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1. Executive Summary

Despite the increasing popularity of timber as a structural material choice among many European nations, the adaptation rate of this construction material has not been widely used in Singapore. Till date, only 3 Mass Engineered Timber (MET) major projects have been completed and about 4 MET projects are still under construction. Among these projects, the most significant project is arguably the Nanyang Technological University (NTU) The Wave, which is the first large-scale indoor sports building in Southeast Asia built using MET.

Throughout the years, numerous efforts have been taken by the Singapore government and building authority to promote the use of MET through the revision of the fire code in the year 2014 to approve the usage of Cross Laminated Timber (CLT) and Glued Laminated Timber (Glulam). However, it can be observed that various completed MET projects within Singapore are mainly restricted to only low-rise development and nothing beyond 10 stories.

This report aims to discuss the feasibility of using MET as an alternative structure material choice for the construction of an upcoming Build-To-Order (BTO) public-housing project in Singapore. The report will look into the potential construction-related issues and the limitations associated with the use of timber as a structural material by taking references to local-based and international-based case studies. Besides exploring the possibility of using timber, this report will also further explore the use of a hybrid system which is the incorporation of MET with other conventional materials such as steel and concrete in an effort to promote an alternative construction method for the new residential project in Singapore.

The study’s data are compiled from a mixture of primary and secondary research, ranging from the reference from research journals, news articles to conducting an interview session with RSP Architects Planners & Engineers Pte Ltd to gather more insights with regards to the construction of the upcoming NTU Academic Building South (ABS) Building.

Through this proposal, we hoped to shed some light into the Singapore construction sector by going beyond the conventional ways to introduce MET as an alternative choice of structural material with the combination of a hybrid structure system for the construction of a new residential development in Singapore. We believed that MET will finally realize its potential to revolutionize the construction industry, by pushing the boundaries of timber structures, with Singapore being the next country to make a massive breakthrough through the development of a high-rise timber structure residential building.
2. Introduction

2.1 Background

In Singapore, many Housing & Development Board (HDB) residential blocks have utilised a mixture of prefabricated concrete panels and concrete Prefabricated Prefinished Volumetric Construction (PPVC) methods for the construction of the residential development. Today, approximately 70% of a typical HDB blocks concrete structure is constructed using the prefabricated method (HDB, 2018).

Some of the HDB projects that have leveraged on PPVC, Prefabricated Volumetric Construction (PVC) and Prefabricated Bathrooms Unit (PBU) include Fernvale Lea, the first PBU BTO Project in Sengkang and West Terra at Bukit Batok that uses PVC. Despite the active usage of games changing technologies, PPVC, PVC, and PBU are among the more popular options as compared to Mass Engineered Timber (MET).

There have been numerous concerns over the use of MET elements such as insect infestation and fire hazard. However, the main concern of using MET in Singapore will be weathering aspect due to the humid and wet climates. Due to the constant exposure to high moisture, relative humidity or even wetting especially during the monsoon season where heavy rainfall is expected, the properties and functionality of the MET elements may be affected.

2.2 History of Construction Materials

Concrete is one of the most widely used materials for the construction of buildings (A. Acheampong, 2013). In 1849, a mixture of two materials, steel and concrete, brought about reinforced concrete (Bone Structure, 2016). Reinforced concrete has been used in structures such as bridges, buildings and highways, amongst other things. Concrete is a popular material used as it can be recycled to form a new concrete mix when broken and demolished.

Steel is also among one of the popular materials to be used for building structures due to its strength and durability. In addition, it is also termite-proof and non-combustible, unlike timber (Lyons, 2009).

Timber is more widely used in continents such as North America, due to their expansive supply of timber. It is also relatively inexpensive, which is why it is becoming more popular in recent years. Timber has been used for construction of houses even 10,000 years ago, mainly used for home structures (Bone Structure, 2016).

The greatest disadvantage that deters organisations from using it for construction is moisture infiltration. A vapour barrier must be included between the lining of the inner wall and the insulation to prevent vapour passing through. Also, timber frame structures does not achieve the same level of sound insulation as concrete or masonry as they are not as dense. Performance has to be improved by constructing two separate wall leaves with a structural break between them, filled with a sound absorbent material (DBW, 2018).

Although masonry and steel frame structures can fail if subject to sustained high temperatures,
there is a misconception that timber frame structures are more at risk, thus deterring usage of the material for the fear of susceptibility to fire. However, when timber burns, the outer parts char and becomes charcoal which insulates against heat and prevents burning. This means that the centre of the timber is protected from damage (DBW, 2018).

Timber has great potential to be a sustainable and convenient material for building structures, moving away from conventional materials such as concrete and steel. It is crucial to change the mindsets of stakeholders in the building industry towards timber, to that of a positive one, before any major change can be introduced.

2.3 About Mass Engineered Timber (MET)

MET is an example of a DfMA technology. MET elements are pre-fabricated off-site and are delivered to the construction site to be assembled preferably on a just-in-time basis. MET can be used for elements of the structure above the floor slab of the ground floor such as columns, beams, and floor slabs.

2.4 Common Types of MET & their Benefits

2.4.1 Cross Laminated Timber (CLT)

CLT is renewable and has low carbon content compared to other available building materials. It is manufactured in panels which are laid on top of each other in odd numbers at right angles and are glued together under pressure. CLT can be used for floor slabs which are pre-fabricated as panels. The benefit of using CLT is that it is time-saving as it reduces the time required for construction of the structures due to prefabrication (Designing Buildings Ltd., 2018).

2.4.1.1 Benefits of Cross Laminated Timber

- Design Flexibility
  The cutting process used for the manufacturing of CLT is computer numerical controlled. This enables the panels to be shaped accordingly to the requirements of the client (BCA, 2018).
- **Strength**
  CLT is stronger than timber due to its distribution of natural defects from the cross-lamination process and high standard of board strength grading (BCA, 2018).

- **Structural Capability**
  CLT can be used for floor, roof and wall elements. It has high in-plane strength and stiffness, thus can be used efficiently for those above-mentioned structures (BCA, 2018).

- **Quality**
  CLT is manufactured to strict quality assurance requirements from stress-graded timber (BCA, 2018).

### 2.4.2 Glued Laminated Timber (Glulam)

![Figure 1.1: Glued Laminated Timber](image)

Glued laminated timber, also known as Glulam, is another common type of manufactured timber product used for construction. Glulam can be made by bonding together individual layers of solid timber panels with moisture-resistant adhesives. Glulam can be used for structures such as columns and beams (Designing Buildings Ltd., 2018).

#### 2.4.2.1 Benefits of Glued Laminated Timber

- **Design Flexibility**
  Glulam, similar to CLT, can be manufactured to form various shapes and sizes. It can be manufactured curved or straight. The material can be either be of a ‘homogeneous’ layup, where the laminations are all of the same strength or ‘combined’ where the outer laminations are of a higher strength (BCA, 2018).

- **Good Strength-to-Weight Ratio**
  Glulam beams are able to carry loads as heavy as that of concrete or steel beams. However, glulam beams have a weight lighter than that of concrete or steel beams, due to their high strength-weight ratio (BCA, 2018).

- **Time-Saving**
  Using prefabricated MET raises construction productivity. It allows work to be done off-site, and assembly to be done on-site. Less people are required on-site as well. CLT
and Glulam can contribute time and manpower savings up to 25% at the project level. (BCA, 2018)

2.5 Benefits of MET Construction

![CLT Benefits: 21 Reasons to Use Wood](image)

Figure 1.2: MET Benefits

2.5.1 Sustainable
MET is produced from relatively small trees which are a renewable resource harvested from sustainably managed forests. In sustainably managed forests, harvested trees are replaced by newly planted trees. Timber is a material that traps carbon that would be released into the atmosphere if it is allowed to decay. Thus, utilizing timber in building prevent the release of carbon and this help to minimize carbon footprint (Lin, 2017)

2.5.2 Speed of construction
According to BCA, MET construction can achieve up to 35 percent savings in time and manpower because of prefabricated MET components which are factory processed for easy assembly on site. The high strength to weight ratio of timber also contributes to the speed of construction, as it is easier to handle compared to steel and concrete.

2.5.3 High strength to weight ratio
MET has a higher strength to weight ratio than steel and concrete, achieving up to 30 percent less in weight than concrete. This reduces the dead load of the building and thus the foundation required to support the building.

2.5.4 Better construction environment
Using MET for construction also leads to a better construction environment. Using MET for construction also leads to a better construction environment. MET usually done prefabrication thus it reduces the amount of work done on site. It will lead to lower dust and noise pollution as only assembly of the MET elements are needed to be done along with the chosen finishes. Timber is also non-toxic, hence not harmful to the environment.
2.6 Current Built-Environment Sector Initiatives to Promote the use of Mass Engineered Timber (MET)

With increased expertise and knowledge of timber, stakeholders can better understand and implement timber into building projects. In 2017, Building and Construction Authority (BCA) published an issue of *Buildsmart: A Construction Productivity Magazine* promoting the use of MET. It featured four local projects that have adopted MET construction – The Wave at Nanyang Technological University, JTC’s LaunchPad at one-north, the Zero Energy Singapore Sustainability Academy, and the BCA SkyLab Visitors’ Gallery and Lounge. Through measures as such, BCA aims to help the industry build up technical competency in advanced technologies (BCA, 2017).

Figure 1.3: *Buildsmart Magazine promoting MET*

On September 2018, Building and Construction Authority (BCA) published the MET Guidebook. This guidebook is the third in the series of Design for Manufacturing and Assembly guidebooks. The aim of this guidebook is to serve as a reference material on the usage, construction, and assembly of the MET.
2.7 Current adoption rate of MET in Singapore

According to the Minister for National Development Lawrence Wong (2017), only 10% of the construction project in Singapore used new techniques like mass engineered timber. Singapore government aims to increase this adaptation rate to 40% by 2020. Mr. Wong also mentioned “If we continue to rely on existing building methods … we will end up simply with a far larger pool of foreign workers than we can possibly accommodate in Singapore”.

2.8 Overseas MET projects

Internationally, there have been numerous records breaking tall-timber buildings constructed from lightweight and strong super-materials such as CLT and Glulam. Some of the most significant MET projects includes Forté Living - a ten storey apartment block, LCT One - an eight-storey office building, Brock Common - an eighteen storey student residence.
2.9 Current Built Environment Initiatives in Singapore

Firstly, Building and Construction Authority (BCA) announced in 2017 that as part of the productivity drive, it aims to reduce 20% to 30% among the larger pool of foreign workers by 2020.

Secondly, as mentioned by Minister for National Development Lawrence Wong (2017), the public sector led by public sector agencies will be the main driver, in which they will lead and adopt new productivity technologies.

Thirdly, BCA 3rd Green Building Masterplan aims for Singapore to be a global leader in green buildings. It aims to green 80% of all buildings and reduce Greenhouse Gases emissions intensity by 36%, both by 2030.

Fourthly, as part of the ‘Pre-Project Innovation Consortium’ launched by Singapore’s Economic Development Board (EDB), BCA has encouraged the test-bedding of CLT in Singapore. They have sought Lend Lease Singapore to be the leading consortium to explore CLT pilot projects within Singapore. BCA also push the use of innovative construction technologies such as MET through government land sales (GLS) projects.

Lastly, the government has provided funding through Construction Productivity and Capability
Fund (CPCF) in support of leveraging on game-changing technologies and construction methods.

2.10 Singapore Fire Code

In 2014, the Singapore Civil Defence Force (SCDF) revised its fire code to allow the use of MET for building structural components after a thorough safety assessment. However, there are several regulations set in place by the Singapore government that restricts the use of timber in certain ways. During the pre-design phase, the qualified person (QP) is responsible for informing the S regarding the project, before the commencement of the construction and design phase.

There are several regulations with respect to the building design:

1) The habitable height (height from lowest to highest level) of healthcare occupancy in an engineered timber building shall not exceed 12m metres.
2) Where the habitable height exceeds 12 metres, a fire safety performance-based (PB) approach shall be adopted in the design of the engineered timber building.
3) The engineered timber building shall be fully protected by an automatic sprinkler system. Except where:
   a) There are alternative fire-protection measures.
   b) Building habitable height does not exceed 12 metres.
   c) There is an automatic fire alarm system protection in line with CP 10 Code of Practice for Installation and Servicing of Electrical Fire Alarm Systems.
   d) The building does not contain any healthcare occupancy.
4) The structural elements permitted for the use of MET are areas above the floor slab of the ground floor. The ground floor slab and basement floors are not allowed to have structural elements constructed from timber.
5) Escape routes such as staircase shafts and lift shafts should be constructed of non-combustible materials.
6) The use of flammable gas cylinders for cooking is not permitted if the engineered timber building has access to piped-gas supply for cooking.
7) Residential engineered timber building projects shall fully comply with the technical requirements for household and storey shelters.

During the construction phase of the project, the QP has to ensure that project work site complies with the Fire Safety Requirements for Buildings Under Construction (in the current Fire Code).

Despite following the regulations set out by SCDF, the owner is still required to obtain necessary permits and approval from the relevant authorities, including SCDF.

2.11 Singapore MET Product Verification and Certifications

Besides compliance with the SCDF Fire Code, the usage of MET products for the construction of a building require a range of product verification and certifications. Below comprises of the lists of MET product verification and certifications based on Singapore context.
2.12 Purpose of report

This report aims to study the feasibility of using MET as an alternative construction material for the construction of residential development in Singapore which had been built in other countries like Australia, Canada, and Norway. In addition, we wish to find out the possibilities of using of hybrid structure system that comprises of MET and pre-cast concrete for the future residential development within Singapore.

The objective of the report is to:

(1) increase the usage of MET construction in Singapore by taking references to a range of internationally established MET buildings;

(2) increase the confidence of Singapore developers and construction companies in adopting MET as a construction material by addressing the various concerns and challenges associated with MET construction;

(3) suggest other methods on top of the existing methods adopted by the local-based MET building projects.

Through this report we aim to achieve the following:

- To boost usage of MET construction in Singapore by taking references to a range of internationally established MET residential development.

- To increase the confidence in Singapore developers and construction companies in adopting MET as a construction material by addressing the various concerns and challenges associated with MET construction.

2.13 Methodology

To achieve these objectives, research journal and news articles on local and international-based MET buildings were reviewed. In addition, an interview was conducted with RSP Architects Planners & Engineers Pte Ltd to gather more insights with regards to the construction of the upcoming NTU Academic Building South (ABS) Building.
3. Case Studies

The following sections will comprise 5 local-based and international-based MET buildings, mainly LCT ONE, NTU The Wave, JTC LaunchPad @ one-north, NTU Academic Building South (ABS) Building and Forté Living. The challenges associated with MET and the adopted solutions will also be highlighted under each case study section.

4. LifeCycle Tower (LCT) ONE

4.1 Brief Background

LCT ONE is located in Dornbirn, Austria. The building started construction in September 2011 and was completed in November 2012. This 27 metres tall eight-storey office building developed by Cree GmbH has a width of 13 metre, length of 24 metre and floor area of 1600m² (Cree GmbH, 2012). LCT ONE was a prototype project to prove the feasibility of constructing with mass timber (i.e. glulam wood beams) as the primary building material incorporated with concrete using prefabricated design and construction approach. This hybrid system consists of wood-concrete slabs supported by glulams columns at the perimeter of the building and by the central core and interior columns and beam frame on the interior (Forestry Innovation Investment [FII], 2014).
4.1.1 Floor plan of LCT ONE

Figure 2.1: LCT ONE Floor Plan

4.1.2 Building section view of LCT ONE

Figure 2.2: LCT ONE Sectional View
4.2 Construction Sequence

Figure 2.3: LCT ONE Assembly Sequence

LCT ONE hybrid timber building system consists of a reinforced concrete foundation, basement, ground floor slab and central core which were first built on-site using traditional in-situ reinforced concrete construction. The central core which acted as a stiffening element of the building houses the elevators, stairwell, wet rooms and shafts. For each storey, the building enclosure which is made up of prefabricated timber wall panels were assembled followed by prefabricated wood-concrete hybrid floor slabs mounted above the wall panels. This repetitive assembly of wall panels follows by floor slabs for every storey were completed in record time of one storey per day with a building team of five (Tahan, 2013).

4.3 LCT System

The three main components of the LCT system are the central core, hybrid slab and façade columns.

4.3.1 Central Core

Figure 2.4: Central Core

LCT ONE used a rectangular concrete core as the basic structure and was erected in two sections that are 32 metres tall each. The precast concrete construction allowed shortening of the construction time but the arrangement does not promote the efficient use of floor area because the second escape route resulted in rentable space ratio that is less favorable. The core was chosen mainly for its structural properties of maximising ductility and stiffness to
resist lateral forces. Concrete was selected for LCT ONE as it is a non-combustible material which enables easier authorities approval but other materials like timber and steel can also be considered (Rhomberg, n.d.).

4.3.2 Hybrid Slab

Each slab section is made up of glulam beam and reinforced concrete which forms a composite rib element. This design allows a large span of up to 9.45 metres in length and 3 metres in width. The shape of the rib structure also helps improve acoustic performance. In addition, building services are integrated into the spaces between glulam beams which are subsequently covered by aluminium panels. The reinforced concrete further acts as a fire barrier between combustible timber elements in each floor. (Cree, GmbH, 2012)

4.3.2.1 Off-site prefabrication of hybrid slabs

Timber glulam beams were cut to the required size and added with metal fasteners and connectors before they were sent to the precast concrete manufacturer as shown in Figure 2.6 below. These metal fasteners and connectors to the sides and the upper surface of the beams provided the connection between glulam and the 8 cm concrete topping slab. Before concrete was poured over the glulam beams, metal formwork was put in place, reinforcement bars were placed over the connectors and 4 corrugated steel tubes were placed at the 4 corners. These tubes created holes at each corner of the slab which facilitated the connection between the hybrid slab and wall panels during assembly. Each slab panel is 2.7 metres by 8.1 metres in size and comprises 4 glulam beams (24 cm by 28 cm). The prefabricated process allowed for off-site curing of the concrete in a controlled environment (Tectonica, 2014).
4.3.3 Facade Columns

The facade columns of LCT ONE consists of double columns which meet the fire resistance requirements in the context of Austria. The double wood columns are shop-prepared, connected at their lower ends with a galvanised steel plate incorporating two pins that are inserted into the steel tubes embedded in the top of the column at the level below as seen in Figure 2.9 below (Tectonica, 2014). It transfers the facade forces directly to the slab and this then allows it to avoid transverse compressive stresses. The lateral forces between the double columns and the hybrid slabs prevent the possibility of separation with the use of strong tenon joints. Furthermore, wooden frames are used to link several pairs of columns into one unit and this is then installed together with the facade. An advantage of using facade columns is that the site work is able to progress more quickly as compared to conventional systems as this is a completely dry method in which no curing times are involved. This has been made possible due to the combined installation of primary and secondary facade elements (Rhomberg, n.d.).

4.3.3.1 Facade Panels

The facade panels were prefabricated in a local carpentry shop. Engineered timber was used for all wood members, including the studs as well. Five different types of self-supporting facade panels enclose the building’s perimeter. The panels are fabricated from 6 x 32cm and 6 x 16 cm glulam timber framing, with 18mm fire and humidity resistant fibre cement board sheathing on the exterior and oriented strand board on the interior surface. The exterior and interior joints between facade panels were sealed to create a hermetic envelope with special adhesive joint tape for each material to reach maximum energy performance due to Austria’s cold climate. The cavity between the two-panel surfaces is filled with thermal-acoustic mineral wool insulation or, at the openings, with composite wood and aluminium window framing as seen in Figure 2.10 below (Tectonica, 2014).

Figure 2.8: Concrete poured over glulam beams

Figure 2.9: Formation and structure in real life and in design of the facade columns

Figure 2.10: Formation and structure in real life and in design of the facade columns
The panels were first manufactured and horizontally placed on tables and this was followed by the installation of the timber frame, sheathing and insulation. The panels were then made to stand in order to install the window as seen in Figure 2.11 below. After manufacturing of the walls was complete, both the slab and facade panel elements were shipped to the construction site and it then allowed for assembly works to start. Five skilled carpenters were needed to assemble all the components, as well as the installation of water and air-tight measures in eight days for all eight storeys (Tahan, 2014).

![Figure 2.10: Installation of window](image)
![Figure 2.11: Production of Timber Frame Panels](image)

4.3.3.2 Facade elements

As implied in the previous paragraphs, it can be said that the building process of LCT ONE is a system that combines large wooden prefabricated facade-cum-load bearing glulam columns in a slot-in connection with hybrid glulam beam-cum-concrete slab floor elements according to the building’s grid.

The facade elements are prefabricated according in sets covering up to four grid spans and they are thermally insulated. They are manufactured combined with the floor high peripheral glulam columns at half grid interval. All of the facade elements, as well as the glulam columns were delivered to the building site as one piece. It was then lifted into place as a complete piece including fixed and mobile double glazing. This ensures that the assembly of each floor thereafter is progressively weather protected before the next floor is assembled. Furthermore, it must be noted that the facade corners are pre-assembled in the workshop. This would increase the costs of transportation, however, this increase in cost is of little impact in comparison to the costs incurred by the complexity of corner assembly on site (Wood solutions, 2018).

4.4 Wall and Floor Assembly

![Figure 2.12: Bottom of ground level column (left) and bottom of upper level column (right)](image)
Flat plates are attached to the bottom of the ground level columns as opposed to flat plates with pins for upper-level columns. The ground level columns are secured to the reinforced concrete basement through screwing the flat plates in place. Subsequent wall and floor construction for the upper levels are repetitive as shown in Figure 2.14 and 2.15 below.
For each upper storey, 5 wall panels are joined together to form the building’s perimeter wall. Once the perimeter wall of a storey is up, the hybrid slabs for the next storey which consist of holes at each corner connect with the tubes protruding out from the columns below. The gaps between the tubes and holes are filled with cement grout before the wall panels for the next storey are mounted above the slab. After cement grout application, the pins at the bottom of the columns for the next storey are inserted into the tubes of the columns below. The two ends of the columns with pins at the bottom and tubes at the top ensures column-slab-column connection. Each storey consists of 9 hybrid slab sections that form the floor structure. Any remaining spaces surrounding the column-slab-column connection are sealed with non-shrink grout after collar-form made from steel angles are put in place. The joints between the slab sections are also filled with polyurethane foam and non-shrink grout and this bonding between the slab sections is aided by the notched keys at the edges of the concrete layer (Tectonica, 2014).

Similarly, the other end of each slab section is supported by steel angles attached to the concrete core as shown in Figure 2.21. These steel angles with guide pins will connect with the holes at the corners of each slab. The gaps between the pins and holes are sealed with cement grout.
In the absence of the concrete core to support the other end of the slab section in some parts of the building, precast concrete beams with steel angle and guide pins similar to the ones attached to the concrete core are used to support the slab sections. The beams are supported by two isolated gulam column posts in the interior.

4.5 Material Handling and Mechanisation

Prefabricated components were bundled together before they were loaded onto the trucks and delivered to site. As the components were assembled quickly upon arrival, it reduced the need for large storage space. Components to be used at a later time were placed above raised platforms to protect them from physical and water damage. Protective plastic sheets were also provided to cover the components whenever necessary.
The construction of this development used only a mobile crane and a tower crane. The tower crane used was the self-supporting type with hammerhead jib since the height of the building is only 27 metres and the site allowed space for movement. The mobile crane was employed to lift components up to the third storeys while the tower crane for higher storeys.

The scaffolding was erected in tandem with the assembly of each storey. It provided a working platform for the workers to install the wall and floor components, the aluminium cladding panels and other non-integrated elements like guardrails.

### 4.6 Fire Protection System

![Timber column structural core protected by sacrificial layer](image)
Although timber is a combustible material, the layer exposed to fire transformed into charcoal as it burns. This charcoal layer is an excellent heat insulator that prevents the inner layer from being heated up (Arup, 2010). Furthermore, the concept undertaken by the LCT ONE uses concrete for the minimum core (escape routes and fire elevators). The slabs are used as a fire barrier between floors. The glulam beams and columns in LCT ONE are designed to withstand at least 90 minutes of fire.

The structural core of the timber columns is built to carry the load imposed on it during normal operation and in the event of a fire. Surrounding the core is another layer of timber that is designed to carry the additional load during normal operation but can be sacrificed in case of fire. Timber elements generally char at a predictable rate of 0.7mm per minute and with a sacrificial layer of approximately 42mm, it can protect the structural core from fire damage for an hour. Additionally, a firestop glass fiber or cardboard interlayer protects the structural core from combustion (Hein, 2014). Fire sprinklers are also installed between the ribs of the floor slabs. The exterior surface of the building is also covered with non-combustible aluminium panels.

4.7 Challenges in Construction of LCT ONE

4.7.1 Restrictive Building Regulations
The building regulations for timber buildings in Austria before 2010 allowed a maximum height of 4 storeys. The project team of LCT ONE had to prove and educate the relevant authorities on the merits of the building using timber and address any concerns by them especially on the fire protection aspect (Creebyrhomberg, n.d.).

4.7.2 Rain and Weather Protections
The moisture content of timber should not exceed 28 percent and needed to be quickly dry out when contact with water to prevent fungi growth (Think Wood, n.d.).

4.7.3 High Skilled Labour Required
Product suppliers need to be educated on the unfamiliar prefabrication process and the installation crew on the proper connection between wall and floor components (FII, 2014).

4.7.4 Reduced Speed in Construction
Schedule gained by the prefabricated components was reduced due to curing time required for cast-in-place concrete construction for the central core (FII, 2014).

4.7.5 Higher Cost
Several studies have indicated that the hybrid timber-concrete construction for LCT ONE costs 5 to 10 percent more than building using traditional concrete frame construction (Hein, 2014).
4.8 Solutions Adopted in LCT ONE

4.8.1 Early involvement of building authorities
The relevant authorities were engaged early in the research and design stage and they worked closely with the project team to resolve issues especially those related to fire. The initial plan was to construct a timber central core which houses the escape routes and fire elevators but due to regional building regulations, reinforced concrete was decided to be used for the central core. This compromise allowed faster approval by the authorities. Concrete was also used to separate timber to timber contact between storeys as required by fire protection regulations. In addition, a mock-up was built to test the structural integrity of mass timber building and several fire tests were also conducted in full-size fire chamber to determine the optimal dimension of the timber-concrete hybrid. The fire performance successfully achieved a REI 90 (90 minutes fire resistance) certificate from the PAVUS Test Institute in the Czech Republic.

4.8.2 Protection from rain and weather
To protect the timber structure from rising damp, the foundation, basement and ground floor were built using reinforced concrete. In addition, once the wall and floor components were installed for each storey, the timber elements of that storey were protected within the envelope. Timber elements have a higher risk of being damaged by moisture during transportation, storage and mid-way installation. To prevent moisture damage, protective sheets were used to cover the prefabricated components during storage, and components unloaded on-site were stacked on top of the raised platform to protect against rising damp. During assembly of the building components, a temporary emergency plywood roof was constructed during wet weather to protect the installed components. However, this roof required 1.5 hours to be put in place but was only used once due to the extended period of dry weather during construction. Finally, the aluminium cladding installed around the exterior created a ventilation layer that allows any water penetration to drain before it reaches the building enclosure.
4.8.3 Training provided to the labour
Labours were trained in structural timber and modular construction techniques, increasing industry capacity. Furthermore, they were also educated on protecting the exposed wood surfaces from physical damage and staining as they progressed through the finishing sequence (Adivbois Bulletin, 2014).

4.8.4 Precast concrete to replace cast in-place concrete core
Since curing time is needed for cast in-place concrete core, both the developer as well as the design team learned that they should have chosen prefabricated concrete core and precast concrete core elements, rather than cast-in-place concrete, to avoid losing the schedule gains offered by the other prefabricated components. Therefore, for future projects involving MET, following lessons from this case study, they might want to adopt a prefabricated concrete core instead of a cast in-place concrete core (Adivbois Bulletin, 2014).

4.8.5 Reduced life-cycle costs in the long-term
The LCT ONE is able to provide up to 90% improved carbon footprint. The operating costs of the building are optimised by automatic energy consumption monitoring as well and these would reduce the maintenance costs in the long term. The building requires a low-energy, passive house or plus-energy standard. Integrated in the facade also comprise of the following possible elements, for example, the use of regenerative energy including solar thermal systems for hot water, regenerative fuel plants where high water temperatures are needed and photovoltaic systems. The higher energy expense involving the use of passively cooling ceilings to cool the building with higher temperatures in summer despite sun protection measures can be reduced by an intelligent control concept and correct user behaviour (Cree Buildings, 2013). With energy savings, the costs of maintaining the LCT ONE in the long term can be assumed to be way lesser than the costs incurred for a normal office building. Furthermore, a timber building would use 39% fewer resources during its lifetime. (Adivbois Bulletin, 2014) Therefore, it can be concluded that although hybrid timber-concrete construction for LCT ONE costs 5 to 10 percent more than building using traditional concrete frame construction, in the long term, LCT ONE would provide for more cost savings.

5. Nanyang Technological University (NTU) The Wave

5.1 Brief Background
The Wave is the first large-scale building in Southeast Asia built using MET. It is a three-storey sports hall located in NTU, Singapore with a 9,800 m² surface, capable of housing 3 full sized basketball courts or 13 badminton courts (Ng, 2017). NTU aimed to construct a low carbon building with an innovative method and technology to push for productivity and sustainability,
in line with its EcoCampus initiative (“About EcoCampus”, 2011). Under the EcoCampus initiative, NTU looks to achieve a 35% reduction in energy and water consumption by 2020 with a baseline of 2011. The Wave has a large span roof structure constructed using CLT that helps to provide heat insulation five times better than concrete (Ng, 2017). The facade was also constructed using CLT and Glulam. The Wave marks a new milestone for Singapore’s push to be more productive in the construction side. In this chapter, we will be looking into the construction techniques, challenges, and solutions that can potentially be used in future constructions in Singapore.

![Figure 3: Overview of The Wave - East Facade](image)

![Figure 3.1: Overview of The Wave - West Facade](image)

### 5.2 Construction Techniques

#### 5.2.1 Foundation

The superstructure constructed of MET will sit on a reinforced concrete (RC) raft foundation.

#### 5.2.2 Structural system

It is constructed based on 3-ply solid wood panels principle. The first storey floor slabs were constructed using RC and the subsequent storey slabs and internal finishes were constructed using CLT. Glulam was used for the beams, columns and the long span roof support. The project comprises of features walls with special metal coils with chilled water flowing through, which helps to cool the incoming air and each external wall has two layers with an insulating pocket of air to insulate heat.
5.2.3 Arch Roof

The Wave has a 72-metre roof that was built without any temporary support. This is due to the high strength to weight ratio of timber compared to other materials like steel and concrete. The roof consists of seven arrays of parallel glulam arches supported by vertically positioned steel A-frames.
A 3-point arch support is made use in this construction technique to minimise the lateral movement of the side joints. It is important to choose a system that allows the surface and side joints to be easily moved for such a large span without putting additional load on the wood components. It was also necessary to reduce the lateral movement of the steel frame surfaces to restrict the deflection of the roof to a minimum (Binderholz, 2016).
Each of the two halves of the arch was split into three separate components, which had previously been joined by a temporary connection - a combination of full thread bolts and custom-made steel plates (Binderholz, 2016). It can obtain a high degree of rigidity and restore the structural behavior of the two halves of the arch.

The vaulted roof was stabilised with a rigid layer of cross-layered wooden panels. 60mm thick CLT were used bent over the Glulam to guarantee optimum adjustment to the curvature of the roof. Therefore, it is possible to achieve the aim of a consistent rigidity ratio across the entire roof and, at the same time, accelerate the construction process of the roof. The wood can support a weight several times heavier than concrete or steel in relation to the ratio of thickness and weight. No columns or beams are thus needed in the interior to support the seven wooden arches weighing a total of 440 tonnes. The structure will be able to support a continuous 72-m wave-like roof without internal columns.
5.2.4 Passive Displacement Ventilation (PDV)

The Wave is the largest hall in Singapore to rely on the PDV system for cooling. It uses the natural convection of heat transfer without the need for any air-conditioners or fans, thus saving over 40% of energy. The walls have special metal coils installed with chilled water flowing through them. By taking advantage of the natural buoyancy of warm air, stratification is achieved across the height of the room (Twenty80, 2010).

Due to the relatively low velocity of the air supply, an undesirable draft is eliminated. This
allows for the temperature in the 12m-high space to be stratified such that only the occupied space will be cooled. In addition, the use of mechanical fans are eliminated as the convective force is provided by the heat load in the space (NTU, 2015).

![Passive Displacement Ventilation (PDV)](image)

Figure 3.11: Passive Displacement Ventilation (PDV)

The absence of mechanical fans implies that acoustics standard can be greatly enhanced and maintenance cost can be kept at a minimum. The PDV system saves energy and reduces the need for maintenance associated with a conventional air-conditioning system.

5.2.5 Natural lighting

To fully optimise the use of natural daylight, the common areas in The Wave are designed to receive adequate daylight. Daylight sensors are installed to reduce the energy consumption by dimming or turning off electric lights based on the natural daylight entering the space (Lutron, 2014). The light level in the area is maintained by the daylight sensors and no manual work is required to adjust them to the daylight level changes. For example, as seen in figure 3.12, when the daylight sensor sensed a 75% natural light entrance, it will automatically dim the light indoors to 25%. The daylight sensors ensure that the level of brightness indoor is always maintained the same but with the advantage of saving electricity.

![Daylight sensor](image)

Figure 3.12: Daylight sensor

Sun buffer is installed on the west facade to cut off the harsh sunlight from the west side. A top light shelf is set up at the top of the buffer to allow natural light to diffuse within the sports hall. The edge of the roof protrudes out to protect excessively light from entering the sports hall (NTU, 2016).
5.2.6 Application of BIM and VDC

Building Information Modeling (BIM) and Virtual Design and Construction (VDC) are adopted to enhance collaboration among various stakeholders of the project. VDC process helps integrate design, prefabrication, and construction to identify upstream design clashes and simulate downstream construction workflow (BCA, 2018). This allows the project team to plan and build in a virtual environment 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 cost savings and save time through better coordination and elimination of abortive works, but also improves safety off and on site. Every model and model element must be developed to be a reliable virtual representation of the physical structure, and to the level of geometric and information granularity required to perform all intended activities and analyses. According to statistics, the BIM implementation in projects includes a 30% reduction in abortive works and up 80% reduction in change orders (BCA, 2017).
5.2.7 Prefabricated Prefinished Volumetric Construction (PPVC)

The method of PPVC allowed for reduced dust, noise, and manpower on-site as MET components are prefabricated off-site before being brought to the site for assembly (BCA, 2017). As the components already fitted perfectly, the roof was completed in record time with only 14 workers over a period of three weeks. According to statistics, the construction time and manpower requirements can be reduced by approximately up to 20% and 40% respectively. It has very high requirements for the quality control when fabricated in the factory as the measurements and design need to be accurate to allow for stacking at the main location.

5.2.8 Eco-Friendly Adhesives

To ensure that the construction technology is fully eco-friendly, it is not just the materials that is used, but also the method of putting materials together. Hexion Inc. introduced a new two-component adhesive system that reduces waste and clean-up costs, enhances durability and supports indoor air quality. This adhesive system, which includes the Ecobind 6500 resin and Wonderbond Hardener M650Y, is ideal for applications like cross-laminated timbers for tall wood buildings and glue-laminated wood beams (Hexion, n.d.). The two components are extruded separately and then mixed when the wood is pressed together. This unique feature provides the user with reduced costs for adhesive waste and clean-up of equipment. Hexion’s adhesive technology can meet or exceed all market performance and emissions criteria which include heat performance, customer quality and emissions regulations. The highly valued chemistry provides thermal stability, is flame resistant and results in a stable polymer matrix that is highly durable and safe under its intended conditions of use (Panels, 2017).

5.2.9 Protection Features

The durability of The Wave project is ensured through a combination of measures including provision of a sacrificial layer and protection capping to ensure water-tightness, waterproofing
and prevent water stagnation to preserve the viability of the MET elements. The chars rate is based on 0.75mm per minute and inclusive of an extra buffer layer of 50mm to withstand fire for an hour. The "sacrificed" for charring also act as insulation and protection to the inner core from heating.

Furthermore, to address termites concern, the floor slab adopted on the first storey will be constructed using RC to mitigate any termite issues. The MET structural materials used for this project will be subjected to termites inspection on annual basis.

5.3 Challenges in Construction of The Wave

5.3.1 Lack of storage space

Although the PPVC allows for a more efficient method of construction, it requires a large storage space for the prefabricated. Especially in the case of Singapore, there are limited land available and thus this can be a potential challenge. In addition, the transportation of PPVC need to pre-planned and existing road has to be analysed for the maneuvering. The deliveries need to be planned and coordinated to avoid congestion outside the site especially for urban build-up areas.

During the temporary storage period, the MET elements might be exposed to water, moisture and dirt and this can potentially threaten the quality of the material. They need to be kept in a dry area free from potential damage and under good ventilation (BCA, 2018).
5.3.2 Impacts from Lifting and Handling of materials

During the process of fabrication or assembly, the elements can be potentially exposed to grease and dirt stains due to the transportation by the forklift.

MET materials have high chances of exposure to threats which can potentially result in defects of the material. Furthermore, MET is often lifted due to its lightweight characteristics. The anchoring and lifting can cause harm to the material itself.

5.3.3 Lack of expertise

As this was the first standalone MET project constructed in Singapore, there was a lack of expertise for the new construction technology. Today, in the whole of Singapore, only about 10% of our construction projects are being built with new technologies like MET. Singapore
aims to have approximately 40% of the construction projects to be built using new technologies.

5.4 Solutions Adopted in The Wave

5.4.1 Just-In-Time (JIT) Operation

To counter the problem of the lack of storage space, the contractor engaged the Just-In-Time (JIT) operation. The system is a management strategy that aligns the material order directly with production schedules (BCA, n.d.). This method of operation will require the contractors to plan out their demand for material clearly. Companies will only receive goods when they need them for assembly and hence, decreasing any possible wastage of resources. Applying the JIT operation to the PPVC method, extra storage space will not be required as the prefabricated parts will be done and sent to on-site for assembly. Precast supplier, therefore, does not need to purchase any extra raw materials resulting in a cost saving method.

The JIT operation also reduce the need for temporary protection and instead of taking various measures to provide for temporary storage of the MET elements, they can be straight sent to on-site for assembly. This eliminates another possible threat to the elements for construction.

To better facilitate better deliveries, precast suppliers can employ the service from Traffic Monitoring and GPS for Prime Movers. This will allow the JIT operation to be smoother and prevent any traffic accidents that can potentially delay the operation.

This cost-saving method eliminates the demand for storage space and also reduce the risk of fire or any potential threats to the prefabricated components. At the same time, resources are not wasted due to the prefabricated process, making the construction process with the new technology an even more eco-friendly one.

5.4.2 Lifting points

To prevent harm on the material during the process of prefabrication and assembly of the material, lifting points are designed, predetermined and provided for during the production (BCA, 2018). For instance, as seen in Figure 3.19, a single lifting loop with the threaded sleeve is used with socket steel tube welded onto a flat plate for lifting.

![Figure 3.19: Lifting loop](image_url)
In the case of The Wave, they adopted mostly the softlifting method (BCA, n.d.) to lift the Glulam beams and CLT panels. This ensured that the beams and panels are assembled safely without causing harm to them or cause any dirt during the process of assembly.

![Image: Soft lifting sling method during assembly](image)

Figure 3.20: Soft lifting sling method during assembly

5.4.3 Training of workers

Singapore is still new in engaging new technology in our construction sector. In the case of The Wave, the contractor B19 Technologies had to send their workers to Austria for training. There was also a need to bring in overseas specialists to help in the understanding and guidance of the new construction method (MND, 2017). Although more resources than expected are used to train the workers and gain knowledge regarding the new technology and use of MET, it is actually a good investment for the company. B19 Technologies now fully expertise in the area of MET and new technology and in the next project, they can probably get a higher profit ratio as compared to other companies who have yet to gain the knowledge in this new area.

6. JTC LaunchPad @ one-north (Block 81)

6.1 Brief Background

MET was adopted for the construction of Block 81, which is a 3-storey multi-user light industrial building that comprises plug-and-play spaces to support the startup ecosystem. Reinforced concrete (RC) is used to construct the first floor of Block 81. The building structure frames were constructed using Glulam, while CLT was used for slabs. The roof comprised of roof beams of Glulam and steel purlins. Easy onsite assembly translated reduced manpower by 10 to 15 percent, as compared to conventional construction methods. Block 81’s area is 3088 m², and 3.2 m² were completed per day.
6.2 Construction Techniques

6.2.1 First Floor
The first floor was built using RC which was precast before being transported to the site. The use of RC is a durable first storey solution as it acts as a form of support for the structure, and also prevents the foreseeable issue of termites that might occur should the timber be too close to the ground.

6.2.1.1 Glulam & CLT
Timber has an average of 1.5 times the strength to weight ratio as compared to steel. The building structure frames made use of glulam, while the timber slabs used for flooring and ceilings used CLT. Special timber pieces are tailored to the project’s exact specifications and were made under factory conditions in Austria before being shipped over to Singapore. Lengths of timber were then cut to size and glued from end to end, forming laminates. These laminates are glued together along their flat surfaces, and pressure is applied. The resulting glulam beam is then cut to the required shape.
Engineered timber components are joined manually by galvanised nails and screws, while nuts and bolts keep the galvanised steel parts together. Workers need not use large machinery such as heavy-duty tower cranes, but only need to handle smaller equipment such as hammers and electric screwdrivers. Simple machinery such as mobile cranes was used to hoist columns into place.

Figure 4.2: Timber being transported to site

Figure 4.3: Timber slabs cut to the required shape

Figure 4.4: Nails hammered into timber slabs
Acoustic membranes are then laid on the timber slabs.

6.2.1.2 Use of steel

Block 81 was not optimised for MET, but rather was converted from a steel and Bondek design. Thus, it did not solely consist of timber but employed the use of steel in certain parts of the structure, such as the roof of the building and some crucial structural beams.

Steel tension cables and steel purlin were used instead of CLT roof slabs.
6.2.1.3 External Finishes

Wood beams and columns inside the building are exposed to add to the aesthetic value. Also, to protect the wood from Singapore’s humid and rainy climate, the exterior of the building is covered with dry board and metal cladding. The exterior is painted over in yellow and grey.
6.3 Challenges in Construction of JTC Launchpad

6.3.1 Complicated planning required

Block 81 proved to be a challenge to design and construct as MET construction is not common in Singapore, and those working on the project do not have much experience in timber construction. Thus this led to the structure designed to accommodate the differences in strength to weight ratio. Especially for a humid climate and environment like Singapore, this project has not been done before much and people, such as workers, do not have the relevant experience in that specific trade. There was found to be an M&E services clash, which had to be properly planned and executed in order to prevent problems in the future stages of the project.

6.3.2 Costly

As Singapore does not have any natural sources of timber, we are required to import timber from Austria. The timber used in this case study as mentioned earlier was Glulam and CLT which was obtained and specially manufactured in Austria before being exported to Singapore. There were also additional costs for the transportation of the material to the construction worksite.

In addition, as the method of building with timber is relatively unknown in Singapore, there are extra costs for example, machinery and cost of training workers.

6.3.3 Singapore Regulatory Requirements

Since this technology is relatively new, Singapore has restrictions on what can and cannot be built. There are regulations set out by the Singapore Civil Defence Force (SCDF) that may deter the construction industry from using timber for their construction. For example, for healthcare buildings, the habitable height of a timber constructed building cannot exceed 12 metres. The use of engineered timber for elements of the structure shall be permitted only for areas above the floor slab of the ground floor. Another regulation set out in the SCDF fire code is that the ground floor slab and basement floors are not to have elements of the structure constructed using MET (SCDF, 2016).
6.3.4 Durability of timber

Different types of timber are more resistant or susceptible to fungal decay and insect attack. This often happens when the moisture content is above 22 percent for a prolonged period of time - which can be due to weather, defects in the building design or poor maintenance, thus allowing the moisture to build up (STA, 2011).

6.4 Solutions Adopted in Block 81

6.4.1 Using Building Information Modelling (BIM) to overcome challenges

Technology such as BIM was used in this project to ensure proper coordination and higher effectiveness. For the MET specialist, competency in BIM is key. A structural model is first constructed and its timber specifications and measurements are defined. It is then inputted into the BIM software. The architects first construct single component drawings using hsbCAD, and it is combined with the structural model to form the main design. This helps to prevent clashes in design, structural systems and engineering systems, and it also helps team members who may not have much experience in MET to better understand the project.

There was found to be an M&E clash in the designing stage of the project, and this was detected through the use of BIM coordination. As the project was still in its early stages before construction, M&E engineers and the architect agreed to lower all M&E services to avoid any clashes with timber beams.
Therefore it can be seen that many problems can be avoided through the use of technology that allows team members to see an overview of the entire structure and discover issues before they are being constructed.

6.4.2 Continual Research and Development (R&D)

Continuous lab testing has to be done in order to keep tackling the weaknesses of timber and to make it a more feasible material for use in Singapore. Due to Singapore's hot and humid climate, timber is not seen as one of the main choices when it comes to the construction of buildings. Timber is also subject to various regulations in Singapore since it is a relatively new material that is not widely researched and experimented with in Singapore. Thus, it is important to continuously discover methods of dealing with issues such as fire and termite infestation issues.

One of the main concerns of using timber in any structure is its susceptibility to ignitability, heat release and flame spread. Although timber is a combustible material, it is also a fire-safe material. While burning, wood chars evenly at a speed of about 0.7 mm per minute, thus its load resistance and liability to collapse can be accurately and precisely predicted. Research is currently being done to determine the best structural fire-resistance period. It is achieved with structural protective cladding, also take charring into account. Cavities in the structure can also be filled with non-combustible insulation material, which protects the wood structures and slows down the charring of the wood.
Timber is also constantly being improved in termite reduction. Venturer Timberwork, the timber consultant of Block 81, have performed blind, 3rd-party laboratory and field termite testing on engineered spruce (CLT/Glulam) to EN 118 using an aggressive local termite species *Coptotermes gestroi*. Precast to timber is a durable solution for the first storey of the building to prevent termites.

Multiple products were tested to determine efficacy against local termites in local conditions with imported spruce, *Picea Abies* (a species of wood). The termites were unable to survive and feed off the treated spruce. FRIM field tests of treated CLT located in termite infested soil showed active termites on the surface, but no trace of attack after 16 weeks.
7. Nanyang Technological University (NTU) Academic Building South (ABS) Building

Figure 5: Proposed model of ABS Building

7.1 Brief background

NTU is in the midst of constructing Asia’s largest wooden academic building. This is a six-storey academic building designed by Toyo Ito & Associates Architects in collaboration with RSP Architects Planners & Engineers (Pte) Ltd. It has a floor area of 40,000m². The building is the first of its kind to be constructed using mass-engineered timber (MET). The building will be constructed using a mixed combination of both Cross-Laminated Timber (CLT) for slabs and Glued Laminated Timber (Glulam) for beams and columns.

The materials are procured from renewable forests and prefabricated before being installed on site, making it less polluting and requiring less manpower than traditional construction methods. One prominent feature will be the fully exposed MET concept, whereby there will be an absent of false ceilings to cover the building services. The expected date of completion will be at 2021.

We have chosen NTU ABS building as one of the case study to investigate if there are any changes to the construction of MET building in Singapore compared to previous MET building projects.

7.2 Materials

The NTU ABS building will be built mainly using MET. RSP Architects Planners & Engineers (RSP) has conveyed to us that they have chosen Glue Laminated Timber (Glulam) to be used for columns and beams. Cross-Laminated Timber (CLT) will be used for floors slabs. Reinforced concrete (RC) will be used for the foundation, the building core structure, and the essential escape provisions. Usage of materials other than the mentioned Glulam, CLT, and RC was not disclosed to us.

MET was stated to be chosen for the numerous benefits it may provide to the project. Such as off-site prefabrication that can lead to lesser manpower requirement as compared to traditional construction methods. Another benefit is the positive environmental sustainability contribution that MET provides, such as having a lower carbon footprint and net carbon emission when compared to steel or RC buildings. Lastly, MET has a higher strength-to-weight
ratio compared to concrete. Leading to lower loads acting on the foundation and the need for distribution of loads. Furthermore, being lighter and stronger, MET may be easier to build with compared to steel or concrete. While there are benefits for using MET, it is considered a relatively new construction material in Singapore (Tradelinkmedia, 2018). Thus, there is still a lack of expertise in using MET. RSP will be working with its partners to address challenges faced to ensure requirements are met (Tradelinkmedia, 2018).

7.3 MET sources and production

RSP has mentioned that they will not impose restriction on the sources and production of the MET. They have however stated that the MET supplied has to be tested to meet the BS EN 14080 (Glulam) and BS EN 16351 (CLT) standard. The MET members will also have to be tested and certified on all fire performance tests by Singapore Civil Defence Force (SCDF) Accredited Certification Bodies to ensure the safety and performance condition of the MET members.

7.4 Construction Techniques

7.4.1 Demolition of previous building

The NTU ABS building is to be built on the site where the previous NTU innovation centre reside at 50 Nanyang Avenue, Singapore 639798. The old NTU innovation centre is currently undergoing demolition works to prepare the site for the NTU ABS building. The demolition work is expected to be completed by the end of 2018.

7.4.2 Foundation

It has currently been planned that the NTU ABS building will be supported by RC pile foundation. The RC pile foundation will be casted in-situ. RC pile foundation was adopted by RSP is due to compliance with Singapore fire regulation which has stated that MET may be used only for areas above the floor slab of the ground floor. Structural elements below the the ground floor slab should not be constructed using MET elements.

7.4.3 Basement Structure

A basement will be constructed for the NTU ABS building. It has not been disclosed what will be the uses of the basement. The basement will be constructed using RC. While there has yet to be an appointed contractor, we were informed by RSP that the basement will be constructed in-situ along with the 1st-floor slab above the RC pile foundation.

7.4.4 Material Handling and Mechanisation

During the construction of the foundation, basement and the 1st floor slab, concrete will be used. Concrete may be supplied through concrete batching plant found near the site or supplied and delivered using concrete mixer truck from a supplier. The building core will be precast off-site and delivered to the site when they are required. The building core will contain staircases and toilet cluster. The choice of lifting equipment has yet to be decided. The MET
members will be prefabricated and planned to be delivered following a just-in-time approach. The MET members will likely be stored off-site for most of the time, and only delivered when they are required. Due to moisture being a concern, RSP has mentioned that they will require the contractor to protect the MET during delivery, storage and construction stages to avoid any damage to the timber surface. Measures taken to minimise the effects of rainwater includes, daily sweeping of standing water; minimising exposure to weather through planning; installation of temporary rainwater drainage pipe (RWDP); and reviewing of moisture content prior to finish application. Since the MET members will be prefabricated, there will also likely be instances of repeated designs and dimensions. RSP has proposed the usage of identification methods such as radio-frequency identification (RFID), printed barcode, printed QR code to identify each MET members. The exact choice of identification method will be decided by the to-be-appointed MET specialist contractor.

7.4.5 Core structure
The building’s core structure will be constructed next after the completed construction of the basement and 1st floor ground slab. The components of the core structure will be precasted off-site and delivered to the site for construction. The core structure will include staircases and toilet clusters. It will also be used as the essential escape provision.

7.4.6 Superstructure
MET will be used as the primary building material for the superstructure. Glulam will be used for columns and beams while CLT will be used for floor slabs. The designers for the NTU ABS building wishes to bring to reality an architectural vision called fully exposed MET. As such, they plan to not have any false ceilings to hide the building services.

The designers have also suggested an innovative layout that alternates long and short span grids. They have found that this layout one of the best for an education building where there are lecture theatres, seminar rooms and corridors need to access them. Having a short span in some parts will lead to having a shallower beam depth, allowing for spaces between these beams to house MEP services. It will also ensure that the building does not exceed the height restrictions for the site.

It has been reported that the designers may be attempting to hide all connections between load-bearing beams and columns to realise their architectural vision of a fully exposed MET (BusinessGhana, 2018). Moreover, Aurecon, a consultant firm, has suggested that they have come out with some plans to improve the buildability of the building while ensuring that the connections between members are embedded within the timber (BusinessGhana, 2018). It has been further explained that this form of embedding connections within the MET members may also protect it better from fire (BusinessGhana, 2018).

However, there is still a lack of information on what the joints and connections will be as we have asked RSP about how will each building element be connected. RSP responded the project is currently under design development stage, and they do not wish to restrict the type of structural connections to be used by the contractor. BCA has suggested that for modern MET structures, it will use large dowel type connections with steel plates for Glulam members. For CLT connections, BCA has suggested using screws and nailed brackets. The connection between RC and MET members can be done using steel plates and connectors.
7.5 Mechanical, Electrical and plumbing (MEP) services for NTU ABS building

RSP has suggested that MEP services will be planned and coordinated at the early design stage to avoid the penetration of MET structures. There will be no service penetration at Glulam columns and beams, and they aim to minimize services penetrations at CLT slabs.

Existing features of The Wave may also be incorporated into the ABS design which includes energy-saving LED lighting and solar powered systems, natural wind and solar ventilation, and special air-pocketed external walls (Gaia Discovery, 2018). The special air-pocketed external wall is a design where a pocket of air will be designed in between two wall layers. It will insulate the building from heat in hotter days (Gaia Discovery, 2018).

These features that may be included will also have to be accounted for during the early design stages. The early planning and coordination between stakeholders in the early design stage will reduce the occasions where openings for MEP services that need to be manually opened on site. These on-site opened holes will have to undergo treatments to protect it from termites and UV light. Furthermore, fire requirement and structural integrity will also have to be checked to ensure that when these holes are cut open, they will not undermine the safety of the structure.

To accomplish this feat, Aurecon has suggested for a ‘services highway’ to be incorporated into the design (BusinessGhana, 2018). ‘Services highway’ is a channel to house all services along the corridors of short spans. The services will then branch into the long span areas where lecture halls reside (BusinessGhana, 2018).

7.6 Challenges in Construction of NTU ABS

While the NTU ABS building has yet to be constructed, RSP has listed out several challenges that they may experience during the project.

7.6.1 Specification of the suitable type of timber

Choosing the type of timber may be challenging due to Singapore having a tropical climate. Compared to other overseas MET projects, having a different climate may make the choice of timber challenging because of Singapore relatively higher humidity level and our abundance of rainfall. Being a timber product, MET remains susceptible to moisture during construction and thus have to be sheltered with care during this period.

7.6.2 Finishing

How should the MET members be finished can be challenging as a timber surface will need to be cared for properly during operation period against fire and moisture. It also needs to be considered for acoustic purposes as the building will be used for education. Hence, the choice of finish to meet these requirements may be challenging to RSP.

7.6.3 Structure

While there have been successful MET projects overseas, NTU ABS building will be one of the first in Singapore. Being the pioneer, there is a lack of knowledge on how it should be built.
7.6.4 Fire protection

MET has been shown to be able to meet fire safety requirements with the use of charring method. However, there still remains a need to protect MET from the fire. While RSP has not explicitly stated why they found fire protection a challenge, it may be inferred that it may be due to numerous fire regulations that they have to comply to. To increase fire protection for MET, RSP has suggested implementing additional measures. Exposed timber will be designed to act as additional 'sacrificial' timber to protect the inner material from damage when exposed to fire. Protection will be installed to conceal the fixing plates and bolts of MET structure. A full building sprinkler system, water monitoring system, dry risers, hose reel, fire extinguishers, exit lights, fire exit staircases, fire engine accessway and fire hydrants will be also built and installed. The external facade of the building will be protected with a deluge system or other effective suppression system to prevent vertical fire spread.

7.6.5 Termite protection

Although RSP did not explicitly state why termite protection is a challenge to them, we may infer it as due to MET as a timber product is prone to termite infestation. Furthermore, the various precautions that they have taken to reduce that risk. RSP has revealed to us some their mitigation plan by constructing the foundation, basement and 1st storey ground slab in RC material, it is thought to be able to prevent subterranean termites attack. The soil will also be subjected to anti-termite treatment and regular termite inspection. The MET members will also be treated during production for protection against termites, insects, fungal attack, moisture and UV.

7.6.6 UV and moisture protection

RSP has not explicitly stated why UV and moisture protection is a challenge. However, it may be due to its inherent property where when exposed to moisture over a period of time, MET may mold and rot which could undermine structural integrity. To improve UV protection, other than being treated during production, the MET members will be sheltered off-site and delivered following a JIT approach when they are needed for construction. This is to reduce the instances where the MET members will be exposed to UV. Moisture protectives will also follow the JIT delivery approach to reduce exposure to moisture. Other measures such as the installation of RWDP, daily sweeping of standing water, and review of moisture content prior to finish application are also adopted.

7.6.7 Acoustic treatment

Due to a need to meet the certain acoustic requirement, RSP has suggested that acoustic treatment may be provided above or below the CLT slab to prevent transmission of noise. Rockwool and plasterboard will also be installed at the underside of CLT to address the acoustic concern.

7.7 Lesson Learnt

There are several lessons that had been learned from the NTU ABS building case study.

Firstly, due to fire regulations, NTU ABS building has adopted the usage of RC ground floor slab. Similar to other case studies that have been done on MET buildings, an RC ground floor slab has been used. The rationale behind it was to create a barrier between the MET elements
and the ground, reducing the occurrence of termite infection.

Secondly, CLT will be used for floor slab and wall elements, and glulam to be used for column and beam. The usage of this different MET elements in different structural area are also found in other case study such as Forte Living. The MET elements used in this manner can be attributed to their material properties.

Thirdly, MET protection has been adopted to shield it against fire and moisture. For fire protection, an active sprinkler system within the building and a deluge system for the building exterior. The adoption of an active system has been seen in other case studies. However, NTU ABS building seems to be the only case study that will install a deluge system for the exterior of a MET building. From what we understand from RSP, the installation of the deluge system is to comply with the fire regulation as they wish to expose the MET elements. For moisture protection, NTU ABS building has similarly adopted a JIT approach in delivering of MET elements to reduce exposure to moisture. They have also taken a more active approach in dealing with moisture on-site, such as sweeping of standing water, checking of moisture content and installation of RWDP.

Lastly, the implementation of a ‘service highway’ to reduce the openings of holes for services in MET elements. While other case studies have also pre-plan and pre-cut service holes in MET element during production, they did not specifically mention to arrange MEP services in such a way that it forms a ‘service highway’.

8. Forté Living

8.1 Brief background

Forté Living located at Victoria Harbor in Melbourne, Australia, was held the record of the world’s first tallest timber residential building with the height of at 32.2 m and gross floor area of 2431 m² in 2012, but this was overtaken by Treet (The Tree) constructed in Norway in 2015. The building comprises of ten stories, in which 9 storeys in CLT sit on top of a concrete podium while the ground floor is used for retail space.

It is made up of only 3 apartments on each floor and a total of twenty-three rooms include 7 one-bedroom apartments (59 square metres), 14 two-bedroom apartments (80 square metres) and two penthouse apartments with two-bedrooms (102 square metres). It was designed and developed by Lend Lease in 2012. This development is constructed from CLT using a total of 758 CLT panels of European spruce (picea abies). These materials are procured from CLT manufacturer KLH Massivholz in Austria and then being shipped to Australia.

Figure 6: Artistic impression and Actual Forté Living Apartment Building
8.1.1 Floor Plan of Forté Living

The development comprises of 9 level with the ground floor used for retail purposes, followed by similar floor plan for the subsequent 7 levels and unique floor plan layout for level 8 and 9 respectively.

Figure 6.1: Floor Plans
8.1.2 Building Section View of Forté Living

8.1.3 Forté Living Project Achievements

The success of the project lies with the time savings of 30% in on-site time over the use of concrete as the base material. According to Land Lease (2013), they reported that CLT construction of every floor took about 1 week, which involved the manpower deployment of 5 skilled workers, 1 supervisor and 1 trainer to be deployed onsite.

In addition, during the construction stage, Forté reduce delivery truck trips to site by 90% with the use of CLT, unlike concrete construction where many trucks are needed to be deployed throughout the day. The project relies on only one load of CLT per day to make the construction schedule. Furthermore, the use of CLT omits the need for delivering rebar for concrete casting, which plays a part to improve onsite noise and air quality.

Besides enhancing the productivity rate, this project further proof that CLT can be used as an alternative material choice for the structural component of the building. The lighter weight associated with CLT allows fewer and smaller pilings needed to reach the bedrock, which can incur a big cost saving as well as a reduction of excavation unexpected obstruction risks.
8.2 Construction Methodology

8.2.1 Construction Timeframe of Forté Living

According to Land Lease (2013), the construction of Forté Living took a total of 11 months from February to December 2012 instead of a typical 14 months with the use of concrete as the main material.

<table>
<thead>
<tr>
<th>Table 2: Construction timeline of Forté Living</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Timeline of Forté Living</td>
</tr>
<tr>
<td>February 2012</td>
</tr>
<tr>
<td>June 2012</td>
</tr>
<tr>
<td>August 2012</td>
</tr>
<tr>
<td>December 2012</td>
</tr>
</tbody>
</table>

8.2.2 Construction Sequence of Forté Living

The construction method adopted by Forté is based on a bottom-up approach. The foundation of the development was built first before the construction of the superstructure components. Below comprises of a detail construction sequence of the development:

1) Pilling was carried out first. Due to timber being a lightweight material, pilling did not require to go as deep.
2) Construction of the ground floor and first storey floor slab. Hardened concrete quick dry flooring will form the base substructure layer.
3) Once concrete had set, CLT panels will be transported from the storage area to the construction site.
4) Selective CLT panels such as vertical stair and lift cores panels were first erected
5) Once cores panels are in place, subsequent panels were placed on their sides to form internal and external walls to form a box construction. These include the installation of story-height wall panels, followed by floor panels and prefabricated bathroom was installed to complete each floor.
6) All panels that were raised to their final position and being connected together with screws and metal brackets.
7) At certain locations where a long span was required such as balcony doors, glue-laminated timber beams were used to help span the openings.
8) The process was step-repeated until the full height of the building was reached
9) The roof was constructed in the same way as each of the floors
10) Finally, the exterior cladding was applied, followed by the removal of the scaffolding and screen.
8.2.3 Construction Floor Cycle of Forté Living
Each floor was being erected according to a 6-day cycle in order to ensure that CLT panels erection and installation able to meet the stipulated deadline of within 2 months.

Table 3: Construction sequence of Forté Living

<table>
<thead>
<tr>
<th>Day</th>
<th>Types of Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0:</td>
<td>Level 1: RC Slab Completed</td>
</tr>
<tr>
<td>Day 1:</td>
<td>First Panel - Lift Core Erected</td>
</tr>
<tr>
<td>Day 6:</td>
<td>Level 1: Walls and Podium</td>
</tr>
<tr>
<td>Day 7:</td>
<td>Level 2: Floor</td>
</tr>
<tr>
<td>Day 13:</td>
<td>Level 2: Floor Completed</td>
</tr>
<tr>
<td>Day 14:</td>
<td>Level 3: Floor</td>
</tr>
<tr>
<td>Day</td>
<td>Level</td>
</tr>
<tr>
<td>-------</td>
<td>---------------</td>
</tr>
<tr>
<td>20</td>
<td>Level 3: Floor Completed</td>
</tr>
<tr>
<td>21</td>
<td>Level 4: Floor</td>
</tr>
<tr>
<td>27</td>
<td>Level 4: Floor Completed</td>
</tr>
<tr>
<td>28</td>
<td>Level 5: Floor</td>
</tr>
<tr>
<td>34</td>
<td>Level 5: Floor Completed</td>
</tr>
<tr>
<td>35</td>
<td>Level 6: Floor</td>
</tr>
<tr>
<td>41</td>
<td>Level 6: Floor Completed</td>
</tr>
<tr>
<td>42</td>
<td>Level 7: Floor</td>
</tr>
<tr>
<td>48</td>
<td>Level 7: Floor Completed</td>
</tr>
<tr>
<td>49</td>
<td>Level 8-9: Floor</td>
</tr>
<tr>
<td>60</td>
<td>Level 8-9: Floor and Roof Completed</td>
</tr>
</tbody>
</table>
8.2.4 Construction Sequence Overview of Forté Living

Figure 6.5: Reinforced Concrete Foundation

Figure 6.6: Construction of Structure Core

Figure 6.7: Construction of Level 1 CLT Panels around Structure Core and Formation of Load-Bearing wall (LBW)
Figure 6.8: Installation of Level 1: CLT Panels (Left to Right Sequence)
Figure 6.9: Installation of Level 2 CLT Panels and Formation of LBW (Left to Right Sequence)

Figure 6.10: Extension of Structure Core for Level 3 and Above
Figure 6.11: Installation of Level 3 CLT Panels and Formation of LBW (Left to Right Sequence)
Figure 6.12: Installation of Level 4 CLT Panels and Formation of LBW (Left to Right Sequence)
Figure 6.13: Installation of Level 5: CLT Panels and Formation of LBW (Left to Right Sequence)

Figure 6.14: Extension of Structure Core for Level 6 and above
Figure 6.15: Installation of Level 6 CLT Panels and Formation of LBW (Left to Right Sequence)
Figure 6.16: Installation of Level 7 CLT Panels and Formation of LBW (Left to Right Sequence)
8.3 Materials

The building uses 759 CLT panels of European spruce (picea abies), these type of CLT material was considered as non-durable i.e. Class 4 timber. Below summarises the types of timbers material used for this development:

![Figure 6.17: Installation of Level 8 & 9 CLT Panels and Formation of LBW (Left to Right Sequence)](image)

![Figure 6.18: Completion of Forté Living](image)

<table>
<thead>
<tr>
<th>Types of Timbers used for Forté</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exterior</strong></td>
</tr>
<tr>
<td>Decking:</td>
</tr>
<tr>
<td><strong>Interior</strong></td>
</tr>
</tbody>
</table>
Flooring: CLT - European Spruce
Internal Paneling: Shear Walls - CLT - European Spruce
Featured CLT wall - European Spruce
Architrave: Timber (finger jointed pine)
Doors: Timber - solid core fire doors to entries, and hollow core to interior
Joinery Cabinetry: HMR Board
Interior Stairs: Fire stairs: CLT - European Spruce
Penthouse apartments: Victoria ash
Interior Rails Balustrades: Penthouse apartments: Victoria ash

Apart from timber material, the development uses a wide range of materials. Concrete was used substantially throughout the construction of the development in areas such as base slab, columns, walls - first floor slab and also low concrete screeds was used for the purpose. Furthermore, the external facade comprises of windows that are made up of glass in aluminium frames and the use of external cladding. Finishes in the apartment comprise of plasterboard for the walls and ceiling and low shrink concrete screed and a rubber-like layer for the purpose of soundproofing the flooring.

### Table 5: Material Requirements used by Forte

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm thick Unroll</td>
<td>1503</td>
<td>m²</td>
</tr>
<tr>
<td>200mm hollow block wall</td>
<td>273</td>
<td>m²</td>
</tr>
<tr>
<td>164mm stud wall</td>
<td>361</td>
<td>m²</td>
</tr>
<tr>
<td>Alubond</td>
<td>1478</td>
<td>m²</td>
</tr>
<tr>
<td>Shotcrete reinforcement</td>
<td>83.24</td>
<td>tonne</td>
</tr>
<tr>
<td>CLT, 090 mm thickness, 3 layer</td>
<td>47</td>
<td>m²</td>
</tr>
<tr>
<td>CLT, 094 mm thickness, 3 layer</td>
<td>48</td>
<td>m²</td>
</tr>
<tr>
<td>CLT, 095 mm thickness, 3 layer</td>
<td>343</td>
<td>m²</td>
</tr>
<tr>
<td>CLT, 129 mm thickness, 5 layer</td>
<td>379</td>
<td>m²</td>
</tr>
<tr>
<td>CLT, 129 mm thickness, 5 layer</td>
<td>379</td>
<td>m²</td>
</tr>
<tr>
<td>CLT, 149 mm thickness, 5 layer</td>
<td>597</td>
<td>m²</td>
</tr>
<tr>
<td>CLT, 149 mm thickness, 5 layer</td>
<td>2575</td>
<td>m²</td>
</tr>
<tr>
<td>CLT, 158 mm thickness, 5 layer</td>
<td>90</td>
<td>m²</td>
</tr>
<tr>
<td>Conrete, 15MPa, including lh 70 mm screed and flooring</td>
<td>110</td>
<td>m²</td>
</tr>
<tr>
<td>Concrete, 40MPa</td>
<td>552.4</td>
<td>m³</td>
</tr>
<tr>
<td>Concrete, 50MPa</td>
<td>24</td>
<td>m³</td>
</tr>
<tr>
<td>Gazing, double</td>
<td>687</td>
<td>m³</td>
</tr>
<tr>
<td>Gypsum</td>
<td>1.68</td>
<td>m³</td>
</tr>
<tr>
<td>Gresel</td>
<td>192</td>
<td>tonne</td>
</tr>
<tr>
<td>Hebel autoclaved concrete panels</td>
<td>252</td>
<td>m³</td>
</tr>
<tr>
<td>LDPE film</td>
<td>395</td>
<td>kg</td>
</tr>
<tr>
<td>Glass wool insulation</td>
<td>100</td>
<td>m³</td>
</tr>
<tr>
<td>Plasterboard 13mm</td>
<td>9380</td>
<td>m³</td>
</tr>
<tr>
<td>Plasterboard 16mm</td>
<td>3910</td>
<td>m³</td>
</tr>
<tr>
<td>Sand, at Mine</td>
<td>36.08</td>
<td>tonne</td>
</tr>
<tr>
<td>Structural steel</td>
<td>5.02</td>
<td>tonne</td>
</tr>
<tr>
<td>Window frame, aluminium</td>
<td>120.6</td>
<td>m²</td>
</tr>
</tbody>
</table>

8.3.1 Preparation of CLT Panels

Each CLT panels will be cut to specific dimensions using AutoCAD drawing. It relies on a CNC router that uses a computer-guided saws and drills that forms the panel to its final shape. During this stage, opening for doors and windows and channels for electrical wiring and other services were being cut into the panels.
8.4 Construction Technologies

Below comprises of the construction technologies aspect in the construction of Forté Living.

8.4.1 Foundation

The building structure stands on deep driven PC piles (30m) with raft concrete slab foundation. All forces and loads are transferred between the timber elements at each level down to the concrete podium.

8.4.2 Structural System

The ground and first floor were constructed from geopolymer concrete due to the larger spans required in the retail space and with a design purpose of isolating timber from the ground. The first storey of the building made up of a concrete frame and a transfer slab, while the rest of the apartments such as the structure’s load-bearing walls, floor slabs, staircase and elevator cores are composed entirely with CLT element panels.

![Figure 6.19: Structural System of Forté](image)

Furthermore, CLT panels will be able to withstand the structural loading due to double spanning members of floor slabs and shear walls.

8.4.2.1 Structural System Tests

The entire structure has undergone lab and prototype testing to determine structure stability and disproportionate collapse so that in the event whereby any of the load-bearing walls were compromised, it will not potential affect the structure stability of the above or below.

In addition, the design of the walls and floors was based on evaluated European test data and computer simulation.

![Figure 6.20: Overview of Connection of Prefabricated CLT panels](image)

8.4.3 Wall System

All internal walls are classified as load-bearing shear walls. The walls are built from 5 layers of
128 mm thick panels with one layer of gypsum board directly affixed from level 2 upward. In between residential units, a total of three layers of gypsum board are used with a furring wall for additional acoustic performance and a single layer of gypsum board used on the opposite face. Internally, a portion of the CLT is left exposed to be used as an interior wall finishes also known as the feature wall. The feature wall comprises of highest grade panels based on a careful selection in terms of aesthetic quality and finishing. Aside from wall finishes, CLT is also being left exposed on the balcony ceiling as well as the main stair tower.

**Figure 6.21: Balcony with Exposed CLT**  
**Figure 6.22: Interior Exposed CLT**

### 8.4.4 Floor and Ceiling Systems

The floors are made up of 5-layers of 148mm thick of CLT panels with additional layers applied on both top and bottom to achieve a 90-minute fire rating from level 2 upward. Under the CLT floor decks, suspected ceilings with acoustic insulation are used with 2 additional layers of gypsum board directly attached to the CLT. At the top of the CLT floor decks are a vapour barrier that made up of 70mm layer of screed and finishes wood flooring. Structurally, 3 layers of CLT panels can support the building, but 5 layer panels were selected so that the outer layer can burn-through without affecting the load-bearing capacity of the structure.

**Figure 6.23: Cross Section of CLT Floor**  
**Figure 6.24: Installation of Insulation at CLT Panels Base**

### 8.4.5 Lift Core

The elevator is made up of a timber shaft build using CLT. Plates with studs attached were installed from outside of timber shaft and standard lift brackets were then installed inside onto the studs. Metal door frames and lift doors were used together with timber shaft with coach
bolts.

While conventional thinking that escapes routes such as lift shaft and staircase, should be in concrete, Forte has chosen timber instead. Although the lift and fire shafts are made of timber, they are made with a design called “Double boxes”, where one timber box-like structure is enveloped by another timber box. It will improve the fire protection capabilities of the lift shaft as an additional layer of timber is used to enveloped it, which can be understood as using the additional layer of timber as 'sacrificial wood'. Due to the predictability of how a MET may burn over time, an approximate 0.7mm/min rate, and the emergence of the charred layer, it will prevent the inner box from further heating.

Figure 6.25: Internal view of CLT elevator shaft

8.4.6 Staircase

The fire staircase and stairwell incorporate natural lighting with nearly full-height windows at one end as well as natural materials including the fully exposed CLT panels as finish material and a linoleum floor. The stairs also incorporated internal fire systems such as sprinklers, hose reels, or internal hydrants.

Figure 6.26: CLT Stairwell
Figure 6.27: Fire Stair and Internal Fire System
8.4.7 Connections

CLT panels are fixed to the sub-structure or between itself using engineered timber wood screws and steel brackets, which allows CLT panels to be stacked as a platform on top of each other. According to Land Lease (2013), in total 5,500 metal brackets and 34,550 screws were used in the construction of the entire structure.
Floors and walls are connected using angled steel connection plates then fastened with screws. The usage of screws and plates compared to welding is that the MET elements will not be put at risk of being damaged during the process of welding as the wood product might catch on fire. It is a form of connection that improves the shear force resistance of the MET panels, a tie down method. As the designers have chosen to use a panelised system to construct Forte, it does not follow the common column and beam system. It uses prefabricated MET panels to form fixed walls that are suitable for residential homes layout which is similar for every storey. The usage of penalised system will result in less flexibility in customization and changes after the project is completed, as each panel may be considered a structural element.
8.4.8 Formwork
Scaffolding surrounded with dust protection sheet was used during the construction of the development.

Figure 6.33: Dust Protection Sheet Surrounded Scaffolding

8.5 Internal and Exterior Features of Forté Living

8.5.1 Internal Features
Within the development, prefabricated bathroom units (PBU) was adopted for the apartment bathrooms. The purpose of using PBU was to simplify systems integration and increase the building assembly process. Project Modular in Brisbane was responsible in prefabricated these PBU off-site from light gauge steel and delivered as a single modular component to onsite for installed at a scheduled time. PBU was sealed and not opened until construction was completed.

Figure 6.34: Modular Bathrooms used in Forte and Integration of M&E services to PBU

The balconies are constructed by the method of extensions of the CLT flooring of the main structure. Both the balconies and roof are constructed with CLT and have a waterproof membrane finish. The CLT is covered with screed and a waterproof membrane then finished with tiles. The underside of the CLT used on the balcony floor is exposed. With a timber stain and polyurethane seal protecting the timber.

The interiors of the apartments are lined with plasterboard and followed by painting. Each apartment has a featured CLT wall and it is sealed with a clear coat to blend in with the light colours used within the apartment interior. The living areas flooring uses an Australian hardwood blackbutt engineered wood floor.
Internally, the metal framing and insulation and gypsum board were used in the construction of the apartment CLT ceiling.

8.5.2 Exterior Features
The exterior of the building is mostly clad with metal commercial façade consisting of AluBond® and minor parts covered with Lysaght® products and recycled hardwood timber. These exterior finishes provide rain screen protection to the CLT structure.
8.6 Material Handling

8.6.1 Machinery

Below table summarises the types of transportation and construction machinery used for Forte Building. In addition, the purpose of the usage of such machinery is being discussed under the comment section of the table.

Table 6: Transportation and Construction Machinery for Forte Building

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Unit</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavator</td>
<td>35.6</td>
<td>hr</td>
<td>Excavator removes 5 m³ per hour on average</td>
</tr>
<tr>
<td>Gravel</td>
<td>282.2</td>
<td>tonne</td>
<td>200 mm thick layer as road base during piling works</td>
</tr>
<tr>
<td>Rigid truck</td>
<td>1.724E4</td>
<td>tonne.km</td>
<td>Transport of steel beams and reinforcement, plasterboard, window frames, glazing, alubond, glulam, uniroll, and insulation</td>
</tr>
<tr>
<td>Concrete truck</td>
<td>1.74E4</td>
<td>m³.km</td>
<td>Transport of concrete</td>
</tr>
<tr>
<td>Grasmere Maersk</td>
<td>3.498E5</td>
<td>TEU.km</td>
<td>Transport of CLT panels</td>
</tr>
<tr>
<td>Maersk Karachi</td>
<td>6.219E5</td>
<td>TEU.km</td>
<td>Transport of CLT panels</td>
</tr>
<tr>
<td>Transport, lorry 7.5-18t, EURO5</td>
<td>1.541E5</td>
<td>tonne.km</td>
<td>Transport of CLT panels by road</td>
</tr>
</tbody>
</table>
8.6.2 Transportation

All CLT panels were transported from their storage site to the construction site for installation by the lorry.

8.6.3 Lifting Method

Once all CLT panels are being delivered onsite, the panels will be raised and lifted by cranes to its final position. The construction of this development used a total of 84 tower crane - hammerhead crane to move all the prefabricated CLT panels for a period of 14 weeks. Lifting tools such as a ratchet clamp to hold walls together during installation phase and hoisting chains and sling to lift CLT members. During the lifting process, before the connection of each panel, the builder will first adjust to its accurate position before connecting it to the adjacent elements.

According to Mr Michael Clark, Clark Cranes Managing Director commented that “Unlike a traditional concrete panel that you can put props on and drill into if necessary, the CLT’s are facade panels, so the challenge for us was ensuring great care was taken to retain their finished condition.” Due to the presence of 4 luxury townhouses located beside the construction work site, special precaution was taken in ensuring low noise output made evening and weekends.
8.6.4 Storage

No precautions were taken to protect the timbers from weather on-site during the construction stage. As the CLT edges were sealed on-site and the panels were stored in a nearby facility near to the construction site before being delivered and installed onsite. Storage sheds were located more than 10m from the construction site.

Figure 6.40: Markings made on CLT Panels

Figure 6.41: Storage of CLT Panels by Stacking Method

8.7 Services Integration

8.7.1 Mechanical and Electrical (M&E) Works

All plumbing penetrations and mechanical and electrical components are integrated into the PBU modular as well as moulded onto the CLT panels for integration of electrical services, before delivery to the construction site. According to Mr Andrew Nieland, Land Lease Manager commented that CLT being a prefabricated material provides easy integration of services as compared to fixing it into concrete. Once PBU were installed services were installed by a plug-and-play method whereas M&E services and wiring were attached to the false drop down ceiling within each apartment.
8.8 Challenges in Construction of Forté Living

8.8.1 Soil Stratification
During the site investigation, it was discovered that the presence of poor site soil condition, in particularly - Coode Island silt.

8.8.2 Fire Protection
Due to the restriction of Building Code of Australia that does not permit the use of timber as a construction material for building above three stories high, fire safety was a paramount concern.

8.8.3 Material Properties of Timber
Due to the nature of Timber being susceptible to termites attacks and moisture penetration, there is a need to ensure the durability of the use of timber as the main structure element material.

8.8.4 Acoustics and Vibration Concerns
There is a need for both walls and floors to achieve the essential acoustic performance based on Australia current code requirement.

8.8.5 Seismic and Wind Loads Considerations
Given the context that Melbourne Australia is a moderate risk seismic zone and the topography of Melbourne is flat and affected by strong winds from nearly every direction. Consideration such as seismic forces and wind load that may affect the lateral stability of the building was discussed in the design stages.
8.9 Solutions Adopted in Forté Living

8.9.1 Using of Light Building Structure Material

Due to the soil stratification of the site, there is a necessitated for the use of a light structure material. Timber was discussed as an optimal choice. Prior to the construction, multiple structural wood options were considered and undergo several pilot testing on the site development by Land Lease. Eventually, CLT was selected due to the characteristics of it being a lighter alternative construction material and the vast amount of benefits.

8.9.2 Using of Several Fire Protection Methods

Prior to the construction, Lend Lease identified every type of service penetration in the building and the methods of treatment to meet fire safety requirements.

First line of action involves an exhaustive series of full-scale fire tests on different assemblies and building conditions to verify the safety level. Such tests were being conducted on the following items that includes fire doors, unit entries, lift doors, fire dampers, electrical conduit, sprinkler pipes.

Upon the completion of the fire testing over the safety of material and design for a period of six months, Land Lease proceeded with the application of permit to build.

During the construction stage, Lend Lease adopted a combination of protection and sacrificial methods to achieve fire protection to the structure and services installation. The following 3 methods were being adopted by Land Lease:

(i) Provision of Sacrificial Layers and Charring of the Timber Materials
Fire resistance is initially achieved through floor and walls assemblies rely on the use of charring and use of sacrificial gypsum wall board cladding to ensure that the structural components required meet the fire requirement for high-rise building.

The Fire Resistance (FR) is achieved through charring, typically 0.7mm per min.

Materials used as part of this development was accordance to the following charring rates:

<table>
<thead>
<tr>
<th>Layer Configuration</th>
<th>Fire Resistance (FR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 layer wall panels</td>
<td>30min FR (integrity, insulation and thermal)</td>
</tr>
<tr>
<td>5 layer wall panels</td>
<td>60min FR (integrity, insulation and thermal)</td>
</tr>
<tr>
<td>FR of 90min or greater</td>
<td>90min FR or greater with protective cladding such as gypsum board</td>
</tr>
</tbody>
</table>

The fire test was conducted based on the principle of Structural Adequacy, Integrity and Insulation. For this development, 3 scenarios were tested and accepted:

- ** FR 90/90/90: 128mm wall panel with 13mm fire grade plasterboard direct fixed.
- ** FR 90/90/90: 158mm wall panel – bare.
- ** FR 120/120/120: 146mm floor panel with 2 layers 16mm fire grade plasterboard directly fixed.

The exterior walls of Forte are constructed based on the principle of 60-minute fire rating and most interior walls are constructed based on the principle of 90-minute fire rating with the
exception of the stairs and elevator core that were constructed based on the principle of 120-minute fire rating. To achieve 2 hours requirement, the development uses a double layer CLT assembly with a small air cavity in between.

(ii) The connections of the wall panels to floor panels maintain the appropriate fire ratings through by being incorporated within the centre layer of the panel or through being covered by screed / fire grade plasterboard.

(iii) The fire isolated stair shaft and lift shaft used a double shaft system in which each shaft achieves the required fire rating, however each does not rely on the other for structural connection.

(iv) Installation of Sprinkler systems throughout the building.

8.9.2.1 Characteristics of Forte Living Walls and Floors

The walls are generally 128 mm thick of CLT with 13 mm fire resistant plasterboard direct fixed both sides. The bare timber wall used as a feature in the apartment is 128 mm thick of CLT. All required walls achieve the deemed to satisfy fire rating required of FRL of 90/90/90.

The floor is generally 146 mm thick with 2 layers of 16 mm fire resistant plasterboard again direct fixed. The floors again achieve the fire rating required of FRL of 90/90/90.

The external wall uses a combination of fire resistant plasterboard and the char capacity of timber itself and was considered through fire safety engineering analysis to achieve the deemed to satisfy fire rating from the inside but through fire safety engineering analysis for a fire exposure from outside. The outer layer of CLT to one elevation where the building is exposed within 6m of another allotment is thickened to provide the resistance from fire in that direction.

Moreover, site specific requirements was arranged when dealing with timber. This includes the placement of fire hydrant system on operational from when the timber construction commenced, two escape exits were available off the site and no welding occurred within one hour of the end of the day and lastly ventilation penetrations through floors or exterior walls for exhaust use fire-rated dampers to maintain overall structure fire rating.

8.9.3 Protective Measures

8.9.3.1 Durability - Moisture Protection Measures

During construction, finishes were not applied to the timber panels unless it meet the requirement of a dry to between 12-14% of moisture content. A 12%-14% moisture content can be achieved by specifying for kiln-dried timber.

In addition, moisture in the exterior wall assembly was measured prior to the sealing of building and the use of moisture detector sensor rods are strategically located within the CLT panels to monitor façade performance.
8.9.3.2 Durability - Termites Protection Measures

Under the building code of Australia, it is essential for timber structures to be protected from termites. Several termite protection measures taken by Land Lease includes the erection of the CLT structure on a concrete slab of 3.5m height to separate the podium from the ground as well as using chemical free physical termite barriers known as TermiMesh installed between the concrete structure and timber. Lastly, an annual regular inspection will be conducted on Forté building at the various access points.

8.9.3.3 Durability - Weather Protection Measures

To control moisture ingress, a ventilated rainscreen with a metal exterior cladding punctuated at the north facade by wrapping sunscreen. The design of the exterior of the building ensure that the inner CLT skin is protected by interior wall linings whereas the outer CLT skin is protected by polyvinylidene fluoride (PVDF) coating and façade cladding. The cladding panels consist of a 4 mm thick LDPE core with two aluminium sheets of 0.5 mm thickness on either side of this core. A passive ventilation (cavity) draws heat away from the timber. Apart from the facade design, moisture detector sensor rods are also strategically located within the CLT panels to consistently monitor the facade performance throughout the lifecycle of the building.

In order to reduce moisture seepage, waterproof membrane are being placed in between the floor tiles and the screed, and below the screed. The usage of two waterproof membrane could be seen as a two layer defence to prevent moisture seepage from reaching the MET members.

Trims were also found to be used during the construction of Forte. Trim is a form of finishing element that covers openings. Trim pieces can improve a building’s weather resistance, such as against rain and moisture seepage.
8.9.3.4 Durability - Thermal Insulation Measure

To meet the building thermal and vapour performance requirements, a sustainable and “breathable” thermal insulation composite (Polymax absorb HD 50mm Breathable) was used to form a breathable reflective facing. This prevents the accumulation of moisture that enables timber to breathe and protect the structure’s timber shell.

8.9.4 Acoustic Performance Measures

The floors in the living area are constructed using engineered timber, there is a need to achieve a reduction in impact noise consideration. Timber serves as an effective material to block out most frequency of sound waves. The developers uses methods such as adding mass to the floor slabs, concrete screed topping, direct fixed and or resilient mounted
plasterboard and suspended ceiling and resilient mat to improve airborne and impact noise. In particularly, a 70mm thick layer of non-structural cementitious screed and a 10mm rubber-like layer on the CLT floors was adopted to achieve a low frequency vibration performance.

8.9.5 Robust Connection Methods

In order to ensure the structure stability to counter against the imposed seismic and Wind loads, Forte development uses robust connection methods. The development uses a series of heavy duty-bolted connections through timber hold-down connection to the ground floor concrete structure. Connection were based on the principle of timber to timber connection method with the aid of metal brackets, nails and screws. Self-tapping, angled screws along with steel plates were used to secure joints to act as a tie down method. Number of connections increased and the use of hardwood bearing taps at floor panel was used in areas that required a high compression loads.

![Figure 6.47: Reinforce Angle Connectors for CLT](image)

9. Summary of Case Studies

<table>
<thead>
<tr>
<th>Structural System</th>
<th>LCT ONE</th>
<th>NTU The Wave</th>
<th>JTC Blk 81</th>
<th>NTU ABS</th>
<th>Forté Living</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(i) Concrete base</td>
<td>(i) CLT slabs</td>
<td>(i) Precast reinforced concrete (RC) base</td>
<td>(i) Concrete base</td>
<td>(i) Concrete base</td>
</tr>
<tr>
<td></td>
<td>(ii) Glulam columns and beams</td>
<td></td>
<td>(ii) Glulam building structure frames and beams, timber slabs used for flooring</td>
<td>(ii) Column and Beam Structure (iii) Glulam column and beam</td>
<td>(ii) CLT Load Bearing Structure</td>
</tr>
<tr>
<td></td>
<td>(iii) Parallel glulam arches supported by vertical steel A-frames for roof</td>
<td></td>
<td>(iii) CLT ceilings</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(iv) Steel tension cables and steel purlin</td>
<td></td>
<td>(iv) CLT slab</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Summary of case studies
<table>
<thead>
<tr>
<th><strong>Fire Protection</strong></th>
<th><strong>Moisture and Weather Protections</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Provision of sacrificial layers with firestop glass fiber interlayer&lt;br&gt;(ii) concrete core houses staircase and lift shaft&lt;br&gt;(iii) Provision of fire sprinklers&lt;br&gt;(iv) Non-combustible aluminium cladding on the exterior surface of building</td>
<td>(i) Concrete base protect timber from rising damp&lt;br&gt;(ii) Timber elements enclosed within the envelope&lt;br&gt;(iii) Protective sheets, raised platforms and emergency plywood roof for timber on-site protection&lt;br&gt;(iv) Aluminium cladding</td>
</tr>
<tr>
<td>(i) Provision of sacrificial layer&lt;br&gt;(ii) JIT operation</td>
<td>(i) Protection cappings to ensure water tightness&lt;br&gt;(ii) JIT Operation</td>
</tr>
<tr>
<td>(i) Cavities in the structure filled with non-combustible insulation material</td>
<td>(i) Exterior covered with dry board and metal cladding</td>
</tr>
<tr>
<td>(i) Provision of sacrificial layers&lt;br&gt;(ii) Concrete core that house essential escape provision&lt;br&gt;(iii) conceal the fixing plates and bolts of MET structure&lt;br&gt;(iv) Full building sprinkler system, water monitoring system, dry risers, hosereel, fire extinguisher s, fire engine accessway and fire hydrants&lt;br&gt;(v) External facade of the building will be protected with a deluge system</td>
<td>(i) MET elements treated with UV and moisture protections during production&lt;br&gt;(ii) MET members will be sheltered &amp; JIT approach&lt;br&gt;(iii) Installation of RWDP&lt;br&gt;(iv) Daily sweeping of standing water&lt;br&gt;(v) Review of finishes use meet the requirement of a dry to between 12-14% of moisture content&lt;br&gt;(ii) moisture detector sensor rods&lt;br&gt;(iii) ventilated rainscreen with a metal exterior cladding&lt;br&gt;(iv) waterproof membrane are being placed in between the floor tiles and the screed</td>
</tr>
<tr>
<td><strong>Termites Protection</strong></td>
<td><strong>Connections and Joints</strong></td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>(i) Exposed timber elements for easy detection</td>
<td>(i) Ground level columns with flat plate at the bottom are secured to the concrete basement using screws</td>
</tr>
<tr>
<td>(ii) Annual inspection</td>
<td>(ii) Upper level columns have hollow tubes at the top and pins at the bottom that connects with each other.</td>
</tr>
<tr>
<td>(i) Termite testing on CLT/Glulam using an aggressive local termite, Coptotermes gestroi</td>
<td>(iii) Holes at each corner of the slabs connect with tubes from columns or steel angles with pins attached to concrete core</td>
</tr>
<tr>
<td>(ii) FRIM Field tests</td>
<td>(i) Each of halves of the arch split into three separate components, previously joined by temporary connection: combination of full thread bolts and custom made steel plates</td>
</tr>
<tr>
<td>(ii) Anti-termite soil treatment and regular termite inspection</td>
<td>(i) joined manually by galvanized nails and screws</td>
</tr>
<tr>
<td>(iii) Termite treatment during production</td>
<td>(ii) Nuts and bolts keep galvanized steel parts together</td>
</tr>
<tr>
<td>(i) RC foundation, basement, ground floor slab</td>
<td>(i) Connections and joints will be concealed to protect it from fire.</td>
</tr>
<tr>
<td>(ii) RC foundation, RC concrete slab and foundation</td>
<td>(i) series of heavy duty-bolted connections</td>
</tr>
<tr>
<td>(i) using chemical free physical termite barriers known as TermiMesh</td>
<td>(ii) timber to timber connection method with the aid of metal brackets, nails and screws.</td>
</tr>
<tr>
<td></td>
<td>(iii) Self-tapping, angled screws along with steel plates were used to secure joints to act as a tie down method.</td>
</tr>
</tbody>
</table>
10. Proposal for Upcoming BTO Project Incorporating MET

After looking at the case studies, our group would like to propose the use of MET to be used for a future BTO Project.

10.1 Construction sequence

10.1.1 Foundation

For the foundation of the building, we propose the usage of reinforced concrete (RC) using a combined piled raft foundation as seen in the Forte Case Study as seen in figure 7.2 below. With the usage of this combined foundation system, it will be advantageous for a residential building in this case as the foundation system possesses advantages of both shallow and deep foundations. The raft foundation will also act as the ground floor slab of the eventual MET hybrid building. There are other alternatives to the choice of foundation, however, the
focus is that the ground floor slab and foundation should not be constructed using engineered timber for compliance with Singapore fire code. The choice of using RC raft foundation is to utilise its large continuous footing as the hybrid MET building ground floor slab. Having a RC ground floor slab will provide the building with a barrier that prevents underground termite from invading MET elements and affect its structural integrity. The usage of RC was seen in all of the previous case studies.

10.1.2 Core Structure

Building cores will be erected soon after the foundation and ground floor slab work has been completed. The core structure will be made using RC which has been proven workable by LCT ONE and will include staircase and lift shafts. In addition, the household shelters would act as part of the concrete core for the building. While the fire code did not ban the usage of MET for essential escape provision, it has banned the usage of MET element for essential escape provision in buildings that exceed 12m. The core structure may be cast in-situ or precast but precast would be recommended so that speed of concrete core construction aligns with the speed gain from the other prefabricated components. This was a lesson we learned from LCT ONE case study. The core structure will also act as a structural element that transmits vertical and lateral loadings. Steel connectors will be installed during the construction of the core structures to ensure structural connection with the slabs later, further emphasising the hybrid system. The core structure is to be erected first before the MET structure is constructed.

10.1.3 Superstructure

We suggest for the 1st-storey of the building to be constructed with RC. The reasoning for using RC instead of MET elements is due to the usage of the ground floor in a HDB estate. It is commonly found that the ground of a HDB flat will be a place for gathering of habitants. In recent times, commercial stores and kindergartens have also been seen on the ground floor
of a HDB flat. The choice of using RC to construct the ground floor will provide flexibility in the usage of the area.

Learning from case studies, we have found that engineered timber building can be constructed with different structures. For example, loading-bearing wall structure in Forte Living, and column and slab structure in LCT ONE. This flexibility is only possible due to the usage of a hybrid system for the MET building we have proposed.

10.1.4 Column and Slab structures

For this project, we suggest the usage of a column slab system which is similar to LCT ONE. The same structure has also been used in Brock Commons, a 18-storey timber building that was completed in 2017. The suggested choice of a column and slab structure over the load-bearing wall structure is mainly due to the amount of weight a load-bearing wall structure is able to carry. As this will be a tall residential building, more than 50 metres in height, the walls at the lower floors will have to be thicker, which lead to increase material used. Furthermore, the flexibility of usage will also be reduced as load-bearing wall are structural elements and should not be amended at random.

Concrete columns will be constructed after the ground floor slab has cured. The end of the RC column which will support the 2nd-storey CLT floor slab which also consists a steel plate with holes and tubes in the middle of the holes as seen in figure 7.4 below similar to the one used in the Brock Commons timber building. These holes in the steel connector will be fitted with steel connectors that has protruding pins on the underside of the 2nd-storey CLT floor slab.

![Figure 7.4: Steel plates with holes and tubes in the middle](image)

10.1.5 Usage of MET elements

The MET elements that will be used are mainly glulam columns and CLT floor slabs. MET elements will be used starting from 2nd-storey of the building upwards, which will be used for residence. The sections below are incorporated following the methods we have learned from the previous case studies.

10.1.5.1 Core to CLT Slab Connection

CLT slab is supported at the concrete core by steel ledger angle welded to an embedded plate cast into the core walls of the building as seen in figure 7.5 below. This connection withstands the vertical and horizontal shear transfer at the connection point (naturally:wood,2016).
10.1.5.2 Connection of Column to the CLT slab

The column to CLT slab connection consists of round steel hollow structural sections (HSS) fastened to steel plates. Unlike the LCT ONE case study where the steel plate is only at the bottom of the column, for the case of our new BTO project, the steel plates will be connected at the top and bottom of each column using threaded rods epoxied into the column. The smaller HSS at the column base fits into the larger one at the top of the column below. The CLT panels are bolted to the steel plates by four threaded rods. The connections transfer vertical loads directly through the columns only (naturally:wood, 2016). This column slab connection is then sealed with non-shrink grout, and this is injected after a collar-form is made from steel angles. The grouting will need to be cured before the upper level floor slab will be connected on the other end of the column. This is further elaborated by figure 7.6 below.
10.1.5.3 Connection of column to the concrete slab

The concrete slab to column connection is similar to the column to column connection except that the bottom plate is bolted to the concrete transfer slab as can be seen in figure 7.7 below.

![Figure 7.7: Column and concrete slab connection](image)

10.1.5.4 Use of Surface spline and steel drag strap

Each CLT slab will be connected to the adjacent panels with spline. A spline may be installed by having timber splines like the ones in figure 7.8 below that will have its ends connected to the two CLT slabs, nailed and screwed in place to form a connection. After all the CLT slabs are subsequently installed, we suggest a steel drag strap as seen in figure 7.9 below to be used to tie all the panels and reinforce their connection to the concrete core. A steel drag strap may be installed by screwing it to the panels and one end of the steel drag strap bolted at the concrete core.

![Figure 7.8: Spline joinery](image) ![Figure 7.9: Steel drag strap](image)

10.1.6 Interior wall

After the erection of the glulam columns, the interior wall will be erected next. The interior wall panel will be using prefabricated CLT wall panels that have various openings, e.g. door openings, pre-cut during its production similar to the case of the LCT One wall panels. The wall panels may be erected and fixed in place using metal brackets fastened to CLT slabs with nails and screws. Most of the interior wall will be concealed using Type X gypsum boards to protect it against fire. CLT wall panels that are exposed are designed with an additional sacrificial layer to provide protection against fire.
Alternatively, conventional steel stud and gypsum boards may be used in place of CLT wall panels to partition the interior area. Installation sequence is as follows:

10.1.7 Exterior wall

The proposed facade wall would be the LCT ONE system where the perimeter wall will be formed by joining facade panels together. The prefabricated panels would be glulam timber frame with oriented strand board on the interior and fire and humidity resistant fibre cement board sheathing on the exterior as seen in figure 7.10 below. Between the exterior and interior surfaces, mineral wool will be inserted to provide thermal, acoustic and fire insulation. Glulams columns would also be bolted to the interior side of the panels for connection to slabs and other columns. Unlike the system from LCT ONE where the windows are incorporated into the wall panels and transported to the site, we suggest adopting the sub-frame system where the sub-frame will be cast into the wall panels during prefabrication while the main frame will be installed on-site at a later stage of construction to minimise the chances of damage.

Figure 7.10: Prefabricated panels with humidity resistant fibre cement board sheathing

Alternatively to the proposed exterior wall connection, CLT wall panels may be connected to the 2nd level floor slab using angled steel plates that will be fastened to the CLT slabs with nails and screws, a similar method had been used in the Forte case study.

After the exterior wall has been installed, the 3rd-storey CLT floor slab will be subsequently installed. The sequence will repeat itself as the building grows, slab, columns and walls. This can be seen on the pictures below taken from the Forte case study.

Figure 7.11: Transition from 2nd storey to 3rd storey
10.1.8 Laying of insulation membrane and protective covers

As the building continues to be built upwards, and the MET elements in the lower levels begin to rest into their position, insulation membranes will be laid onto the CLT slabs. Insulation membrane such as the damp proof membrane (dpm) will be a form of barrier used to reduce moisture penetrating into the MET slabs. A layer of cement screed will be spread over the dpm to cover it, and the second layer of dpm will be laid above it. Finally, the floor tiles will be laid above it. The usage of two layers of dpm has been done in the Forte living case study and is effective in keeping moisture away from the CLT floor slabs.

Underneath the CLT floor slab, Rockwool insulation will be laid to improve the acoustic environment. A fire-management measure we recommend is to encapsulate the bottom of the CLT slabs with one layer of Type X gypsum boards as well as to slow down the spread of fire to upper stories. We recommend either a 5/8" type X gypsum panels are to be used as they have been proven to be 2- and 3-hour fire resistive partition assemblies (Mac Queen, 1984).

10.1.9 Roof

Steel decking and steel beams will be adopted for the construction of the roof. The structural steel roof assembly will be supported by the glulam columns found on the last level of the apartment and RC concrete core. In particular, the steel beam structure supported on CLT columns and the core.

Steel was chosen because of its durability property as it is not feasible to use timber as a roof material due to the high possibility of damage to the mass-MET superstructure due to moisture seepage and water leakage. This aligns with the usage of steel in the case of JTC block 81 whereby steel tension cables and steel purlin was used in figures 4.7 and 4.8 in section 6.2.1.2 of the report. Although given the higher capital cost initially, it must be noted that in the long term the durability aspect will eventually outweigh the initial cost. During the installation process, it is necessary to ensure material tightness and connections are secured. The same roof structure has also been adopted in Brock Commons Building.

Being a metallic element, steel would need protection against corrosion. Hence, it is important to apply metallic coatings so that the potential of corrosion can be controlled and would not be able to affect the integrity and strength of the product. We recommend both 55% aluminum-zinc alloy (Galvalume™ and Galvalume Plus™), zinc (galvanized) and zinc-iron alloy (galvanneal) coatings for this purpose as they provide a tough, non-porous barrier that does not allow moisture to come in contact with the steel (CSSBI, 2001).

10.1.10 Prefabricated Bathroom Unit (PBU)

We recommend the use of PBU for our residential building after learning from the Forte Living case study. As there is a need to ensure a high standard of workmanship in the area of waterproofing, fully precast concrete volumetric PBU will be adopted as part of the development bathroom. Furthermore, the use of PBU is in line with the Housing Development Board (HDB)’s efforts to improve construction productivity through a greater use of prefabricated units that are assembled off-site and can then be installed on-site thereafter. It is believed that this would drive HDB’s construction productivity on a larger scale, setting it on track to achieve a productivity improvement of 25 percent by 2020, compared with 2010 (Huang, 2017).
PBU walls and floors integrated with finishes, pipes and equipments will be pre-assembled off-site in a factory before it is being transported onsite for installation. As part of this development, full pre-cast concrete PBU will be used. Due to the fact, that MET will be used substantially throughout the development structure, thus it is our utmost concern to ensure water does not leak out of the bathroom and get ingressed by the timber components.

10.1.10.1 Construction Sequence of PBU

The sequence of factory production is as follows:

1. Casting of concrete shell
2. Curing of concrete and storage
3. Laying of waterproofing system to floor and wall
4. Tiling
5. Installing finishes and fittings
6. Quality checks
7. Completed unit
10.1.11 Prefabricated Kitchen Unit (PKU)

The concept of PBU as mentioned earlier has evolved over the years and has led to the creation of the prefabricated kitchen unit (PKU) as seen in figure 7.15 below. The PKU is mainly used in residential projects such as holiday resorts, apartment hotels, student accommodation and residential housing which is in this case the exact same type of building the group has proposed for. The PKU can be manufactured from reinforced concrete or galvanised steel (Eurocomponents, 2018). We recommend the development’s kitchen will be constructed with concrete so as not to expose any timber elements to open flame. Furthermore, concrete would also allow help the residential building to attain better fire and acoustic ratings. It must be noted that the use of PKU would also allow for high quality finish due to the possibility of in factury quality control and testing. This method eventually leads to an increase in speed in traditional construction and could even reduce or eliminate highly skilled workers from the construction site such as the tiler and electrician (XCUBE, 2013).
Figure 7.15: Example of a PKU

Construction Sequence of PKU: (Bathsystem, 2015)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Firstly, the kitchen is prefabricated as a module</td>
</tr>
<tr>
<td>2</td>
<td>Gets fully insulated, poured concrete acoustic floor slab</td>
</tr>
<tr>
<td>3</td>
<td>Plumbing and electrical systems installation</td>
</tr>
<tr>
<td>4</td>
<td>Tiling, kitchen and appliances installation</td>
</tr>
<tr>
<td>5</td>
<td>Testing, cleaning and final quality control</td>
</tr>
<tr>
<td>6</td>
<td>Delivery of Kitchen Unit</td>
</tr>
<tr>
<td>7</td>
<td>Connection with wiring and plumbing</td>
</tr>
</tbody>
</table>

11. Fire Protection Measures

11.1 Fire protection during construction

When the MET building is still undergoing construction, MET structural elements will gradually be installed. During this period of time, when MET elements are being installed until receiving fire protection from protective coverings, there is a risk that an accidental fire may occur. Furthermore, automatic fire sprinklers will also not be installed during this period of time. Thus, there is a need to put in place fire protective measures for these MET elements to provide
adequate protection until planned fire protection systems are installed. There are several measures that can be taken during this intermediate period such as controlling ignition sources, measures to provide protection and measures to combat the accidental fire.

11.2 Control ignition sources

There are several ignition sources that can be found in a construction site. Such as welding of metals, open fire, electrical equipment, and flammable fuels. In order to reduce the occurrences of an accidental fire and to protect MET elements from being exposed to fire, ignition sources will have to be controlled.

Firstly, the project managers may want to adopt a no smoking policy near any MET elements to prevent accidental fire being caused by lighted cigarette butts. It can be done by prohibiting smoking within a radius from the MET building.

Secondly, building element connections done near MET elements should not involve welding. Connections between these elements, including MET elements, can be done through a pin-and-tube connection and metal brackets fastened with screws and nails. This form of connections had been found to be used in the case studies which we have conducted and is found to be effective in providing adequate connections between building elements.

Lastly, ignition sources may be controlled by reducing cutting openings in MET elements on site. Cutting openings in MET elements will result in the formation of timber dust. MET elements by itself do not catch fire easily but timber dust produced from MET elements are easier to be set aflame. Hence, there is a need to reduce the timber dust found on site. If it is inevitable that cutting of openings or activities leading to the formation of timber dust, then the formed timber dust is to be disposed quickly and kept away from MET elements. SCDF has also stipulated that there shall be no smoking or use of naked flames within engineered timber worksite (SCDF, 2016).

11.3 Storage and Handling Protection Measures

Although ignition sources may be controlled, there remain incidents where accidental fire may arise beyond the controls of the builder. There is, thus, a need to implement measures to protect MET elements from fire during the construction process.

Firstly, we suggest for MET elements to be stored off-site in a storage facility with adequate active fire protection system. The storage of MET elements off-site will reduce to instances of the MET from being to any accidental fire that may occur on-site. Furthermore, the storage facility equipped with active fire protection systems will be a much suitable location to store MET elements by reducing instances of MET elements being exposed to fire.

Secondly, protective coverings that shields MET elements from fire should be installed as early as possible after the installation of individual MET elements. The early installation of these protective coverings will reduce the intermediate period where MET elements will be exposed to fire.

Lastly, building fire protection systems are suggested to be built along with the installation of the MET elements. For example, after the necessary building elements have been installed to support the fire protection system, builders may want to assign some workers to install the fire protection system for that area while continuing with the construction at other areas. Such installation of fire protection system is suggested to include the provision of ABC dry powder extinguishers at every floor of the MET building and depending on the height of the building,
dry or wet rising mains should be installed in the early construction process to provide an adequate supply of water required of firefighting operations. In events that a wet rising main is to be adopted, it should be constantly charged to provide an adequate flow rate and pressure required for firefighting operations. A water storage tank with a capacity to provide 60 minutes of required supply of water for firefighting operations should also be installed. Dry or wet riser main is suggested to be installed during the construction of the RC core structure. Although this measure may reduce the speed of erection of the building, the MET elements will be less likely to be left exposed to accidental fire during the construction of the building.

11.4 Combat Accidental Fire Measures

After taking measures to control ignition sources and to shield MET elements away from the fire, there may still remain instances where accidental fire may occur. There is hence a need for measures to combat these accidental fires to reduce the damage it may cause to MET elements.

First of these measures that we suggest is to place portable fire extinguisher at accessible areas while installing MET elements. For instance, one portable fire extinguisher can be placed at each floor level during the construction phase. As there may be different sources of fire, we suggest the deployment of ABC dry powder fire extinguisher on site. ABC dry powder fire extinguisher is effective in extinguishing Class A, Class B and Class C fires (Firesafetysg, 2018). Class A fires are caused by combustible materials such as wood which is the material of MET and is a possible ignition source due to the possible formation of timber dust. Class B fires are caused by flammable liquids and gas such as paints and thinners. Although the possibility of using paint or thinner before the MET elements are covered are low, ABC dry powder fire extinguisher is effective in extinguishing Class B fire if it occurs. Class C fires are caused by the gas stove. The occurrence of Class C fire is also low, but if it occurs ABS dry powder fire extinguisher is effective in extinguishing it. The fire extinguisher is to be installed in accordance to SS 578 (SCDF(a), 2018). Installation requirements includes mounting height of 1m above the floor for fire extinguishers that weigh less than 20kg, mounting height of 1.5m above floor for fire extinguishers that weigh more than 20kg, and operating instructions of portable extinguishers should be facing outwards. Figure 7.16 shows the stipulated mounting height of the fire extinguishers that weigh more than 20kg. In addition, extinguishers should be located in an area where no person has to travel more than 15m to reach it (SCDF(b), 2018).

Figure 7.16. An image of mounting height for fire extinguishers that weigh more than 20kg.
The second measure is to ensure that construction workers have gone through basic fire fighting training in the usage of fire extinguishers. Besides training, posters on how to use a fire extinguisher may be put up on the site to remind workers on how fire extinguisher should be used. Figure 7.17 shows a poster of how a fire extinguisher is to be used.

![Figure 7.17: An example of a how to use a fire extinguisher poster.](image)

The third measure that should be the proper liaising with SCDF to obtain their assistance in events of accidental fire. In events where the accidental fire is uncontrollable by on-site fire combating measures, an early arrangement should be made with SCDF for them to arrive on-site in a moment's notice. Spaces should be allocated on-site to allow SCDF to conduct firefighting operations. The allocation of such spaces should provide no hindrance to firefighting vehicles moving around the site. This is to ensure firefighting operations by SCDF is not hindered.

### 11.5 Active and Passive Fire Protection Measures

Besides the following measures taken during the construction stages, it is necessary to also adopt both passive and active measures as part of fire protection for buildings. Passive and active measures can be defined as:

<table>
<thead>
<tr>
<th>Active Measure</th>
<th>used to detect fire occurrence, to notify building occupants of the potential danger, to extinguish fires and minimize their dispersal within a building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive Measure</td>
<td>used to minimize the potential for fire occurrence and to slow the spread of fire throughout a building</td>
</tr>
</tbody>
</table>

The following table summarises the types of passive and active measures to be adopted for our residential development.
11.5.1 Passive Fire Protection System

11.5.1.1 Reinforced concrete core, ground floor slab and kitchen
In accordance with SCDF circular dated 10 August 2016, essential escape provisions of MET building shall be built using non-combustible materials with the required fire resistance rating. The concrete core shall house the fire escape staircase, lift shafts and fire-fighting facilities (such as fire extinguishers, rising mains and landing valves). In addition, timber is only permitted for elements above the ground floor slab according to the Fire Code (SCDF, 2016). While SCDF specified that the use of flammable gas cylinders is not allowed in engineered timber building premises if the building has access to piped-gas supply for cooking, the material allowed to construct the kitchen is not specified. For fire-prone kitchen area, it is recommended to not expose any timber in this area and shall be fully built using non-combustible materials such as concrete for added fire protection.

11.5.1.2 Sacrificial timber layer
Exposed timber elements are to be designed with an additional layer of sacrificial timber which is adopted by all of the buildings in the case studies above and in accordance with BCA guidebook. LCT ONE system with the provision of firestop glass fiber or cardboard interlayer between the inner core and outer layer is recommended to further prevent the inner core of the timber element from combustion.

<table>
<thead>
<tr>
<th>Overview of Passive Fire Protection System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced concrete core, ground floor slab and kitchen</td>
</tr>
<tr>
<td>Fire rated board</td>
</tr>
<tr>
<td>Concrete topping slab</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overview of Active Fire Protection System</th>
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</thead>
<tbody>
<tr>
<td>Detection &amp; Communication Systems</td>
</tr>
<tr>
<td>--------------------------------------</td>
</tr>
<tr>
<td>Detectors (Smoke/Heat)</td>
</tr>
<tr>
<td>Alarm</td>
</tr>
<tr>
<td>Fire Alarm Panel</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

11.5.1 Passive Fire Protection System

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Exposed timber elements are to be designed with an additional layer of sacrificial timber which is adopted by all of the buildings in the case studies above and in accordance with BCA guidebook. LCT ONE system with the provision of firestop glass fiber or cardboard interlayer between the inner core and outer layer is recommended to further prevent the inner core of the timber element from combustion.
11.5.1.3 Fire rated board

An alternative to sacrificial timber layer is the use of sacrificial timber board as seen in the Forte building and Brock Commons student residence in the Vancouver, Canada. Brock Commons uses 4 layers of Type X gypsum board (which has special core additives and commonly used for fire rated designs) for its columns and 3 layers for the underside of the CLT floor slab of 1 to 2-hour fire-resistance rating (Canadian Wood Council [CWC], n.d.). In Singapore, common types of boards used are gypsum based and calcium silicate mineral boards with the latter performing better in the fire. The fire rated board are subjected to test standards of BS EN 520 for gypsum plasterboard or ISO 1896 for calcium silicate or cement board (SCDF, 2018).

Fire rated boards can be secured to the timber elements using plasterboard screws as shown in Figure 7.19 above. After securing the fire rated board in place, any gaps would be properly sealed with infill material to provide the necessary fire resistance. Acoustic sealant, corner beads, joint tapes, jointing compound and topping compounds can be used for joints treatment. For fire rated board fixed to timber columns, corner beads help to ensure visually straight corner and protection the edges against damage. Before installing the corner bead, a coat of joint compound should be applied. Similarly, after corner bead is installed, apply three coats of joint compound at stipulated intervals according to the method statement. Joint compound is also applied to any screw holes or defects. After the compound dries, the surface is usually sand smooth or applied with a layer of finishing compound skim coat before paint (BCA, n.d.).
11.5.1.4 Joints and connections
There are many types of connection systems that can be used to connect timber elements together but when it comes to fire resistance, the concealed metal plates system has added advantages over exposed plates and brackets (Mohammad et al., 2013). In the concealed metal plate system, the ‘T’ shaped metal plate are screwed into a timber element and the protruding part of the metal plate will fit into the hollow tube of the other timber elements to be connected to it, similar to that of dowel joint which is sturdier than nails or screws.

The LCT ONE used a unique variation of the concealed metal plate system for the connection between column-slab-column. In LCT ONE, the “T” metal plate is replaced by a hollow tube or pin that are prefabricated together with the column and located at the top and bottom of the column section respectively. However, to allow for flexibility during assembly, the holes at the corners of the floor slabs are purposely made larger than the dimension of the tube and as a result leaving gaps between them. It is important to ensure that the gaps are properly sealed up with non-shrink cement grout such that load can be properly transferred between members and the whole section can be airtight to prevent smoke passage during fire and flame spreading to other timber elements through the gap.

If exposed hardware such as metal brackets (refer to Figure: 7.21 below) are used, protective membrane (i.e. fire rated board) or concrete cover are needed to improve fire resistance.

11.5.1.5 Concrete topping over the slab
Built-in or cast in-place concrete cover over the timber slab adopted by LCT ONE and Brock
Commons respectively provide a fire separation between each floor as timber-to-timber contact between floors is eliminated. In Brock Commons, the concrete topping was not poured immediately after the assembly of the timber floor slabs and columns for a particular floor. The construction of the upper storeys floor slabs, columns and walls continued while the concrete topping was cast in-situ for the bottom floors at a lag time of no more than 5 floors below active construction. Before concrete was poured, a layer of wood sealant was applied on the timber slab which already had a layer of sealant applied in the factory to protect the CLT panels from moisture (FII, 2017).

To speed up the rate of construction, the concrete layer can be prefabricated together with the timber slab and subsequent joints between slabs can be filled with non-shrink cement grout as seen in LCT ONE. The concern for built-in concrete cover is the need to seal up the joints properly to provide the necessary fire resistance. The method of construction whether built-in or cast in-place depends on the priority of the owner. Cast in-place can be chosen for better quality in terms of connectivity while built-in for reducing construction duration.

11.5.2 Active Fire Protection System (AFPS)

According to Faust (2003), AFPS can be defined as a set of systems that can be activated by the means of manually or automatically or even both. He also added that fire alarm systems are the main component for the active protection measure.

In a typical HDB residential development that is constructed of concrete as the main structural material, AFPS such as sprinkler systems and fire extinguishers are not fitted in any interior units or common areas. Only certain areas within the residential development that fire protection systems or devices were used. According to Tai (2014), bin centre is the only area fitted with heat detectors and automatic sprinklers. With reference to our MET residential apartment, AFPS will be installed during mid-way through the construction phase and substantially at many strategic locations within the building premises.

11.5.2.1 Singapore SS and CPs and International Standard for Fire Protection Systems

In Singapore, the requirements of the different fire systems are determined by the Fire Safety Act, Singapore Civil Defense Force (SCDF) Fire Code, and its design and installation must be accorded to the Singapore Code of Practices, Singapore Standards. Below comprises of the following codes and standards for the fire protection systems:

<table>
<thead>
<tr>
<th>Fire Protection Systems</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire alarm and detection systems</td>
<td>(i) CP10: Code of practice for the installation and servicing of electrical fire alarm systems and sect. 6.3 of CP for Fire Precautions in Building 2007</td>
</tr>
<tr>
<td>Automatic fire sprinkler system</td>
<td>(i) CP52: 2004 (Code of practice for automatic fire sprinkler system) and sect. 6.4 of CP for Fire Precautions in Building 2007</td>
</tr>
</tbody>
</table>
Besides the local-based standards, there are also international standards that SCDF Fire Code also recognised. Below are some of the international standards in accordance with fire protection systems.

<table>
<thead>
<tr>
<th>Category</th>
<th>Fire Protection Systems</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRITISH STANDARDS</td>
<td>Fire Hydrant Systems Equipment</td>
<td>BS 5041</td>
</tr>
<tr>
<td></td>
<td>Components for Smoke and Heat Control Systems</td>
<td>BS 7346</td>
</tr>
<tr>
<td></td>
<td>Components for Smoke and Heat Control Systems</td>
<td>BS 7346</td>
</tr>
<tr>
<td></td>
<td>Fire Detection and Alarm Systems</td>
<td>BS EN 54</td>
</tr>
<tr>
<td>EUROPEAN STANDARDS</td>
<td>Fixed Firefighting Systems.</td>
<td>EN 671 - 1</td>
</tr>
<tr>
<td></td>
<td>Hose Systems.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hose Reels with Semi-Rigid Hose</td>
<td></td>
</tr>
</tbody>
</table>

As the safety of the building occupants and working committees are utmost priority, there is a need for all AFPS to be inspected and certified by professional engineers on annual basis. Active fire protection can take the form of a number of systems. The systems can include the following:
11.5.2.2 Rising Mains

Rising mains are vertical mains providing “fire hydrants” that can be found on each floor of the building. The “fire hydrants” are in the form of landing values. Rising mains are essential for high-rise building when there are difficulties for the firefighters to reach from outside in time of emergency. There are 2 types of risers: Dry Riser and Wet Riser.

![Figure 7.22: Rising mains](image)

Accordance to the fire regulation, one rising main will have to be protected for every 930m² of any floor level subject to all parts of the floor to be within 38m from the landing valve. For instance, with reference to Forté Living GFA of 2431 m². The number of rising main required will be 3 rising mains placed on every floor based on Singapore context.

Accordance to SCDF Fire Code, strategic placement of rising mains are recommended to be placed in the order of priority from:

<table>
<thead>
<tr>
<th>Priority</th>
<th>Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>within a fire lift lobby, smoke-stop lobby or external corridor immediately outside the door of the exit staircase,</td>
</tr>
<tr>
<td>2)</td>
<td>located in common area and within a protected shaft, immediately outside an exit staircase, if there is no smoke free lobby</td>
</tr>
<tr>
<td>3)</td>
<td>Inside the exit staircase when smoke stop lobby and common area are not provided</td>
</tr>
</tbody>
</table>

11.5.2.2.1 Dry Riser

Dry riser is vertical dry water pipes installed in a building for firefighting purposes, fitted with inlet connections at SCDF access level and landing valves on various floors. The riser is normally dry but capable of being charged with water through the breeching inlets by fire engines. It should not exceed 60 m in height to avoid excessive pumping pressure.
11.5.2.2.2 Wet Riser

Wet Riser is vertical pipes installed in a building for firefighting purposes and are permanently charged with water from a pressurised supply, and fitted with landing valves on various floors. It has a water storage capacity for about 60 mins. The breeching inlets, usually provided at ground level, are meant for replenishing the water tank.

11.5.2.2.3 Rising Mains Key Regulations

1) All buildings with the habitable height exceeding 10m would require one or more rising mains. Each rising main shall not serve more than 930 m² of any floor space subject to all parts of the floor to be within 38m from a landing valve.
2) All buildings fitted with rising mains shall have a fire engine accessway/fire engine access road for firefighting appliances within 18m of the breeching inlet. The breeching inlets shall be visible from the fire engine accessway/fire engine access road.

3) Any building under construction required to be equipped with rising mains, rising mains shall be installed progressively as the building attains height during the course of construction. All outlets, landing valves and inlets, water tanks and pumps, and hydrants shall be properly installed so as to be readily operational in case of fire.
Given the context of the upcoming residential development being a high-rise building, the wet riser will be provided for the building instead of dry riser due to the building had exceeded 60 m in height. The rising mains and landing valves will be first located at the lift lobby, then followed by placement inside protected staircase. During the midst of construction, the wet riser will be incorporated into the under constructing building when it has exceeded 60 m in height.

11.5.3 Hose-Reel
Hose reel is a first aid fire fighting equipment, consisting of tubing fitted with a shut off nozzle and attached to a reel with a permanent connection to a pressurized water supply.

11.5.3.1 Hose Reel Key Regulations
Hydraulic hose reel(s) conforming to the requirements in SS 575 shall be provided to every storey of every building regardless of building height.

With reference to the SCDF fire code, hose reel will be provided on every storey and it will be strategically located within the building. For instance, hose reel should be sited adjacent to exits along the escape route.
11.5.4 Sprinkler System

It is a system of water pipes fitted with sprinkler heads at suitable intervals and heights and designed to control or extinguish a fire at its incipient stage by discharging water. The purpose of the sprinkler system is to slow down the growth of fire in order to ensure there is sufficient time for building occupants to escape and provide some leeway time for the arrival of the firefighters. In addition, sprinkler water tank with 2 equal compartments needs to be provided as the source of water supply.

11.5.4.1 Method of Activation of a Typical sprinkler system

In activation, a sprinkler is fused by the heat of the fire at about 68 degrees or at other temperature. The bulb fused will allow water to be discharged from sprinkler head onto the fire. This will automatically operate the sprinkler pump. The discharge of water will cause the activation of the fire alarm.

11.5.4.2 Sprinkler System Design Criteria

The sprinkler system shall be electrically monitored so that on the operation of any sprinkler head, the fire signal is automatically transmitted to a SCDF Operations Centre through an approved alarm monitoring company. Design of sprinkler system needs to comply with SS CP 52: 200 (CP 52 Code of Practice for automatic fire sprinkler system).

11.5.4.3 Sprinkler System Key Regulations

Where sprinkler system is required by this Code, provision of automatic thermal or smoke detectors in sprinkler-protected premises will be exempted except where such detectors are required to activate or operate the sprinkler or other systems.

11.5.4.4 Automatic Sprinkler System Key Regulations

In accordance to SCDF Fire Code (2016), every engineered timber building shall be fully protected by an automatic sprinkler system. Sprinkler systems can only be exempted under the following circumstances:

(1) Alternative fire protection measures (eg. fully encapsulated timber elements)
are provided to minimise fire damage to the timber structures, in lieu of the sprinkler system

(2) The building does not exceed 12m in habitable height

(3) The building is protected by an automatic fire alarm system compliant with CP 10 Code of Practice for Installation and Servicing of Electrical Fire Alarm Systems

(4) The building does not contain any healthcare occupancy

If the external facade of the engineered timber building is unable to meet the stated performance in the prevailing Fire Code for the prevention of external fire spread, 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.

The sprinkler systems will be interconnected to the fire alarm system so that when the sprinkler system activated, the alarm will concurrent triggered as well. For a typical residential building sprinkler system are not required irrespective of its height. Based on SCDF Fire Code, automatic sprinkler system (with fast response heads) need to be installed at all the levels within the MET development.

The reasons for using the sprinkler system with fast response heads instead of slow response heads will be solely due to the large volume of MET used throughout the building. 2 types of fast response head the designer can consider using will be Extended Side –Throw type or Fully Concealed Flush type. Alternatively, sprinkler can be mould into a sprinkler column to be installed at level 1 of the MET building.
Due to the potential fire hazard risk, externally the MET residential building will be protected by a deluge system in accordance to CP 52 to prevent the spread of external vertical fire spread in accordance to SCDF Fire Code. Deluge system is a system which all sprinklers are opened, once any detection of fire signal, water will be discharged through all sprinklers heads. For the purpose of our development, the deluge system will be connected to the fire panel and bring installed at the building facades vertically and horizontally to reduce the spread of fire.

The use of the deluge system not only ensure the effectiveness of suppressing fire but also reduce the risk of leakage as water discharged of the piping upon the activation of the deluge valve. Thus, this will ensure the structural stability of the MET building.
11.5.5 Fire Alarm Panel

Fire Alarm Panel is essential to detect the presence of fire by monitoring any environmental changes associated with combustion by relying on the inputs signal obtained from various sensors and detectors. The purpose of the panel system will be to identify fire location in accordance to the fire alarm.

Figure 7.35: Fire Alarm Panel

11.5.5.1 Fire Alarm Panel Key Regulations

i) According to SCDF Fire Code, where an automatic sprinkler system and/or electrical fire alarm system is provided to the non-residential part of the building:

1. Alarm sounders shall be installed within the non-residential units, at the common areas of the non-residential floors and extended to the immediate two residential floors above the non-residential floor.

2. The alarm sounders shall be able to produce a minimum sound level of 65dBA, or 5dBA above the ambient noise level in all parts of such areas.

3. Connection of the fire alarm system to an approved alarm monitoring company stipulated under Cl.6.3.7 is not required if the number of nonresidential floors is not more than one storey.

ii) All automatic systems which are activated via the general building alarm shall be connected directly to the fire alarm panel.

iii) The fire alarm panel shall be located near the main entrance of the building, in the Fire Command Centre (FCC), in the guardhouse or in the fire lift lobby.

iv) Sub fire alarm panel, where provided, shall comply with the requirements in SS CP 10 be located at the fire lift lobby, smoke-stop lobby, or protected staircase, in that order of priority, or at the main point of entry into the area covered by the alarm zone.
11.5.5.2 Working Principle of Fire Alarm Panel

The panel contains signals from networks of manual call points and detector-heads. During a fire emergency, this system will receive inputs from the detectors and manual call points and translated to system actions such as sounding the alarm devices and activating auxiliary fire suppression system.

![Simplified System Diagram]

Figure 7.36: simplified system diagram of a typical fire detection and alarm system

For this development, automated fire panel will be used. As the development is a residential development, manual fire panel would not be adopted.

![Indoor and Outdoor Call Point]

Figure 7.37: Indoor and Outdoor Call Point

Fire alarm panel will be installed at the level 1 lift lobby and the type of Fire Alarm Panel, we have decided to adopt will be the addressable system. Some of the characteristics of an addressable system will be:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(I) Each detector is provided with an address that denote specific location</td>
<td></td>
</tr>
<tr>
<td>(ii) Alarm is identified by zone and specific address and location</td>
<td></td>
</tr>
<tr>
<td>(iii) Addressable detector is also able to indicate various condition such as smoke level</td>
<td></td>
</tr>
<tr>
<td>(iv) System capable of indicating events and have recording feature</td>
<td></td>
</tr>
</tbody>
</table>

Given the characteristics of the addressable system, it would be more efficient and quick to
identify a specific areas in time of a fire as compare to the conventional system whereby detectors and alarm are identified based on zone and it does not provide a comprehensive status of the existing condition due to the indication of either “Fire” or “Normal” status.

The above image depicts a typical addressable fire alarm system with 3 zones. Each zone will be protected by 1 alarm panel, several detector-heads, manual call points and bells. All detector-heads and components are connected in series and will address a specific location. Moreover, the fire alarm system will undergo daily, weekly, monthly and annual test accordance to SS : CP10-2005 Requirements.

11.5.6 Fire Alarm
The purpose of fire alarm will serve as an indication to building occupants to evacuate in the event of an emergency such as fire. The alarm can issue 2 different types of signal - an audible or visible signal.

11.5.6.1 Two types of Fire Alarms
i) Audio alarm
This alarm will trigger a sound during an emergency event.

ii) Visual alarm
This alarm will not produce sound but instead, rely on a strobe light system to provide the signal.

Figure 7.40: Visual alarm

11.5.6.2 Fire Alarm Key Regulations

1) The type, number and location of the alarm device shall comply with the requirements in SS CP 10.

2) Visual alarms shall be provided for buildings protected by fire alarm systems, and shall not be used in place of audible alarms.

3) Home Fire Alarm Device (HFAD) will be installed for individual residential units under purpose group II buildings that includes flat, apartment, condominium.

<table>
<thead>
<tr>
<th>Home type</th>
<th>Number and location of HFAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-storey homes:</td>
<td>Minimum 1 HFAD (smoke detector)</td>
</tr>
<tr>
<td>HDB flats</td>
<td>Installed along circulation area / escape route, i.e. living room, corridor</td>
</tr>
<tr>
<td>Apartments/Condominium</td>
<td>Optional: Additional HFADs can be installed in other spaces for enhanced protection.</td>
</tr>
<tr>
<td>Single storey landed dwellings</td>
<td></td>
</tr>
</tbody>
</table>

| Multi-storey homes:              | Minimum 1 HFAD (smoke detector) per storey                                                 |
| Landed/Non-landed dwellings      | For storeys with circulation area > 70m², at least 2 HFADs (smoke detectors) need to be    |
| HDB flats                        | installed on that storey.                                                                  |
| Apartments/Condominiums          | Installed along circulation area / escape route i.e. living room, corridor, and/or        |
|                                 | Optional: Additional HFADs can be installed in other spaces for enhanced protection.       |

Figure 7.41: Number and location of HFAD for types of home
This home smoke alarm is not linked to any emergency services or a central fire alarm system as it is operated via battery. The function of such devices is to alert occupants when smoke is being sensed. According to SCDF (2017), the home smoke alarms will be designed in accordance to European, Australian or American standards for fire alarms - EN 14604, AS 3786 and UL 217.

Acknowledging the 2 different varieties of fire alarm, our development being a residential development will adopt a mixture of both audible alarm and visual alarm. Being a residential building, it is impossible to anticipate the types of occupants that will be residing there, therefore visual alarms will come in handy for those occupants who have hearing Impairment.

In addition, visual alarms can serve as an alternative source of signaling when there is high background noise that may deter the effectiveness of the audible system. Both alarms will be strategically placed within the building accordance to SS CP 10.
Furthermore, one smoke detector being installed within each unit living room accordance to SCDF Fire Code. An ideal situation is to have smoke alarms installed at every room within an apartment with the exception of kitchen and toilet due to the potential false alarms triggered by smoke produced by cooking and water heater. However, it may not be feasible due to the high cost incurred by the occupants. As reported by Ng and Toh (2017), they mentioned that the estimated cost of home smoke alarm might be around the range of $60 and $80 excluding the installation cost.

11.5.7 Fire Detectors
Automatic fire detectors can be mounted onto ceiling surface or located in the air duct. Detectors are available in 2 different design to detect fire a one point/location known as spot detector or it may detect fire along a continuous path known as line detector.

11.5.7.1 Activation Principle of Fire Detectors
It can be activated based on one or combination of the following conditions:
1) After ignition has occurred and invisible products of combustion are released
2) When visible smoke is produced
3) When there is a flame providing a degree of illumination
4) When ambient temperature rises rapidly or reaches the predetermined point

11.5.7.2 Three types of fire detectors
1) Heat Detectors are spot detectors. It will only be activated when the fire reaches about one-third of the distance to the ceiling.

There are 2 different types of heat detectors which are commonly used:
  i) Fixed temperature heat detectors: activate when the ambient temperature reaches around a predetermined level.

  Figure 7.44: Fixed temperature heat detector

 ii) Rate-of-rise heat detectors: activate when fires raise the temperature of the air in a space rapidly. Due to the rapid sensing ability, this detector will be able to detect the presence of fire much faster than a fixed-temperature detector.

2) Smoke detector may be classified as spot or line detectors. This detector has 2 sensing
principle:

| (i) Ionization chamber type which operates on the change in current flowing through an ionisation chamber upon entry of smoke particles |
| (ii) Optical type which operates on the scattering or absorption of light by smoke particles in a light beam |

There are 3 different types of smoke detectors:

i) Light Scattering
   It is a form of spot detector. Operation is based on the principle of detecting light scattered by smoke particles.

ii) Light Obscuring
   It is a form of line detector. It detects fire by projecting a light beam onto a photocell. If smoke passed the beam it interrupts the light from reaching the photocell and the alarm will be triggered.

   **Operation Principles:**

   ![Figure 7.45: Operation principles of optical detectors](image)

   Both of these optical detectors, Light Scattering and Obscuring detectors are ideal for detecting slow burning fires caused by materials, which produce large smoke particles.

   ![Figure 7.46: An Optical detector](image)

iii) Ionisation
   It is a form of spot detector. The detector use 2 electrically charged plates and a small amount of radioactive material to detect fire. The ionisation detectors are quick and useful for detecting fire caused by materials, which produce small smoke particles. However, this detector may be slow to respond to dense smoke containing large particles. For instance, smoke produced by smouldering materials such as PVC may be less sensitive to such detectors.
According to CP 10-2005 subsection A.4.2.3, the use of smoke detectors should be subjected to the following typical ceiling surfaces:

i) Smooth ceilings. Heated air and smoke usually rise. When they reach smooth ceilings, they travel along the ceiling. As these products flow along the ceiling, their concentration decreases as the distance from the source increases.

ii) Other ceilings. Where deep beams or other obstructions form pockets in the ceiling, the products collect in the pocket and, if sufficient products are being generated, will eventually “spill over” into adjacent pockets. Sawtooth, sloping, open joist, beam construction, or other shaped ceilings must receive special consideration as smoke usually travels in a longitudinal direction at the highest point.

iii) High ceilings. As smoke rises from a fire, it tends to spread upwards in the general form of an inverted cone. Therefore the concentration within the cone varies approximately inversely as the square of the distance from the source.

3) Flame Detector
The detector works on the principle of detecting ultraviolet radiation emitted from the fire. Due to its sensitivity to radiation, careful placement of flame detector is essential to avoid other radiation sources such as sunlight and building lighting.

![Flame Detector](image)

**Figure 7.47: Flame Detector**

<table>
<thead>
<tr>
<th>Type</th>
<th>Detection Speed</th>
<th>Probability of unwanted alarm</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Slow</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Smoke</td>
<td>Fast</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Flame</td>
<td>Very Fast</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

There is no one-size-fit-all fire detectors that would especially suit for specific premises.
The MET building will adopt a mixture of smoke and heat detectors. Smoke detector will used to detect slow developing smouldering fire such as fire involving cardboard whereas heat detector could be triggered by the fire that evolves heat rapidly and with very little smoke. The types of heat detectors that the building can leverage on would be using a combination of both spot and line detectors to detect fire at one specific location and along a continuous path respectively. Spot detectors will be installed within the building premises while line detectors will be installed to protect certain items such as the plant or cabling located in the building. Given the characteristics of rate-of-rise and fixed temperature detectors, both such detectors will be used for general protection of areas. In particular, weatherproof heat detector can be used to sense temperature change.

For the smoke detector, given the wide ranges of response, a mixture of both optical and ionisation detectors will be adopted. Within the premises, in areas when polyvinyl chloride (PVC), optical detectors shall be used due to being more responsive.

Due to the sensitivity in the responses of the detectors, it is necessary to consider its placement location and the selection of the type of detector to avoid a false alarm situation. Smoke and heat detectors will be mounted on the ceiling located at each levels common areas (corridor). These detectors will be strategically located at specific areas to detect emergency and alert occupant. Selection of extract smoke detectors locations will be in accordance to CP 10-2005.

Alternatively, to reduce capital costs of having 2 separate function detectors, multi-sensor fire detectors can be adopted. This detector operate based on the principle of monitors more than one of the characteristic fire phenomena (e.g. heat and smoke) due to the integration of 2 sensors.

Apart from relying on conventional detectors, the building can also detect smoke through the use of an advanced technology known as Video Smoke Detection (VSD). VSD is a camera-based fire detection system, which detects smoke pattern through the use of CCTV cameras video images by leveraging on the advanced image processing algorithms. VSD can be installed along the common areas like the corridor. The reason for the adaptation of VSD due to the reduction of false-alarm phenomena, allow fast reaction time with high accuracy detection method and not solely rely on just the typical smoke detectors. Accordance with SCDF Fire Code (2016), all detectors installed within the MET development are required to undergo annual inspection to ensure its workability and inspection report will be submitted to SCDF for review.
11.5.8 Fire Extinguishers
Portable fire extinguishers act as the first line of defense against fire and they are essential even if other forms of fire protection equipment are installed within the premises. Different types of portable fire extinguishers should be placed and use accordance with SS 578.

Although based on the current SCDF Fire code, it stated that fire extinguishers will not need to be provided on any residential floors of any purpose group II buildings that includes flat, apartment, condominium. Fire extinguishers are usually installs in community spaces in the community areas and in the utilities rooms. Given the composition of timber as a building structural material, we felt that portable fire extinguishers should be placed on every level, preferably at least 2 being placed at each end of a level. Through this initiative, any fire hazard within the common level can be quickly put out without causing any potential damage to any timber structure.

11.5.9 Fire-fighting Operations Facilities Requirement
Accordance to SCDF Fire Code (2016), essential fire safety and fire-fighting operations (such as fire command centre, fire pump rooms, generator room rooms) shall be separated from other areas of the CLT project by using non combustible material or encapsulated engineered timber - Engineered timber elements protected with fire-rated boards to achieve the necessary fire resistance rating.
12. Moisture Protection Measures

Moisture protection remains a challenge for MET products. It has been seen from our various case study, the MET elements used were all protected from moisture in one way or another. The emphasis on moisture protection for MET is due to its material properties. When it comes into contact over a certain period of time and the moisture is unable to leave the MET element, it will cause the growth of fungi (Canadian Wood Council, 2018). The appearance of fungi on MET element may lead to decay which is a process of decomposition of organic material. Decay will lead to rotting which may affect the durability of MET elements. Hence, it is of key importance that we do our due diligence in providing adequate moisture protection for MET elements. In this section, we will discuss moisture protection that can be done to protect MET elements during construction processes, and passive and active moisture protection solutions that will shield MET elements from moisture during the building lifecycle.

MET elements will be in a period of vulnerability in fending off moisture before passive and active moisture protection measures are installed to shield MET elements from moisture. During this period, it will be necessary for MET elements to receive moisture protection measures to reduce its exposure to moisture. There are several ways moisture protection measures can be implemented.

12.1 Kiln-drying of timber before prefabrication

The moisture content of the MET elements has been suggested to be kept below 20% (Seidl, 2009 & Wang, 2016). By keeping the moisture content below 20%, it will prevent the growth of fungi in MET elements. Seidl (2009) and Wang (2016) has mentioned that fungi growth will begin at 26% to 28% moisture content, thus to prevent fungi growth, it was suggested that a cut-off point of below 20% moisture content in MET element to leave a barrier in cases of errors which may lead to higher moisture content. BCA (2018) has suggested that engineered timber used in Singapore should have a moisture content of 12% to 14%.

Kilns can be described as an oven that is located within a thermally insulated chamber (International Timber, 2014). Kiln drying is a controlled process that involves the use of steam to heat up the interior of the kiln and using a fan to extract evaporated moisture. Firstly, timber will be transported into the kiln. Next, the drying process will follow a pre-planned schedule that depends on the specification of the wood (International Timber, 2014). The entire process will take around 6 to 8 weeks. Besides being able to control the moisture content, another benefit of kiln-drying is that the process will also eliminate fungi and insect infestations. An illustration of kiln-drying can be seen in Figure 8.1.

We suggest that kiln-drying process to be adopted as a form of pre-treatment to the MET elements as the moisture content will be controlled.
12.2 Moisture protection during the prefabrication process

There are several ways moisture protection can be applied onto MET elements during the prefabrication process. The application of this moisture protection will provide MET elements with temporary shielding until proper moisture protection is installed on site. Although passive moisture protection measures such as the installation of the waterproof membrane and the concrete layer can also be done during prefabrication process, it will appear to be less effective. This is because, after the application of this protective layer during the prefabrication process, there remains a need to add another layer on-site to seal off the gaps between prefabricated MET elements. There will also be more gaps to seal compared to applying a continuous layer of moisture protection over all the gaps. However, it should be noted that precasting of concrete topping over MET will provide it with adequate fire protection. It will thus be a viable alternative and will depend on the designers and builders to decide whether to precast concrete over MET during the prefabrication stage. The moisture protection that is suggested to done during prefabrication process includes, applying of peel-and-stick membrane (PSM) onto holes and application of Miralite Side Sealer (MSS).

12.2.1 Application of peel-and-stick membrane (PSM) onto MET openings

PSM is a self-adhesive waterproofing membrane. Although there are many different PSM available in the market such as abe peel & stick membrane, ADESO self-adhesive waterproof membranes, and BYTUM base 3000, it can be understood generally as having a moisture protection layer, a self-adhesive layer and a separation layer (rothoblass, 2017). Its installation procedure will be similar as such (a.b.e, 2018):

1. Make sure the surface of the MET is clean, free from dust, oil, and contaminants that may affect bonding issues.
2. It is suggested that a layer of prime is applied to improve adhesion.
3. The release paper should be slowly removed while applying PSM
4. Carefully apply the PSM on to the surface, a roller tool may be used to improve the application process.
5. Lastly, firmly press on the applied PSM to ensure no creases or air pockets and that it has fully adhered onto the surface.
The PSM is able to provide moisture protection to openings made during the prefabrication process. It is important to protect these openings because end grains of MET elements will absorb more moisture compared to other MET surfaces.

12.2.2 Application of Miralite Side Sealer (MSS)

In Brock Commons project, during the construction of the MET building, it was mentioned by the builders that MSS was applied to the MET elements during the prefabrication process. MSS is a clear and penetrating sealer that provide temporary moisture protection to timber products (Cloverdale, 2004). The application methods include airless spray, brush or roller. It takes about 15 minutes to achieve touch dry and 1 hour to achieve hard dry on a 25-degree Celsius surface (Cloverdale, 2004).

Its application process is as follows (Cloverdale, 2004):

1. Ensure that the to-be coated surface is clean and free from surface contaminants.
2. Make sure that the moisture content is less than 20%.
3. Mix the MSS well before using.
4. Use either an airless spray, brush or roller to apply MSS.
5. Wait for 1 hour for MSS to achieve hard dry.

Although the application of MSS is able to provide temporary moisture protection to the MET elements, it should be noted that it may affect the adhesion of concrete layer, if chosen to be adopted, above the MET elements (woodworks, 2018). To overcome this problem, it will be required for the concrete layer to be jointed to the MET element using screws.

The installation and provision of moisture protection is suggested to provide MET elements adequate defense against moisture during their vulnerable construction stage period where their permanent moisture protection may yet to be installed. If there is a lack of moisture protection for MET elements, its durability may be undermined with the growth of fungi.

12.3 Storage facility and Just-in-time approach

A comprehensive transport plan should be put in place for the long distance transportation of MET components. When transporting the MET components, waterproof sheets should be used to shield them against the weather as shown in Figure 8.1 below. It is recommended for MET to be stored off-site and be transported at the right time when they are to be installed to reduce the probability of damage by water. If MET components are needed to be stored temporary on-site such as in the event of inclement weather that cease installation, raised platforms on leveled hard surface is to be provided to stack the elements above ground as shown in Figure 8.2 below.
12.4 On-site moisture protection measures

While moisture protection measures could be done off-site in during the prefabrication process, it does not fully shield MET from moisture. It only provides MET with temporary and partial waterproofing. Moisture protection may only be complete as the building is fully constructed. There are also events where MET elements getting wet is beyond the control of builders, such as rainy days. Hence, there is a need to adopt moisture protection measures on site.

BCA (2018) has suggested some measures builders can adopt to prevent MET elements from getting wet. Firstly, through daily sweeping of standing water on the MET elements surface. This measure was also mentioned by RSP. Sweeping away standing water on MET elements surface will reduce the prolonged exposure of coming into contact with water. It is a measure that should be adopted when building with MET as prolonged exposure to water will increase the moisture content within the MET which is undesirable. Secondly, if due to some reason’s JIT approach could not be adopted or MET has to be stored on site over a period on time, it is necessary to take note that the end grains of MET elements are to be protected and MET elements should be stacked off the ground to prevent them from absorbing moisture (BCA, 2018). Apart from the measures that BCA has suggested, RSP has mentioned that they will be installing temporary rainwater drainage pipes (RWDP) during the construction process. It is, however, unfortunate that RSP was unable to share with us how the RWDP will be temporarily installed.

12.4.1 Mechanical fans and prevent cutting openings in MET element on site

Another on-site moisture control measure is the use of mechanical fans. This measure has been used in the Brock Commons project, shown in Figure 8.4 (woodworks, 2018). In the Brock Commons project, mechanical fans have been deployed to control the moisture within the MET building that is under construction (Fraser, 2018). We understood that moisture could be controlled by using mechanical fans to speed up the drying process of MET elements that have been exposed to moisture. Another measure is to reduce the occasions of having to make an opening in MET elements on site. This is because this opening that is made will be vulnerable to moisture penetration as they are not protected by waterproof membranes such as PSM which are done off-site. If such openings could not be avoided, builders are suggested
to apply a waterproof membrane over this opening as soon as possible.

![Figure 8.3: Mechanical fan deployment in MET building](image)

12.4.2 Rapid erection of building envelope

We suggest that besides the above measures, the MET building envelope should be installed together with the installation of a floor, as seen in Figure 8.5. The suggestion for rapid erection of building envelope will protect the interior MET elements from moisture by serving as a barrier that keeps rainwater away from the interior. This measure will require proper planning to ensure that the envelopes are delivered at the right moment when a storey is completed.

![Figure 8.4: Rapid erection of building envelope](image)

12.4.3 Temporary roofing

Apart from the rapid erection of building envelope, we have also learned from LCT one that temporary roofing can be adopted to prevent rainwater penetration. In LCT one, a temporary emergency plywood roof was installed due to unfavourable weather conditions. It took them 1.5 hours to install it. Although the long installation hour may deter builders from using it. It
should be considered as an alternative in providing moisture protection to MET element in the context of Singapore. Another form of temporary roofing, other than using plywood, we suggest using scaffolding that is wrapped by a waterproof covering at the top to form an overhead shelter. We suggest the usage of tubes and the fitting scaffold due to it being the most versatile form of scaffolding (Chew, 2018). Tubes and fitting scaffold is suggested to leverage on its versatility to be able to construct a temporary roof similar to a tent, to shelter installed MET elements from rainwater. An example of a scaffold with waterproof shelter can be seen in Figure 8.6.

Singapore has a tropical climate, which have abundance of rainfall (Meteorological Service Singapore, 2018). This shows that there will be a higher need for MET elements to be sheltered during its construction. While yet to be installed MET elements can be stored off-site, installed MET elements could only remain in their designated position and brave the weather. Hence, temporary roofing should be considered as an alternative if there are no moisture protection measures in place to protect the MET elements.

Figure 8.5: An example of an overhead waterproof shelter scaffold

12.4.4 Build during months with lower rainfall

Furthermore, as rainfall is Singapore is abundant and may be unavoidable during the construction of MET building, we suggest builders to start building MET-related building during months that have lower rainfall. Builders should consider building from February to October and avoid building from November to January, as seen in Figure 8.7 (MSS, 2018). Among the suggested months, February, June and August have the lowest rainfall (MSS, 2018).
12.8 Concrete topping over CLT slab

Concrete topping as mentioned under fire protection can also help to reduce moisture damage to CLT slab. Proper sealing of joints using non-shrink cement grout helps to block water passages between MET elements. (Refer to passive fire protection system: concrete topping over slab and joints and connections for more details).

12.9 Rainscreen Cladding

MET being a moisture-sensitive material, heavy mass and thickness, it is, therefore, essential to ensure such material remains dry throughout the lifecycle period as there is a tendency to take a longer time for it to be completely dry out. Moreover, the constant wet and dry process can result in the MET material to face expansion and contraction, which may cause potential distortion of the panels that will affect the structural stability of the building.

By taking references to Forte Living, the development adopted a ventilated rainscreen with a metal exterior cladding. The intention of the design help to ensure the inner layer of CLT is fully protected by the facade cladding. It is essential for water and moisture sources to be minimised especially in a MET development. Therefore, a rainscreen cladding can be installed at the exterior facade with the aim of providing an outer layer of protection to the timber material and protecting from natural elements such as rain and it can also serve as an insulation to prevent heat from seeping into the building.

Moisture management strategies will be based on 3 principles:

<table>
<thead>
<tr>
<th>Deflection: Through the installation of cladding to deflect rainwater away from the CLT building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage: Through cross cavity flashing, water can be discharge out from the assembly, thus reduce the tendency of water being absorbed by CLT material</td>
</tr>
<tr>
<td>Drying: Through the use of a ventilated cavity between the cladding and CLT elements, this will reduce the chance of moisture transferring to CLT.</td>
</tr>
</tbody>
</table>
Steps Taken for the installation of Cladding to MET - external wall

1) Insulation fixed to the exterior wall
2) Ventilation cavity will be provided between the insulation and the rain screen external cladding
3) Supporting brackets such as aluminum or steel brackets will be used to support cladding

There are a variety of ways for the installation of the cladding on MET panels. The following will be discussed below:

1) By the means of strapping member that will be attached to the CLT panels by the use of screws

2) By the means of low conductivity spacers that are attached with screws to the CLT wall, this help to provide a rigid support to the exterior cladding.
The use of cladding for the building will be subjected to SCDF Fire Code as they ensure that cladding met the required fire safety standard and BCA as they are the authority that regulates the design, construction and maintenance of every building to ensure structural stability and safety. The adopted rainscreen cladding will be selected based on the SCDF mandates stringent fire safety standards. Based on the existing fire code, there are five classes of certification ranging from 0 to 4, representing the rate of flames spread. According to SCDF fire code, cladding panels that are not rated Class "0" standard will not be permitted to be used as external facade cladding. The industry standard is class ‘0’ in order to ensure that when there is ignition, the fire will not spread along its external surface.
12.9.1 Fire Code Requirements for Cladding

In addition, all external cladding will need to be certify by the Certificate of Compliance (CoC) that indicate the fire rating. Beyond certification, annual periodic testing will be carry out to ensure cladding integrity and compliance with the Fire Code.

<table>
<thead>
<tr>
<th>Usage of composite panel</th>
<th>Test standard(s)</th>
<th>Acceptance Criteria</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladding on external wall</td>
<td>BS 476 Part 4; or</td>
<td>Meet the criteria stipulated in BS 476 Part 4</td>
<td>1) The test sample shall be stripped to expose the core material and the fire tests shall be carried out on the core material.</td>
</tr>
<tr>
<td></td>
<td>BS 476 Part 11; or</td>
<td>Meet the criteria stipulated in BS 476 Part 11</td>
<td>2) External wall for mounting of composite panels shall have a fire resistance rating of at least 1 hour.</td>
</tr>
<tr>
<td></td>
<td>BS 476 Part 7 &amp; BS 476 Part 6; or</td>
<td>BS 476 Part 7: Class 1 &amp; BS 476 Part 6: Class 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EN 13501-1; or</td>
<td>Class B or better</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NFPA 285</td>
<td>Meet the criteria stipulated in NFPA 285</td>
<td>1) The fire test shall be carried out on the whole panel assembly.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2) External wall for mounting of composite panels shall have fire resistance rating of at least 1 hour.</td>
</tr>
</tbody>
</table>

Therefore the type of cladding adopted for the MET building needs to ensure that it is within either non-combustible panels or Class “0” combustible panels to be eligible as an exterior facade. Thus, this would further reduce the possible ignition sources.
12.10 Reinforcement Concrete Foundation and Ground Floor

To prevent moisture from seeping into the timber structural components and rotting of the timber material from occurring, the foundation and the ground floor will be constructed using reinforced concrete. Moreover, through the prevention of moisture penetration, this may minimise the risk of termite attack. This practice was largely adopted by our case studies MET buildings.

13. Conclusion

Generally, the market for MET is still maturing in Singapore as none of the residential building projects has adopted either the CLT or Glulam. Having the next BTO public-housing project in Singapore to be constructed by mainly MET material, this will achieve a significant breakthrough in the Singapore construction sector. Although there are several guidelines and restriction to adhere for the usage of MET, these limitations can be overcome by leveraging on a hybrid construction system - a combination of MET and other conventional materials such as steel or concrete or even both. Through this proposal, we hoped to pave the way for more MET buildings to be built within Singapore in the near future.
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APPENDICES

Appendix A: Interview via email with RSP representative

Construction Technology

1. What form of foundation has been chosen to support the building? What is the material(s) used?
   RSP: Reinforced Concrete (RC) piles foundation.

2. Understanding that the escape routes are often times constructed using reinforced concrete, how has this requirement been incorporated into the design? In addition, please explain how it will be constructed.
   RSP: The essential escape provisions, e.g. exit staircases shafts, lift shafts, smoke stop lobbies, etc. will be constructed in RC. These RC elements will be precast off-site and assembled on-site.

3. Which type(s) of Mass Engineered Timber (MET) has been chosen? Please explain some of the considerations when choosing the type(s) of MET for the project.
   RSP: Glue Laminated Timber (Glulam) will be used for the columns and beams, while Cross-Laminated Timber (CLT) will be used for the floor slabs. Glulam and CLT are the most commonly chosen types in the MET construction. Their benefits have been concisely summarized in the MET Guidebook Item 2.1 (on CLT) and Item 2.2 (on Glulam). You can download a copy of the MET Guidebook from the following link for your reference:

4. Which element of the building will be using MET as its material? Columns? Beams? Floor slab? Others?
   RSP: See reply in Item 3 above.

5. Which element(s) of the building will be using other materials (e.g. reinforced concrete and steel)? May I find out why other materials have been used instead of MET in these elements?
   RSP: The building foundation, basement structure and 1st Storey floor slab will be constructed in RC. This is to comply with the Fire Safety Requirement for Engineered Timber Building Construction as stipulated in SCDF Circular dated 10 Aug 2016, i.e. the use of engineered timber for elements of structure shall be permitted only for areas above the floor slab of the ground floor.
   Similarly, the essential escape provisions, e.g. exit staircases shafts, lift shafts, smoke stop lobbies, etc. will be constructed in RC, so to comply with the fire safety requirement.
   The toilet clusters that are located next to the staircases will also be constructed in RC to form the RC cores of the building.

6. Please explain how the construction sequence will be like for the project.
   RSP: The RC pile foundation, basement structure and 1st Storey floor slab will be constructed in-situ, followed by the precast RC structures for the RC cores.
(containing the staircases and toilet clusters). MET elements will be pre-fabricated off-site concurrently and to be delivered to site for assembly on just-in-time (JIT) basis.

7. There will likely be some MET panels having repeated designs and dimensions, will there be any form of identification method adopted to identify the MET panels?
RSP: Yes, there are different identification methods available in the market, e.g. RFID, printed barcode, printed QR code, etc. The to-be-appointed MET specialist contractor for the project is free to adopt any of the aforesaid method.

8. What types of joints have been chosen to connect MET components to the adjacent elements? What are the considerations behind the choices?
RSP: The project is currently under design development stage. In order not to restrict the types of structural connections and details to be used by the contractors, the project team has decided to indicate both generic connections and proprietary connections in the tender drawings & documents, so to allow the contractors to propose their preferred types of connections and details for consideration.

9. Are there any other technical difficulties, barriers, challenges and constraints met during the design and construction phase due to the choice of using MET as its building material?
RSP: Plenty. Just to name a few: specifying the suitable type of timber, finishing, structure, fire protection, termite protection, UV & moisture protection, acoustic treatment, product & quality certification, etc.
You can refer to the page 3 of BCA’s Build Smart Newsletter Issue 35 dated Jun 2017 for the elaboration.

SG Weather Context - in relation to Construction Technology

10. Understanding that Singapore has a humid weather, will it affect the use of MET during construction?
RSP: Yes. Proper planning, sequence of delivery, storage & construction and quality control are required by contractor to protect the MET during delivery, storage & construction, so to avoid any damage to the timber surface. The following measures shall be taken in order to minimize the effect of rainwater on MET members:
• Standing water to be swept off daily
• Minimise exposure to weather in planning
• Temporary RWDP may be installed
• Review of moisture content prior to finish application

11. MET, being a timber product will likely be prone to termite attacks, what are some of the measures adopted to prevent it?
RSP: Construct the foundation, basement structure and 1st storey slab in reinforcement concrete to prevent subterranean termites attack. Anti-termite treatment has to be done to the soil with regular termite inspection. MET components have to be treated in the production factory for protection against termite, insects, fungal attack, moisture and UV.
12. During the construction phase, MET will likely be exposed to the environment around it. For instance, in Singapore on certain months, there is bound to be a monsoon period. What are some of the considerations and measures in improving MET defenses against rain and other adverse conditions that may hinder its constructability.

RSP: See reply in Item 10 above.

What are some of the waterproofing measures applies to the MET to act as a protective coating against raining Season? Also, what are the precaution handling methods adopted in the event of raining season?

RSP: See reply in Item 10 above.

**Fire Protection**

13. There have been many reported findings that MET has met fire rating requirements, will there be any additional measures put in place to further improve MET’s fire resistance?

RSP: Exposed timber can be designed with additional 'sacrificial' timber, so the layer exposed to fire can protect the inner material from damage. Protect/Conceal the fixing plates and bolts of MET structure for fire protection and aesthetic treatment. The building shall also be fully protected by sprinkler, water monitoring system, dry risers, hosereel, fire extinguishers, exit lights, fire exit staircases, fire engine accessway and fire hydrants.

14. If I recall correctly, the exterior of a MET building, in Singapore, should not be using combustible materials. What are some of the considerations and measures adopted?

RSP: As per Fire Safety Requirement for Engineered Timber Building Construction as stipulated in SCDF Circular dated 10 Aug 2016, 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.

**Building Features**

15. The to-be constructed 6-storey building will be used for education purposes, hence there will likely be a certain level of acoustic requirement. What are some of the measures adopted to meet this requirement.

RSP: Provide acoustic treatment on top or below the CLT slab to prevent transmission of noise from one space to another space. Provide rockwool insulation and plasterboard at the underside of CLT slab to address acoustic concern.

16. Mechanical, electrical and plumbing services will also likely be required, how will these services be incorporated into the building design? Are there any challenges faced when incorporating these services? What will be their construction process to incorporate these services?

RSP: Proper design & coordination of MEP services routing have to be done at the early design stage so to avoid penetration of MET structures, i.e. no services penetrations at Glulam columns and beams, while minimize the services penetrations.
at CLT slabs as much as possible. Building Information Modeling (BIM) tool is used for such purpose.

**Handling, Transportation and Supply Matters**

17. From where were the supplies of the chosen MET sourced? Europe? America? Asia? Others?
RSP: The Client & Consultant Team do not restrict the source of the MET, as long as the MET members are tested and meet the BS EN 14080 (Glulam) and BS EN 16351 (CLT) standard. The MET members shall also be tested and certified on all fire performance tests by SCDF’s Accredited Certification Bodies to ensure the safety and performance condition of MET members, i.e. certified under the Product Listing Scheme (PLS).

18. Where is the MET used in the project manufactured? Is it manufactured within Singapore? Or from neighboring countries, or from a distant country? Is there a reason why the chosen MET was manufactured in that country?
RSP: See reply in Item 17 above.

19. Is there any design consideration to note when manufacturing MET used for the project? Such as the joints used to connect the MET with other components?
RSP: See reply in Item 8 above.

20. How will the MET be delivered to project site? Will it be similar to Prefabricated Prefinished Volumetric Construction (PPVC)? Or, in a form where prefabricated MET components are stacked in a manner that fits efficiently onto the delivery vehicle? Or, are there other delivery methods? Please explain your consideration.
RSP: The MET members shall be stored in the off-site storage facilities provided by the to-be-appointed contractor after the pre-fabricated MET members are delivered to Singapore. The MET members shall then be delivered to site for assembly on just-in-time (JIT) basis. This is to minimize the storage of MET members on site so to avoid the exposure of uninstalled MET members to adverse weather condition.