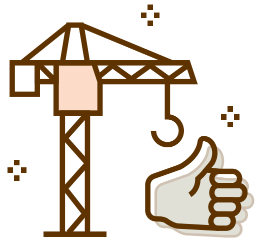
- ***Faster construction and fewer workers on site:*** MET construction can yield up to 35% time and manpower savings at the project level as prefabricated MET components are cut and processed to precise dimensions at the factory for easy and fast assembly on site.
  The construction programme can be optimised through maximum repetition and rectilinear forms.

- ***Easier to build:*** As MET has a higher strength-to-weight ratio compared to concrete, this significantly reduces the foundation loads and distribution requirements, making MET structures easier to build. There is also less need for additional finishing materials, installation of services is easier, and secondary framing or brackets are virtually eliminated with the use of MET.

ENHANCES HEALTH & SAFETY

- ***Feel-good factor:*** Timber enhances the comfort and aesthetics of working and living environments. It also offers superior noise control and acoustics.

- ***Better site safety:*** High-risk site activities are eliminated through offsite construction.



BETTER CONSTRUCTION ENVIRONMENT

- ***Less dust and noise:*** As most construction work is completed offsite, less dust and noise are generated at construction sites.

- ***Cleaner sites:*** Worksites are cleaner as virtually zero construction waste is produced through design for manufacturing and assembly.

IMPROVES QUALITY CONTROL

- ***Better quality control:*** As manufacturing is completed offsite, the construction tolerances are very accurate. High precision manufacturing results in high quality finishing with tolerances within millimetres.

- ***Quality finish:*** The surface grade finish of boards can also be specified for an exposed finish.

ENVIRONMENTALLY SUSTAINABLE & DURABLE

- ***Renewable material:*** MET is harvested from sustainably managed forests, as certified by the Programme for the Endorsement of Forest Certification (PEFC) or Forest Stewardship Council (FSC). This means that new trees are planted to replace harvested trees. By harvesting mature trees, it can prevent them from decaying and emitting carbon back into the atmosphere.
- ***Embodied carbon:*** MET buildings have a lower carbon footprint and net carbon emissions compared to steel or concrete buildings.

Differences between softwood and hardwood

Tree species are broadly divided into two main groups: softwood and hardwood.

Softwoods are the most commonly used timber materials because they are generally less expensive than hardwoods, are readily available, and are easy to work with.

Hardwoods can be further classified into tropical and temperate hardwoods depending on where they grow. For instance, tropical hardwoods are commonly found in Asia. Unlike softwoods, hardwoods are currently not used to manufacture MET as they have not been codified under the Eurocodes and European Technical Standard.

	SOFTWOOD	HARDWOOD
Colour	Lighter colour	Darker colour
Density	Lower density than most hardwoods	Higher density than most softwoods
Cost	Typically less expensive than hardwood	Typically more expensive than softwood
Durability	Weather resistant when treated	Natural weather resistance
Environment	More sustainable	Less sustainable
Strength	Weaker than hardwood	Stronger than softwood
Species	Whitewood spruce, larch etc.	Douglas fir, oak etc.

2.6. Types of Mass Engineered Timber Developments

INFRASTRUCTURE

AIRPORT

RAILWAY STATION

BUS TERMINAL

VEHICULAR BRIDGE

COMMERCIAL

OFFICE

HOTEL

EXHIBITION HALL

SHOPPING CENTRE

INSTITUTIONAL

SPORTS FACILITY

SCHOOL

UNIVERSITY

SPORTS HALL

RECREATIONAL

WINERY FACILITY

COMMUNITY FACILITY

PUBLIC PLAZA

MUSEUM

RESIDENTIAL

MID-RISE APARTMENT

HOUSE

STUDENT RESIDENCE

3. KEY CONSIDERATIONS WHEN USING MASS ENGINEERED TIMBER

3.1. Early Contractor Involvement of Contractors and MET Specialists

It is important to engage the MET specialists and main contractor early upfront during the design stage of the project. By incorporating the MET specialist's inputs into the design, a more effective technical solution can be achieved. This enables the specialist's experience in buildability and constructability to be harnessed and communicated to the main contractor.

In projects that involve an extensive adoption of MET, the Design and Build (D&B) and Design Development and Build (DDB) procurement models facilitate early involvement of MET specialists and the main contractor during the design stage.

Design and Build (D&B) model

D&B is a procurement method where the functions of design and construction are placed entirely with the main contractor. Based on the design brief provided by the client, the main contractor will engage his own consultants and MET specialists to fully design, develop, and construct the project.

Design Development and Build (DDB) model

The DDB model is similar to the D&B model, except that the client will engage his own consultants to develop the conceptual design first. Based on this design concept, the main contractor will work with his own consultants and the MEP specialists to develop the full design and construct the development, included designing and installing the prefabricated MEP systems.

In projects where only a small and partial scope involves the use of MET, the client can adopt the traditional Design Bid Build (DBB) approach, but consider specifying Design & Build (D&B) for the portion of works involving the use of MET components.

3.2. Durability

3.2.1. Moisture

The moisture content of timber varies with temperature and humidity. As timber is hygroscopic, it can tolerate high levels of humidity, and absorb and release water vapour without compromising its structural integrity.

Exposure of MET to water for short periods during construction is not a problem as long as it is surface wetting, which will dry out fairly quickly following installation. However, precautions should be taken to ensure internal surfaces remain dry as staining of the wood is possible.

As moisture content affects the properties of timber, precautions should also be taken based on the service class different environments are categorised under, as shown below. For more information, refer to BS EN 335-1 Durability of wood and wood-based products.

- ***Service Class 1:*** Within the internal environment of a normal conditioned structure where there is negligible risk of decay or insect attack.
- ***Service Class 2:*** Unheated internal environments or where there is a risk of occasional exposure to moisture.
- ***Service Class 3:*** Conditions with risk of wetting or leading to higher moisture content than Service Class 2

The typical moisture content of MET in an occupied building ranges from 12% to 14%.
Timber below 20% moisture content is considered to have a low risk of decay. If its moisture content exceeds 20%, there is a higher risk of fungal decay.

MET buildings can be protected from moisture with proper designs such as cladding and protective screening to keep the timber dry. Adequate protection should be provided to prevent moisture from entering the end grain.

In addition, to prevent moisture from building up, there should be good detailing of timber components to allow proper drainage and drying. Other measures include installing physical barriers such as façade cladding, providing proper ventilation, and conducting regular checks to address moisture concerns. These will reduce the risk of decay and termite infestation of MET.

3.2.2. Insect Attack

Singapore is known to have termites which are active throughout the year. As termites are most likely to attack decaying timber in buildings, it is important to ensure timber does not have long periods of contact with water by implementing sufficient protective measures.

The following steps should be taken to protect timber against termites:

- Elevating wood structure from damp ground (e.g. construct first storey of the building using concrete)

- Installing physical barriers (e.g. termite mesh barrier system to protect the foundation and other openings from termites)

- Applying chemical treatment (e.g. anti-termite chemical treatment to the timber and soil)

- Conducting regular inspection for the presence of termites and regular checks on the moisture content of MET

3.2.3. Ultraviolet (UV) Light

If MET elements are left exposed to sunlight, they can discolour. A surface coating or additional cladding layer can be applied on the MET elements to reduce the impact of exposure to UV light.

Figure 15: *Example of greying/silvering of CLT due to UV light exposure*

3.3. Finish Grade

The surface finishes of MET panels are supplied in domestic grade (visual), industrial grade (visual), or standard grade (non-visual) and the selected surface quality is stated in the performance specification.

DOMESTIC GRADE (VISUAL)

A good quality surface finish suitable for exposed panels. Few open joints and cracks might be visible.

INDUSTRIAL GRADE (VISUAL)

An intermediate finish that can be used internally as an exposed surface, although joints up to 4mm in width are to be expected.

STANDARD GRADE (NON-VISUAL)

A rough surface finish which may have some discolouration, and the outer layer may have knot holes and open joints. It is suitable for lined or concealed locations and is typically covered up with cladding at later stages of construction.

Figure 16: *From left to right - Domestic grade, industrial grade and standard grade finishes (Photo courtesy of Stora Enso)*

For more details, refer to BS EN 13017-1 Solid wood panels – Classification by surface appearance.

4. DESIGN CONSIDERATIONS

In order to ensure the smooth delivery of a MET project, it is important for the project team to design the building in MET from the start of the project. Unlike conventional construction, buildings adopting DfMA technologies such as MET have to commence design as early as possible with inputs from all project parties, as the majority of construction work is prefabricated offsite.

Especially for MET, which is different from reinforced concrete or structural steel, the consultants have to be familiar with the material and understand its design considerations and limitations.

It is also critical for the consultants and builder to consult the relevant regulatory authorities such as the BCA and SCDF early if they have any questions or clarifications on the codes, standards and requirements relevant to MET.

The main codes governing the design and specification of MET are listed below and not limited to the following:

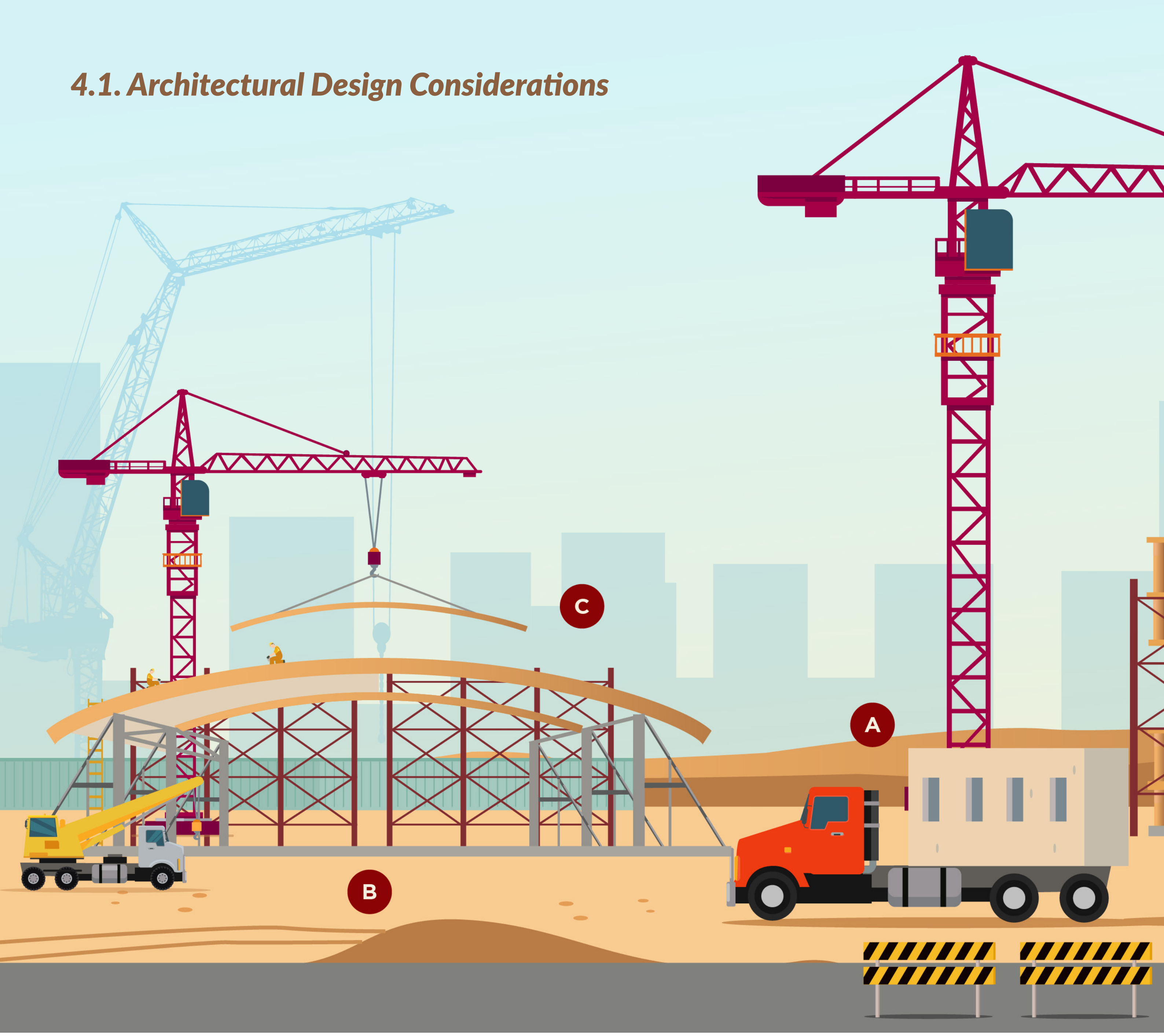
- BS EN 1995-1-1 EC 5: General – Common rules and rules for building including UK's National Annexes.
- BS EN 1995-1-2 EC 5: General – Structural fire design
- BS EN 599-1 - Durability of wood and wood-based products.
- BS EN 14080 - Timber Structures: Glued laminated timber and glued solid timber. Requirements
- BS PD 6693 - NCCI For EC 5 NA (UK)
- BS EN 16351 – Timber structures. Cross laminated timber. Requirements
- BS EN 408:2010+A1:2012 –Timber Structures. Structural timber and glued laminated timber. Determination of some physical and mechanical properties
- BS 8417:2011+A1:2014 – Preservation of wood. Code of practice

CHECKLIST

To ensure the design is effective and efficient, the following technical considerations must be addressed:

- ☑ ***Design responsibility:*** Engineers should design MET with an understanding of the MET supply chain and each company's standard sizes and design codes. Refer to Section 4.2 for more information.
- ☑ ***Grids and spans:*** The span of CLT panels should be limited to 6m, where possible. Greater spans will require thicker panels and secondary beams. Glulam can have longer spans but will require deeper sections.
  Refer to EC5, your MET specialist or manufacturer's technical guidance for more information.
- ☑ ***Building services:*** Early and detailed design co-ordination is required before fabricating the MET panels. This should include all planned openings.
- ☑ ***Acoustics:*** Specialist advice should be sought at the early design stage. Refer to Section 4.1.1 for more details.
- ☑ ***Floor vibration:*** Design limits must be determined for the building's intended use.
- ☑ ***Thermal mass:*** MET has a significant thermal mass but less than exposed concrete soffits.
- ☑ ***Exposed finishes:*** Attention to detail is required for the finishes and an early decision made on the visual surface grade. An allowance should also be set aside for any cost upgrade. Possible issues to address include staining due to rain and UV light, and drying shrinkage cracks which can be prevented through the gradual commissioning of the building heating system.
- ☑ ***Moisture:*** MET needs to breathe and specific types of insulation and vapour barrier must be used to prevent moisture condensation against the MET surface. Refer to Section 3.2.1 for more details.
- ☑ ***Fire:*** MET construction requires a fire engineered approach in accordance with SCDF's requirements. Refer to Section 5.
- ☑ ***Cost-effectiveness:*** Cost comparison should not be limited to the cost of the structure. Due consideration should be given to the programme, foundations, treatment of facades, secondary structures etc.
  for cost-effectiveness.

4.1. Architectural Design Considerations

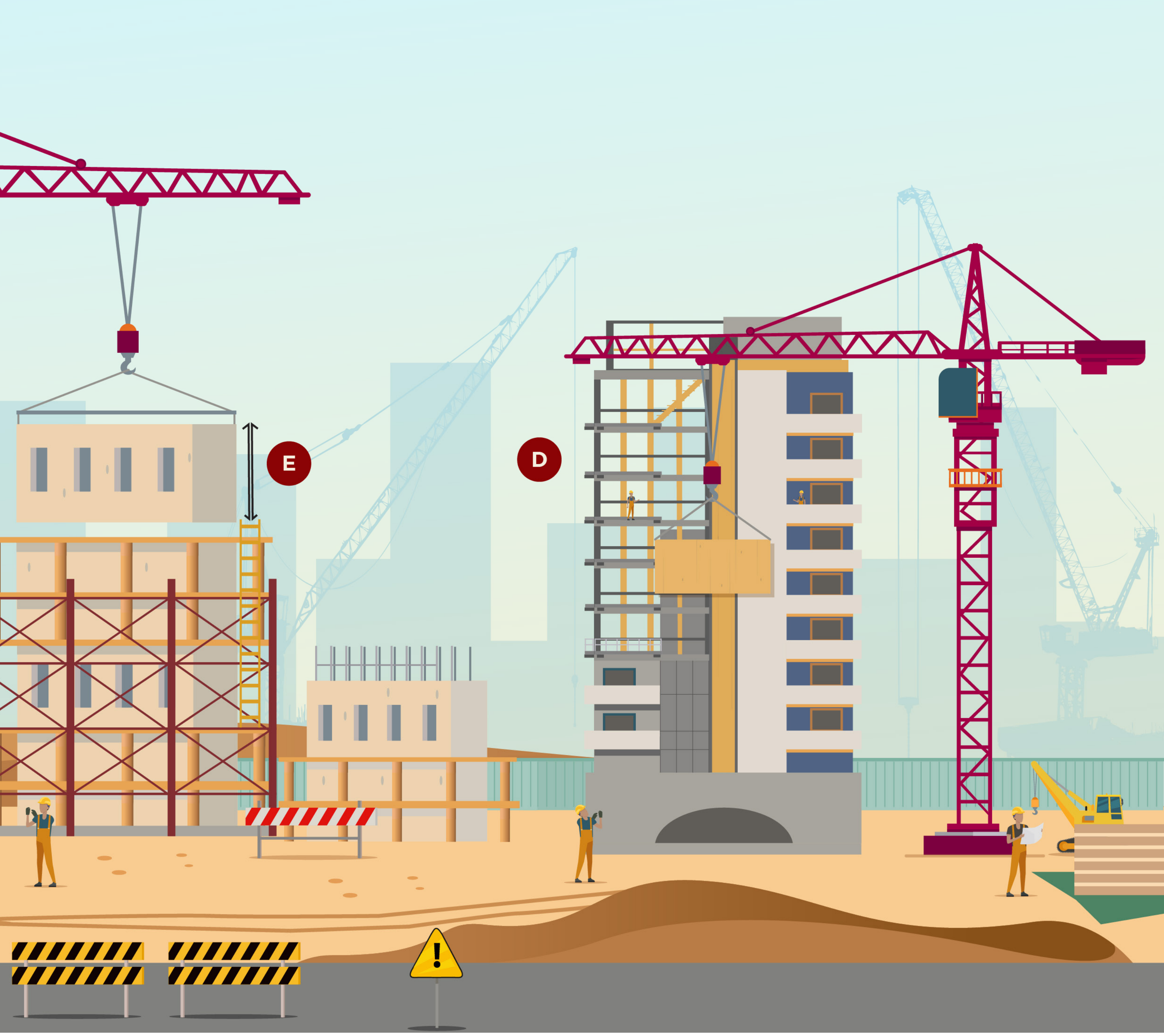


SITE CONDITIONS
The conditions of the site can affect the building form and construction method of the project. As timber is relatively lightweight, consultants have more freedom in their structural design approach.

Adopting DfMA for MET can also address typical construction challenges such as limited site access and other logistics issues through the systematic design, fabrication and installation of MET elements.

BUILDING TYPES
MET is applicable to all building types and has many advantages including greater architectural design flexibility, economical and sustainability benefits, while enhancing users' well-being.

NEW ARCHITECTURAL LANGUAGE
MET buildings follow a certain regime in the design and appearance of the building, creating a new architectural revolution.



D **BUILDING MATERIALS AND SYSTEMS**

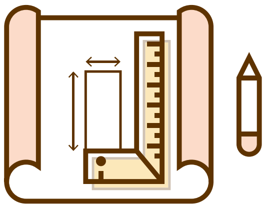
It is essential to learn the different types of MET components and their respective properties applicable to architectural elements. These MET products include Cross-Laminated Timber (CLT) and Laminated Veneer Lumber (LVL) for wall, floor and roof construction, as well as glued laminated timber (glulam) for beams and columns. MET buildings can also be designed with other types of building elements in hybrid and composite construction. For example, prefabricated walls and roofs are composed of layers of timber elements, non-combustible sheathing, weather and thermal insulation, and exterior laminates. Floor systems, on the other hand, can comprise composite timber and concrete panels.

E **FLOOR-TO-FLOOR HEIGHT**

Due to the relatively deep beam of the MET structural system, floor-to-floor height requirements must be ascertained upfront.

Modular MET components increase the speed of construction and make multi-dwelling and office projects economical to construct. Open plan industrial and recreational buildings can be achieved as long span structures can be built using MET. The natural attributes of wood also improve building occupants' health, well-being and productivity, and are suited for healthcare and educational institutions.

4.1.1. Design Principles and Upstream Considerations

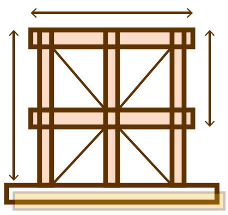


DESIGN PROCESS

Implementing a well-considered structural design requires understanding and co-ordinating several architectural design aspects, such as fire safety, acoustics, building envelope and constructability.

WEATHER PROTECTION

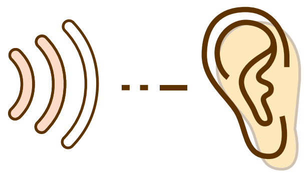
It is recommended not to directly expose MET structural systems to the weather. Sufficient overhang and floor detailing to prevent decay and exposure to rain should be considered. Further protection using various industrial timber protection coating can also be considered.



STRUCTURAL DESIGN SYSTEM

Adopting MET construction requires designing modular structural grids to accommodate the structure's effective strength, efficiency and cost-effectiveness. For example, CLT has a good spanning capability which reduces the number of structural beams.

Likewise, attention to the ratio between the span and beam depth should be considered for the structural design. A typical MET construction would require glulam beams which are comparatively deeper than reinforced concrete or steel beams. This affects the floor-to-floor height which in turn influences the overall form and geometry of a building. Hybrid MET systems with steel framing systems or composite concrete slabs can be adopted to reduce the beam depth and optimise the floor-to-floor height for projects where there is a height constraint.



ACOUSTICS

Properly designed and detailed acoustics are essential for MET construction. Typically, sound can be transmitted directly through wall and floor/ceiling assemblies. Materials with higher mass generally have better control of sound transmission and therefore have better acoustic properties. Therefore, solid timber panels have better acoustics than composite panel frame construction. To improve acoustics, designers and consultants can explore adding concrete panels on MET floors or noise barrier membranes for wall panels.

4.1.2. Involvement of Stakeholders

The design of MET developments should be carefully planned in advance with all project stakeholders establishing the design brief and requirements. There should be open communication between the client and the consultants to firm up the program spaces and facility requirements throughout the design to construction stage as it is difficult and costly to make changes once the manufacturing of MET components is underway.

4.1.3. Early Co-ordination

Early co-ordination among developers, architects, structural engineers, mechanical, electrical and plumbing (MEP) engineers, contractors and MET specialists is essential. This will allow the team to look into the key design aspects upfront including the design system, material, floor-to-ceiling height etc. Building Information Modelling (BIM) and Virtual Design and Construction (VDC) can help facilitate co-ordination between M&E and C&S consultants in determining the exact location of penetrations for MEP systems.

4.1.4. Maximise Repetition and Standardisation

To achieve cost efficiency, consultants should explore repetitive and simple construction systems and consider the manufacturing, assembly, logistics and installation sequence.

4.1.5. Application of BIM and VDC

BIM and VDC can be adopted to enhance collaboration among various stakeholders of the project. The VDC process helps integrate design, prefabrication and construction, to identify upstream design clashes and simulate downstream construction workflow. The project team can plan and build together in a virtual environment first, before the actual construction on site.

The use of BIM technology is integral to the VDC process, to surface problems and clashes before actual construction begins. BIM also supports the integrated DfMA approach where the digital model is used to drive production planning and automation.

This results not only in time and cost savings through better co-ordination and elimination of abortive works, but also improves safety off and on site.

To understand more on the principles of BIM and VDC, refer to Singapore VDC Guide here and the BIM for DfMA Essential Guide here.

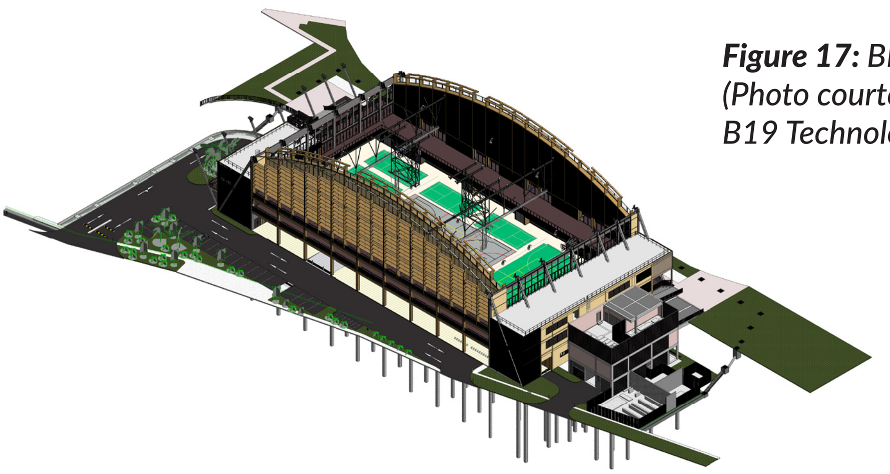


Figure 17: *BIM model of The Wave at NTU (Photo courtesy of NTU Singapore and B19 Technologies Pte Ltd)*

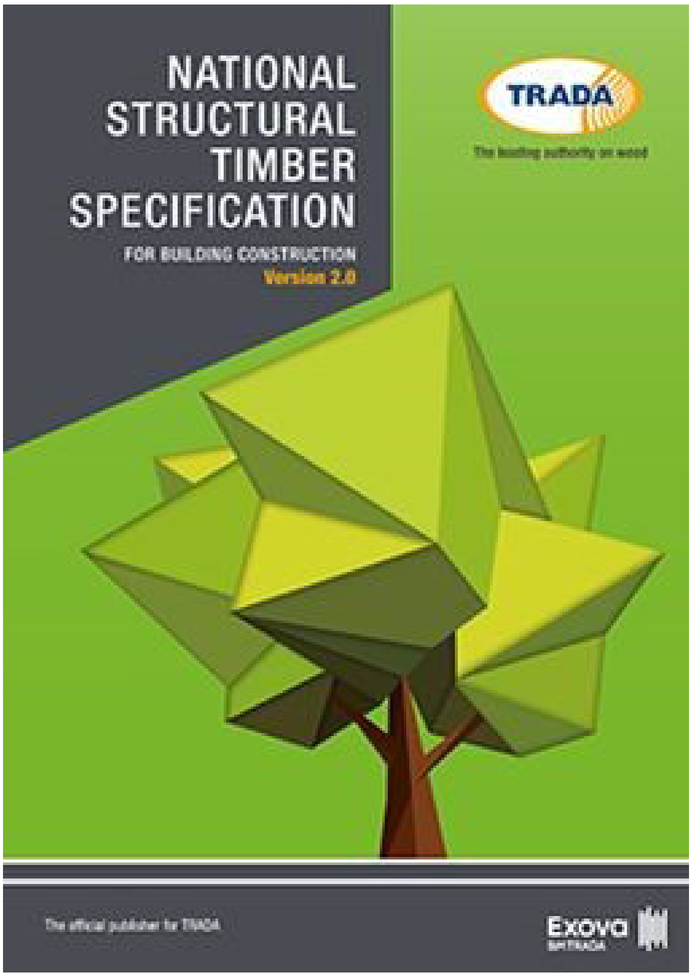


Figure 18: *National Structural Timber Specification by TRADA*

4.1.6. Consideration of Construction Tolerance

The complete 'execution specification' of a structure comprises various contractual documents including drawings. A general specification with technical requirements for the supply of materials, products, workmanship and project-specific requirements for the individual structure should be provided. The specification should clearly state what materials and products should be used and how the fabrication and installation works should be carried out. This ensures that the completed structure meets the designer's assumptions and the client's requirements.

The UK National Structural Timber Specification produced by TRADA provides comprehensive information on the timber material including protection, quality assurance, tolerances, fabrication and installation of timber buildings. Best practices and industry guidelines on timber buildings are also included in the specification.

4.2. Structural Design Considerations

4.2.1. Eurocodes Design Standard

In Singapore, timber buildings should be designed to BS EN 1995 (EC5). Currently, in absence of the Singapore National Annex to EC5, the UK National Annex on timber design to EC5 is adopted for designing timber structures.

EC5 provides guidelines on the design of buildings and other civil engineering works that use timber in its various forms such as solid timber, sawn timber, glued laminated timber or wood-based panels jointed together with adhesives or mechanical fasteners.

The EC5 is intended to be used in conjunction with EN 1990, EN 1991 and EN 1998 which set out the basis of structural design, including the actions and loads on structures and seismic design. The code encourages engineers to gain a greater understanding of timber which will help produce more efficient and innovative designs for engineered timber structures.

Although CLT is not codified to EC5, most suppliers and manufacturers of CLT provide design software to help specify what panel is adequate to resist the applied loads.

For timber design in accordance with EC5, a key consideration is given to the load duration class and exposure condition (service class). Both factors are used to estimate the value of the modification factor, k_{mod}, which influences strength and deformation. The characteristic design resistance of an engineered timber element is directly proportional to the modification factor.

Details can be found in sections 2.3.1.2 and 2.4.1 of the BS EN 1995-1-1:2004.

- ***Load Duration Class*** **–** It refers to the effect of a particular load acting for a certain period of time in the life of a structure. The appropriate class is determined based on the type of load and its variation with time. For example, wind loads are classified as short-term loads that are expected to last less than a week. More details can be found in tables 2.1 and 2.2 of BS EN 1995-1-1:2004.

- ***Service Class*** **–** EC5 characterises the service class into three types based on moisture content, temperature and the relative humidity of surrounding air. For details, refer to section 2.3.1.3 of the BS EN 1995-1-1:2004. Given the humid nature of Singapore, CLT and interior glulam members are typically classified as Service Class 2 whereas exposed glulam members are considered as Service Class 3. Do note that CLT is produced only in Service Classes 1 and 2.

- ***Deflection*** **–** For long span members, deflection and vibration are often the controlling design factor. EC5 considers the effect of creep and provides formulas in section 2.2.3 for instantaneous and long-term deflection calculation. It is worthwhile to note that the service class greatly influences the final deflection values.

Consultants are advised to consult BCA during the preliminary design of timber structures for guidance on the suitability of the proposed design.

4.2.2. Structural Modelling

The 3D modelling of building structures should be carried out using suitable computer analysis software where the stability and robustness of the building is taken into consideration according to the EN 1991.

It is important to ensure that the geometry of the model is compatible with the expected levels of workmanship and tolerances. Expected deviations and deformations during erection and loading must be considered during design and modelling. The joint type (pin or moment) and the number of joints should be considered in the model to correctly reflect the actual behaviour of the building.

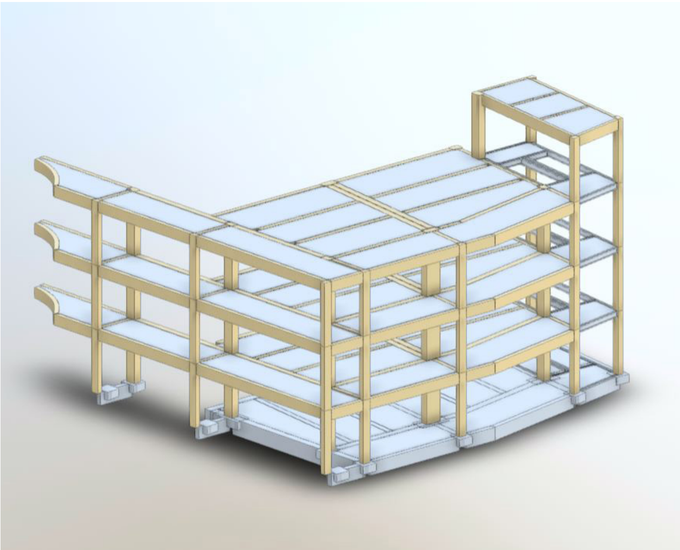


Figure 19: *Structural modelling of a 4-storey MET building*

4.2.3. Structural Applications

LOAD-BEARING CLT

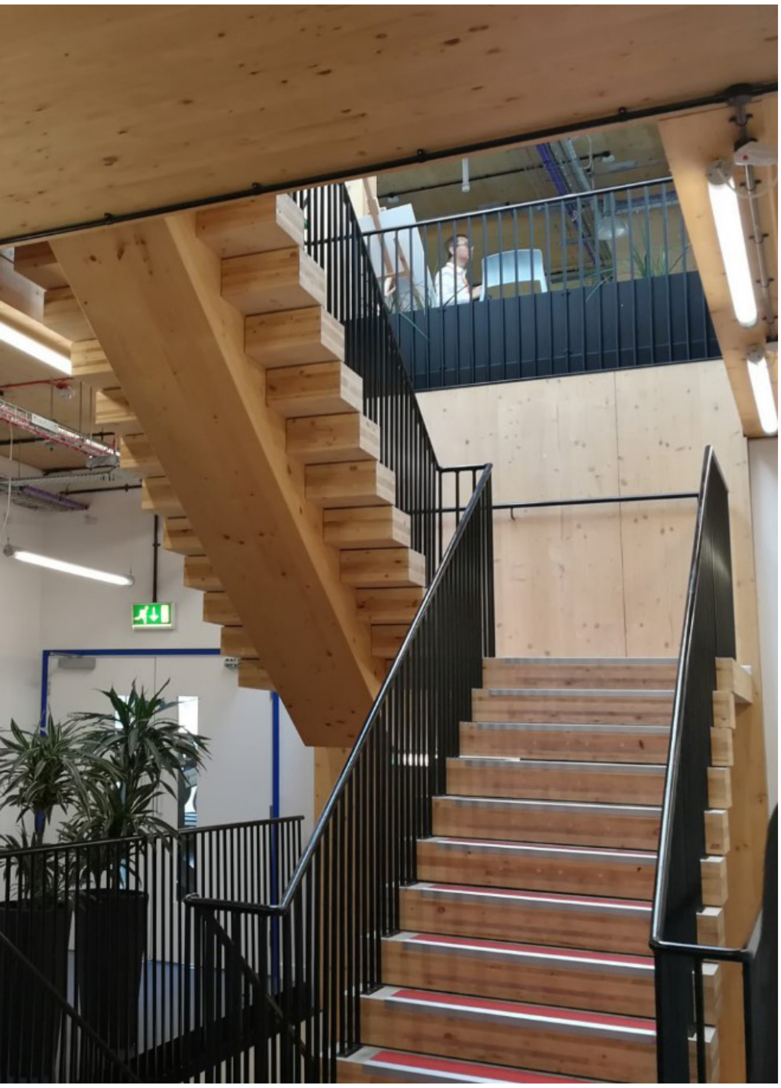
- Load-bearing CLT walls that also provide shear resistance
- One-way spanning CLT floors
- One-way spanning CLT roofs

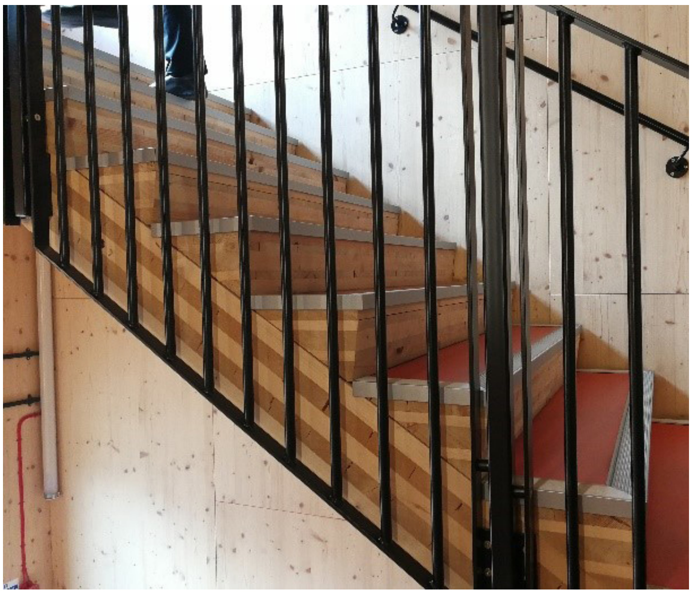
Figure 20:
CLT used for walls, floors and roofs (Dalston Lane, UK) (Photo courtesy of Engenuiti)

GLULAM FRAMES & CLT PANELS

- Glulam beams and columns
- Shear walls, bracing or core (timber, steel or concrete)
- One-way spanning CLT floors
- One-way spanning CLT roofs

***Figure 21:** Glulam beam and column frames (JTC Launchpad @ One-North, Blk 81, Singapore) (Photo courtesy of JTC)*





STAIRCASE

- CLT panels (above)

***Figure 22:** Staircase with CLT (Sky Health & Fitness, UK)*

- Glulam stringer beam and CLT panels (left)

***Figure 23:** Staircase with glulam stringers and CLT panels (Sky Health & Fitness, UK)*

Figure 24: *Hybrid structure using glulam beams and concrete slab (Eunoia Junior College, Singapore)*

HYBRID SYSTEM

- MET with concrete
- Glulam beams and columns, CLT floors with reinforced concrete shear walls
- Reinforced concrete walls primarily used for lateral force resisting system
- Concrete columns and beams with glulam beams and CLT floors

Figure 25: *Hybrid structure using steel beams and columns, and CLT floors (Curtain Place, UK)*

HYBRID SYSTEM

- MET with steel
- Predominately steel frame, with CLT walls, floors and roof panels
- CLT panels with steel beams or columns to accommodate large spans

4.2.4. Joints and Connections

The joints of connecting members are the weakest links of a structure. Therefore, connections rather than the actions in the members usually govern the cross-section of a timber member.

Apart from resisting the applied loads, the connection design must also consider durability and fire resistance requirements. The cost efficiency, fabrication, aesthetic requirements and erection methodology should also be considered. As there are many considerations, there would be more than one set of connections that work best, and it varies depending on the project.

Traditionally, there are two groups of mechanical fasteners used for timber connections. The first group called dowel type fasteners is more common, and include nails, short screws, staples, bolts and dowels. For these fasteners, load transfer causes bending of the dowel, and bearing and shear in the timber along the shank of the dowel. The other type of fasteners are split-rings, shear-plates, punched metal plates where the load is transferred to the bearing at the surface of the members.

Modern MET structures primarily use:

- Large dowel type connections with steel plates for glulam beams and columns;
- Screws and nailed steel brackets for CLT connections;
- Steel plates and connectors at the interface of reinforced concrete and MET elements.

To design a connection, it is important to understand the failure modes. There are ten types of failure modes for timber-to-timber connections which are described in section 8.2.2 of EC5. The description of eleven timber-to-steel failure modes is mentioned in section 8.2.3 of EC5.

To avoid splitting along the grain where the connector resists the action, the minimum edge and end distances for a single fastener, measured between the centre of the fastener and the outer profile of the timber should follow the respective requirements for different types of fasteners according to Section 8 of EC 5.

4.2.4.1. Type of Connections

PIN CONNECTION
Pin connections allow one element to rotate freely in relation to the other. The connections are intended to transfer shear and axial, not bending moment.

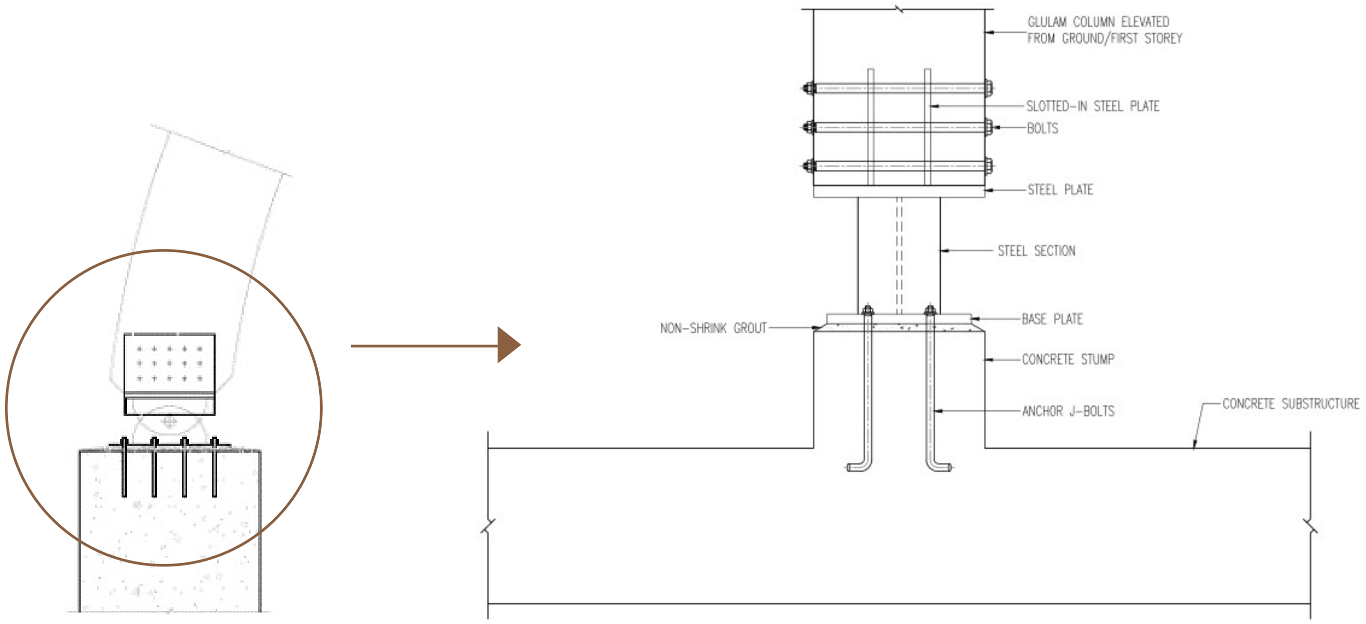


***Figure 26:** Pin connection between MET and the base support member*

MOMENT CONNECTION
Moment-resisting connections restrain one element from rotating freely in relation to another. The measure of resistance to rotate lies in the bending capacity of the joint.

***Figure 27:** Splice connection (moment) with top, bottom and side plates*

HORIZONTAL AND VERTICAL ELEMENT CONNECTION

The connection can either be exposed or concealed depending on architectural, aesthetic and fire resistance requirements. The following are examples of such connection.

Wall-to-slab connection

Figure 28: *Non load-bearing CLT wall-to-slab/column connection (NTU The Wave, Singapore)*

Beam-to-column connection

Figure 29: *Steel column to glulam beam connection (G3 Shopping Center, Austria)*

Figure 30: *Glulam beam-to-column connection (Sky Believe in Better, UK)*

Slab-to-slab connection

Figure 31: *Typical CLT slab panel joint*

Beam-to-beam connection

Figure 32: *Glulam beam-to-beam connection (GSK Carbon Neutral Laboratories, UK)*

Figure 33: *Concealed glulam beam-to-beam connection*

Figure 34: *Glulam bracing to glulam tie beam connection (Ahmad Ibrahim Secondary School, Singapore)*

4.2.5. Structural Robustness

MET structures should be designed to sustain localised failure with the structural system as a whole remaining stable. The overall stability of the structure is typically achieved by adopting braced frames, shear walls or reinforced concrete core walls as a lateral force resisting system. The design should also have sufficient continuity and redundancy so that the loads can be transferred from the locally damaged region to adjacent regions capable of resisting loads without any loss in stability.

Another important consideration for the structural integrity of the timber structure is exposure to fire. This topic will be covered in depth in Section 5 of this guidebook.

4.3. Mechanical, Electrical and Plumbing Services Design Considerations

Building projects adopting MET will need to comply with prevailing regulatory requirements and the Code of Practice for mechanical, electrical and plumbing (MEP) services. The adoption of MET should not affect the design and installation of electrical, water, sewerage, sanitary and other common building services. Consultants and builders should check with the regulatory agencies on the latest requirements for such services prior to the design stage.

The project team and the builder will co-ordinate with all project disciplines on the locations of building services and requirement for notches and holes in the structure. Before commencing fabrication, all stakeholders should agree on the locations of the notches and holes. It is important to ensure proper co-ordination to avoid cutting openings on site as any newly cut surfaces must have surface protections for termites, UV light etc. Similar to conventional construction materials, the structural integrity and fire requirements of the design should be properly checked before cutting the MET components.


Figure 35: *Example of MEP services suspended from MET ceilings - GSK Carbon Neutral Laboratories, Nottingham (Left) and Curtain Place, London (Right)*

4.3.1. Installation and Maintenance

If any MEP services are designed to be concealed within the MET components, proper design and provisions should be incorporated to facilitate future repair and maintenance.

Figure 36: *BSH beam with CNC glueing (Photo courtesy of BinderHolz)*

4.4. Design for Maintainability

Maintainability is the ease in which maintenance can be carried out. In order to reduce upkeep costs and manpower needs, the maintenance of the building should be considered when designing the project.

Designing timber structures for maintainability is similar to other structures such as steel or concrete. Specific measures can be taken during the planning and design stages to minimise building defects, and man-hours and materials needed to maintain the building throughout its lifecycle.

The four principles when designing for maintainability are:
(a) Forecast maintenance
(b) Access for maintenance
(c) Minimise maintenance interventions
(d) Enable simple maintenance

More information can be found in BCA's design guide for maintainability checklist here.

5. COMPLIANCE WITH FIRE SAFETY REQUIREMENTS

Part 1-2 of EN 1995 describes the principles, requirements and rules for the structural design of buildings exposed to fire. Essentially, the design must ensure that in the event of an outbreak of fire:

- The structural stability, integrity and insulation is not compromised for a specified period of time.
- Spread of fire and smoke is limited within the building and neighbouring structures.
- Structural fire design must ensure the safety of building occupants as well as that of emergency responders.

5.1. Local Fire Safety Requirements for MET Construction

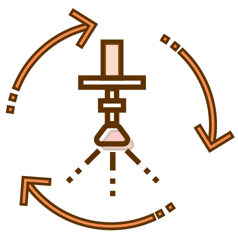
Like concrete and steel buildings, MET buildings must comply with local fire safety requirements in the Fire Code and relevant SCDF circulars. As every MET project is unique, the project team is strongly encouraged to consult SCDF during the preliminary design stage.

Clause 3.15.2 of the Fire Code requires all structural elements to be constructed using non-combustible materials. As MET is a combustible material, additional fire safety requirements have been imposed to manage the fire risks associated with using MET for building construction. Any building constructed using MET must comply with the Fire Code, as well as the additional fire safety requirements stipulated in Annex A of the SCDF circular dated 10 August 2016 for MET construction.

Salient extracts from Annex A are listed below. For detailed requirements, refer to the Fire Code and the SCDF circular dated 10 August 2016.

HEIGHT LIMIT

- The habitable height of any healthcare occupancy in an engineered timber building shall not exceed 12m, including mezzanine levels.
- A fire safety performance-based approach shall be adopted in the design of any engineered timber building where its habitable height exceeds 12m.
- For details on the performance-based fire safety regulatory framework and requirements, refer to SCDF's website "Performance-Based Approach to Fire Safety Design". A performance-based fire safety design must include engineering analysis that demonstrates the ability to meet the root and sub-objectives of the performance-based Fire Code.

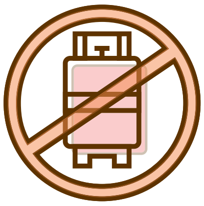


SPRINKLER SYSTEM

Engineered timber buildings shall be fully protected by an automatic sprinkler system and this requirement can only be relaxed under certain conditions as indicated in the SCDF circular.

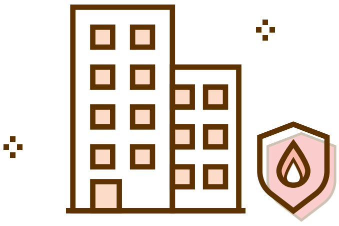
ESCAPE PROVISIONS SUCH AS STAIRCASE AND LIFT SHAFTS

Essential escape provisions such as staircases and lift shafts need to be constructed using non-combustible materials, and this requirement can only be relaxed under certain conditions as indicated in the SCDF circular. There is an exception - MET can be used as elements of structure for escape provisions if protected by a fire-rated board; the habitable height of the building is less than 12m; and the building has no healthcare occupancy.



GAS CYLINDERS

The use of flammable gas cylinders for cooking is not permitted in the engineered timber building premises if the engineered timber building has access to piped-gas supply for cooking.



FIRE PROTECTION FOR EXTERNAL FACADE

If the external facade (external wall constructed using MET) of the engineered timber building is unable to prevent external fire spread (Clause 3.5 of Fire Code), the external facade shall be required to be protected by a deluge system in accordance to CP 52, or any other suppression system that is shown to be effective in preventing vertical fire spread.

PRODUCT LISTING SCHEME (PLS)

- MET building structures need to comply with the requirements of the Product Listing Scheme (PLS) for regulated fire safety products - for structural elements to meet the required fire resistance requirements, as well as the required surface flame spread classification.
- Qualified Persons (QPs) may refer to SCDF's website "Building Materials" for more information on how to comply with the PLS requirements. This is also discussed in more detail in Section 5.2 on the next page.

For further reading, refer to the SCDF Fire Code and its associated circulars.

5.2. Behaviour of MET when Exposed to Fire

When MET is exposed to fire at elevated temperatures between 200°C and 300°C, a process called pyrolysis occurs where gas emissions from combustible components burst into flames. This gradually spreads across timber leaving behind a charred layer. The charred layer then acts as an insulating layer, preventing the inner core from further heating.

Unlike steel, timber can naturally protect itself, enabling MET structures to have excellent fire resistance. The charring rate when MET structures are exposed to fire is also predictable. Hence, building elements can be easily designed for fire safety. For example, the charring rate of glulam is approximately 0.7mm/min when exposed to a standard fire (refer to SS EN 1995 1-2 for details). For the charring rate for CLT, refer to the manufacturer's ETA.

SS EN 1995-1-2 states that for standard fire exposure, elements need to comply with criterion R (mechanical resistance for load bearing), criterion E (integrity) and when requested, criterion I (insulation).

5.3. Typical Measures for Fire Protection

When timber is exposed to standard fire, the outer layer burns and turns to char at a predictable charring rate. Timber sections shall be designed to allow for additional "sacrificial" timber so that the layer exposed to fire can protect the inner core from fire damage.

Other forms of fire protection measures include provisions of automatic fire sprinklers and the use of fire-grade plasterboard to encapsulate and protect the timber elements from direct fire exposure.

6. FACTORY PRODUCTION

6.1. Eurocodes Product Standards

BS EN 14080: Timber structures - Glued laminated timber and glued solid timber – Requirements

This European Standard sets the performance requirements of the glued laminated products including glued laminated timber (glulam), glued solid timber, glulam with large finger joints, block-glued glulam for use in buildings and bridges. It also lays down minimum production requirements, provisions for evaluation and attestation of conformity and marking of glued laminated products.

Examples of key requirements include:

a) Mechanical resistance of glued laminated timber (e.g. modulus of elasticity and bending, compressive, tensile and shear strength);
b) Bonding strength and durability of bonding strength of glued laminated products;
c) Durability of other characteristics against biological attack; and
d) Resistance and reaction to fire.

BS EN 16351: Timber structures - Cross-laminated timber - Requirements

This European Standard sets out provisions regarding the performance characteristics for straight and curved structural cross-laminated timber (X-Lam) both without and with large finger joints as a material for the manufacture of structural elements to be used in buildings and bridges. It also sets out minimum production requirements and procedures for assessment and verification of constancy of performance.

Examples of key requirements include:

a) Timber to be used in laminations;
b) Adhesives for the production of cross-laminated timber;
c) Strength and stiffness properties of cross-laminated timber; and
d) Resistance and reaction to fire.

6.2. Product Listing Scheme

MET used in Singapore is subjected to the requirements listed under the Product Listing Scheme (PLS) and must meet the requirements of the Fire Code. Under this scheme, products that meet the safety and performance standards in accordance with national and international standards are listed and will receive a Certificate of Conformity (COC).

If the product is not listed, independent product certification bodies can be engaged to carry out the required tests and inspections to certify the product. There are three classifications of listing in the PLS. MET may come under two or more of the classes, depending on their applications. QPs should refer to the list of regulated fire safety products and listing requirements on the SCDF website, as well as check with any of the certification bodies to find out which PLS classes apply to their products.

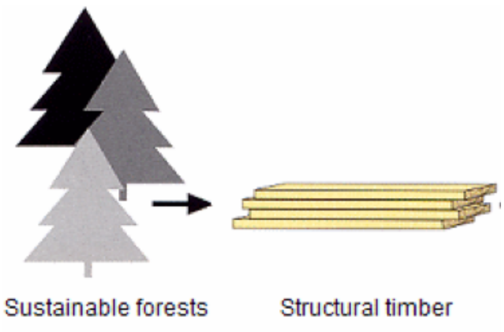
Currently, the accredited certification bodies accepted by SCDF for certifying regulated fire safety products and materials under the PLS are:

a) TUV SUD PSB Pte Ltd
b) Setsco Services Pte Ltd
c) Singapore Test Services

The project team should consider engaging the certification body and registered inspector early, to conduct factory inspection at the overseas manufacturing factory for certification of the products, materials or systems.

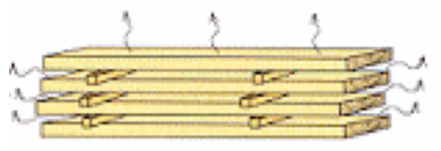
6.3. Production Process

The production process of MET is elaborated below.



1. SPECIES SELECTION

First, certain species of timber are selected to produce the MET. The main species currently used for MET is spruce, although Scots pine, larch and Douglas fir are also available. Other species can be used for the outer layer to provide a high quality finish for exposed panels.

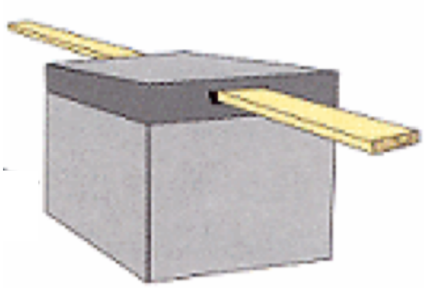


2. DRYING

Planed boards of between 10mm and 40 mm thickness (may vary with different manufacturers) are kiln-dried and conditioned to a moisture content of 12% +/- 2%. Proper moisture content of timber enables proper adhesion and prevents dimensional variations and surface cracking.

3. STRENGTH GRADING

Boards are graded in the range of C16 to C32, depending on the supplier, and in accordance with the BS EN 14080.

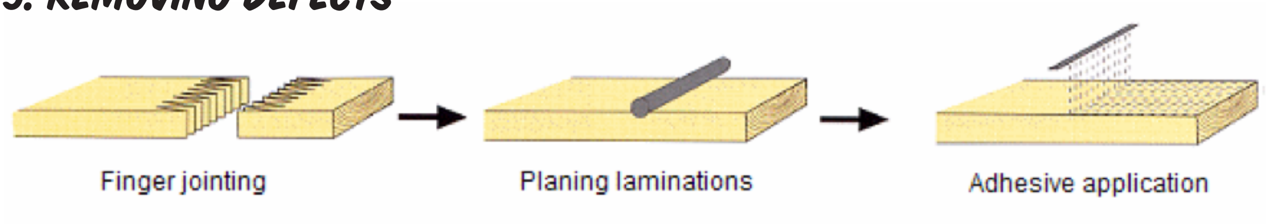


4. VISUAL GRADING

They are also classified by surface appearance. For more details refer to Section 3.3 of this guidebook. Surface quality is defined by BS-EN 13017-1 Solid wood panels.

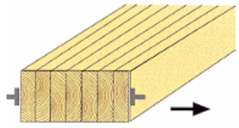
Figure 37: *Grading of MET (Photo courtesy of Rubner Holzbau)*

5. REMOVING DEFECTS



Depending on the strength and final visual quality to be achieved, defects such as large knots and resin or bark pockets are cut out.

6. GLULAM ASSEMBLY



Glulam components are made up of lamellas (layers) of uniform thickness of either 40mm or 45mm softwood, up to 2m deep. Lamellas are assembled by bonding along the edges of each lamella up to the desired depth. Surface-bonding adhesives are usually applied mechanically.

Similarly, individual boards can be joined to make an endless lamella using finger joints to combine the boards. As such, the length of a glulam component is not limited by the length of grown timber. In Singapore, the practical length of glulam components is up to 12m for easier transportation to site. Nonetheless, larger dimensions are possible as break bulk items can be shipped to Singapore.

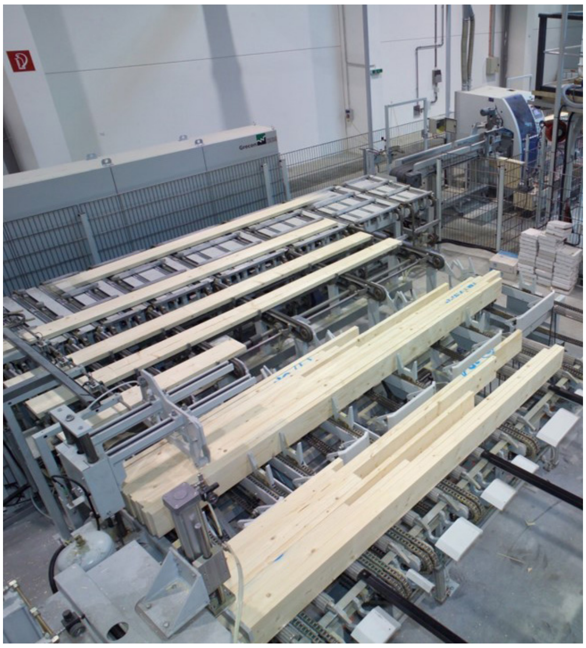


Figure 38: *Finger jointing process (Photo courtesy of Rubner Holzbau)*

Figure 39: *Glueing the lamellas (Photo courtesy of Rubner Holzbau)*

7. CLT & LVL ASSEMBLY

CLT and LVL panel sizes vary by manufacturer and application. CLT panels can be manufactured by combining three, five, seven or more layers, typically up to 300mm in thickness (larger dimensions are possible). The typical width of the panels is between 1.25m and 3m, with its length up to 24m long. Similar to glulam components, the practical length of CLT panels in Singapore is up to 12m for easier transportation to site.

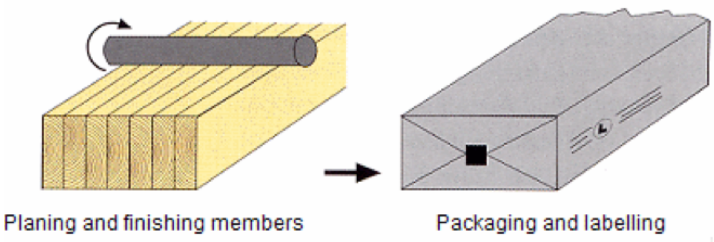
For CLT, the outer layers of the panels are usually orientated to run parallel to the span direction. For walls that are normally oriented, the outer layers of the CLT panels have their grains parallel to vertical loads to maximise resistance. Likewise, for floor and roof CLT panels, the exterior layers run parallel with the span direction.

The lamella strips are spread with adhesives and then joined perpendicularly to the lamellas of the adjacent layer using either vacuum or hydraulic press techniques. The completed CLT panel is trimmed along the edges.

For LVL, once the logs are peeled using a rotary lathe, all the veneers are usually arranged in a longitudinal direction. After drying and strength grading, the veneers are passed through an adhesive application and joined together.

Figure 40: *Pressing and curing (Photo courtesy of Rubner Holzbau)*

8. PLANING & FINISHING



The completed assembly is then planed and/or sanded before transferring to the machine station where a multi-axis machine cuts out openings for windows and doors in walls, and staircase openings in floors.

Figure 41:
Planing and finishing MET members (Photo courtesy of Rubner Holzbau)

Figure 42:
Packing and transportation to site (Photo courtesy of Binderholz)

6.4. Factory Production Control

The factory production control (FPC) is a system where the manufacturer documents operations and keeps records to ensure and demonstrate that the product meets the requirements of the relevant standards such as the EN 14080 and EN 16351 as referred to in this guidebook.

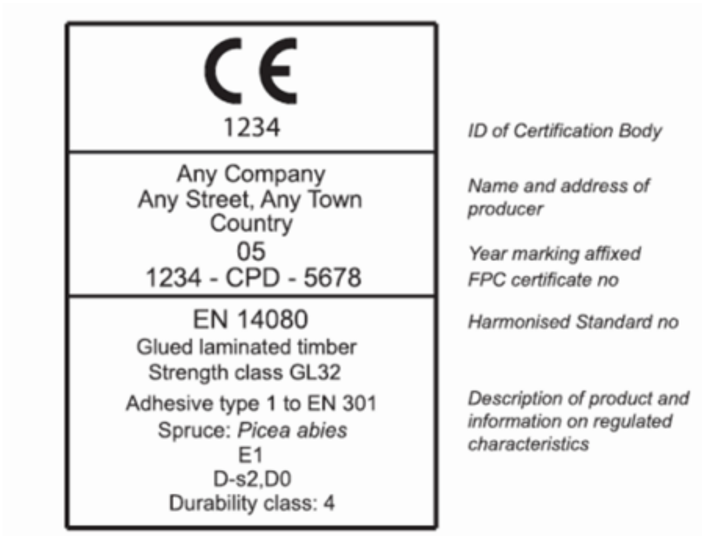
An internal audit of the factory and the FPC is carried out by a notified body who will review the audit findings and a positive certification decision is made should the system comply with the technical specifications of the product.

Regular audit and testing are required to check the system, identify any errors that need to be corrected, and ensure quality standards are maintained. It is important to ensure that the product continues to be certified, if not, it cannot claim to have complied with the technical specifications.

The FPC must be designed in a manner to ensure sufficient confidence in the manufacturing process of the product, to consistently achieve the performance as claimed in the Declaration of Performance (DoP), which will eventually enable the product to obtain the CE mark.

6.5. CE Mark

The CE mark is a key indicator of a product's compliance with relevant standards and requirements.

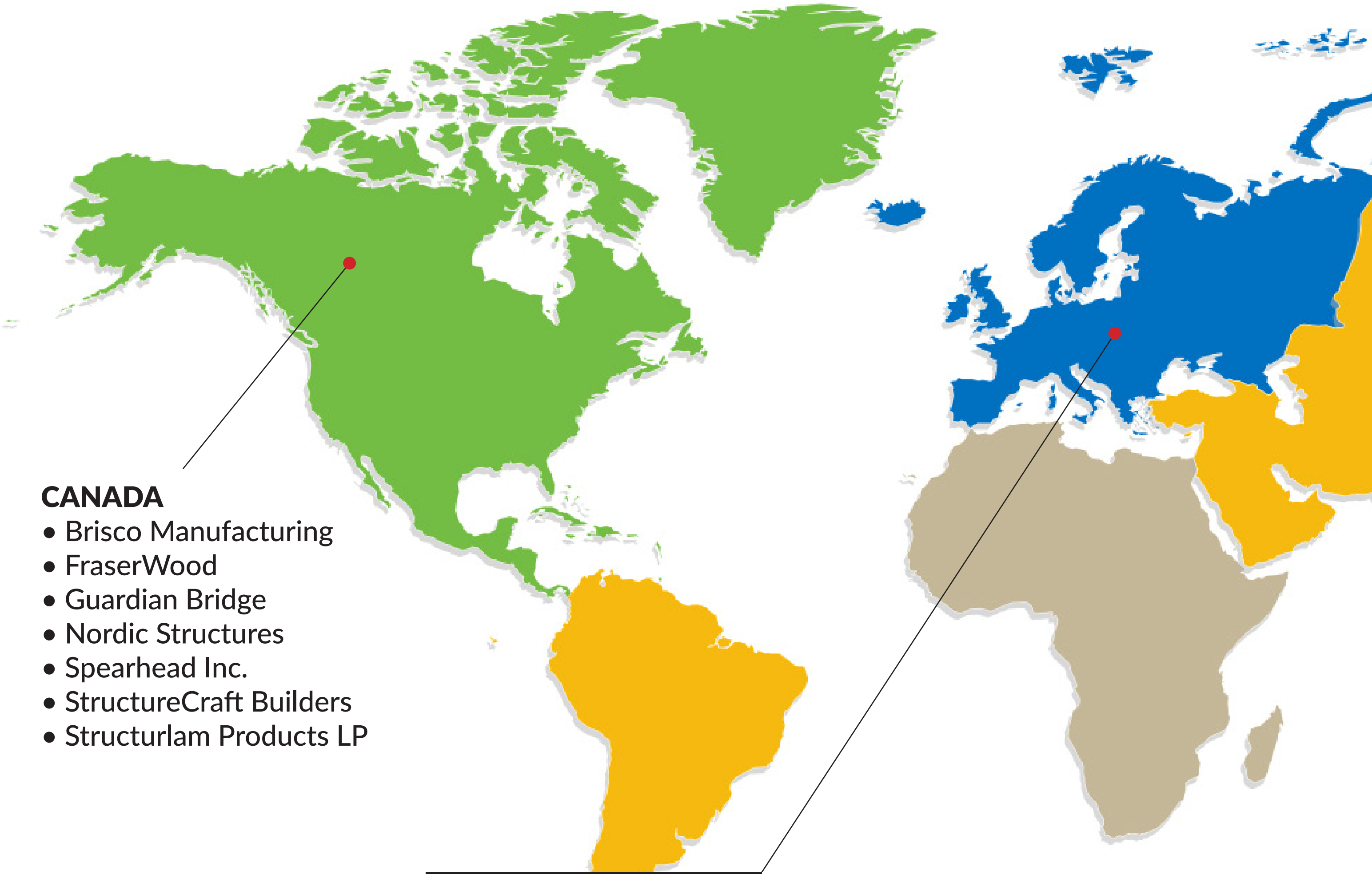


A CE mark affixed to a product will bear the following key information:

- ID of certification body and number
- Name and address of producer
- Date marking
- FPC certificate number
- Harmonised standards
- Product type and intended use
- Strength class
- Adhesive type
- Species
- Formaldehyde emission
- Fire performance
- Declaration of performance number

6.6. Supply Chain

There are many manufacturers of structural timber products worldwide. The most prominent suppliers are shown below and on the next page (this list is not exhaustive):



CANADA
- Brisco Manufacturing
- FraserWood
- Guardian Bridge
- Nordic Structures
- Spearhead Inc.
- StructureCraft Builders
- Structurlam Products LP

EUROPE

AUSTRIA
- BinderHolz Bausysteme
- Hasslacher Norica
- KLH Massivholz
- Mayr-Melnhof
- Stora Enso
- Thoma Holz
- Rubner Holzbau
- Wiehag Holding
- KLH
- Handlos
- Holz Hahn
- Huter & Sohne
- Kulmer GesmbH & Co
- Mosser
- Holzindustrie Pabst
- Holzindustrie Pfeifer
- Bruder Theurl
- Weinberger Holz
- Haas Fertigbau

BELGIUM
- Korlam

DENMARK
- Lilleheden

GERMANY
- DERIX
- Eugen Decker
- FinnForest Merk
- MERK Timber
- HESS Timber

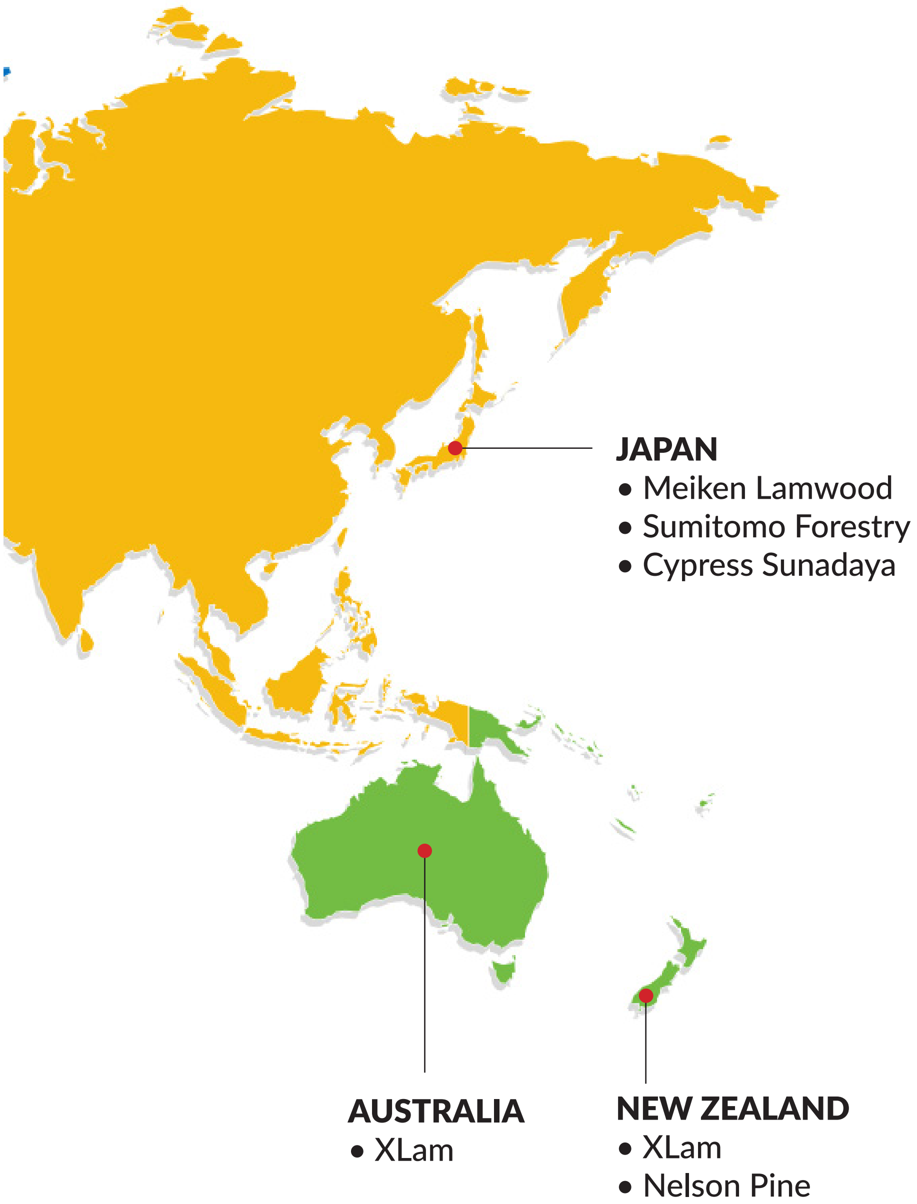
ITALY
- XLAM Dolomiti

NETHERLANDS
- Mevo Houtindustrie

NORWAY
- Moelven

SPAIN
- Egoin

SWEDEN
- KLH
- Martinsons
- Moelven


JAPAN
• Meiken Lamwood
• Sumitomo Forestry
• Cypress Sunadaya
AUSTRALIA
• XLam
NEW ZEALAND
• XLam
• Nelson Pine

7. CONSTRUCTION AND PROJECT MANAGEMENT

The construction and project management of MET projects are where the client can get additional savings. Through DfMA, MET structures can be built in a shorter time compared to traditional construction methods. This section focuses on the considerations that project parties using MET need to make, when managing the project.

7.1. Shipping

Figure 43: *Transportation of MET to Singapore*

As shown in Section 6.6 of this guidebook, MET is mainly manufactured and supplied from Europe. Developers, designers and main contractors should be aware that the time taken from manufacturing MET in Europe to its delivery in Singapore could take more than eight weeks, after shop drawings are approved by the client. Therefore, they should factor sufficient time for the transportation of MET in the construction programme.

7.2. Transportation

Figure 44: *Transportation of MET to the project site*

Although MET elements can be manufactured in very large sizes, the actual dimensions of the elements used for a project are limited by transportation practicalities.

In order to ensure the quality of MET, it is important to set up a comprehensive transportation plan to analyse and mitigate issues during delivery. This is to avoid potential damage to the material for long distance transportation. The transportation plan should comply with LTA's traffic regulatory requirements.

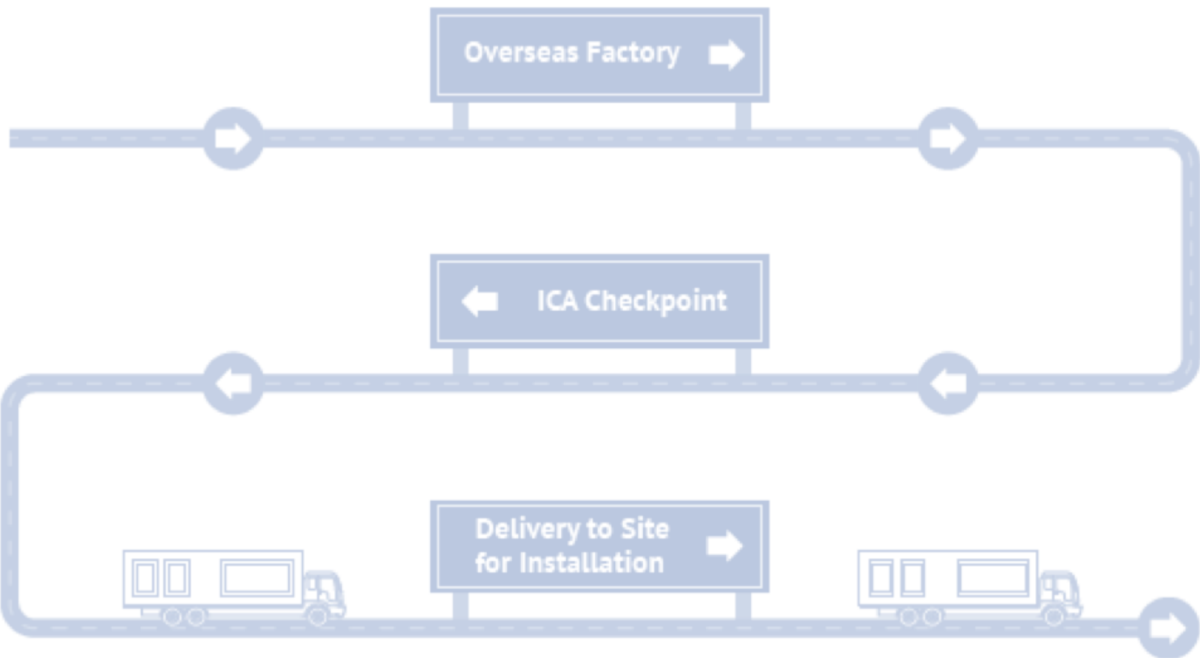
A permit from LTA should be obtained for laden or unladen vehicles which fall into either of the following categories:

Rear overhang of load	≥ 1.8m or 40% of the vehicle length whichever is lesser
Width	> 2.6m when travelling on controlled roads
Laden Weight	> Allowable weight limit

In addition to a permit, auxiliary police escort is required if the laden or unladen vehicles fall into either of the following categories:

Height	> 4.5 metres (inclusive of truck height)
Width	≥ 3.4 metres
Laden Weight	> 80 tonnes
Length	> 12 metres

At the same time, Just-in-time (JIT) delivery can be implemented to ensure the following:
1. The right time of delivery;
2. Management of storage on site;
3. Optimal crane usage;
4. Minimal hoisting and handling of MET



7.3. Delivery

The condition of roads surrounding the construction site must be able to accommodate the weight and size of MET delivery. It is a basic requirement to ensure that the access road to the construction site and its unloading area is accessible and can be used by heavy haulage trucks, long vehicles and truck cranes. The turning radii of the vehicles have to be considered during the planning stages of the project to avoid restriction of vehicle access.

When MET elements are delivered to site, the following should be checked to ensure the quality of elements:

- Quality of material (e.g. strength grades and correct grade of sheathing and decking, fire and sound performance of linings etc.)
- Quality of assembly (correct nailing and jointing), correct dimensions, the squareness of sheathed panels, straightness of sheathed panel, perimeter studs/joists, moisture content, preservative treatment and schedules where applicable.

Where possible, MET elements should be offloaded within the site compound and the offloading process should be supervised by either a site safety supervisor from the sub-contractor or a member of the site team. Deliveries should be supervised by a Qualified Person. Care should also be taken when unloading and handling all components.

Checklist

- Check that all components are delivered
- Check for any damages
- Report shortages and any damages

7.4. Temporary Storage and Protection

Temporary storage of MET elements is typically required on site as the delivery of elements could arrive all at once, but this could be reduced through just-in-time delivery. In addition, adequate care should be taken to protect the MET elements from water, moisture and dirt during construction.

Figure 45: *Temporary protection of MET on site*

7.4.1. Rainwater Management during Construction

Timber elements should be stored in a dry area free from potential damage. For instance, they should be kept under cover with good ventilation, supported on level supports on a compacted hard surface that is levelled, well drained and protected from other trades and traffic movement.

Below are some rainwater management measures that should be taken during construction:

- Standing water on MET elements should be swept away daily.
- Protect MET elements from weather if stored for a prolonged period and allow adequate ventilation.
- Ensure the end grain is protected to reduce moisture absorbed by MET.
- Stack components off the ground or deck on a levelled dry area to avoid soiling and distortion.
- Review moisture content prior to the application of finishes.

The contractor should also take preventive measures to minimise mechanical (scoring or reasonable levels of impact) and visual defects (e.g. dirt, finger or footprint markings) on exposed surfaces that may arise during fabrication and erection.

Figure 46: *Grease and dirt stains from forklifting*

Figure 47: *Wrapping of forklift to prevent transfer of grease and dirt to glulam beam*

Checklist

- Keep material off ground, cover and ensure proper ventilation
- Store panels flat with sheathing side up
- Ensure MET materials on site are protected via barriers

7.5. Just-in-time Installation

MET can be delivered to the site when required as long as sufficient time has been provided for the design review, BIM co-ordination, manufacturing, procurement and transportation to site. However, by storing MET on site, there is a risk of MET being in contact with water for a long duration, which can result in a higher moisture content, fungi and insect attack. Therefore, just-in-time (JIT) installation is a better option, and it is also more efficient.

For a smoother JIT operation, the rate of installation needs to be determined upfront. The MET supplier can also employ traffic monitoring systems and GPS for prime movers to facilitate and improve the predictability of deliveries.

It is advisable to set aside space for unloading and storage in the event where JIT installation is not possible, such as during inclement weather etc.

7.6. Handling and Lifting of Materials

Sufficient preparation and precautions should be taken during the planning stages to avoid defects and mishandling of material.

As MET is comparatively lightweight, large MET components can be lifted, minimising the lifting operations on site. Different anchoring and lifting systems can be used for the handling and lifting of MET elements.

Figure 48: *Lifting of CLT slab (Dalston Lane, London) (Photo courtesy of Binderholz)*

All lifting points should be designed, predetermined and provided for during production. This should be co-ordinated with local installers and overseas manufacturers.

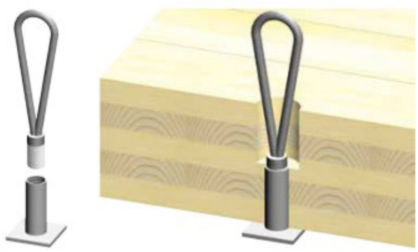


Figure 49: *a) Single lifting loop with threaded sleeve used with socket steel tube welded onto a flat plate.*

b) Soft lifting sling used without support for vertical and horizontal panels

Figure 50: *Lifting and installation of glulam roof beam (The Wave at NTU)*

Figure 51: *Lifting and installation of CLT panels (The Wave at NTU)*

Figure 52: *Installation of glulam beam (The Wave at NTU) (Photo courtesy of NTU Singapore)*

7.7. Assembly and Installation

Before MET elements arrive on site, temporary works and risk method statements should be approved by the main contractor. During assembly and installation, adequate measures to ensure temporary stability should be provided and verified by a Qualified Person.

Checklist

- Ensure proper care during installation to prevent damage.
- Follow drawings, details and standards.
- Ensure temporary stability of structure.
- Ensure floors are not overloaded.
- Implement workplace safety regimes.

8. MAINTENANCE, REPLACEMENT AND RENOVATION

It is essential to exercise care during maintenance to prevent damage to the timber. A competent contractor should also be engaged for the maintenance and refurbishment works of MET buildings.

8.1. Maintenance Regime

Regular building maintenance checks is applicable to all structures during their operational lifespan. Where treatment or coating has been applied, as recommended by the supplier and/or specialists, there should be a maintenance regime for the reapplication of treatment or coating.

For MET buildings, the Professional Engineer (PE) should also focus on the potential defects commonly found in timber:

Checks on:	Method of Checking	Frequency
Moisture Content	Using Moisture Meter	To be advised by the PE
End Grain	Visual Inspection	
Insect & Fungi Attack	Visual Inspection	
UV Treatment	Visual Inspection	
Corrosion	Visual Inspection	
Significant Cracks, Delamination, Warpage	Visual Inspection	
Deflection (For long-span structure of more than 20m)	Measurement	

8.2. Periodic Structural Inspection (PSI)

Buildings serve the needs of people using them. It is important that they remain structurally sound and do not pose a safety hazard to occupants and members of the public. To ensure that building structures are properly maintained and safe for continued occupation, structural inspections must be conducted so that defects can be detected and rectified early to ensure buildings remain structurally sound.

In Singapore, it is a requirement under the Building Control Act for building owners to conduct Periodic Structural Inspections (PSI). PSI should be carried out by a Professional Engineer (PE):

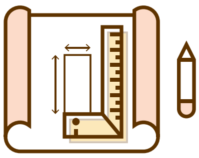
- Every 5 years for non-residential buildings
- Every 10 years for residential buildings*

*Detached, semi-detached, terraced, or linked houses which are used exclusively for residence, as well as temporary buildings are exempted from PSI.

Building owners have to appoint a qualified PE to inspect the building structures and recommend how structural defects such as steel corrosion, decay, cracks, deflection of structural members, if any, should be repaired. Where necessary, building owners should engage a contractor to repair the defects according to the PE's recommendations.

The PSI typically involves the following:

a) Assessment of loading and usage;
b) Identification of defects, deterioration, distress and deformation;
c) Determine whether such defects, deterioration, distress and deformation are of structural significance;
d) Assessment of whether addition and alteration works have been carried out to the building structure according to approved plans;
e) Identification of aggressive environments that may be detrimental to the building structure; and
f) Recommendation of remedial measures to be carried out.



PE responsibilities during design:

- To indicate maintenance strategy during the design
- To describe key inspection requirements in drawings and specifications

PE responsibilities during PSI:

- To study drawings/specifications and develop an inspection strategy
- To use appropriate instruments (moisture meter, borescope etc.) to conduct an inspection, and if necessary, consult a specialist to assist inspection
- To conduct visual inspections, and if needed, use instruments during checks
- Check moisture content.
  The measurement would indicate the durability of MET and risk to rotting, termite and material deterioration

Figure 53: *Moisture content monitoring using a moisture content reader*

8.3. Replacement and Renovation

There are many ways to repair MET buildings. The right solution is the one which works for the building and ideally the client as well. A Qualified Person should be consulted prior to the commencement of any replacement or renovation work.

9. APPENDIX

9.1 MET Projects in Singapore (Completed and Upcoming)

SINGAPORE SUSTAINABILITY ACADEMY (COMPLETED)

(Photo courtesy of CDL and VMW)

Developer: City Developments Limited (CDL)

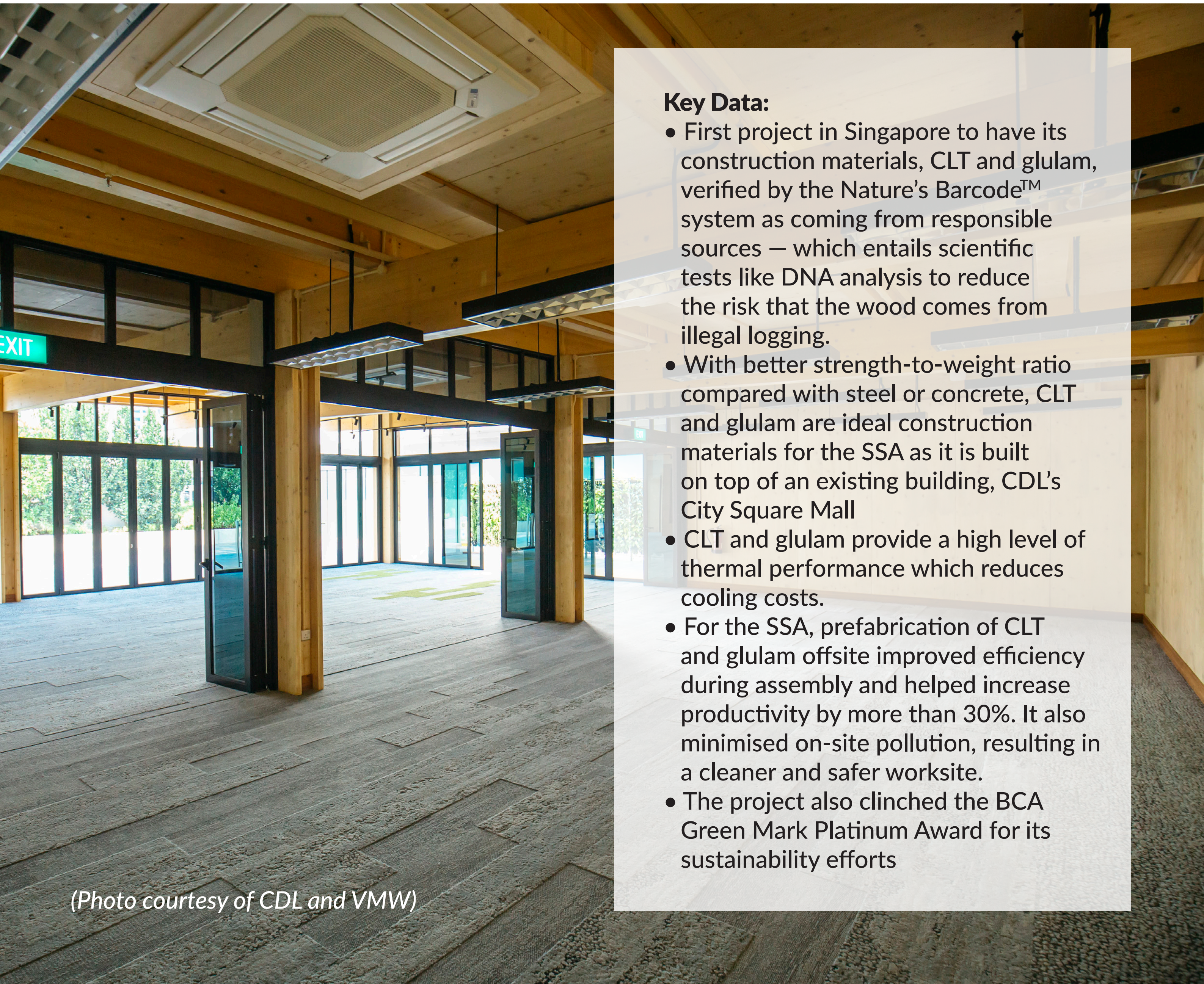
Development Type: Training and networking facility on sustainability

Completion Date: March 2017

GFA: More than 400m^2

Volume of MET: 108m^3

Structural System: Glulam beam and column with CLT wall and slab



(Photo courtesy of CDL and VMW)

Key Data:

- First project in Singapore to have its construction materials, CLT and glulam, verified by the Nature's Barcode™ system as coming from responsible sources — which entails scientific tests like DNA analysis to reduce the risk that the wood comes from illegal logging.
- With better strength-to-weight ratio compared with steel or concrete, CLT and glulam are ideal construction materials for the SSA as it is built on top of an existing building, CDL's City Square Mall
- CLT and glulam provide a high level of thermal performance which reduces cooling costs.
- For the SSA, prefabrication of CLT and glulam offsite improved efficiency during assembly and helped increase productivity by more than 30%. It also minimised on-site pollution, resulting in a cleaner and safer worksite.
- The project also clinched the BCA Green Mark Platinum Award for its sustainability efforts

THE WAVE AT NANYANG TECHNOLOGICAL UNIVERSITY (COMPLETED)

(Photo courtesy of NTU Singapore)

Developer: Nanyang Technological University, Singapore (NTU Singapore)

Development Type: Indoor sports hall

Completion Date: December 2016

GFA: 9775m^2

Volume of MET: 3800m^3

Structural System: Long span glulam roof beam with CLT wall and roof panels, together with steel frames

Key Data:

- First multi-purpose sports hall in South East Asia to use MET on a large scale
- No temporary supports needed for 72m long span glulam arch roof construction as timber is lightweight compared to concrete
- Use of timber provides five times better heat insulation than concrete
- MET components cut to precision and prefinished in a controlled factory environment reduces wastage and need for additional materials
- Overall manpower savings of 25%
- The project also clinched the BCA Green Mark Platinum Award for its sustainability efforts

JTC LAUNCHPAD @ ONE-NORTH BLK 81 (COMPLETED)

(Courtesy of JTC)

Developer: JTC Corporation

Development Type: Multi-user light industrial building

Completion Date: December 2016

GFA: 5400m^2

Volume of MET: 700m^3

Structural System: Glulam beam and column framing with CLT slab and wall, together with concrete core walls and steel frames

Key Data:

- Compared to traditional building materials like steel, prefabricated MET components are lighter, and only requires simple manual hoists and ladders to be used during installation which enhances workers' safety and reduces construction time
- Reduction of noise and dust generated on the worksite with minimal impact on the LaunchPad community.
- Easy on-site assembly enabled manpower savings of about 15% compared to conventional construction methods
- The project also clinched the BCA Green Mark Gold^{PLUS} Award for its green building efforts

EUNOIA JUNIOR COLLEGE (UPCOMING)

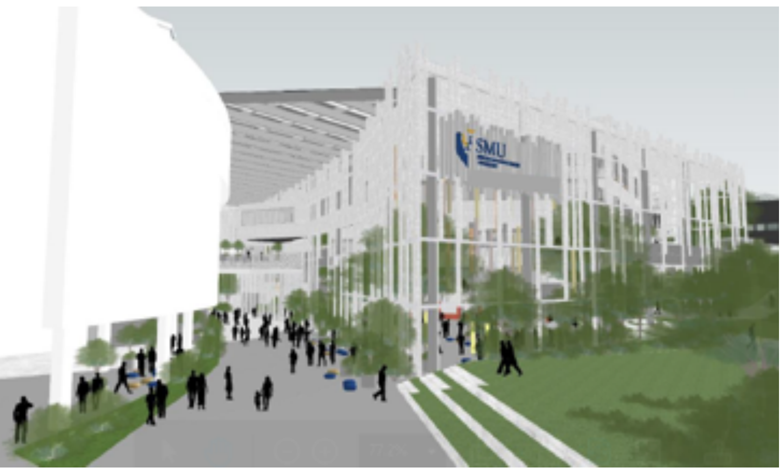
(Artist's impression courtesy of MOE)

Developer: Ministry of Education (MOE)

Development Type: Academic building

Key data:
- Two academic blocks that are 10 and 12 storeys high
- Target completion: 2019

SMU-X (UPCOMING)



(Artist's impression courtesy of SMU)

Developer: Singapore Management University (SMU)

Development Type: Teaching and learning facility

Key data:
- Two blocks of 5-storey buildings, with a total GFA of 20,000m^2
- Target completion: 2019 and 2021 respectively

RIVERVALE COMMUNITY CLUB (UPCOMING)

(Artist's impression courtesy of PA)

Developer: People's Association (PA)

Development Type: Community club

Key data:
- Four storeys with basement and roof garden
- Target completion: 2020

9.2 Tall Timber Buildings Globally

COMPLETED MET PROJECTS

Stadthaus (9 Storeys, 29m) London, UK	**Status: Completed in 2009** The first high-density residential building built from prefabricated CLT panels, including all load-bearing walls and floor slabs as well as stair and lift cores.
Life Cycle Tower (8 Storeys, 27m) Dornbirn, Austria	**Status: Completed in 2012** The floors above the ground floor were built from prefabricated hybrid MET and concrete components.
Forté Living (10 Storeys, 32.2m) Melbourne, Australia	**Status: Completed in 2013** Australia's first CLT high-rise building was the world's tallest when it was completed in 2013.
The Treet (14 Storeys, 49m) Bergen, Australia	**Status: Completed in 2015** The Treet had four storeys of CLT modules stacked on top of platforms (on the 4th and 9th floors) which are supported and reinforced by 3m high glulam lattice beams to achieve its 14-storey height.
Brock Commons Tallwood House (18 Storeys, 53m) Vancouver, Canada	**Status: Completed in 2017** Currently the tallest timber building in the world.

UPCOMING MET PROJECTS

25 King (10 Storeys, est 46.8m) Brisbane, Australia	**Status: Under construction** Set to become the world's largest and tallest MET office tower when completed in late 2018.
HoHo (24 Storeys, est 84m) Vienna, Austria	**Status: Under construction** Currently under construction, this mixed-use tower is set to become next tallest timber building in the world.

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