GUIDELINE

FOR VOLUMETRIC MODULE HOUSE
MANUFACTURING DESIGN AND CONSTRUCTION FOR MALAYSIA

CIDB MALAYSIA

CIDB TECHNICAL REPORT PUBLICATION NO: 187

GUIDELINE

FOR VOLUMETRIC MODULE HOUSE

MANUFACTURING DESIGN AND CONSTRUCTION FOR MALAYSIA

CIDB TECHNICAL REPORT PUBLICATION NO: 187

CIDB MALAYSIA

Copyright

Published in 2019 by
CONSTRUCTION INDUSTRY DEVELOPMENT BOARD MALAYSIA (CIDB)
IBS Centre, CIDB Malaysia,
IBS Gallery Component,
Lot 8, Jalan Chan Sow Lin,
55200 Kuala Lumpur
MALAYSIA

ISBN 978-967-0997-58-2

PREFACE

Architects and engineers for many years have aspired to design and build the 'dream house' that can be produced by the construction industry. While, modernisation, mechanisation and industrialisation are key drivers in delivering mass production housing using technology to raise the efficiency and effectiveness of the construction industry. The Industrial Building System (IBS) in Malaysia, is a modern construction method where building components are manufactured in a controlled environment, then erected and assembled in construction works. Whereas, modular construction is a new method to construct a building based on factory made units using three-dimensional (3D) volumetric modules that are installed and assembled on site to create functional buildings.

This document "GUIDELINE FOR VOLUMETRIC MODULE HOUSE MANUFACTURING DESIGN AND CONSTRUCTION FOR MALAYSIA" produced by the Construction Industry Development Board (CIDB) will be used as the primary reference, to provide information and guidance for developers, architects, engineers, manufacturers, contractors and relevant authorities to understand and produce volumetric modules (VMs) for housing construction. The guideline aims to provide a practical overview of house manufacturing using the volumetric construction method. Furthermore, the information contained in the guideline intends to assist those parties engaged in architecture design; structural design; mechanical, electrical and plumbing design; the manufacturing volumetric modules process; installation; construction; logistics and project management.

The CIDB wish to express their gratitude and appreciation to the Ministry of Works, the National Housing Department, IBS manufacturers, contractors, consultants and all industry players involved in the development of this guideline. This guideline will be a useful reference towards increasing productivity, high-quality construction, improving onsite safety, minimise environmental impacts in construction, and achieve economies of scale in IBS manufacturing.

IBS Centre,
Technology Development Sector,
Construction Industry Development Board Malaysia (CIDB)

ABOUT THIS GUIDELINE

This guideline is one of the initiatives commissioned by the Construction Industry Development Board (CIDB) to assist construction industry players and stakeholders in moving forward concerning industrialisation. This guideline was produced by the Construction Research Institute of Malaysia (CREAM) and various industry players and stakeholder experts through a series of workshops.

As a reference document, the guideline will be a valuable resource used by developers, manufacturers, consultants, contractors and other construction industry players, aiming to provide a practical overview of house manufacturing using the volumetric module construction method. The information contained within this guideline can be used to assist those within the housing construction industry engaged in design, manufacturing, installation, construction, logistics and project management.

The guideline consists of Eleven (11) Chapters. The first chapter introduces the Volumetric Module (VM) within the context of Malaysia and the associated benefits. Chapter two to Chapter four briefly touches upon the design considerations for architecture, the structural and mechanical aspects, and electrical and plumbing. Chapter five describes the process of VM manufacturing, although, the process only touches upon prefab concrete VMs and steel VMs given these two materials are the preferred materials used in Malaysia for construction. Chapter six presents the logistics associated with VM from the factory to the construction site and the installation process. In this chapter, the transportation and lifting limitations of the VM are described. Chapter seven describes the aspects and importance of project management and Chapter eight for quality control, inspection and verification. This is followed by Chapter nine which talks about building maintenance and renovation. In this chapter, homeowner user manual criteria are also discussed. For compliance with the building codes and regulation, Chapter ten presents and discusses their importance, also listing the relevant documents such as the Acts, standards and guidelines. Finally, Chapter eleven provides a case study example regarding VMs in Malaysia and globally.

Accordingly, this guideline is intended to be an evolving, dynamic document and to be regularly reviewed by a larger community of technical professionals and organisations, both in Malaysia and globally.

EDITORIAL

This project was funded by the Construction Industry Development Board (CIDB) Malaysia and executed by the Construction Research Institute of Malaysia (CREAM). We would like to thank the following members for their contribution and support.

EDITORS

CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA (CREAM)

Ir. Dr. Zuhairi Abd. Hamid, FASc (**Chief Editor**)

Mrs. Maria Zura Mohd Zain

Ms. Nurulhuda Mat Kilau

Mr. Ahmad Farhan Roslan

Mr. Mohammad Faedzwan Abdul Rahman

Ms. Intan Diyana Musa

CONSTRUCTION INDUSTRY DEVELOPMENT BOARD (CIDB)

Datuk Ir. Elias Ismail

Mr. Ahmad Farrin Mokhtar

Mr. Mohd Rizal Norman

Mr. Mohamad Razi Ahmad Suhaimi

Mr. Ahmad Nazrol Ahmad Kamal

SECRETARIAT

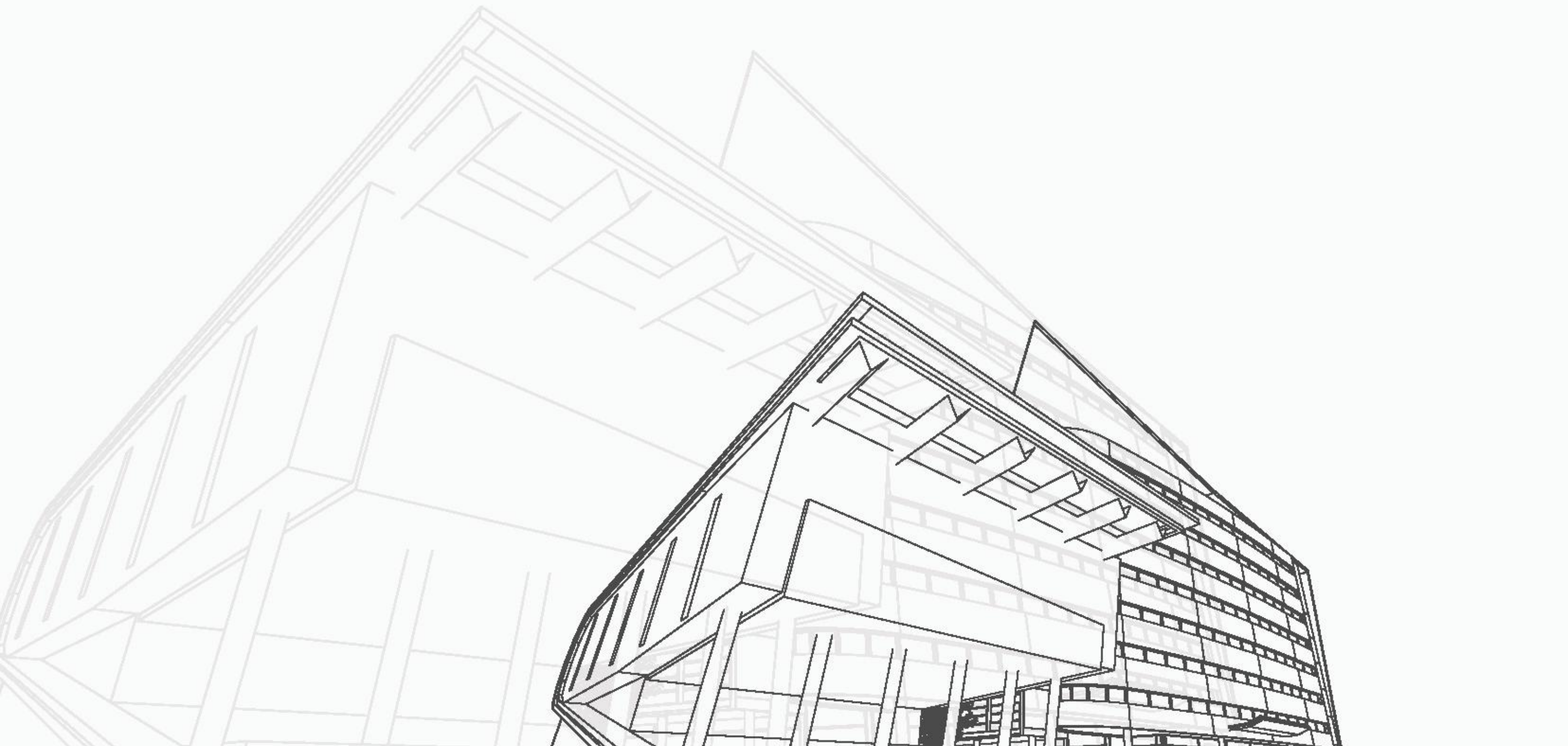
CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA (CREAM)

Mrs. Natasha Dzulkalnine

Mrs. Ihfasuziella Ibrahim

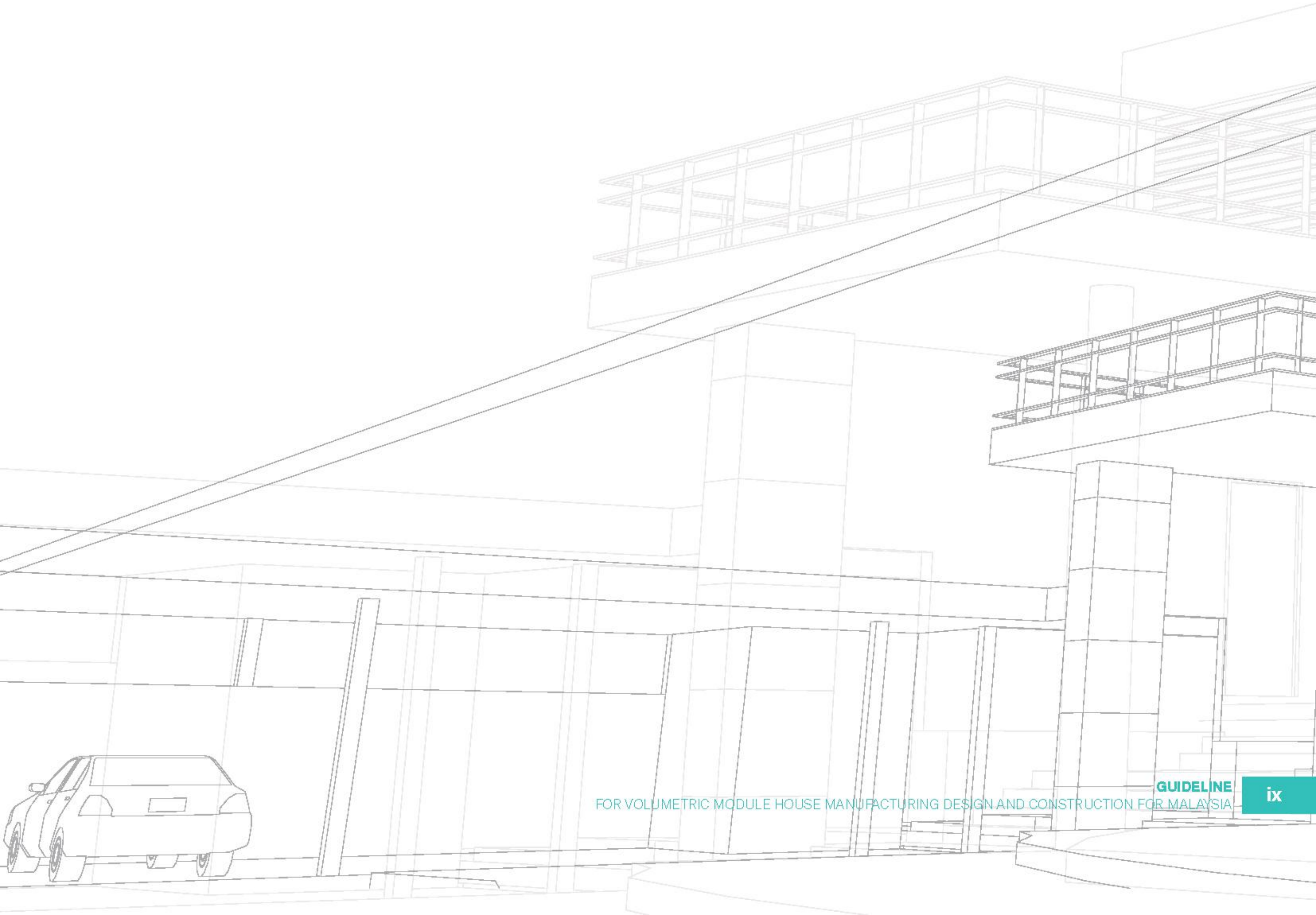
Mr. Tengku Mohd Hafizi Raja Ahmad

TABLE OF CONTENTS



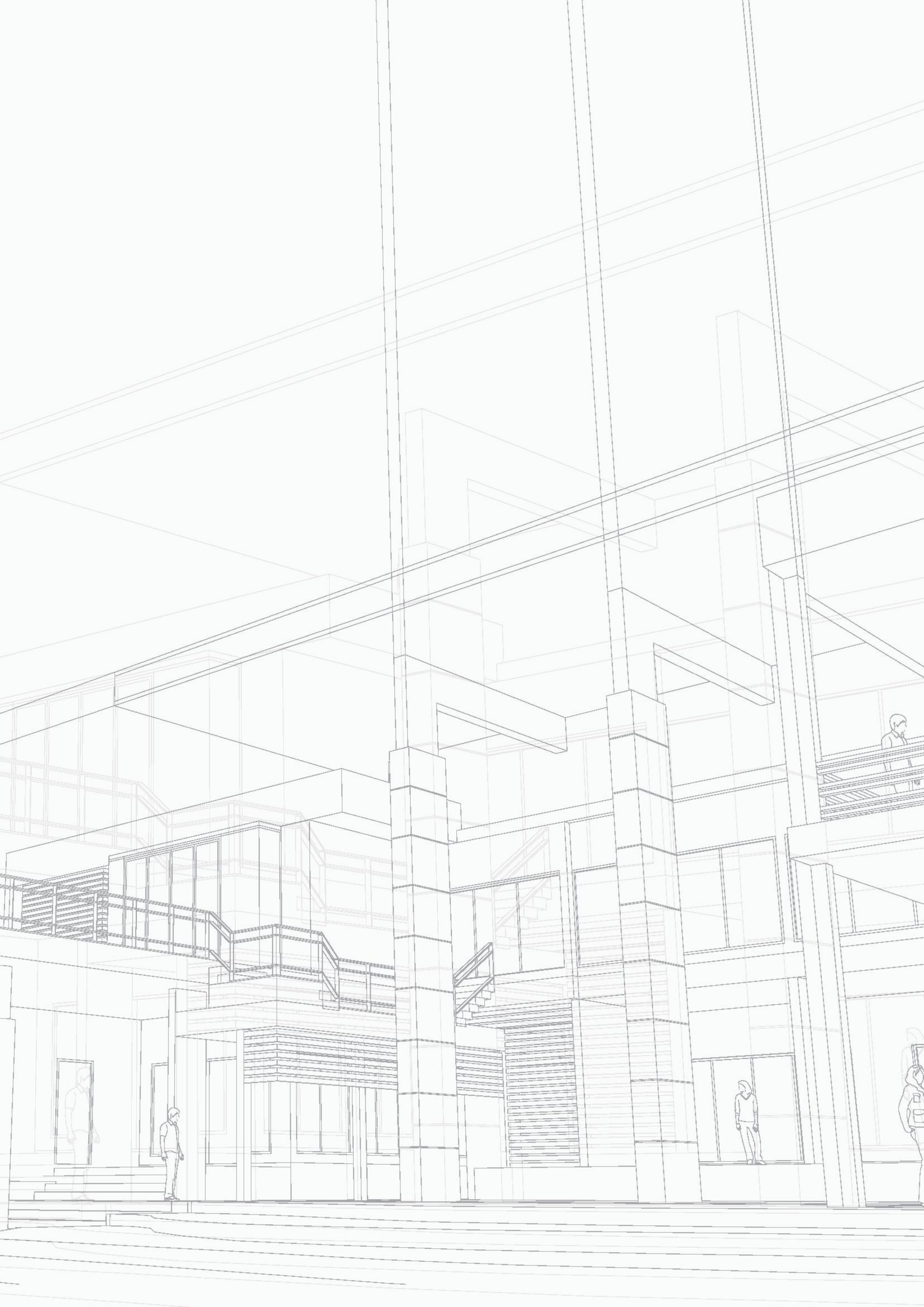
LIST OF FIGURES

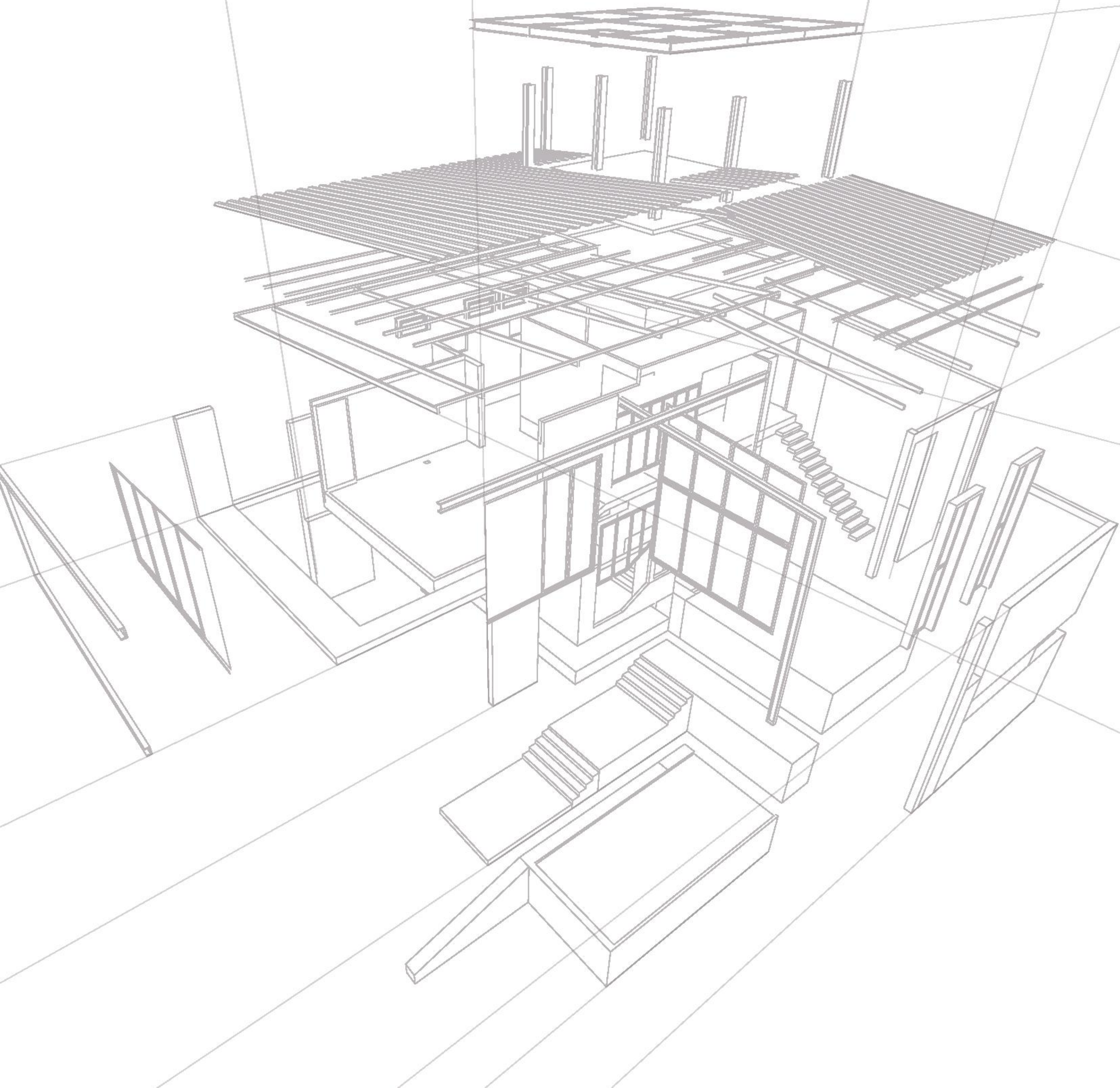
LIST OF TABLES



LIST OF ABBREVIATION

ASTM	American Society for Testing and Materials
AU	Australia
BCA	Building and Construction Authority, Singapore
BIM	Building Information Modelling
BS	British Standard
C&S	Civil & Structure
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CIDB	Construction Industry Development Board, Malaysia
CIS	Construction Industry Standard
CITP	Construction Industry Transformation Programme
CNC	Computer Numerical Control
CoG	Centre of Gravity
CREAM	Construction Research Institute of Malaysia
DfMA	Design for Manufacturing and Assembly
ELV	Extra Low Voltage
FAS	Fall Arrest Systems
FMEA	Failure Mode and Effects Analysis
FRS	Fall Restraint Systems
GBI	Green Building Index
GPS	Global Positioning System
HVAC	Heating, Ventilation, and Air Conditioning
IBS	Industrialised Building System
IFD	Intensity, Frequency and Duration
JIT	Just in Time
JKR	Jabatan Kerja Raya, Malaysia
LPG	Liquid Petroleum Gas
MEP	Mechanical, Electrical and Plumbing
MEWP	Mobile Elevating Work Platform
MKRM	Makmal Kerja Raya Malaysia
MMC	Modern Method Construction
MMI	Modernisation, Mechanisation & Industrialisation
MS	Malaysian Standard
MyCREST	Malaysian Carbon Reduction and Environmental Sustainability Tool
NZ	New Zealand
OSM	Offsite Manufacturing
OSCT	Off-site Construction Techniques
PBU	Prefabricated Bathroom Unit
PPE	Personal Protection Equipment
QC	Quality Check
REAM	Road Engineering Association of Malaysia
RFID	Radio Frequency Identification
SIRIM	Standards & Industrial Research Institute of Malaysia
SPAN	Suruhanjaya Perkhidmatan Air Negara
TIM	Technical Interchange Meeting
UBBL	Uniform Building By-Law





CHAPTER 1: INTRODUCTION

1.1 Overview

The construction industry presently records low productivity levels relative to other sectors in Malaysia and is at the lower end of the productivity spectrum in global benchmarks (refer to Figure 1.1). The relatively low productivity level is seen as a reflection of the limited modernisation of construction methods and practices as well as the reliance on low-skilled labour (CIDB Malaysia, 2015).

The Malaysian construction industry continues to build housing and residential buildings to support the Malaysian government's housing programme. In Malaysia, particularly in areas of the Klang Valley, Selangor, Penang and Johor, the demand for housing remains high despite the rapid development that has been occurring in realising Malaysia's dream to become a highly developed nation. This continues to be challenging particularly given that the supply of housing in Malaysia is unresponsive to the rising demand given the unaffordability of housing.

In 2016, according to Bank Negara, the maximum affordable housing price in Malaysia was estimated at around RM282,000 with an average nationwide household income of about RM5,228. The actual median housing price was around RM313,000, thus making housing in Malaysia seriously unaffordable. This fact was especially evident between 2016 and early 2017 when 35% of Malaysian households could only afford a house priced to RM250,000. However, only 24% of new housing supply offered prices within that range (Almeida & Wei, 2017).

One of the main factors resulting in the unaffordability of housing has been the inequality in growth between household income and house prices. Since 2007, house prices had surpassed the national household income especially between 2012 and 2014 when the growth in house prices more than doubled the growth in income levels of 26.5% and 12.4% respectively (Almeida & Wei, 2017).

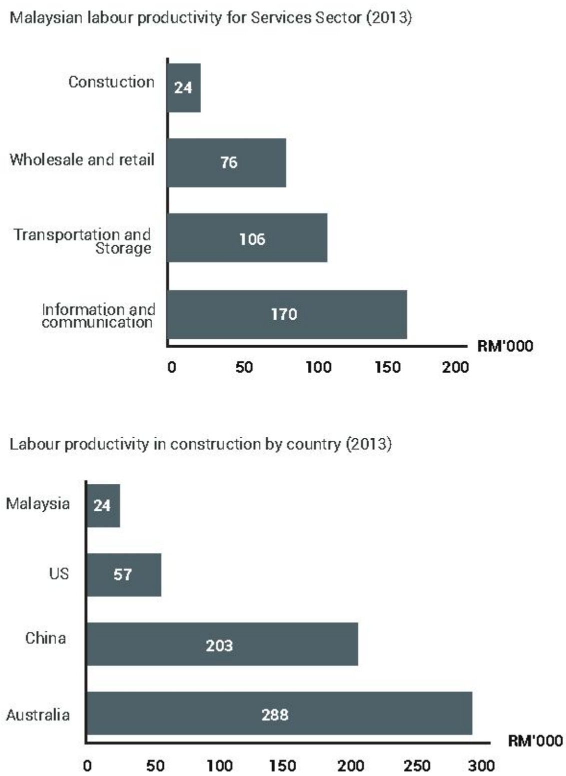
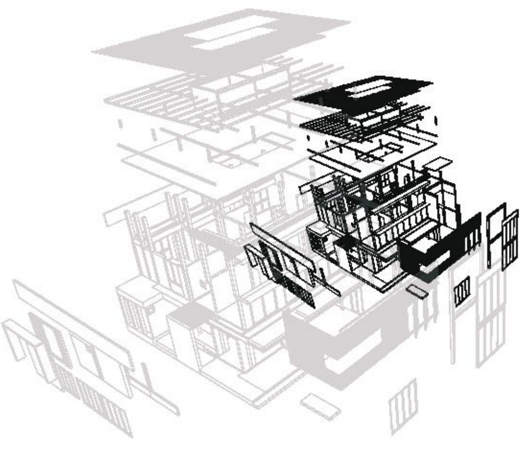


Figure 1.1. Selective Comparison on Productivity in 2013 (CIDB Malaysia, 2015)

Prevailing median house prices continue to be beyond the reach of most Malaysians. This is mainly attributable to the gross mismatch between housing supply and demand and amid the diverging expectations between households and developers. Moreover, the issue has been compounded by the fact that the distribution of new housing supply has been concentrated in the higher-priced categories. Consequently, this has led to the undersupply of housing in the affordable housing market segment. Likewise, the provision of affordable homes has become a significant challenge for policymakers globally, with Malaysia being no exception. Indeed, it is a similar problem in the United States (US), United Kingdom (UK), Australia (AU) and New Zealand (NZ) (Demographia, 2015).

Therefore, to keep pace with the massive demands for housing, houses need to be built at a much faster rate; however, this is what Malaysia is struggling to achieve. Unfortunately, the local construction industry continues to lean toward the conventional building system due to the abundance of low-skilled and cheap foreign workers. While, thinking that relatively cheaper labours can reduce construction costs, Malaysia is ignoring the Industrialised Building System (IBS). The problem with the labour-intensive conventional building system is that it is less productive and the development takes much longer to complete, thus resulting in higher costs overall. Interestingly, Singapore has successfully proven that the adoption of IBS reduces overall construction costs, and has consequently saved more than 45% in labour costs compared to conventional means (Almeida & Wei, 2017).



1.2 Modernisation, Mechanisation and Industrialisation (MMI)

The shortage of skilled workers is one of the main factors that has driven many countries to industrialise production in order to increase productivity by replacing workers with machines. However, in many developed countries, such as Japan, there has been a change towards a more industrialised construction approach. For example, in Japan, automation and robotic technologies are widely used in construction, including the production of components in factories and assembly of components on site.

Industrialisation in the construction industry has demonstrated the capacity to promote sustainability, reduce costs, improve the quality of products and to produce complex products to a vast majority of consumers. In fact, most of the construction and building material offered on the market nowadays adopted industrialisation. For instance, roof trusses, windows, doors, tiles, curtain walls, precast concrete elements are examples of industrialisation in the construction environment. However, thus far, industrialisation in the Malaysian construction industry has not been applied to the building in its entirety.

Industrialisation usually requires an offsite plant or factory where the work is organised centrally; production operations are mechanised and focused on mass production. Based on the study by Richard (2005) (Figure 1.2), the large number of components in construction are sub-assemblies. Therefore, construction is still forever a site-intense handicraft. As an outcome, the degree of industrialisation should be an indicator to measure the level of industrialisation adoption in construction.

Adaptation from Richard (2005)

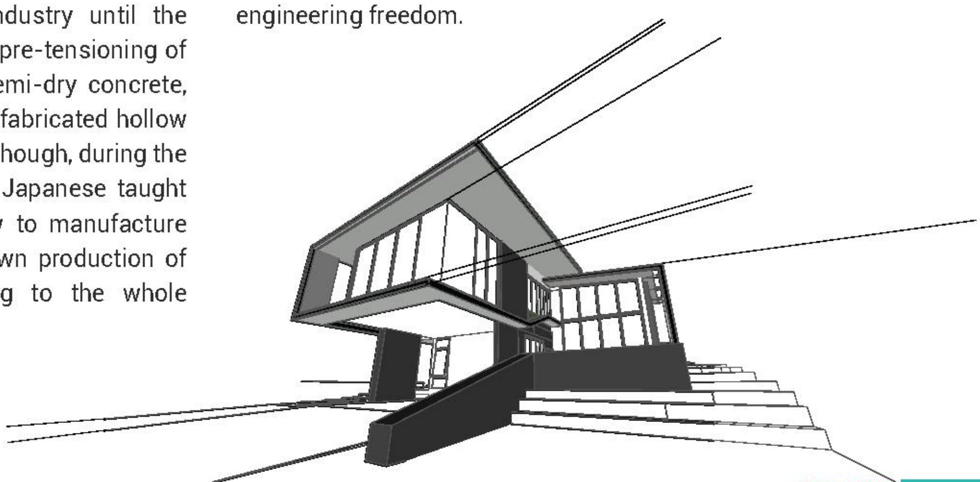
Figure 1.2. The Degree of Industrialisation (CIDB, 2017)

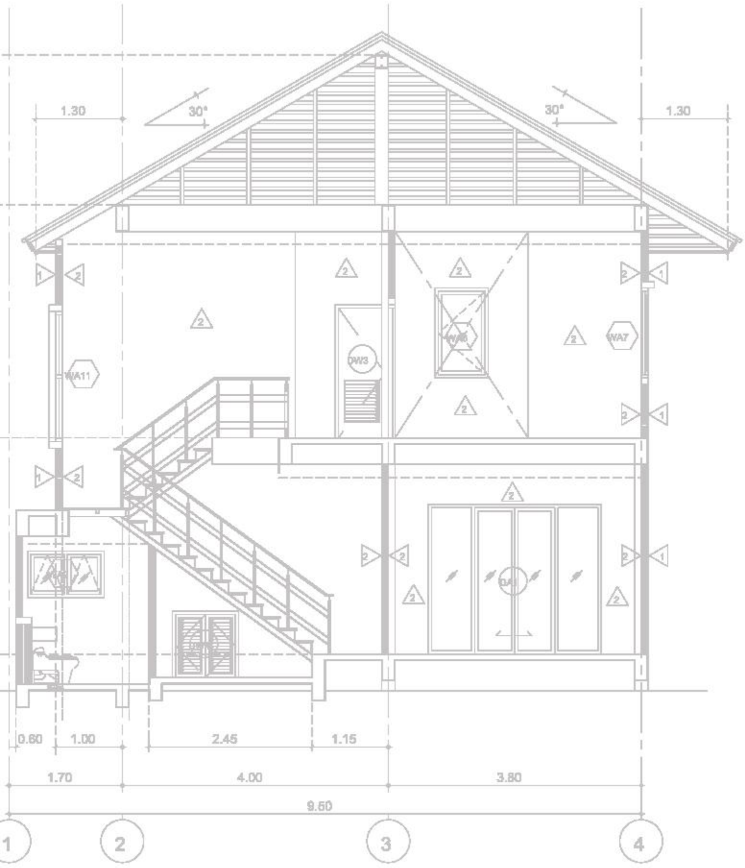
Accordingly, the modernisation and industrialisation of the construction industry, through the means of prefabrication of building elements together with the computerisation of design, detailing and scheduling, has taken a long time to arrive. Although, the once aspired paperless journey originating from the architect to the factory floor and beyond is gradually closing. Indeed, construction on such a large-scale thought to be "industrialisation"; the linear and manual process of design, detailing, scheduling and manufacturing were no more advanced compared to early twentieth-century construction.

Furthermore, while there has been minimal automation in the construction industry until the combined technologies of long line pre-tensioning of steel wires and the extrusion of semi-dry concrete, this has led to such elements as prefabricated hollow core floor slabs during the 1950s. Although, during the 1970s, changes occurred after the Japanese taught the Europeans and Americans how to manufacture cars; with forward/sideways/up/down production of the individual components leading to the whole production.

Nowadays, such automotive methods are used in the carousel table-top production of concrete wall panels and façade units, together with CAD/CAM, Auto-CAD systems, TIM scheduling, and the automated supply of drawings and component schedules to factories. The age of modernisation, mechanisation and industrialisation (MMI) of the construction industry has finally arrived.

Today fully bespoke and individually tailored building elements can be designed and erected into many diverse forms to cover the vast spectrum of building architecture; all of which are industrialised by MMI. The term IBS can now be used with architectural and engineering freedom.





1.3 Industrialised Building System (IBS)

In Malaysia, IBS is a well-known term used to represent modern construction technology which is quite different from the conventional method. In the United Kingdom (UK), Modern Method Construction (MMC) is the term used by the government to describe a number of innovations in building houses, most of which are off-site technologies. The term Offsite Manufacturing (OSM) is the term used both in the Australian (AU) and United Kingdom (UK) construction industry, whereas, in the United State (US), off-site manufacturing in the construction industry is described as Off-site Construction Techniques (OSCT) (Azman et al., 2011).

Other terms that are used to describe MMC are Factory Built/Assembled Innovative Systems Constructed On-site, Off-site Assembly, Off-site Construction, Off-site Manufacture, Modular Construction, Pre-fabricated Construction, Industrialised Construction and System Building (Ross et al., 2006). Although, Malaysia still has a low take-up rate of IBS in construction. IBS refers to a technique of construction where building components are manufactured in a controlled environment, either on-site or off-site and then installed or erected into construction works.

The IBS method of construction has many benefits, including:

i. Accelerated construction stages considering that manufacturing of prefabricated elements in factories and the construction of building foundation work at the site(s) can coincide before the on-site erection of IBS components occurs;
ii. Higher quality of construction given the sheltered and controlled environment in which prefabricated elements are manufactured;
iii. Safe environment on-site, as temporary works, are minimised; and
iv. Cost savings with the repeated use of standardised IBS components with site material wastage minimised.

In Malaysia, the government has promoted the use of IBS through government projects where the IBS score needs to achieve a 70 IBS Score for a government project to proceed. In this sense, IBS is defined as a construction process that uses standardised building components mass produced in a factory or site and then transported and assembled into a building structure with minimal workers with proper planning and integration. In the current Malaysian context, the CIDB has classified the IBS into six categories as shown in Figure 1.3.

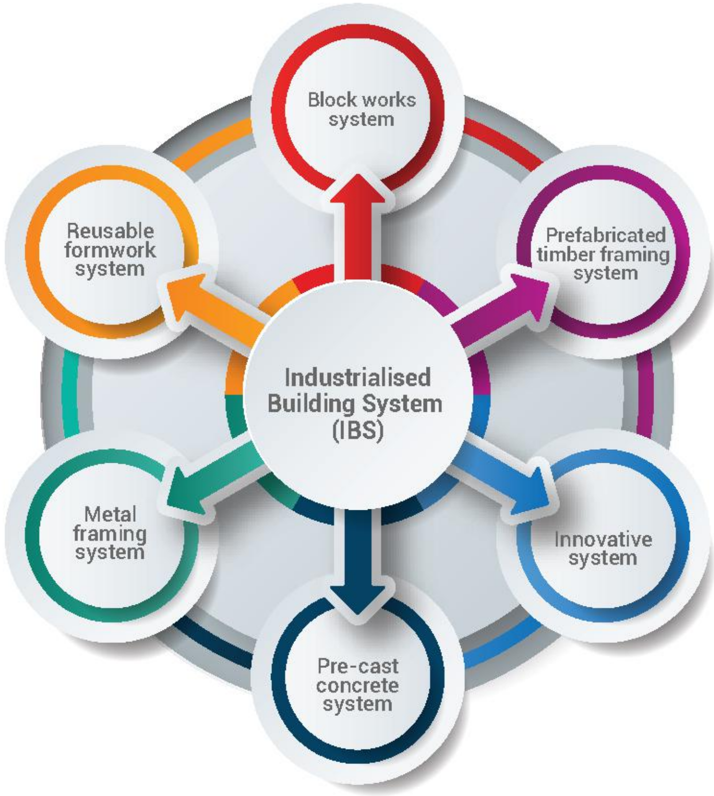


Figure 1.3. IBS Classification in Malaysia Context (CIDB, 2017)

Accordingly, the future classification of IBS in the Malaysian construction industry should be expanded to include the modular or volumetric prefabricated building system. However, Malaysia is still in the hybridisation construction stage and in the initial phase to implement modular construction.

Modular construction is a method to construct a building using a three-dimensional (3D) modular unit or Volumetric Modules (VMs), which are assembled and produced in a factory (CIDB, 2017).

The building is constructed off-site, under controlled plant conditions, using the same materials, designed to the same codes and standards, then transported and installed to become a complete building (MBI, 2018; Musa et al., 2014). The building modules can be made from most materials including a light gauge steel frame, timber frame, concrete and composites and the VMs are sometimes used alongside panels (ready-made walls, floors and roofs) in hybrid construction (Ross et al., 2006).

1.4 Volumetric Module (VM)

The term Volumetric Module (VM), in this guideline, is used to indicate the construction process using the modular/volumetric method. The VM is a standardised unit of construction designed for the ease of manufacturing and assembly, having different levels of finishes.

The VM can be produced using various materials such as a steel module, prefab concrete module, reuse of a shipping container, a timber-based module or other materials, which are pre-fitted with electrics, plumbing, heating, doors, windows and internal finishes and commissioned prior to leaving the factory, ensuring that defects are minimised, and quality control is very high. They are then transported to the project site and carefully craned into position on prepared foundations.

1.4.1 VM Overall Process/ Stage

Figure 1.4 illustrates a typical VM process starting from the project brief to the handover.

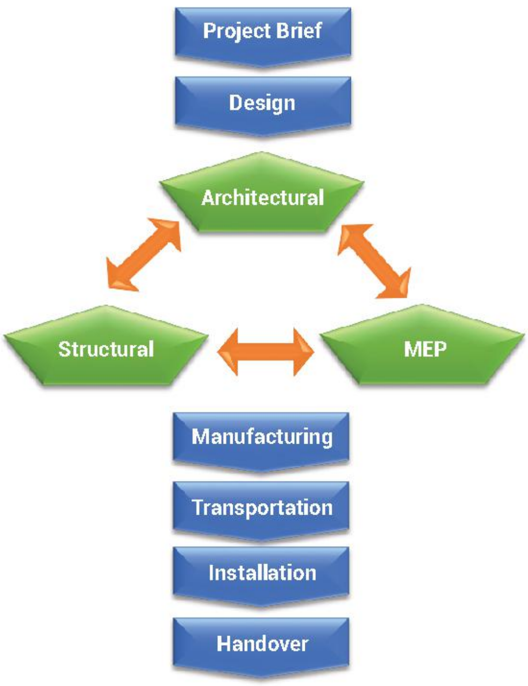


Figure 1.4. Typical VM Overall Process

Note:

- The design process for the architecture will be further elaborated in Chapter 2; Chapter 3 for the structural aspects and Chapter 4 for Mechanical, Electrical and Plumbing (MEP).
- The manufacturing process will be elaborated in Chapter 5.
- Transportation and installation will be discussed in Chapter 6.
- For quality control during the overall process, this will be discussed in Chapter 8.

1.4.2 Type of VM

Sources: Aurélie Cléraux (2018)

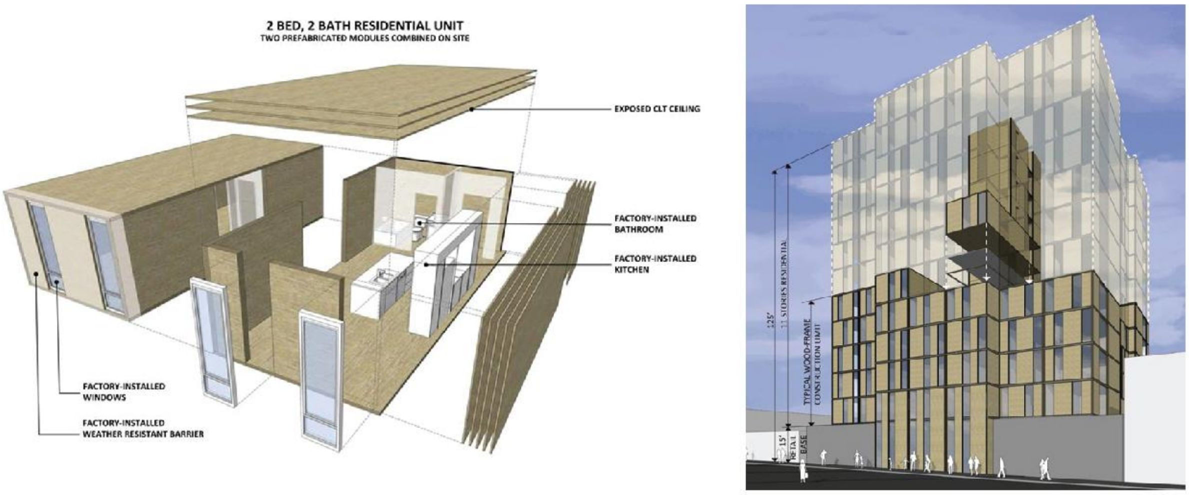
Figure 1.5. Example of a Prefab Concrete VM

Sources: Shift Modular (2014)

Figure 1.6. Example of a Steel VM

Sources: Bridgette Meinhold (2010)

Figure 1.7. Example Reuse of a Shipping Container



Sources: Alter (2014)

Figure 1.8. Example of a Timber VM

Sources: K-Structures (2015)

Figure 1.9. Example of a Prefabricated Bathroom Unit (PBU)

Sources: PCE Ltd (2017)

Figure 1.10. Example of Access Core VM

1.4.3 Benefits of VM

BENEFITS OF VM

Time Saving

Rapid deployment on site ensures practical completion is achieved faster compared to conventional construction.

Safety

Most of the construction is completed in manufacturing facilities; reduces on-site labour and on-site storage requirements.

On-site Labour Reduction

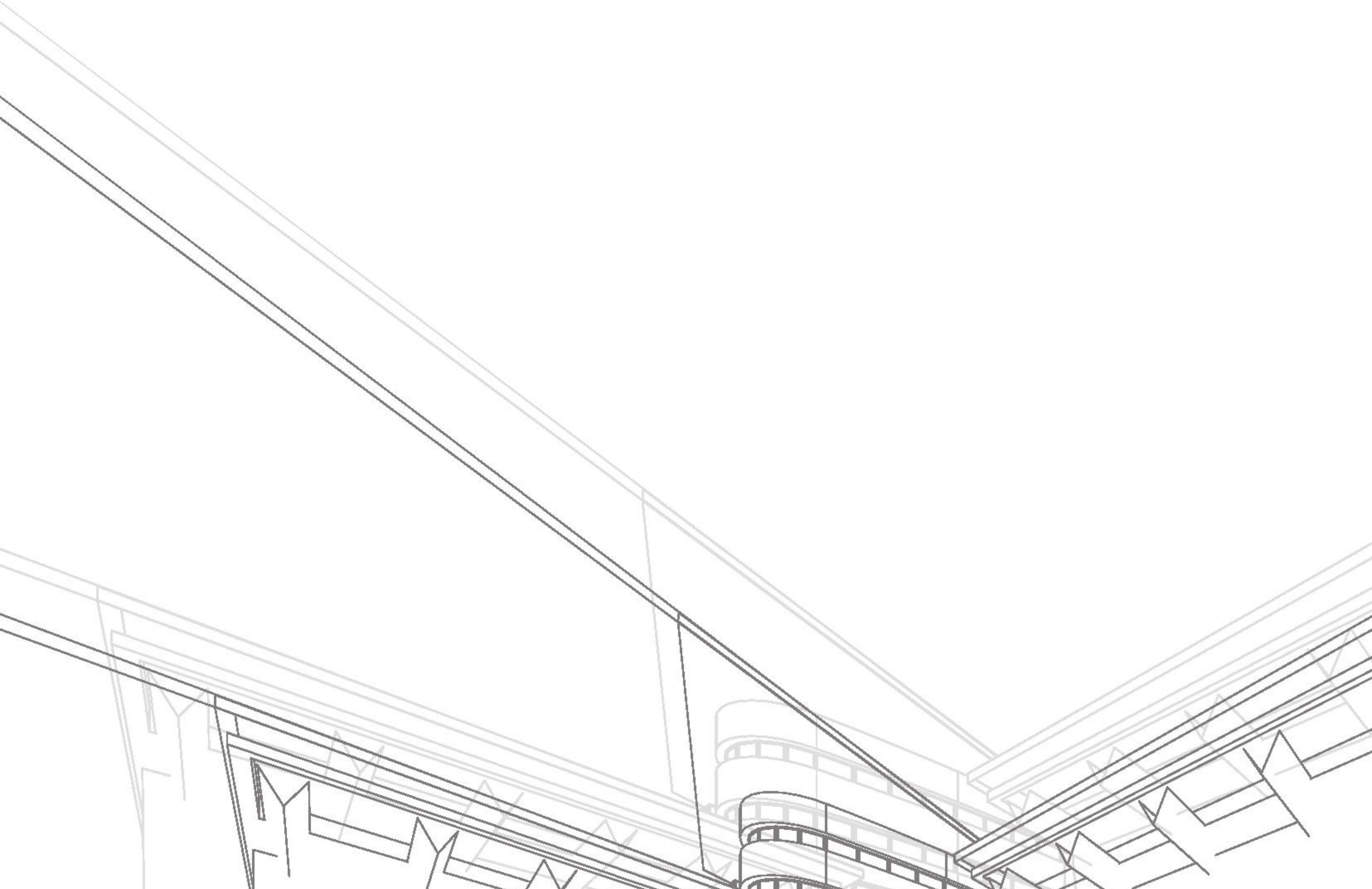
Most of the construction process is performed off-site.

Environmental

Minimal impact on the environment since most of the construction process is performed off-site. Little waste generated will create a lower cost, clean, safe and sustainable site.

Quality

Maintaining complete control over the manufacturing environment. VMs are fitted out before transporting to the site; quick smart technology can assure a level of quality, consistency and certainty that site-based construction can rarely offer.



CHAPTER 2: ARCHITECTURAL DESIGN CONSIDERATIONS

2.1 General Principles

2.1.1 Statutory Requirement

Design of VMs should comply with all statutory requirements and regulations such as the requirements imposed by local authorities, technical agencies and others.

2.2 VMs Building Planning

The design of buildings using VMs is a complex inter-relationship between the desired space and function of the building and the economical use of similar-sized VMs.

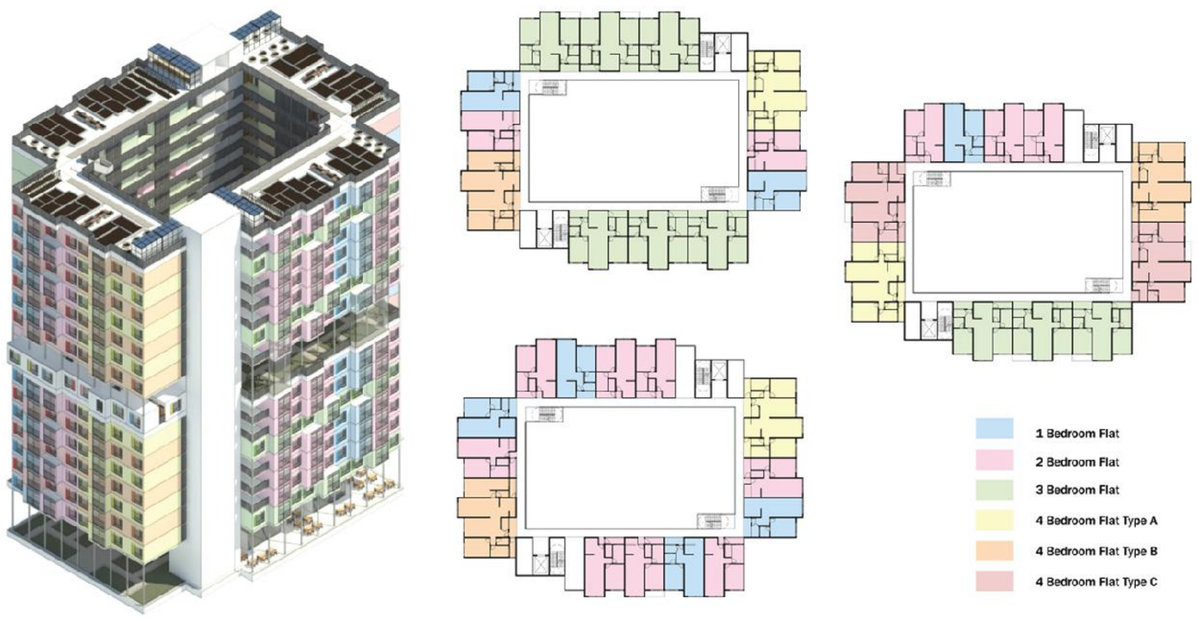


Image copyright: CIDB, CREAM & EJA (2018)

Figure 2.1. Example of the Building Planning Stage (Flat Block Plan)

When designing using VM, certain general principal should be applied such as:

i. Deciding whether four-sided VMs satisfy the spatial and functional requirements, or whether open-sided VMs are required to achieve more efficient utilisation of space.

ii. Designing the building layout to achieve as much repetition as possible in the size and fit-out of the VMs. The load-bearing capacity of the VM structure can be varied while maintaining the same external geometry.

iii. Choosing the VM size to be compatible with transport, local access, and installation constraints.

iv. Deciding how the building can be stabilised using a group of VMs, or in combination with additional bracing, or for high-rise buildings, using a concrete or braced steel core; lift core; staircase; shear wall system; or gable end; or the combination of any of these systems (see Figures 2.2, 2.3 and 2.4).

v. Pre-fitting the services and equipment within the VMs and deciding how these services are accessed from the outside of the VMs, and how they are distributed through the building.

vi. Considering the fire safety strategy and effective fire compartmentation provided by a group of VMs.

vii. Considering the cladding system to be used and how it may be connected to the VMs. Deciding whether the joints between the VMs are to be emphasised or hidden as part of the architectural concept.

viii. Sustainable design of the layout including natural ventilation and daylighting (Figure 2.6).

ix. Referring to the Malaysia sustainable rating tool, i.e. GBI, MyCREST should be referred to in order to calculate carbon reduction in the building design; construction; operation and maintenance.

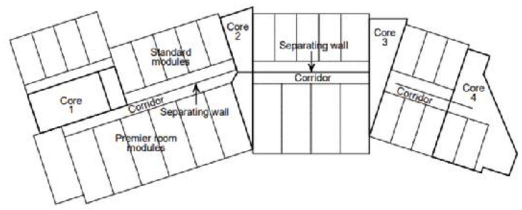
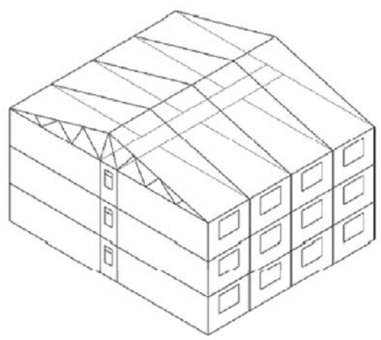
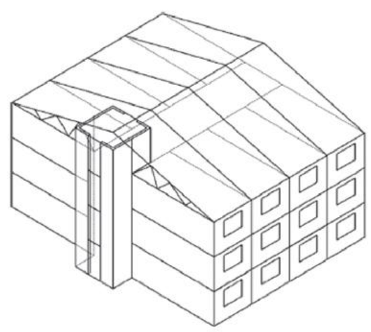


Figure 2.2. Example of Building Stabilising (Lawson & Ogden, 2010)



(a) Corridor arrangement – no stabilising core



(b) VM with corridor and stabilising core

Figure 2.3. Example of the Corridor-type Building form using Groups of VMs (Lawson et al., 2014)

Figure 2.4. Example of a Building Stabilised by Concrete (Lawson & Ogden, 2010)

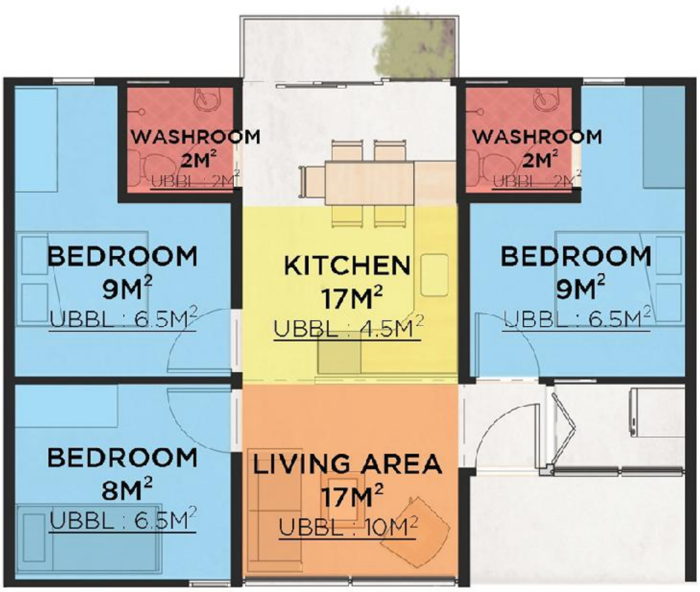


Image copyright: CIDB, CREAM & EJA (2017)

Figure 2.5. Example of Typical Plan Layout for a High Rise Building

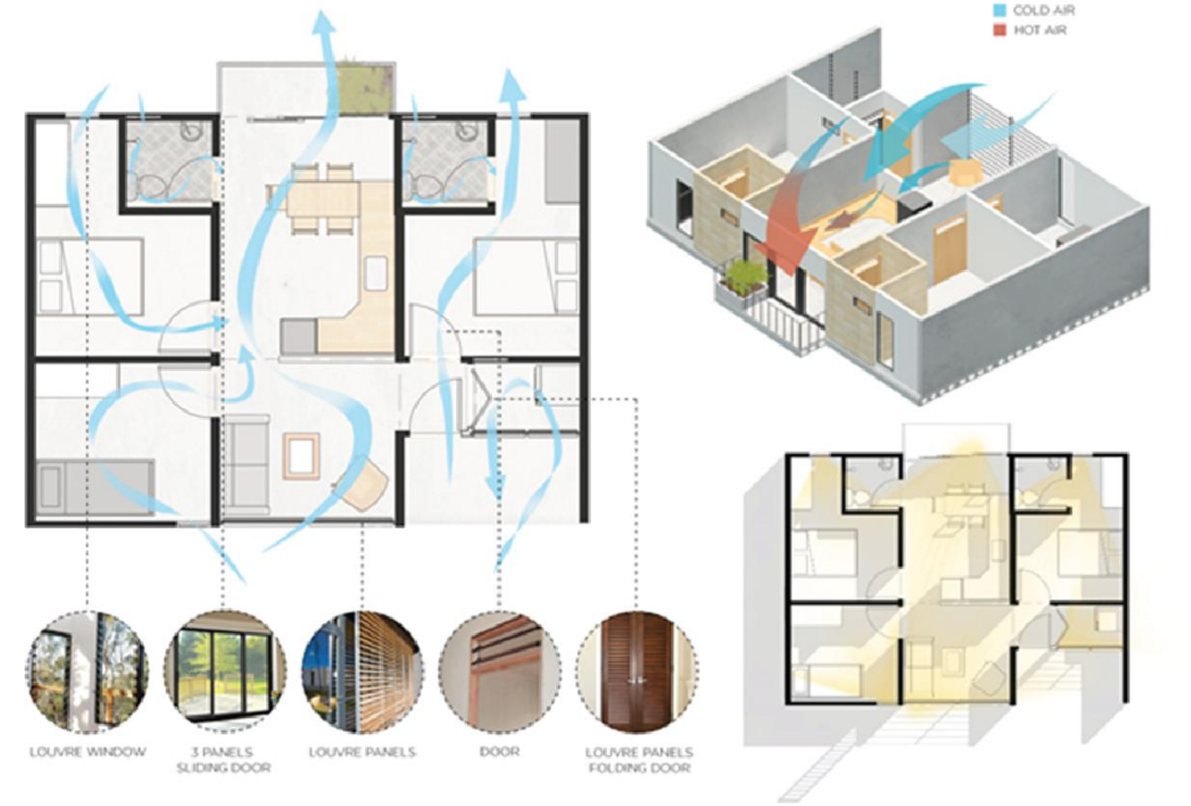


Image copyright: CIDB, CREAM & EJA (2017)

Figure 2.6. Example of Sustainable Design

2.2.1 Early Coordination

Early coordination between the Developer, Architect, Structural Engineer and MEP Engineer, Contractor and VM manufacturing specialist(s) are important given this will enable the team to analyse the key design aspects upfront including the design layout, floor and ceiling height, etc. Also, with proper upfront planning to integrate VM prefabrication into the design layout, unique designs and different building features such as curved façade, balcony, planter and non-rectangular layouts can be achieved. Importantly, the design should maximise the repetition of the VM to realise economies of scale and consideration of removable non-structural partitioning walls for future renovation.

The Architect should consider how the geometry of the constituent VM components depends on a range of factors, including:

i. Limitations to the structural systems needed to develop the architectural solution;

ii. Adherence to the desired internal planning and external imagery; and

iii. Logistical constraints: width, height, length and weight of the VMs being transported and installed.

2.2.2 Configuration of the VMs

The VMs are configured according to the design layout, and the geometry of the VMs can be simplified in order to design for ease of manufacturing, transportation and installation. The number of VMs may vary, depending on the residential unit typology. The total number of VMs can typically range from 1 to 8 per unit.

Demarcation of a typical VM is as follows:

i. M1: Two bedroom with an inbuilt bathroom
ii. M2: Kitchen, dining and living area
iii. M3: Master bedroom with and inbuilt bathroom

Image copyright: CIDB, CREAM & EJA (2018)

Figure 2.7. Example of a Typical VM layout

2.3 Dimension and Space Planning

The dimension of the plan and section of the VMs should comply with regulatory requirements and according to the MS 1064 (Guide to Modular Coordination in Building). The vertical controlling dimensions that are generally used are the storey heights, with a minimum story height of 27M (2700 mm). However, when the controlling dimension used is the room height, instead of the storey height, the height should be calculated in multiples of 1M (100 mm) therefore complying with the minimum requirements as specified in the Uniform Building By-Law 1984 (MS1064-2, 2001).

The size of the VMs should also be considered when transporting them from the factory to the site and to maximise the useable room space and ceiling height by considering all of the services to be coordinated within the allocated spaces.

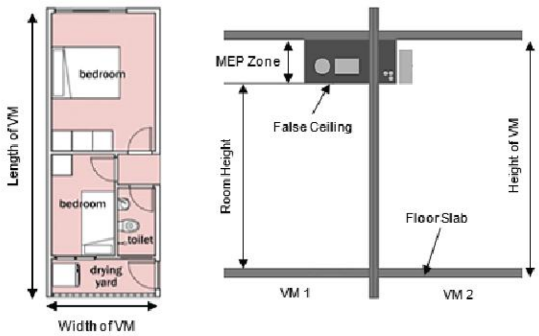


Image layout copyright: CIDB, CREAM & EJA (2018)

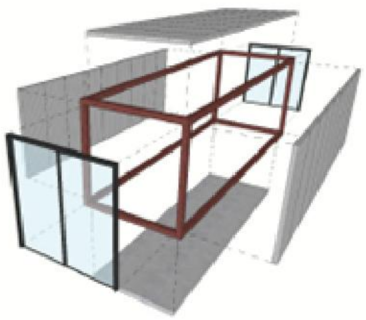
Figure 2.8. Example of Typical Dimensions of the Plan and Section of the VM

2.4 Selection of VM Material

The choice of material will further dictate the size and number of VMs in the design given weight is a major factor for hoisting the VM. Other major factors will include transportation logistics, site layout and holding area, and the crane or hoisting position. These requirements and limitations will be further discussed in Chapter 6: Transportation and Installation.

In this guideline, prefab concrete VM and steel VM are referred to because these two construction materials are preferable and widely used in Malaysia.

Table 2.1. Example of the Selection of VM Material

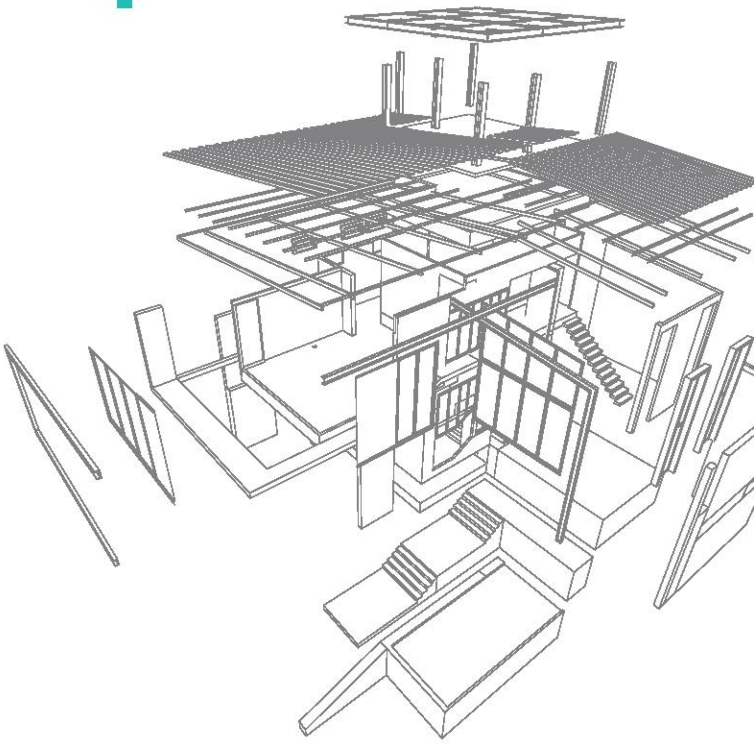
	Prefab Concrete VM	Steel VM
		
Weight	20 to 35 tons (20,000 – 35,000 kg)	15 to 20 tons (15,000 – 20,000kg)
Handling and Transportation	• Protection for completed VMs • May require permanent / temporary roof decking • May require minimal temporary stiffening • Require a lifting frame	• Protection for completed VMs • May require permanent / temporary roof decking • May require temporary stiffening • Require a lifting frame
Installation Method	Stacking method or structural framing	
Hoisting Machinery	Hoisting by crane	
Familiarity to Renovators in Maintenance, Replacement / Renovation Works	Similar to conventional construction	To include information from the supplier manual
Statutory requirement	Refer to respective Uniform Building by Law	

CHAPTER 3: STRUCTURAL DESIGN CONSIDERATIONS

3.1 General Principles

3.1.1 Statutory Requirement

The design of the VMs should comply with all statutory requirements and regulations such as the requirements imposed by local authorities, technical agencies and others. Example of the regulations and standards are the Uniform Building by Law (UBBL), the British Standard (BS), Eurocode, the Malaysian Standard (MS) and the Construction Industry Standard (CIS).



3.2 Design Consideration

Important considerations in the structural design of VMs include safeguarding people, protecting property and preventing damage to the structure. The Design Engineer is to account for all actions that might reasonably be expected, (refer Chapter 10 for more details: Compliance with Building Codes and Regulations). The actions for consideration include:

- Permanent actions (dead loads)
- Imposed actions (live loads)
- Wind action
- Seismic action
- Liquid pressure action
- Groundwater action
- Rainwater action
- Earth pressure action
- Differential movement
- Time-dependent effects
- Thermal effects
- Ground movement
- Construction sequence
- Termite actions
- MEP joint

3.3 Temporary Loads on the VM

3.3.1 Imposed Load during the Manufacturing Process

The aspects that should be considered during the manufacturing stage include the following:

Temporary supports – During the manufacturing process, the VM should retain the same vertical support arrangements throughout the process. Preferably, the vertical support at this final stage should be designed as temporary support during the manufacturing stage unless the length of the VM is too long which will then require additional temporary support.

Stacked materials at manufacturing process – Pre-cambering of the main beams of the VM may be considered to support the infill loads. Also, loading conditions need to be controlled at the time when any structural connections are made, and any residual stresses (e.g. from welding) should be well managed.

Stacking of VM during storage – Pre-cambering of the main beams of the VM should be considered to support the temporary stacking of VMs during storage at the factory and site.

Residual stresses – Any induced material stresses or deformations from lifting or reorienting of the VM or subassemblies during manufacture should be checked. This includes the effect of composite capacity creation within the VM from the floor, wall or ceiling lining, which may be unintended and damaging. Similarly, consideration should be given to any changes to support the configuration or structural load paths.

3.3.2 Imposed Load during Lifting and Support

The support arrangements for a VM during manufacture may be similar or may differ from those during lifting, transportation and installation. The potential for any differences must be controlled by specifying what is required at each stage of the process.

For all stages of the structural life of the VM, from partially complete during manufacture, through all lifting phases during manufacturing, transportation and installation, the Design Engineer should specify the intended support configurations required.
Importantly, the Design Engineer should also consider the capacity of the crane for lifting the VM at all stages and consider all safety factors in accordance with the safety requirements imposed by the authority and endorsed by a qualified engineer.

The Design Engineer and contractor should also consider the Centre of Gravity (CoG) of the lifted VM during all stages including subassembly, which should be indicated on the design and plan drawings. Also, the lengths of multiple lifting slings (crane hook/spreader frame to the VM attachment point) may require prior adjustment to ensure control of the VM's orientation to the placement location. Likewise, multiple slings may require the use of load-equalisation devices. Slings inclined towards each other induce compression forces between them in the suspended VM. Importantly, the Design Engineer should check the VM for such forces, if applied.

Before lifting the VM, attention is required to ensure that the crane hook is vertically positioned above the VM's CoG to avoid any swing once suspended. Permissible wind loading requirements and restrictions during lifting may need to be considered especially for high rise construction sites.

The Design Engineer should clearly specify the lifting and connection arrangements where the VMs are to be temporarily stacked or otherwise interconnected. Modular construction commonly involves the stacking of VMs in a project building and may also include temporary stacking in storage before, during or after transportation including additional details. Any lifting assumptions made by the Design Engineer should be explicitly specified on all relevant documentation.

3.3.3 Imposed Load during Transportation

During transportation, VMs are subjected to dynamic loading with variable intensity, frequency and duration (IFD). These loads are typically described as multipliers (or acceleration coefficients) applied to the gravity-driven permanent actions, often as a worst-case value and additive to the vertical downwards effect of gravity itself. In this case, the Design Engineer should assess the effects of the dynamic forces in all applicable directions. Consideration also needs to be given to peak instantaneous loads on strength resistance, cyclic effects on fatigue and structural response, variable positioning of the VM during transportation and the means to increase or reduce the dynamic effects.

Given the variability in transportation conditions (i.e. weather exposure, vehicle response, duration of stages) and that it usually coincides with a boundary between subcontracts, it is prudent to be conservative in the design provisions for transport-induced actions. Notwithstanding, building materials which are more sensitive (e.g. glazing, brittle or moisture-sensitive linings, temperature-sensitive compounds) should consider installation at the site.

The Design Engineer should account for additional forces on any of the VMs where they are positively restrained by tie-down action. The VM's internal structure must also be able to resist the additional forces generated by tie-down and the restraint against movement accelerations.

3.3.4 Imposed Load during Installation

Before installation of the VM, the contractor should ensure that the alignment is within the allowable tolerance(s). The Design Engineer should make provisions within the connection design to accommodate any misalignment of components within the required tolerance(s). The measures considered can include:

i. Shims/packers;
ii. Racking correction/plumbing via active braces; and
iii. Localised flexural displacement around non-slip connections

3.3.5 Imposed Load for Temporary Structures

The Design Engineer should consider the loading requirements for temporary structures during the construction stage. This information should be provided to all relevant competent individuals having control of the temporary structure. Likewise, appropriate signage on the structure is recommended advising of the occupancy capacity.

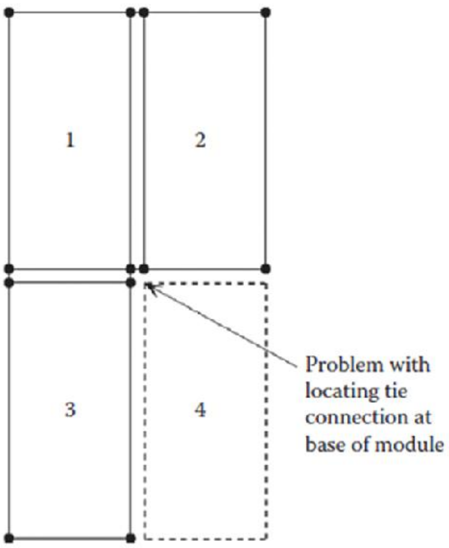
3.4 Structural Integrity in VM Construction

Structural integrity or robustness is concerned with the stability and localisation of damage in accidental or extreme loading events. In constructing VMs, the means of assessing the stability of the group of VMs is to consider the notional removal of one support to the corner of a VM and to ensure that the effect of damage to the VM is localised.

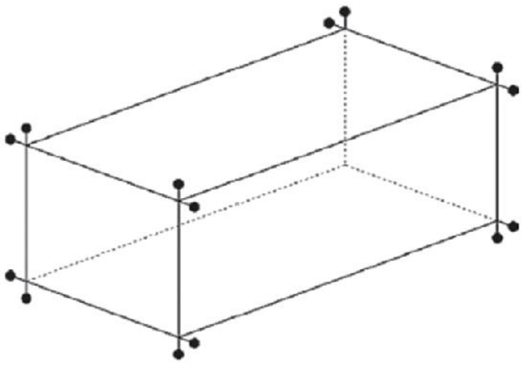
Steel VMs are generally tied horizontally and vertically at all four corners, as illustrated in Figure 3.1. These connections are made through plates and single bolts, which are installed sequentially as each steel VM is positioned. However, tying at an internal junction of a group of steel VMs can prove problematic, as illustrated in the figure.

As shown in the figure, the fourth VM to be positioned cannot be easily connected at its base unless access to the connection is through the service riser or another opening.

As for prefab concrete VMs, the structures are extremely resistant to lateral loads due to a large number of load-bearing walls. However, in the design of open-ended VMs, stability may be more problematic where lateral loads act perpendicular to the walls. Therefore, temporary stability during construction should be considered, and method statements demonstrating temporary stability prepared.



(a) Internal Connection of Group of Steel VMs

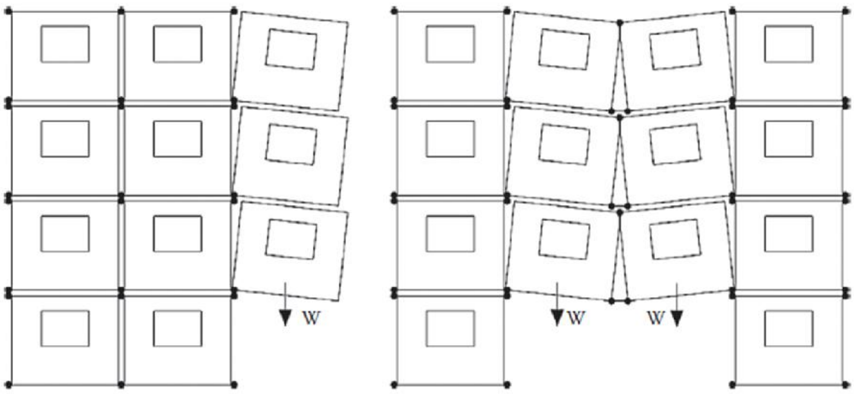


(b) Effective Tying Action for Individual Steel VM

Figure 3.1. Example of Tying Action between Steel VMs (Lawson et al., 2014)

For VM construction, robust structural action may be established by considering various scenarios for the localisation of damage corresponding to loss of support at the ground or intermediate floor. Figure 3.2 illustrates two extreme cases for loss of a corner support or an intermediate support due to the notional removal of part of the ground floor VM.

This corresponds to a loss of corner support or for continuously supported VMs, loss of support to one end and half of the long side of the VM. The forces due to loss of this support are resisted by the tying forces between the VMs and VMs to the core structure such as lift core, gable end, staircase, shear wall, etc.



(a) Loss of Corner Support (b) Loss of Intermediate Support

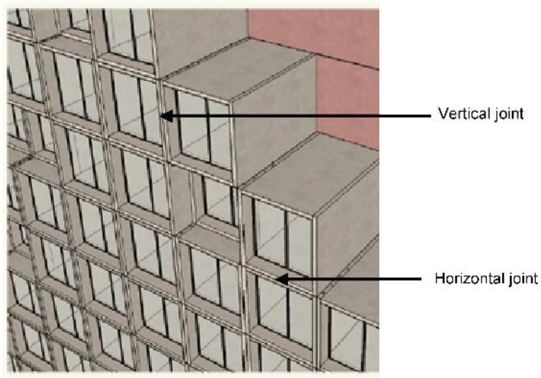
Figure 3.2. Example of Robustness Scenarios in VM Construction (Lawson et al., 2014)

3.5 Connection between the VMs

Connections strongly influence overall structural stability and robustness of the assembly of VMs and should be designed to transfer horizontal forces (e.g. due to wind loading), and extreme forces due to loss of support in the event of accidental events. Adequate vertical shear transfer (for example as a result of wind-induced uplifts or differential movements) between the units must be considered to maintain the integrity of the system.

In the case of new or innovative connection detailing, the Design Engineer should employ multiple methods towards proving the design. However, where recognised and appropriate test methods do not exist, these methods should be developed in conjunction with a testing entity with independent approval (e.g. SIRIM, MKRM, etc.).

The design of VMs should give due consideration to the scenario of sustaining an extent of localised failure through the redistribution of internal forces to the nearest load bearing elements such that progressive collapse is entirely prevented.



Sources: (BCA, 2017)

Figure 3.3. Example of Typical Vertical and Horizontal Joint between VMs during Construction

3.5.1 Vertical VMs Connection

The vertical VMs connection is crucial for structural behaviour, especially for high rise buildings as they have a direct effect on the building stiffness and its corresponding response under wind, seismic (if applicable) and lateral design action conditions. Hence, detailing of the VM vertical connection must satisfy the design requirements. Notably, vertical joints between the VMs should also be designed for eccentricity or imperfection.

3.5.2 Horizontal VMs Connection

The horizontal VMs connection forming the floor diaphragm, are equally important, contributing to the overall building stiffness. In particular, peripheral ties and internal ties should be provided. The VM layout should be laterally connected and designed such that the horizontal forces (e.g. wind load) can effectively be transferred to the building's lateral load resisting system.

Furthermore, due to repetitions, and as far as practicable, the horizontal joints should be designed in a manner that affords implementation at the site to be speedy and simple. An example of steel VM joints is the bolting system, whereas in concrete VMs on-site grouting of joints is quite common.

3.6 Manufacturing and Construction Tolerance

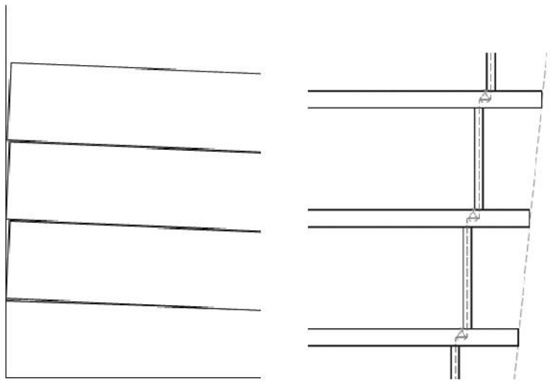
The construction tolerance on vertical and horizontal joints between VMs and the existing building part (building core/corridor) at the site should be considered and allowed. Tolerances are necessary due to the practical inability to make anything to an exact measure. There is a distinction between accuracy and precision. Accuracy refers to how close a measure is to the correct value, whereas precision refers to the consistency in repeated measurements (Monash University, 2017).

The Design Engineer should clearly state all design tolerances including but not limited to:

i. Required physical properties of all materials;
ii. Tolerances in physical dimensions (e.g. tolerances for bolt holes);
iii. Minimum additional length for electrical and data cables to ensure ease of connection on site;
iv. Tolerances in service connections (for example, plumbing connections may require some flexibility to account for imperfect alignment); and
v. The tolerance should be within 3 mm or lower for any tolerance measurement.

Accordingly, this will help to ensure ease of manufacture and assembly on-site. The manufacturer should also ensure that the tolerances indicated in the design are incorporated into the manufactured VMs. The Design Engineer should be aware of prevailing or common industry tolerance expectations and highlight where any differences are required for the VMs project.

Control of vertical and horizontal tolerances between VMs for high-rise buildings is important as the differences in the height of a VM can cause stepping out, or vertical out-of-alignment effects where VMs become wedge-shaped.



(a) Effects due to vertical tolerance

(b) Effective Tying Action for Individual Steel VM

Figure 3.4. Example Accumulated Errors of Manufacturing Tolerance

3.7 Vertical and Horizontal Alignment

The possibility of misalignment of the floor, wall and ceiling at the joints between the VMs either horizontally or vertically need to be considered. Details regarding the interface between the VMs and in-situ construction such as core walls, staircases, corridors, and other parts of buildings should be taken into account. Also, detailing for water-tightness on the vertical and horizontal joints of VMs should be specified, and method statements for water-tightness should be tested and verified (Refer to Chapter 10; Compliance with Building Codes and Regulations).

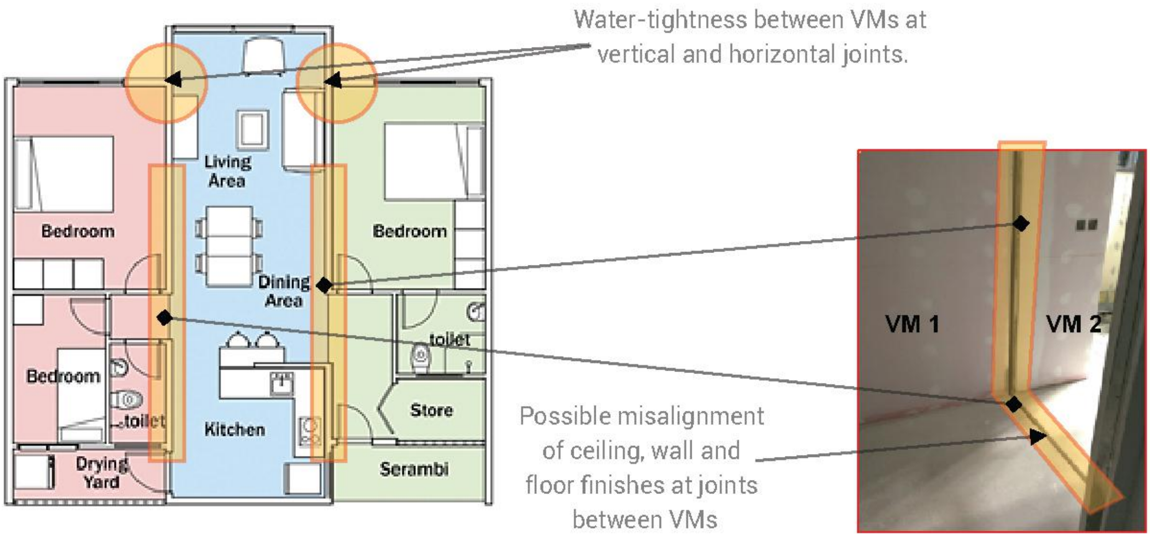
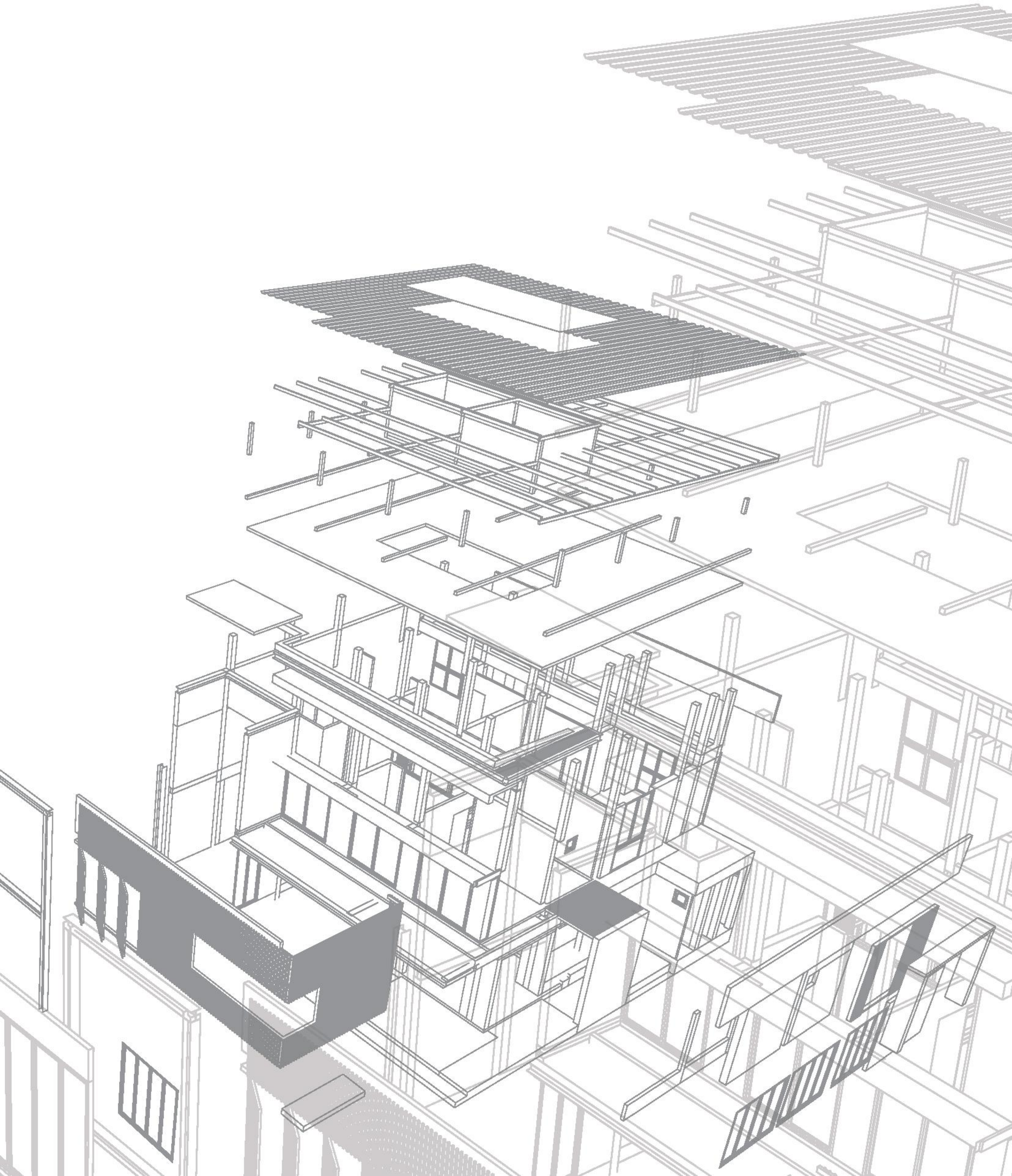


Image layout copyright: CIDB, CREAM & EJA (2018)

Figure 3.5. Vertical and Horizontal Alignment between VMs



CHAPTER 4: MECHANICAL, ELECTRICAL AND PLUMBING (MEP) DESIGN CONSIDERATIONS

4.1 General Principles

All MEP materials should comply with relevant statutory requirements and regulations such as the requirements imposed by the local authorities, technical agencies and others. Example of regulations and standards are SIRIM, SPAN, etc.

4.2 Services Interfaces

4.2.1 Basic Considerations

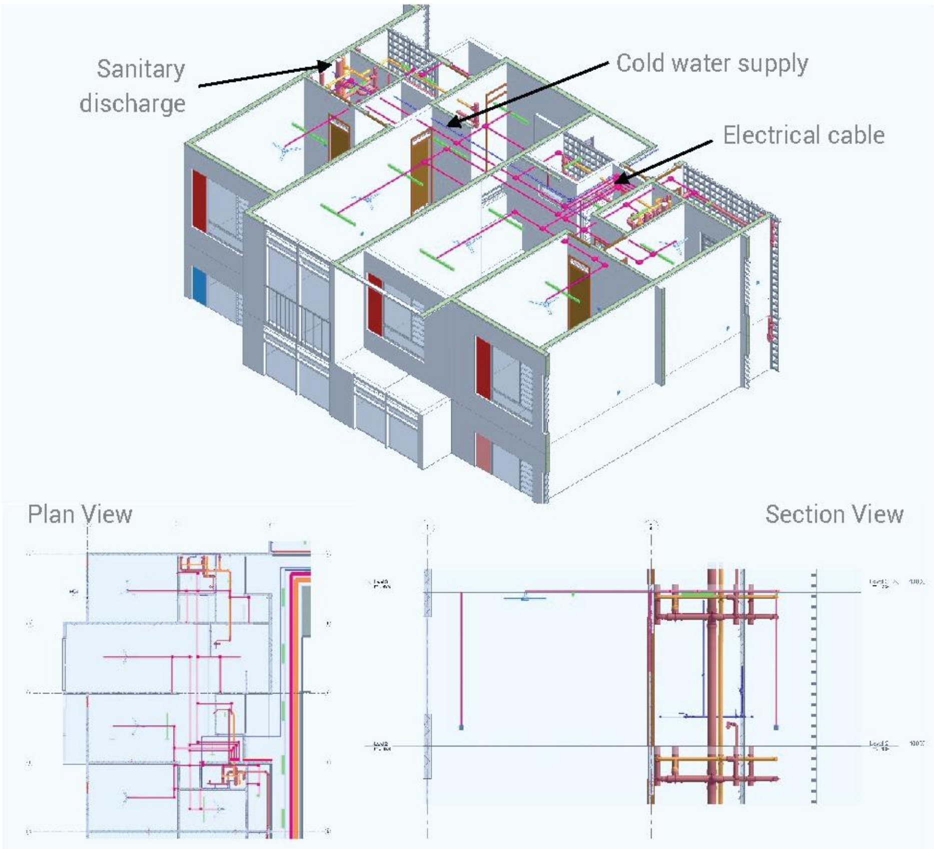


Image layout copyright: CIDB, CREAM, EJA & Numaginelab Sdn Bhd (2018)

Figure 4.1. Example of Typical MEP Services in VMs

a) Typical MEP Services

Typical MEP services include fire protection, electrical, an extra low voltage (ELV), lightning protection, water supply, sanitary, heating, ventilation and air-conditioning (HVAC), liquid petroleum gas (LPG), and any other system part of the VM.

b) MEP Coordination

Early coordination of services should be performed, and constraints for installation and maintenance should be addressed early to avoid impact on finished works in the later stage. Upfront design coordination in conjunction with the structural prefabrication component is important.

c) Impact to Structure and Fire Safety

Necessary openings, recesses and concealed components in the VM's should be considered for structural strength, fire safety measures and in other relevant designs.

d) Integrity of MEP Services

Continuity and system integrity of all MEP services should be dealt with accordingly. Also, due to the modularisation nature of VMs, the connection of the MEP system components between VMs may be required. However, the connection methodology (if used) should not compromise the integrity and performance of the system.

e) Accessibility for Installation and Maintenance including Access Panel

The means of installation should enable ease of maintenance and for future replacement when necessary as well as allocating sufficient space to carry out installation, maintenance and future replacement work. Likewise, pipework enclosures (e.g. ducts, castings, etc.) should be of a suitable size, and sufficient in providing ready access for performing maintenance, inspection, testing and repairing/replacing of the enclosed pipework.

f) Design and Construction Errors

The tolerance of the gradient of pipe-work connections should also be considered as the angle and levelling of the fittings may be affected following the positioning of the VM in-place. Importantly, the tolerance of these level differences should be considered in the initial design and planning stage.

4.3 Electrical and Lightning Protection

4.3.1 Electrical

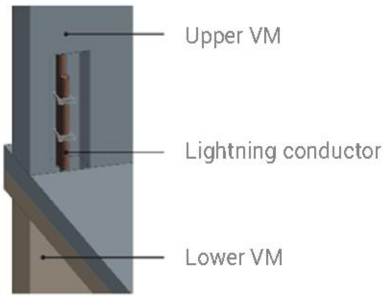
The design of electrical services should consider the following:

i. The connection of components including the conduit, cable trunking and cable trays.
ii. Joint of cable infrastructure (modular cable jointing unit) between VMs to ensure proper protection for the cable.
iii. Joint of cable should ensure complete continuity with an acceptable connection methodology if joint of cable is unavoidable.
iv. Concealed cable infrastructure not to compromise fire safety including the cable joint area.
v. Electrical connections between two VMs or more should be safely carried out in accordance with the Electricity Supply Act 1990 (Act 447).

4.3.2 Lightning Protection

The design of lighting protection should consider the following:

i. The connection of the lightning conductor.
ii. Connection joint(s) should ensure proper conductivity with the acceptable methodology.
iii. If a structure rebar and/or a structural steel section is used as a conductor, proper measures need to be taken to prevent erosion of the conductor



Sources: (BCA, 2017)

Figure 4.2. Example of Typical Lightning Conductor Connection between VMs

4.4 Water and Sanitary Piping

4.4.1 Water

The design of the plumbing services should consider the following:

i. Water fittings that are to be concealed should be water-tight and suitable for default conditions (e.g. pressure, temperature, etc.).
ii. Concealed components embedded in structural elements should be taken into consideration for structural strength design.
iii. The method for future repair work for servicing or leakage should be taken into consideration in the design.

4.4.2 Sanitary

The design of sanitary should consider the following:

i. All sanitary discharge pipes and ventilating pipes including the shallow floor trap should comply with relevant requirements.
ii. All gravity discharge pipes should have a suitable gradient to maintain a self-cleansing velocity to ensure smooth flow.
iii. All joints of pipes should be tested to ensure water-tightness and air-tightness.
iv. A shallow floor trap shall not be used if there are connections from the kitchen sink or dishwasher.
v. Consider the potential of the slab thickening factor for the use of a shallow floor trap (subject to regulatory compliance and approval), including the impact on weight, transportation and storage requirements.
vi. Proper protection to all protruding and exposed pipe works from mechanical damage during transportation, storage and shifting of VMs to be carried out.
vii. Protect pre-installed pipe works from heat, ultra-violet radiation and other possible detrimental factors.
viii. Concealed components embedded in structural elements should be taken into consideration for structural strength design.
ix. Ensure suitable access, and working space is provided for pipe connections between the VMs.
x. The method for future repair works for clogging or leakage should be taken into consideration in the design.
xi. Consider the mounting type of the WC (floor-mounted or wall-mounted).

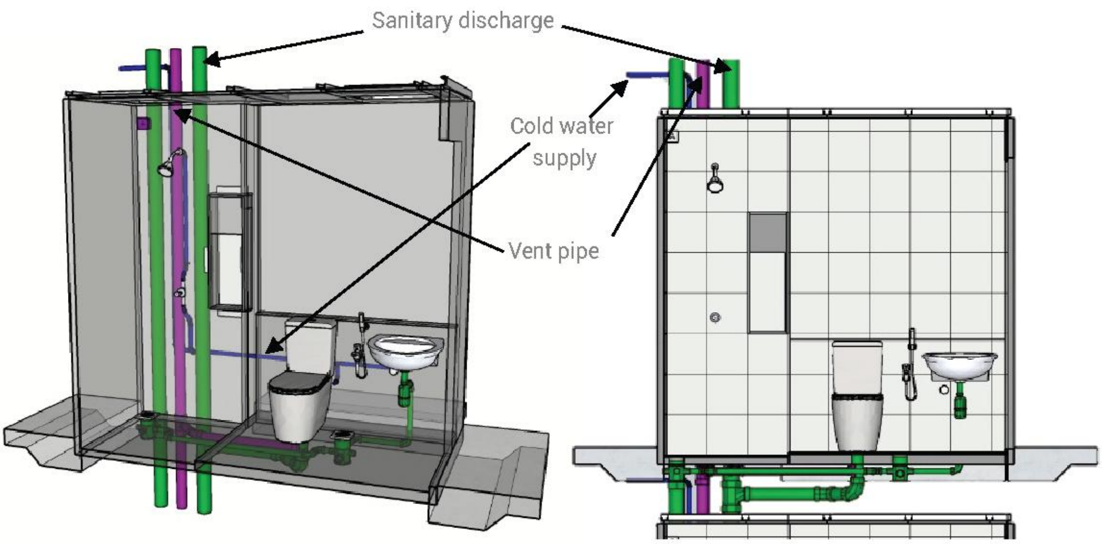


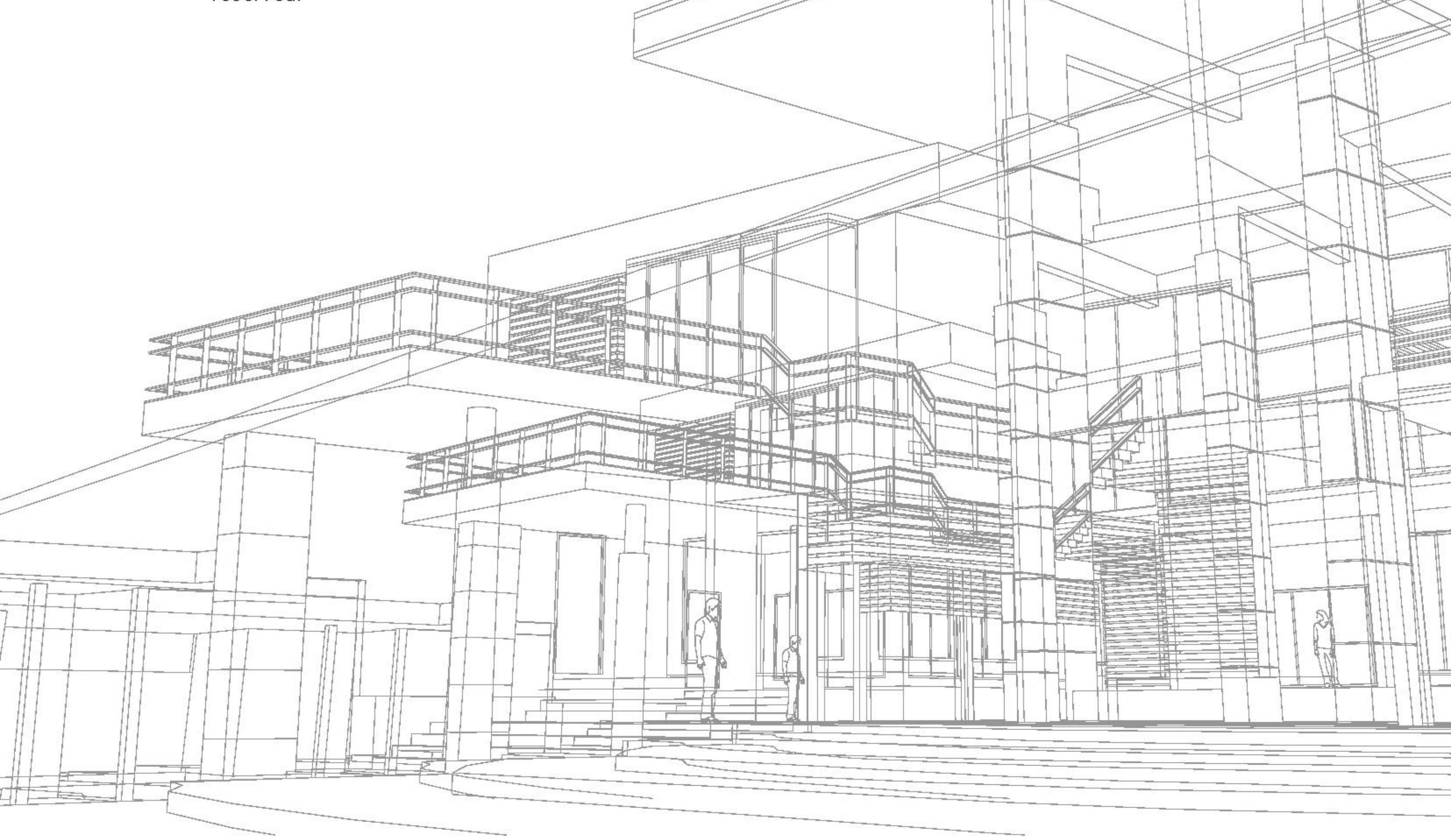
Image courtesy: Gamuda IBS

Figure 4.3. Typical Water and Sanitary Piping in VMs

4.5 Heating, Ventilation and Air-Conditioning (HVAC)

The design of HVAC should consider the following:

i. The connection of air-conditioning components which include the refrigerant pipe, condensate drain pipe, a respective insulation layer, and wiring.
ii. Opening at the VM for refrigerant pipe routing.
iii. Joints of the refrigerant pipe, if required, should be able to withstand operating pressure and not be eroded easily.
iv. Maintenance and repair measures should be taken into consideration.
v. The connection of mechanical ventilation components which include a mechanical fan, air-duct and wiring.
vi. Inspection and replacement access for equipment such as a mechanical fan should be reserved.



CHAPTER 5: MANUFACTURING

5.1 Type of Production Line

5.1.1 Static Production

Static production is where the VMs are manufactured in one location, with materials, services, and workers brought to the site. Here, the geometry of the VMs needs to be precisely controlled using manual methods, although a steel-framed jig is frequently used to control the accuracy of the vertical placement of the walls.\

Importantly, the space around the VMs must be sufficient enough to provide for temporary storage of materials and prefinished components, such as windows, which are manhandled or lifting by an overhead crane. The rate of construction is controlled by the availability of personnel to perform the specialist tasks at the required time. As a result, the process can be relatively slow, but conversely, the critical path, in this case, is not reliant upon the completion of any one task. When completed, the VMs are lifted using an overhead crane and either stored temporarily or transported to the project site.

Sources: Satow (2013)

Figure 5.1. Example of Static Production

5.1.2 Linear Production

Linear production means that the manufacturing process is sequential and is carried out in a discrete number of individual stages, similar to an automotive production line. The VMs may be manufactured on fixed rails or trolleys and moved between stations. Each station has a number of production teams or trades associated with it and a prescribed zone on the factory floor. The key difference between this form of production and static production is that the VMs are moved between dedicated stations, rather than the production teams having to move from one VM to another VM.

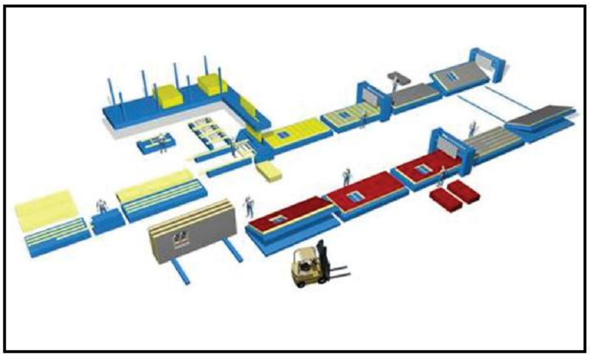
Sources: Forta Pro

Figure 5.2. Example of Linear Production Line

5.1.3 Semi-automated Linear Production

Modern semi-automated factories for modular production are based on the same principles of conventional linear production as non-automated lines but tend to have more dedicated stages. Typically, automated facilities have separate lines for the manufacture of walls, ceilings, and floor panels as light steel-based facilities are often incorporated on line roll-forming machines for each type of panel.

Automated lines commonly include facilities for creating window and door openings (often by the incorporation of subassemblies), and installing insulation and inbuilt services, such as cabling and telecoms. However, they do not usually include automated systems for bathroom fit-out and installation of fitted furnishings, as bathroom pods are often prefabricated off-line or brought in. Furnishings are generally more difficult to automate and become follow-on operations. Therefore, semi-automated production lines tend to comprise a highly automated series of operations requiring specialised equipment, followed by a series of relatively conventional manual operations.



Sources: Alter (2016)

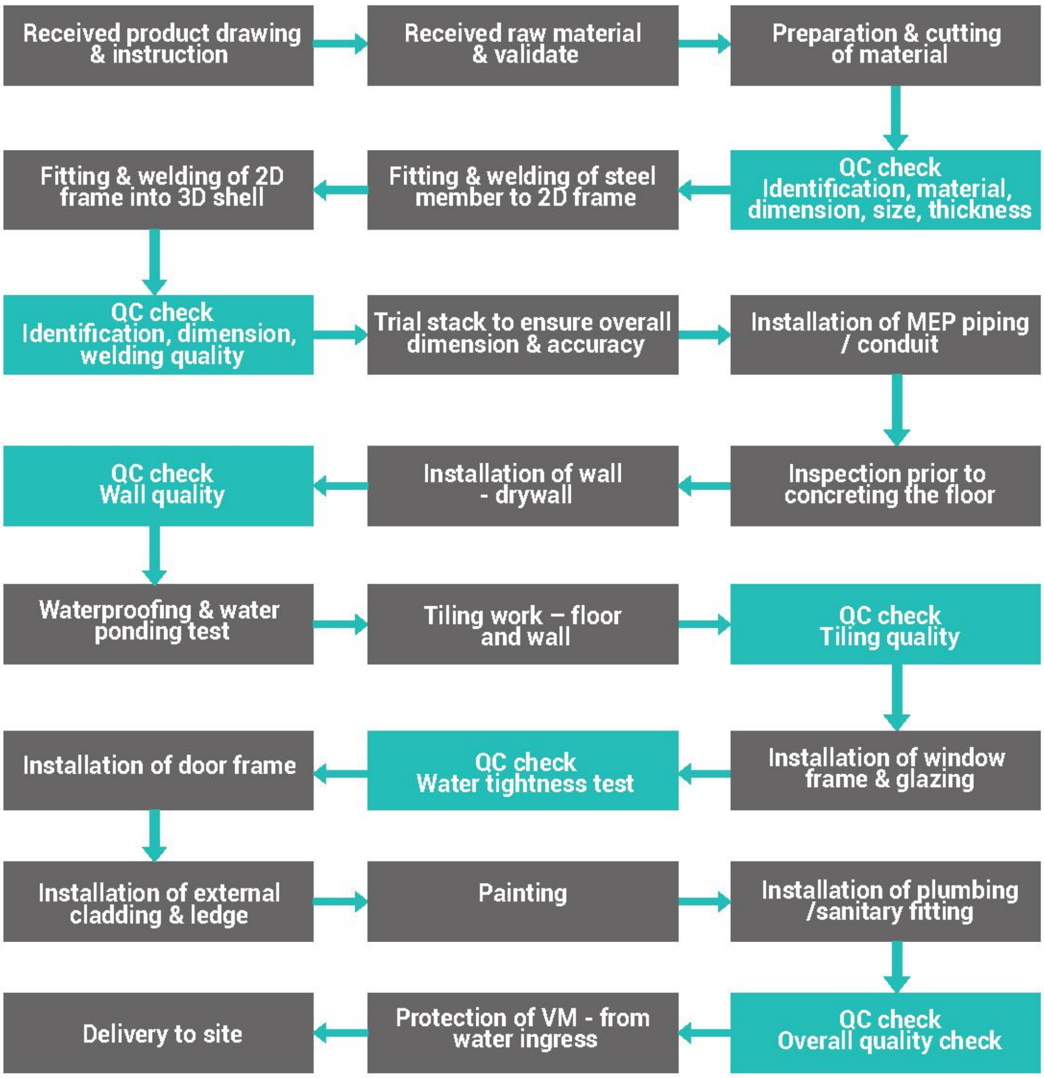
Figure 5.3. Example of Semi-automated Production Line

5.2 Steel VM Manufacturing Process

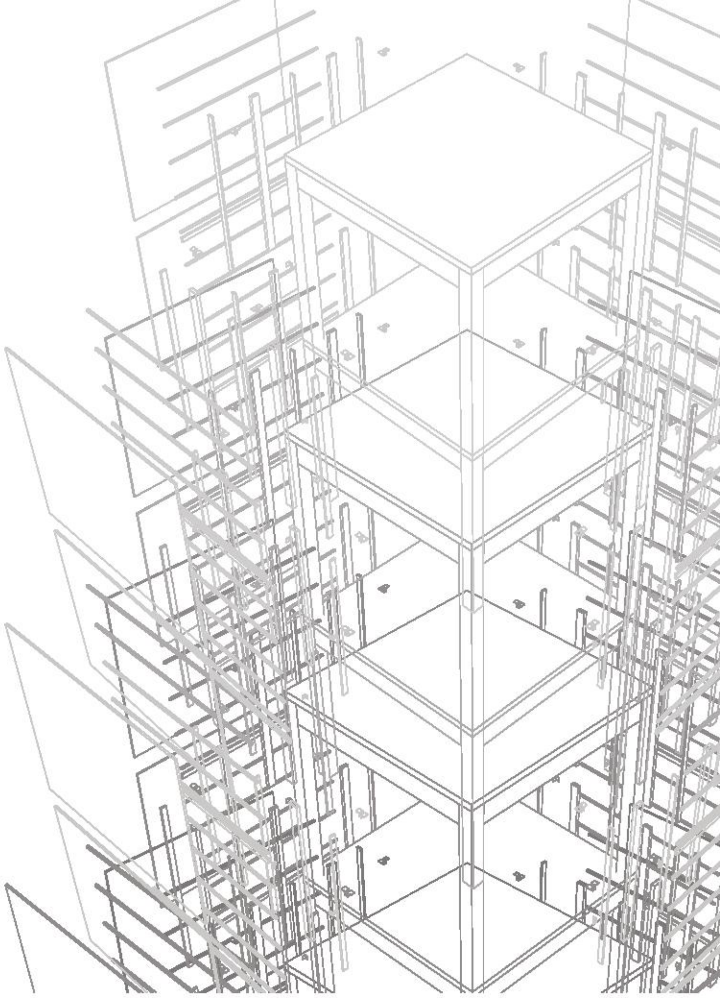
5.2.1 Preparation of 2D and 3D Jigs

The jigs used for the production line should be designed and fabricated in order to withstand the additional forces caused by heat transmitted between and within the steel sections of the VM to ensure the accuracy of the 2D frame and 3D shell remain unchanged during and after the welding work. The total number of jigs required for each project is determined by the design and type of VMs, the fabrication schedule/rate and the flexibility of the jigs, which is different with each project.

5.2.2 Typical Production Process of Steel VM



5.3 Prefab Concrete VM Manufacturing Process



5.3.1 Shop Drawing

The shop drawings produced by the manufacturer show the position of fixings, penetrations, cast-in items, openings and lifting anchors, including the location and size of the service voids. Before the design is finalised, coordination with the broader project team (client, consultant and contractor) is vital, in particular for the services, cladding, and foundations. The shop drawings should be prepared according to the construction drawings provided by the client (i.e. Architecture drawing, C&S drawing & MEP drawing).

5.3.2 Preparation of Mould

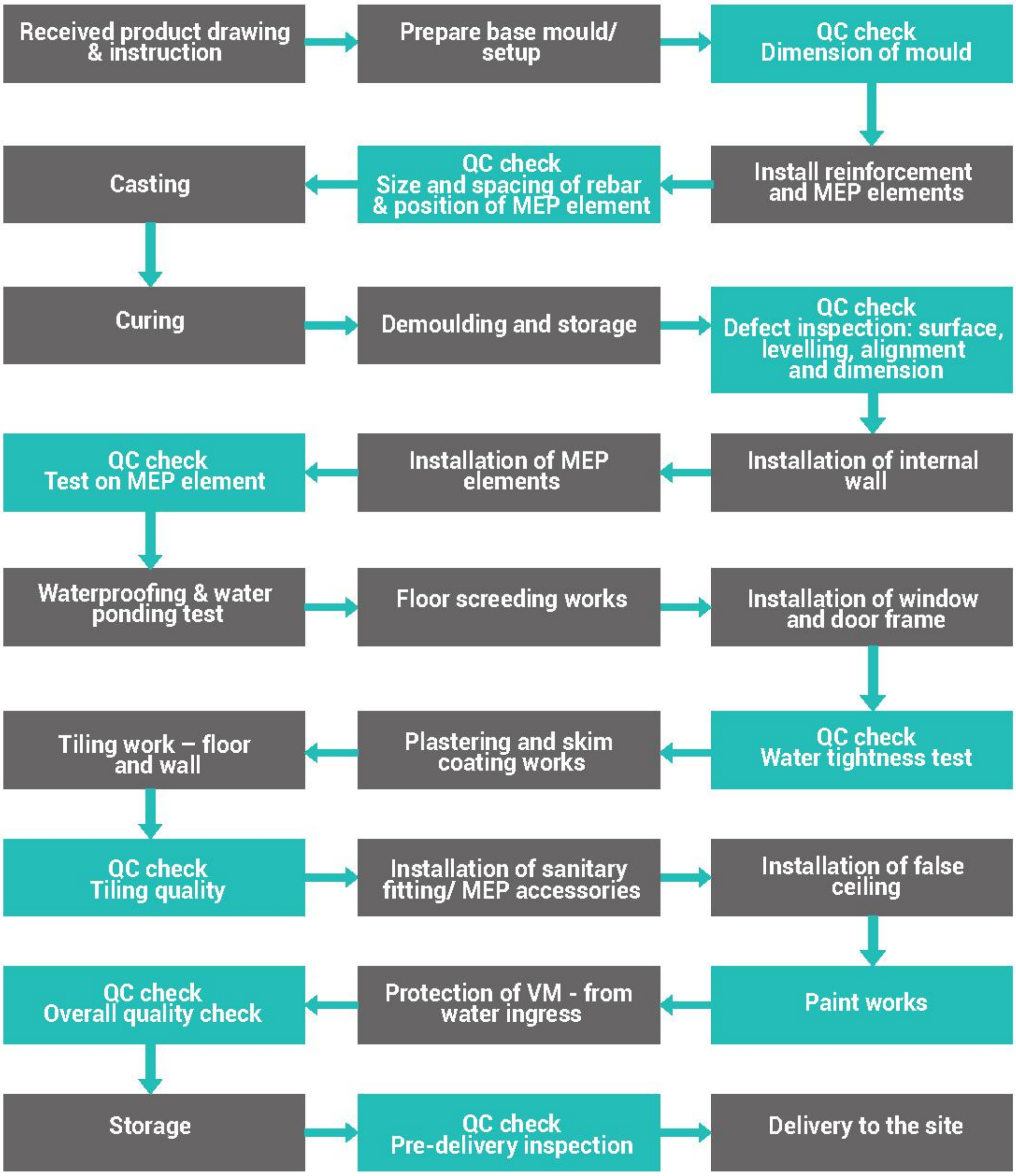
Prefab concrete VMs are cast in moulds or formwork with their reinforcement fixed in place. The mould should be designed and fabricated according to the approved shop drawings. Importantly, it is recommended to use steel mould given it can withstand the handling and production process for the lifetime of the mould required in production. Moulds are of a three-dimensional form and may be adjusted to cater for different combinations of dimensions. The other factors that influence the concept of the mould design include:

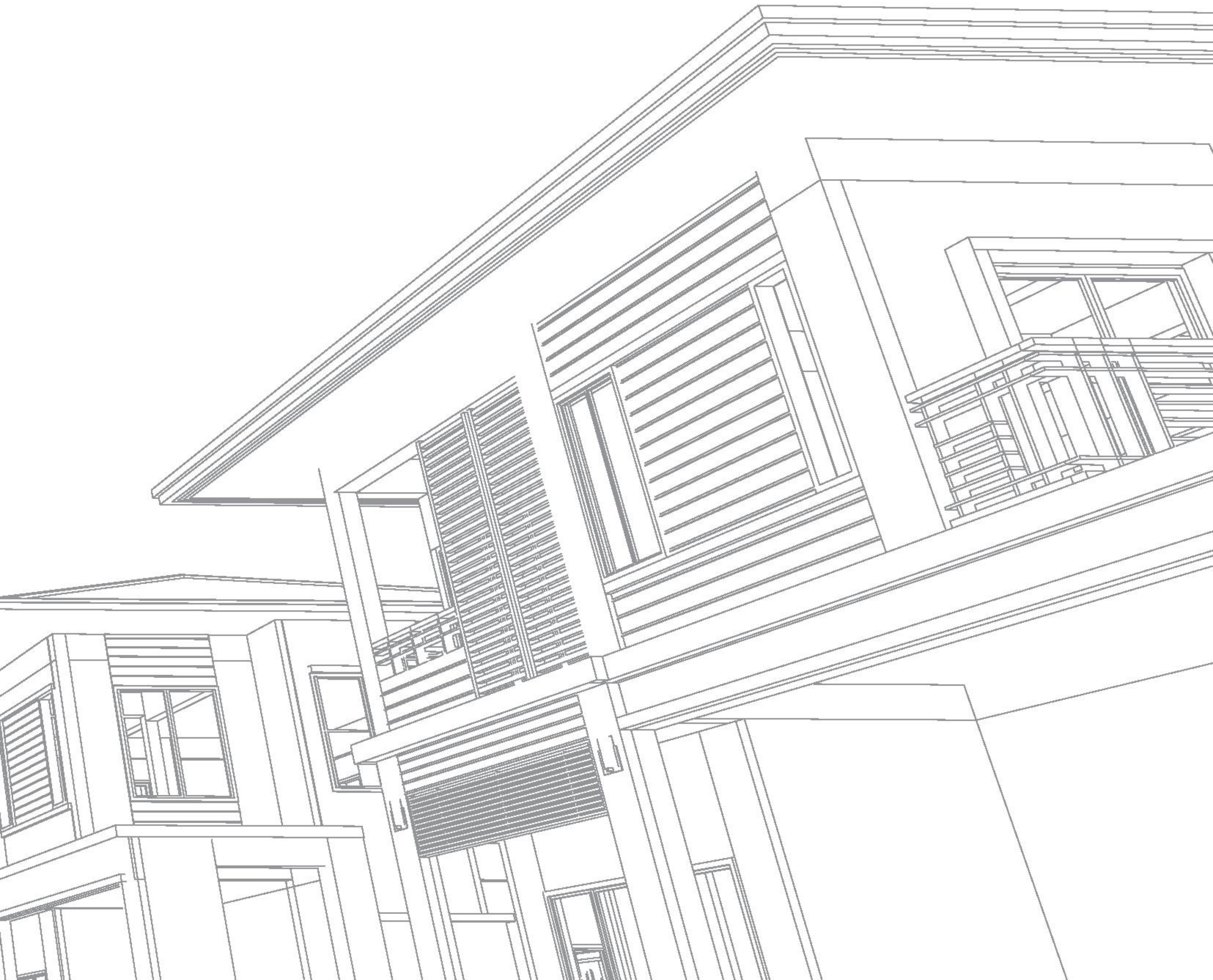
i. Adjustable mould for flexibility.
ii. Transportation of the mould.
iii. MEP services.
iv. Safety consideration (e.g.: accessibility, working at high place, workability).

Sources: BFT International (2015)

Figure 5.4. Example of Steel Mould

5.3.3 Typical Production Process of Prefab Concrete VM





CHAPTER 6: LOGISTICS AND INSTALLATION

6.1 Logistics

6.1.1 Transportation Plan

To ensure the integrity of the VMs, it is important to develop a comprehensive transportation plan to analyse and mitigate potential issues which may arise during deliveries. This is to avoid potential damage to the VM in travelling long distances. The transportation plan should comply with all relevant regulatory requirements such as the Road Transport Act 1987: Act 333 (Amendment 2017).

The size of a VM should be limited to the dimensions allowed for transportation on public roads without requiring special measures to be taken, such as having a police escort (Table 6.1). Height considerations should be factored in accordingly if the route involves passing through overhead bridges, utility cables and other obstructions.

Also, the existing road configuration around the site should be examined for manoeuvring and holding of the VMs. The deliveries should also be planned and well-coordinated to avoid any congestion outside the site, especially for urban built-up areas. In this case, a sufficient staging area should be provided to prevent traffic congestion at the site and other areas (Refer to Chapter 7: Project Management).

Table 6.1. Standard Width for Lane and Marginal Strip

Design Standard	Lane Width (m)	Marginal Strip Width (m)
R6/ U6 – Rural and Urban Expressway	3.65	0.50
R5/ U5 – Highway, Primary Road and Arterial Road	3.50	0.50
R4/ U4 – Primary Road, Secondary Road, Minor Arterial and Major collector	3.25	0.25
R3/ U3 – Secondary Road, Collector or Major Local Streets	3.00	0.25
R2/ U2 – Minor Roads and Local Streets	2.75	0.00
R1/ U1 – Minor Roads and Local Streets	5.00* (*2-way width)	0.00
Interchange Ramps		
Single lane	4.50	Lt 1.50 Rt 0.50
Multi lanes	3.50	Lt 0.50 Rt 0.50
Single Lane Loop	4.50	Lt 1.50 Rt 0.50

Sources: JKR (2015); REAM (2002)

Table 6.2. Dimension of Design Vehicles

Design Vehicles		Dimension (m)						Turning Radius (m)	
Type	Equivalent type in AASHTO	Wheel base	Overhang		Overall length	Overall width	Height	Inner	Outer
			Front	Rear					
Rigid Truck	SU	6.1	1.2	1.8	9.1	2.6	4.1	8.5	12.8
Semi-trailer	WB-15	9.1	0.9	0.6	16.7	2.6	4.1	5.8	13.7

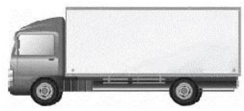
Note:

A. Maximum allowable overall lengths under current Malaysian Legislation are as follows:
   i. Rigid vehicle - 12.2 m (40.0 ft)
   ii. Articulated vehicle - 16.0 m (52.5 ft)
   iii. Semi-trailer - 12.5 m (41.0 ft)
   iv. Trailer - 9.0 m (29.5 ft)
   v. Truck trailer - 18.0 m (59.0 ft)

B. Maximum allowable overall width under current Malaysian Legislation is 2.5m.

Sources: REAM (2002)

Table 6.3. Approved Summary of Weight Restriction Order, Peninsular Malaysia

Vehicle Type	Maximum Vehicle Weight (kg)	Scheme
2 Axle – Rigid vehicle (1+1)	19, 000	
3 Axle – Rigid vehicle (1+2)	27, 000	
3 Axle – Articulated vehicle (1+1+1)	31, 000	
4 Axle – Articulated vehicle (1+1+2)	39, 000	
5 Axle – Articulated vehicle (1+2+2)	45, 000	
6 Axle – Articulated vehicle (1+2+3)	50, 000	

Source: ACT 333 (Amendment 2017)

Importantly, the road conditions surrounding the project must also be able to accommodate the weight and size of the VM delivery. This includes access to and within the site which must be able to accommodate trailers carrying heavy cargo as slopes, and undulating terrain might prove challenging for heavy vehicles. The turning radiuses of the trailers should also be considered during the planning stage of the site to avoid choking of vehicle access. Trailers with heavy cargo pose potential hazards upon entering and navigating the site. Therefore, a traffic controller should be employed to ensure the smooth flow of traffic in the site.

6.1.2 Consideration of Just in Time (JIT) Operations

Compared to usual precast elements such as beams, columns, slabs and wall panels, VMs cannot be stored on site. Therefore, Just in Time (JIT) installation is used as an efficient and productive method, although, the rate of installation needs to be determined for uninterrupted JIT operations.

To facilitate efficient deliveries, systems such as Traffic Monitoring and GPS for Prime Movers should be employed to make JIT operations smoother and more predictable. Also, it is advisable to acquire space for unloading and storage in the event where JIT installation is not possible, (e.g. during inclement weather conditions, etc.).

6.1.3 Consideration of Just in Time (JIT) Operations

The packaging of the finished VM should be controlled and inspected to ensure conformance with the specified and/or contracted requirements.

In addition, the protection of the VM should be extended, in order to prevent potential damage, deformation or deterioration of the installed finishing components and/or to the structure while in transit or during unloading at the project site. This includes the provision of appropriate protection sheets to the internal finishes and the external surface of the structures.

All finished VMs should have the manufacturer's label for identification (e.g. RFID, barcode or tagging by number).

6.2 Craneage and Lifting

6.2.1 Lifting of VMs

VMs are generally lifted from their corners using a lifting beam or a frame that minimises the inward component of forces exerted on the VM due to the force in the inclined cables. Some lightweight VMs are lifted from their base to avoid damage to the internal finishes.

For all types of VMs, an additional force of 25% more than the self-weight of the VM should be considered to take account of dynamic forces during lifting (in addition to standard factors of safety). All lifting beams, shackles, and cables should be load tested to an overall factor of safety of at least two (2) before used and should be load tested regularly (Lawson et al., 2014).

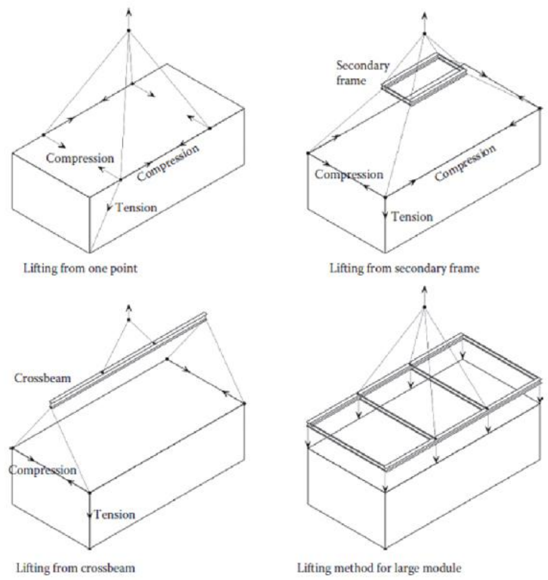


Figure 6.1. Various Forms of Lifting Systems (Lawson et al., 2014)

a) Lifting of Steel VMs

The forces that are developed in the VMs during installation can be much higher than in service. Therefore, it is important that the implications of the method of lifting are considered in the design of the VMs. Lifting points in light steel VMs are normally located at their corners, particularly if shackles or cables can be attached to the corner posts (Lawson et al., 2014).

The preferred method of lifting heavyweight VMs is by using a two-dimensional frame so that the forces acting on the VMs are vertical. Temporary bracing will often be required in open-sided VMs.

a) Lifting of Prefab Concrete VMs

The lifting points on a prefab concrete VM are cast into the unit itself during production and are designed where possible so that the out of plane forces are minimised in the lifting operation. Four-point or sometimes eight-point lifting will generally be required for prefab concrete VMs, depending on their size, so that loads are applied vertically.

The self-weight of a prefab concrete VM can range between 25,000 kg and 40,000 kg (25 – 40 tonnes), depending on its size. An additional force of often up to 50% should be included in lifting after manufacturing due to the suction of the mould, which is higher than the possible dynamic forces during installation on site (Lawson et al., 2014). Additional reinforcement is often required around the lifting points in order to prevent cracking, particularly near the corners. Proprietary devices can also be used, which reduces the need for additional steelwork (as shown in Figure 6.2).

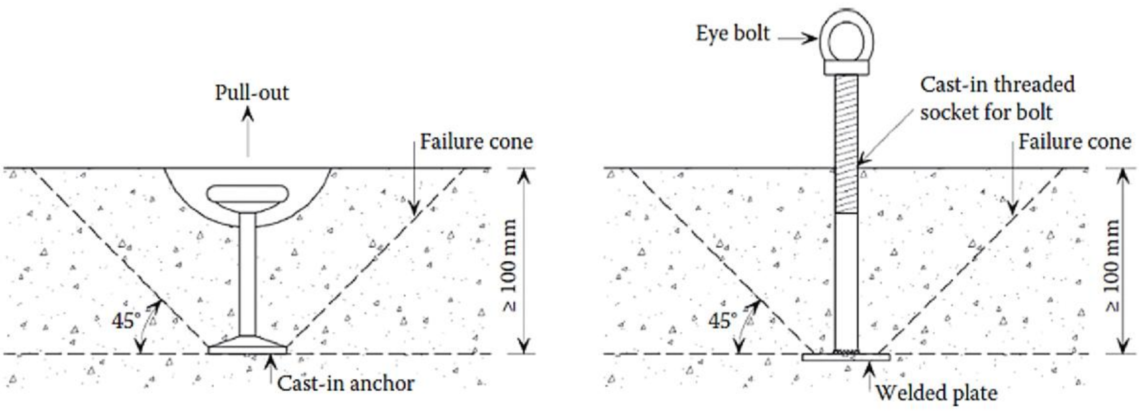


Figure 6.2. Types of Cast-in Lifting Devices in Prefab Concrete VMs (Elliott, 1996)

6.2.2 Lifting Machinery

The sizing and arrangement of cranes on site will be dictated by the total lift weight of the VM and the reach of the crane. As an example, for light steel VMs, a 100,000 kg (100-tonne) mobile crane is often required when the lifting boom is extended to its maximum distance (around 25 m). Tower cranes are often used in high-rise construction, but generally, they cannot lift heavy loads at their full extension (Lawson et al., 2014).

Accordingly, various issues should be considered when selecting a suitable crane and the VM installation sequence, including:

i. On-site and public safety.
ii. Access for the mobile crane.
iii. VM dimensions and weights.
iv. Maximum reach of the crane to the VM location.
v. Site constraints, such as overhead power lines.
vi. Ground-bearing pressures for the legs of the crane.

Table 6.4. Example of Generic Information on type of Cranes Available

Characteristic of Crane	Tower Crane	Mobile Crane	Crawler Crane
			
Crane Capacity	50,000 kg (50 tons)	700,000 kg (700 tons)	500,000 kg (500 tons)
Lifting Capacity	25,0000 – 40,000 kg (25 tons – 40 tons)	25,0000 – 40,000 kg (25 tons – 40 tons)	25,0000 – 40,000 kg (25 tons – 40 tons)
Height of Equipment	120 m	40 m	80 m
Radius of Work	40 m	40 m	40 m
Note: Actual crane requirements and capacity shall vary according to the site condition and should be obtained from the crane specialist accordingly.			

Sources: (BCA, 2017)

6.3 Installation

6.3.1 Sequencing of the VMs Installation

Sequencing and planning the order and progress of the VM installation is critical at the construction site as well the manufacturing supply line. The Engineer and Installer should specify the erection sequence to ensure the integrity of structural staging and any necessary temporary work needed which may extend to progressive weatherproofing for the exposed VMs and particularly for any surfaces not forming part of the building exterior.

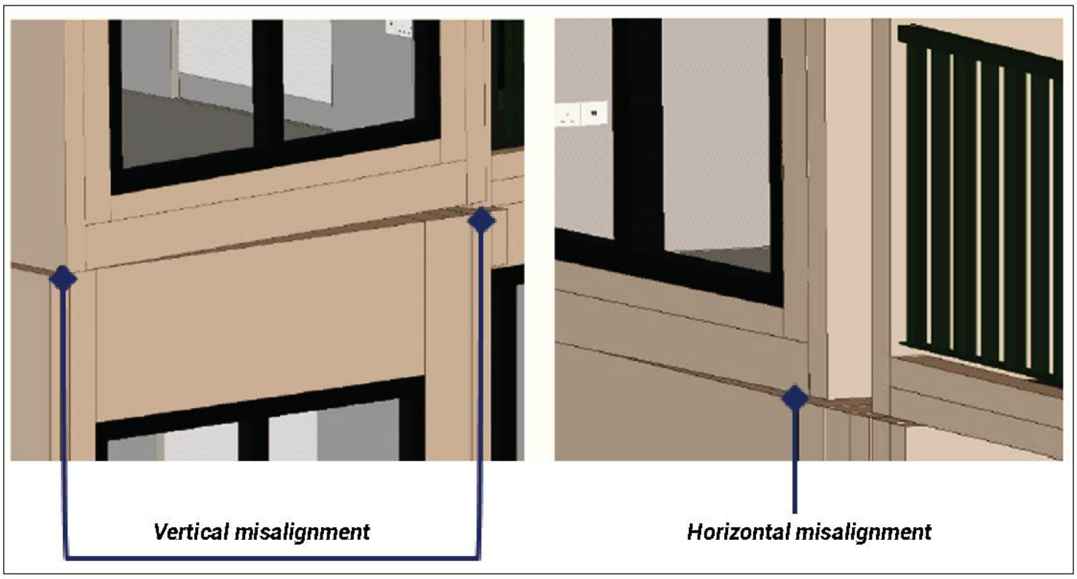
Figure 6.3. Example of Typical VM Installation Process

6.3.2 Vertical and Horizontal Alignments

Special attention should be given to the alignments during installation. The method statement for installation should indicate how proper alignments can be achieved to prevent any work(s) to be aborted. Improper vertical and horizontal alignments cause external gaps which require additional touch-up work such as hacking and plastering. Windows and/or any external fixtures will look slanted as well.

Furthermore, MEP services including lightning protection systems, sanitary and rainwater discharge systems, for example, require proper vertical continuity connection. Installation of a P-trap or S-trap if required, should not impact the finishes undertaken in the factory. If a vertical concealed shaft is provided, space for installation works should be allocated to facilitate vertical connection works.

For MEP services that require installation works horizontally crossing VMs, (including wiring, pressurised pipework, gradient pipework), the method of connection, if required, should not compromise the level of continuity. All connection points should be secured by proper support. The method of connections should not compromise the gradient required for gradient-pipework. Likewise, the proper protection of finishes should be provided if hot work is required for connections. Installation works should be carried out via the space allocated.



Sources: (BCA, 2017)

Figure 6.4. Example of Vertical and Horizontal Misalignment

6.3.3 Access and Egress

As part of the design review, the entire process of which the VM units are to be installed should be reviewed. This should also include how workers would gain access to and egress:

i. From the ground to the top of the VMs loaded on a trailer;
ii. From the ground to the top of the VMs in the holding/storage area;
iii. From the working level to the top of a VM just installed;
iv. From point A to point B of the same level of the installed VMs or cast in-situ areas or working platforms; and
v. From point A to point B of different levels of the installed VMs, cast in-situ areas or working platforms.

Likewise, any open area should be covered with a safety barricade to prevent any worker from falling from a height (Figure 6.5). A demarcated egress should be provided as well to allow workers to exit the work area in case of an emergency.

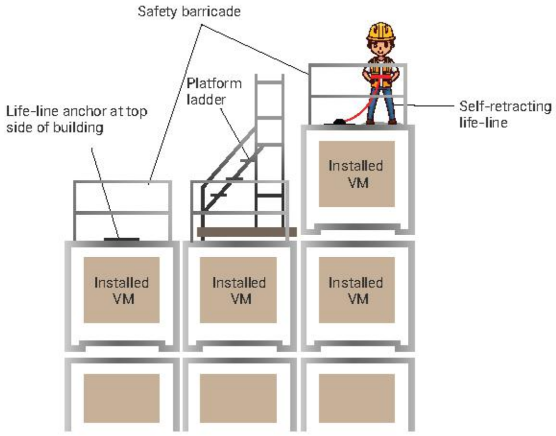
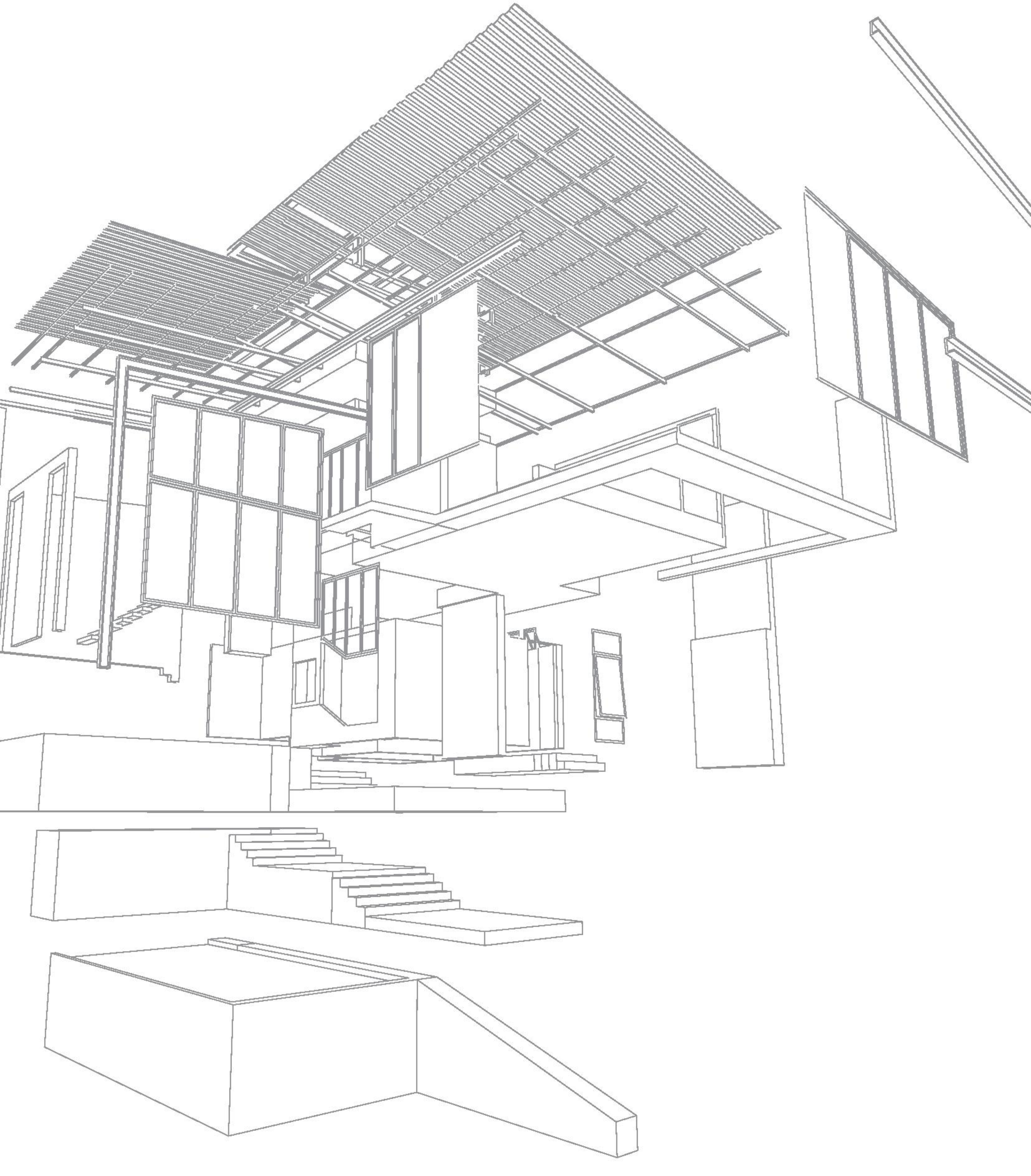


Figure 6.5. Example of Safety Measure during Installation Process



CHAPTER 7: PROJECT MANAGEMENT

7.1 Project Management Plan

Coordination between the Developer, Architect, Structural Engineer and MEP Engineer, Quantity Surveyor, Land Surveyor, Contractor and the VM's manufacturing specialist(s) are important as this will enable the team to analyse the key design aspects upfront including the layout design, floor and ceiling height, etc.

The project management plan is a critical document used to describe every phase of a project. The components may include initiating, planning, executing, monitoring and controlling, and closure. The purpose of the project management plan is to define the roles, responsibilities, procedures and processes that will result in the project being correctly managed and to ensure that the project is delivered and completed:

i. On-time;
ii. Within budget;
iii. With the highest degree of quality;
iv. In a safe manner for both the individuals working on the project and for the travelling public; and
v. To ensure that public trust, support, and confidence in the project is maintained.

The project management plan addresses all stages of the project life cycle and ensures that the project will be managed as a continuum, rather than incrementally as the project progresses.

Strategic Definition	**Identify the client's business case and strategic brief and other core project requirements**
Preparation & Brief	**Develop project objectives, including quality objectives and project outcomes, sustainability aspirations, project budget, other parameters or constraints and develop the initial project brief. Undertake feasibility studies and review of site information.**
Concept Design	**Prepare concept design, including outline proposals for structural design, building services systems, outline specifications and preliminary cost information along with relevant project strategies in accordance with the design programme. Agree alterations to brief and issue final project brief.**
Developed Design	**Prepare developed design, including coordinated and updated proposals for structural design, building services systems, outline specifications, cost information and project strategies in accordance with the design programme.**
Technical Design	**Prepare the technical design in accordance with the design responsibility matrix and project strategies to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with the design programme.**
Construction	**Offsite manufacturing and onsite construction in accordance with the construction programme and resolution of design queries from the site as they arise.**
Handover & Close Out	**Handover of the building and conclusion of the building contract.**
In Use	**Undertake in use services in accordance with schedule of services.**

Figure 7.1. Construction Project Stages (Sinclair et al., 2016)

7.2 Design for Manufacturing and Assembly (DfMA)

DfMA is a design philosophy that stresses a holistic view of the design process. In this overarching view, the Architect and Design Engineer will consider not only the design of the individual elements and the completed structure composed thereof but also the design of the assembly process. Increased focus is placed on how the individual parts are to be fabricated and connected as part of the design process, rather than as an after-thought (Monash University, 2017).

The basis of DfMA is in the form of virtual reality modelling of the project, which should include the following elements:

i. The discretisation of the construction;
ii. 3D design collaboration;
iii. 4D construction planning; and
iv. 5D quantification and costing.

DfMA allows all project elements to be interrogated by the construction team until achieving the optimum solution.

7.2.1 The DfMA Envelope

The key components of the DfMA envelope are described in detail as illustrated in Figure 7.1 (Mcfarlane et al., 2014; Monash University, 2017).

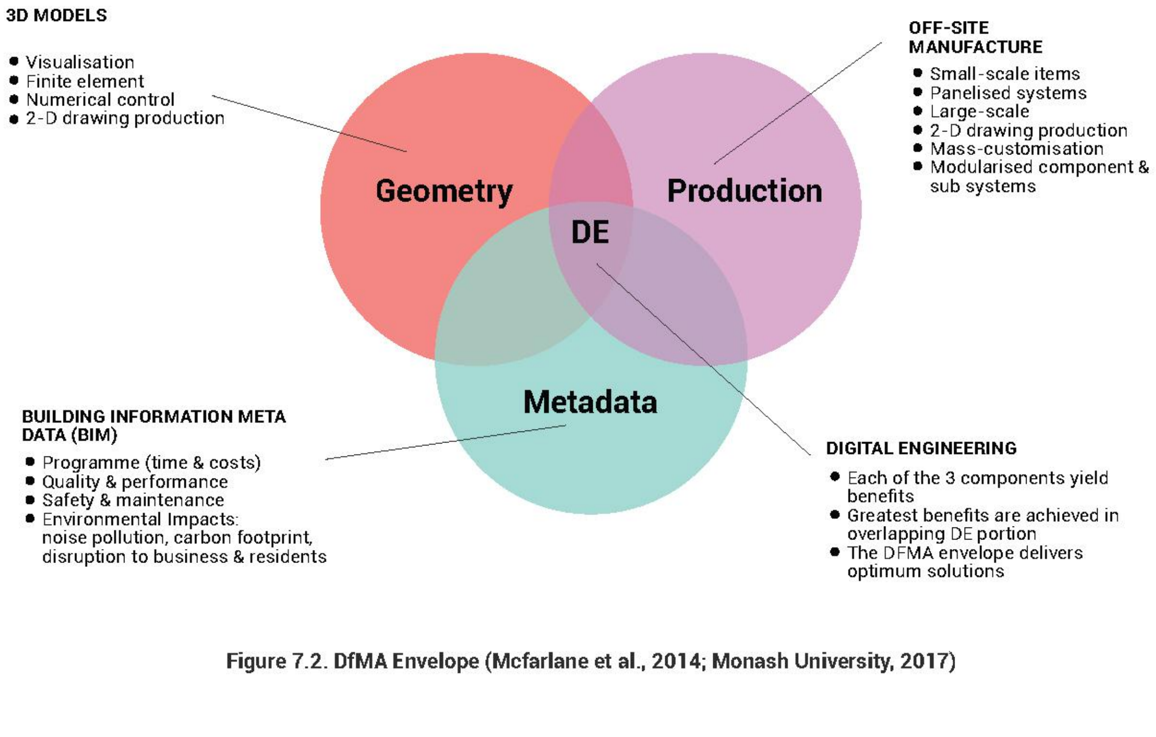


Figure 7.2. DfMA Envelope (Mcfarlane et al., 2014; Monash University, 2017)

a) Geometry

The Geometric Model is the virtual 3D model, as represented in a software package such as Building Information Modelling (BIM) and allows the technical and non-technical team members to visually understand and interrogate the intent of the design. The main components should include the engineers' finite element models, geometrical components and computer numerical control (CNC) models, which enable the automated production of the relevant elements of the project.

The 3D model with adequate naming convention may also be used to produce 2D drawings, which may be required for non-automated processes such as the approvals by statutory authorities, third-party manufacturers of small-scale items, and so forth. However, this should be minimised with a preference for 3D approvals directly from the full model.

b) Production

DfMA production covers off-site manufacturing in a factory environment and the modules produced can include small-scale items, such as electrical fittings; large scale items, such as precast concrete floors and panelised systems in steelwork, precast concrete or timber; and fully enclosed volumetric spaces, such as individual rooms or complete buildings. The entire fit-out process, (i.e., structural, electrical, mechanical and decorative work), is ideally carried out in a factory. Notably, a higher level of quality control (QC) and improved overall quality assurance (QA) is generally achieved through factory production.

Notwithstanding, nowadays, a significant proportion of the work can be automated and performed by robots where the input for the robots should be via computer numerical control software derived from the Geometry Model.

c) Metadata

The Metadata Model is a multi-dimensional database, containing all relevant project parameters. Not only can this model be used to calculate the impacts of time, sequencing, scheduling and costs but it can also be used to analyse environmental impacts, such as the carbon footprint, sustainability, noise pollution, air quality and other impacts to the environment. Additional benefits include waste reduction, error avoidance and reducing costs. When combined with the 3D Geometry Model, the Metadata Model can, therefore, allow all stakeholders to analyse the impacts of different design options.

7.2.2 Benefits of DfMA Approach

One of the main characteristics of DfMA is that it is component driven, using modularisation and a standardisation approach. DfMA requires planning, adapting and optimising the design at an early stage to facilitate the fabrication of VMs off-site and subsequently to assembly on-site.

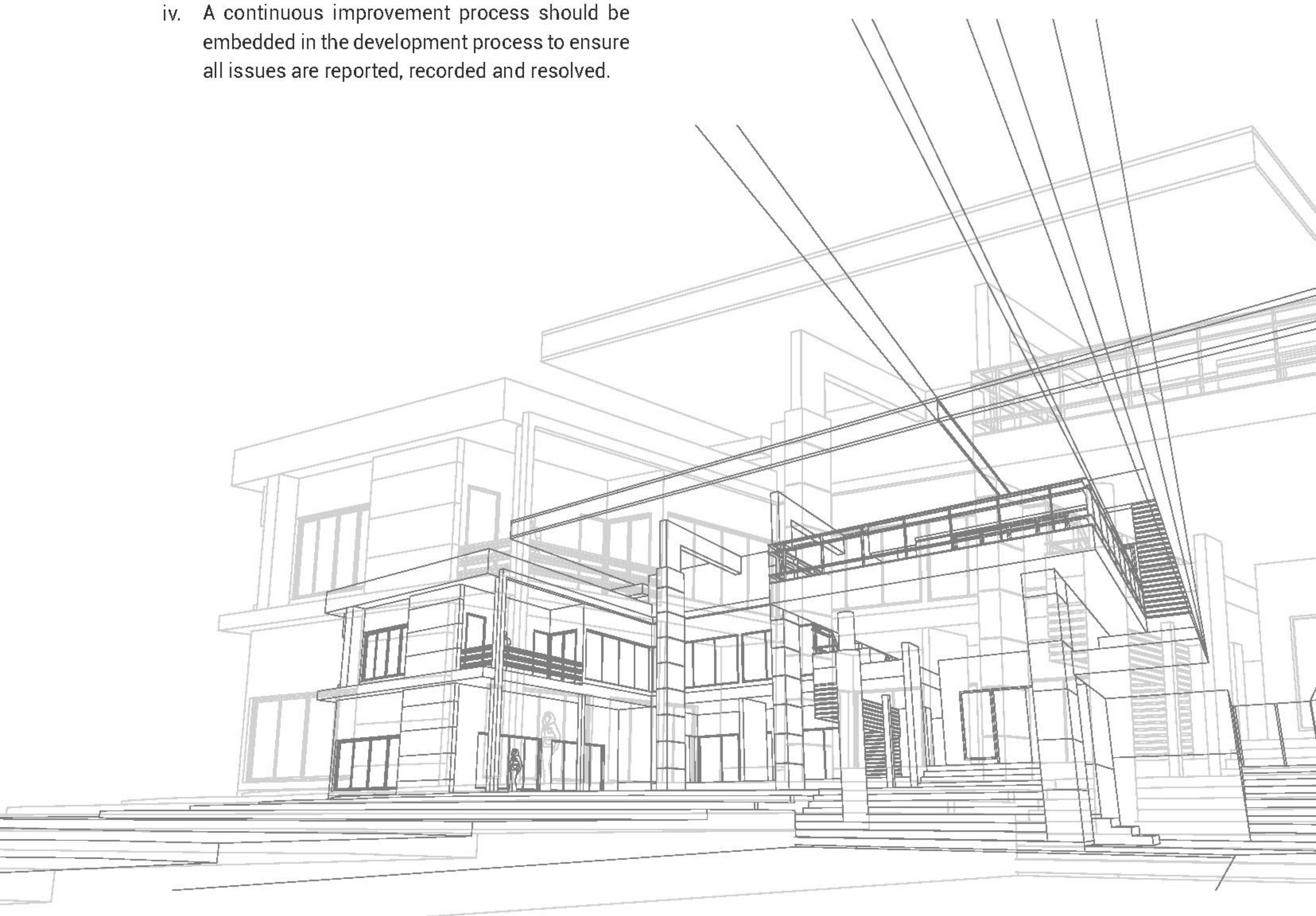
Some of the advantages of DfMA, when compared with traditional construction approaches, are summarised as follows:

i. Interactive participation in the design and planning process by all stakeholders (technical and non-technical), leading to optimal solutions, including rapid implementation of design changes or variances and improvements in overall design integration.
ii. Increased efficiency and reduced costs.
iii. Higher quality construction with guaranteed quality assurance levels achieved on site.
iv. Improved health and safety performance and a safer operational asset over the whole life cycle.
v. Reduced construction time, enabling an earlier return on investment (ROI).
vi. Improved sustainability and environmental performance.
vii. Reduced wastage: factory wastage is reduced to near-zero, and on-site wastage is significantly reduced.

7.2.3 Implementing DfMA

Implementation of the DfMA approach can be made more effective by considering the following:

i. Throughout the design phase, the product Designer should consider the full lifecycle process, including the manufacturing and assembly processes.
ii. Stakeholders should conduct collaborative DfMA, Failure Mode and Effects Analysis (FMEA) and Lean Manufacturing workshops throughout the design phase of the project to maximise production efficiency, reduce program risks and minimise costs.
iii. The involved parties should seek to maximise and quantify the 'value add' in the off-site manufacturing process by creating preassembled elements; for example, façades finished internal walls and services rough-in.
iv. A continuous improvement process should be embedded in the development process to ensure all issues are reported, recorded and resolved.



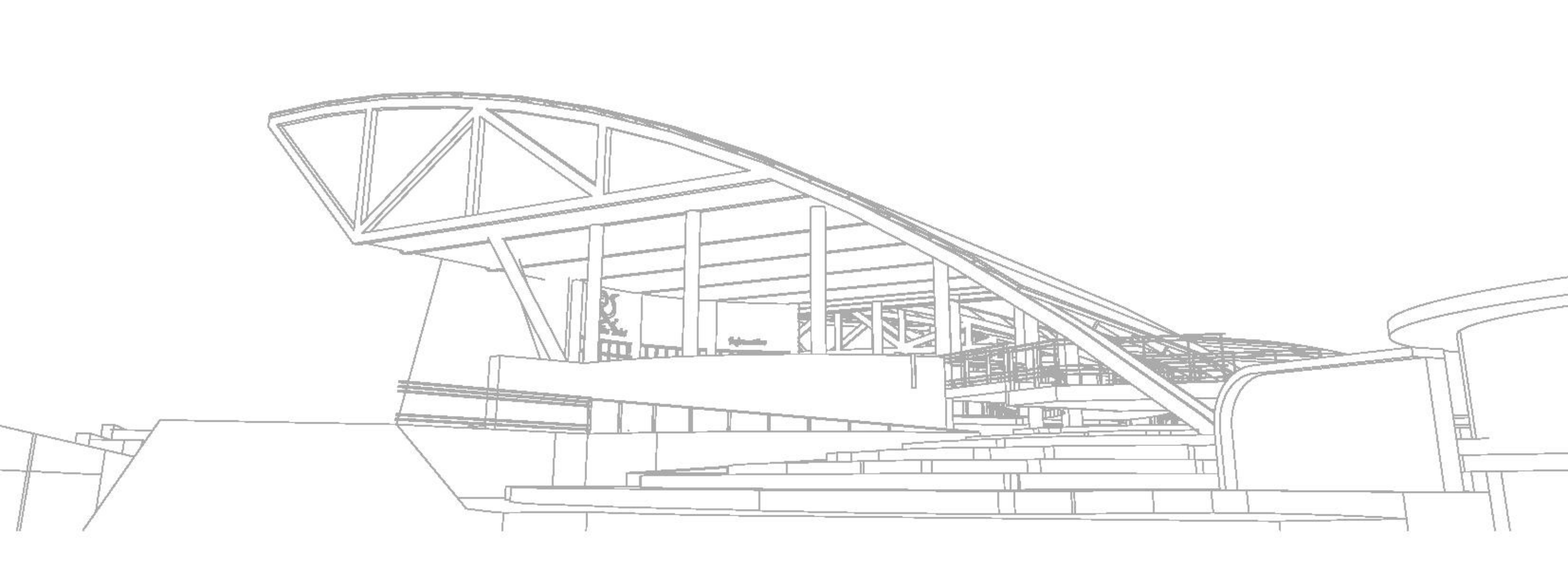
CHAPTER 8: QUALITY CONTROL, INSPECTION & VERIFICATION

8.1 Quality Control (QC)

Quality control (QC) is defined as a system for verification and maintenance of the desired level of quality in a product or process through careful planning, the use of proper equipment, inspection, and corrective action where required. Furthermore, it is a method of assuring compliance with existing standards. A satisfactory product meets an agreed set of requirements that are based on a defined outcome.

Quality control in manufacturing takes three (3) forms (Gass, 1989):

i. Quality of design – relates to the material selected for manufacture; often determined by cost and consumer preference.
ii. Quality of performance – controlled by codes and standards for minimum acceptability based on end-use requirements.
iii. Quality of conformance with specifications – measures the consistency of the manufacturing process itself. The specifications reflect both the design and performance quality whereas, the level of consistency in satisfying the specification measures the overall quality.



8.1.1 Quality Check on Prefab Concrete VM

Implementation of the DfMA approach can be made more effective by considering the following:

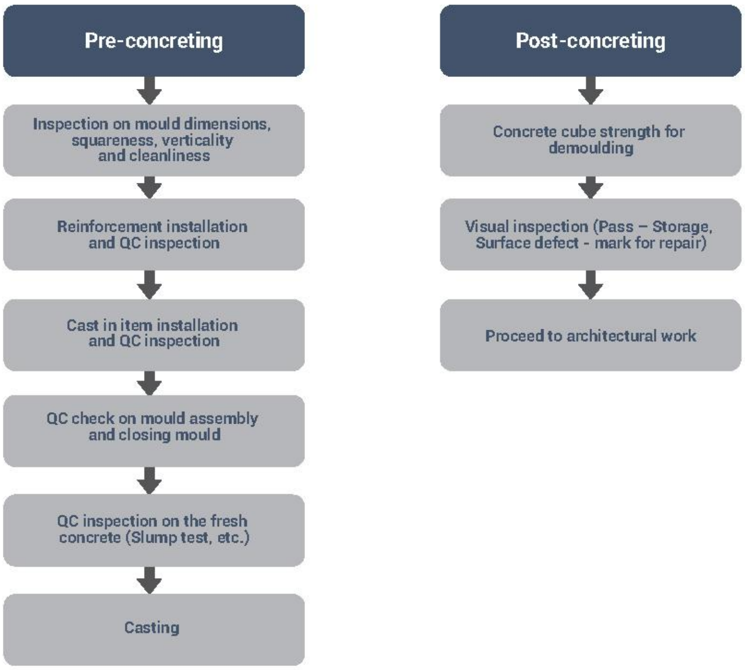


Figure 8.1. Typical Process Flow for Quality Check on Prefab Concrete VM

8.1.2 Quality Check on Steel VM

Figure 8.2 illustrates a typical process for a quality check on a steel VM during the manufacturing process.

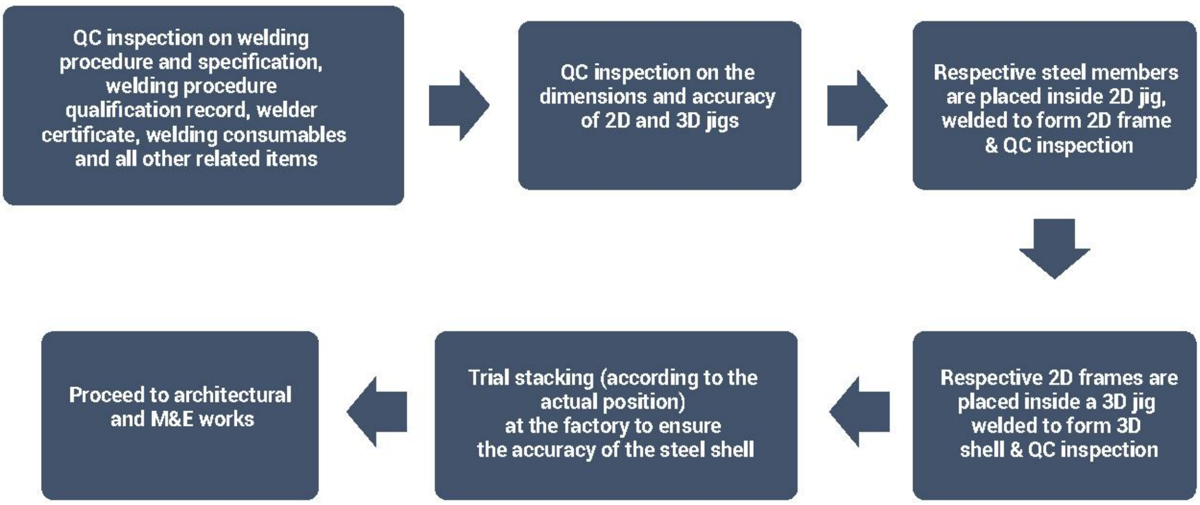


Figure 8.2. Typical Process Flow for Quality Check on Steel VM

8.2 Inspection and Verification Works

8.2.1 Inspection of Architectural Works

All work and tests should be carried out according to the approved method statement as shown in Figure 8.3.

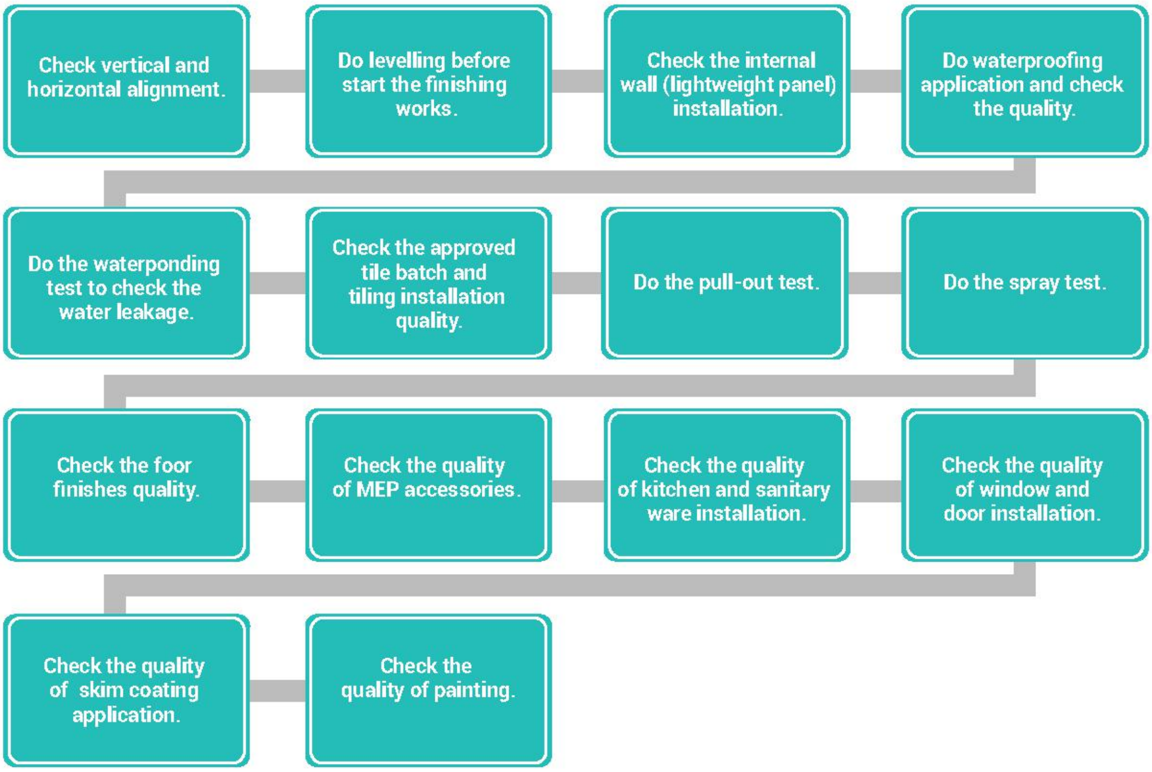


Figure 8.3. Typical Process Flow for Inspection of Architectural Works

8.2.2 Inspection of Structural Works

All work and tests should be performed according to the approved method statement as shown in Figure 8.4.

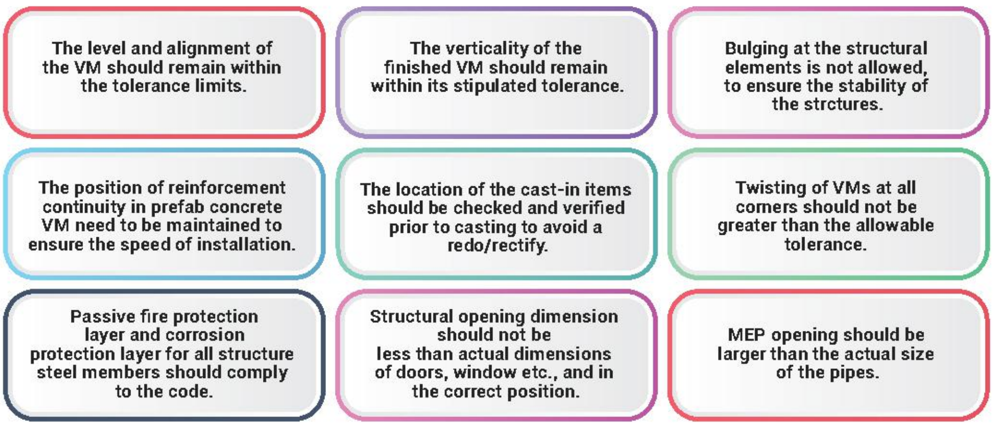


Figure 8.4. Typical Process Flow for Inspection of Structural Works

8.2.3 Inspection of MEP Works

All work and tests should be undertaken according to the approved method statement as shown in Figure 8.5.

Water Tightness Test
Tensure the pipe works are water-tight before and after the architectural finishing works.

Pressure Test
To ensure no leakage in the pressurised pipe works.

Pressure Test
To ensure the cable and wiring are in good condition

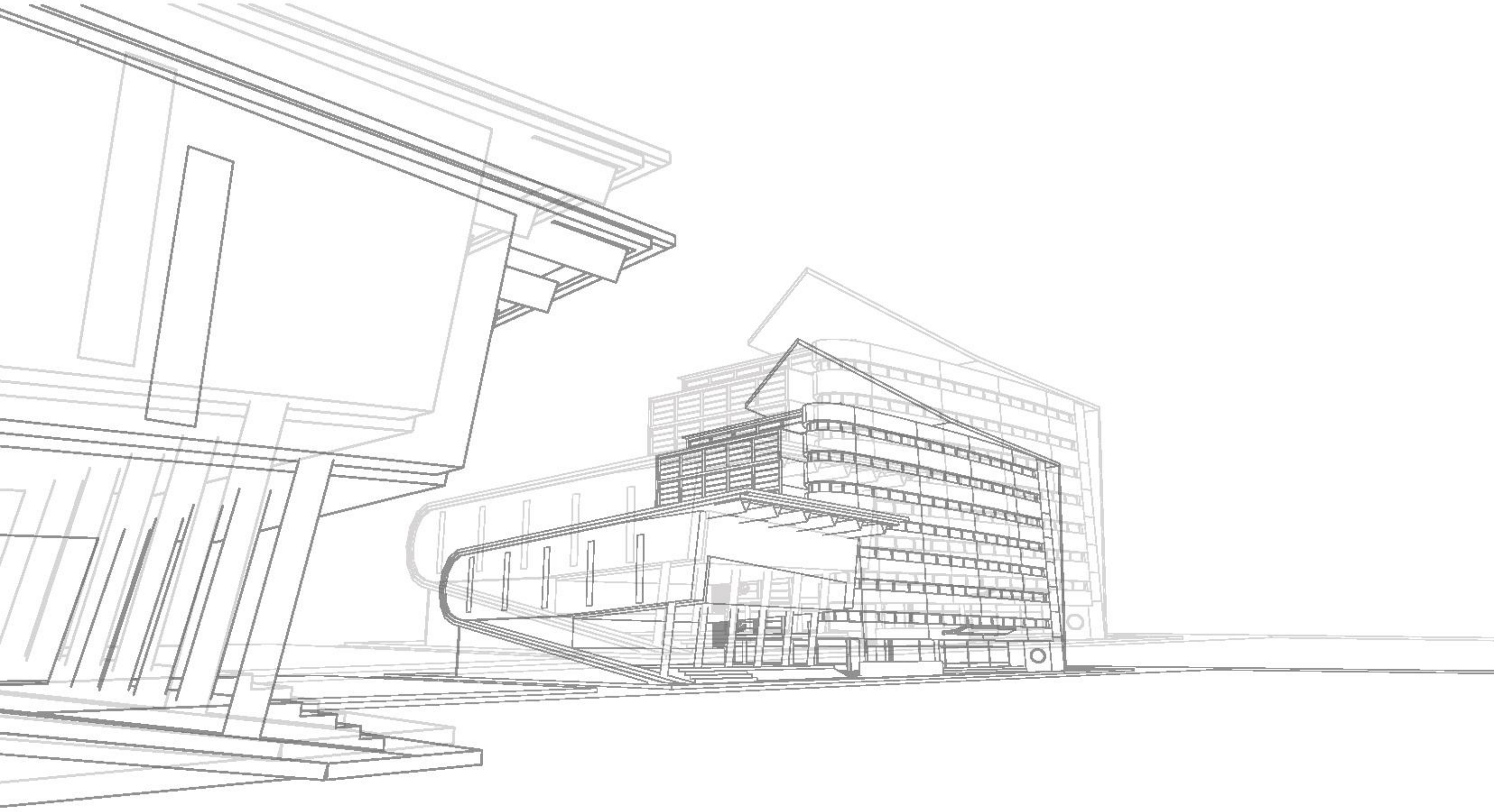
Earthing Megger Test
To ensure the continuity of the conductors for lighthing protection.

Electrical Phase Check
To ensure load is distributed in accordance to the design among all phases.

Shaft Leakage Inspection
To be carried-out in conjunction with the water-tightness test of the vertical pipe shaft.

Electrical Wiring Insulation Test
To ensure wiring conductor is properly insulated.

Figure 8.5. Typical Process Flow for Inspection of MEP Works



CHAPTER 9: BUILDING MAINTENANCE AND RENOVATION

9.1 Maintenance

Maintenance refers to the total set of activities that are performed during the design life of a building in order to retain the building in a state in which it can fulfil its intended function (Monash University, 2017).

In the case where the maintenance of material conditions and the quality is foreseeable in order to maintain material performance for the design life, the Design Engineer must make provision for access and egress to inspect and perform maintenance as and when required. This should take the form of a safe work method statement, detailed within the Safety in Design register and issued to the owner/manager.

The Design Engineer and/or Manufacturer should clearly articulate the expected lifetime to the first maintenance for all components in the VM or building itself which may include, but are not limited to:

i. The selection of material; durability, endurance, and sustainability, etc.
ii. Any anti-corrosion systems which are employed for the components.
iii. The connections or components which are susceptible to long-term fatigue due to cyclic loading.
iv. The connections or components whose service environment may promote material degradation due to effects such as corrosion or creep.

Accordingly, the Design Engineer and/or Manufacturer should develop maintenance plans for all VM components or systems which should cover at a minimum the following aspects:

i. How do maintenance personnel gain access to the components?
ii. What maintenance activities should be performed?
iii. What documentation is necessary for maintenance activities?
iv. What checks are required to ensure maintenance has been performed in a timely and effective manner?
v. Who is responsible for conducting and checking maintenance activities?
vi. What level of competence is required for maintenance personnel?

Following maintenance activities, the personnel responsible should then identify:

i. If any follow-up action is required for any issues identified during maintenance.
ii. The time for the next maintenance to be conducted.

VM structures may present certain difficulties for maintenance due to their nature as an assembly of completed individual VMs will typically result in gaps between the VMs with regards to access complications. Therefore, the Design Engineer should take this into account during the design process; either by modifying the parameters to push back the expected time to first maintenance or by designing in such a way as improving accessibility to the susceptible areas.

9.1.1 Periodical Inspection of the Building

Periodic inspection of the building should be carried out according to the Street, Drainage and Building Act 1974 (Amendment 1978) [Act 133: Section 85A]. An engineer appointed to inspect a building should be a Professional Engineer registered under the Registration of Engineers Act 1967 [Act 138].

The inspection should be carried out based on the following frequency:

i. Every 10 years from the date of the certificate of completion and compliance, in respect of the building, issued; and
ii. After that, at intervals of not more than 10 years from the date of completion of the last inspection of the building.

The inspection of a building may consist of one or both of the following:

i. Visual inspection; and/ or
ii. Full structural investigation

a) Scope of Visual Inspection

Before the commencement of the visual inspection, the engineer should obtain a set of the structural/MEP layout plans of the building from the owner of the building. The availability of the layout plans will help the engineer to:

i. Understand the system and layout of the building;
ii. Identify the critical areas for inspection;
iii. Identify the allowable imposed loads, in order to assess the usage and possibility of overloading; and
iv. Verify if any unauthorised addition or alteration works that affect the structure of the building have been carried out.

In general, the engineer is expected to carry out, with reasonable diligence, a visual inspection of:

i. The condition of the structure of the building;
    - to identify the types of structural defects,
    - to identify any signs of structural distress and deformation,
    - to identify any signs of material deterioration.
ii. The condition of the MEP system used in the building;
    - to identify any sign of corrosion or material deterioration,
    - to identify any sign of potential leakage,
    - to identify any signs of distress and deformation in the MEP connection or system.
iii. The loading on the structure of the building;
    - to identify any deviation from its intended use, misuse and abuse which can result in overloading.
iv. Any addition or alteration works affecting the structure of the building;
    - to identify any addition or alteration works which can result in overloading or adverse effects on the structure.

Accordingly, if there are no signs of any structural/MEP deterioration or defects, a visual inspection should suffice, and unless the engineer otherwise advises, no further action is needed. However, if there are signs of significant structural deterioration or if defects are present, the engineer should make a professional assessment and judgement of the deterioration or defect and recommend appropriate action(s) be taken. Such actions may involve repair works or full structural investigation to parts or the whole building.

b) Scope of Full Structural Investigation

The scope of the full structural investigation includes the following:

i. Obtaining information relating to the design, construction, maintenance and history of the building;
ii. Assessing the structural adequacy of the building by checking the structural plans and calculations and reconstructing the structural plans if not available;
iii. Carrying out tests on the materials used and structural elements of the building;
iv. Carrying out load tests on parts of the building if necessary; and
v. Recommending appropriate safety precautionary and remedial measures to restore the structural stability and integrity of the building structure.

9.1.2 Implementation of Repair Work

Major repair and strengthening work, where necessary, should be treated as building works. Examples include replacement of corroded reinforcement bars and the reconstruction of the main water tank. Underpinning works are also considered as major works. In this case, all relevant applications for approval of plans, permits to carry out building works and supervision of building works should apply. Minor repairs can be treated as routine maintenance and will not require plan submission(s) or permit application(s).

9.2 Renovation

To prevent damage to the VM unit, it is essential to exercise care during the renovation. Renovation works must be approved by a professional, qualified and accredited engineer and the work performed by skilled contractor(s)/trained renovator(s). The contractor(s)/ trained renovator(s) engaged for the project should use appropriate tools and follow the instructions in the homeowner user manual.

9.2.1 Homeowner User Manual

The homeowner user manual is to be provided by the developer and includes the following information:

a) General Information on VM

- Introduction to the VMs installed
- Safety notices
- Instruction to use

b) Cleaning & Maintenance Advice

- Internal fittings, tiles and accessories
- Floor Trap
- Ceiling access panels

c) Layout of the VM

- General layout
- Waterproofing layout
- Location of concealed services
- Location of the access panel
- Location of the manufacturer's label
- As-built drawings for MEP services

d) Structure of the VM

- Floor
- Wall
- Ceiling
- Water piping
- Sanitary discharge pipe/ vertical soil stack
- Electrical conduits

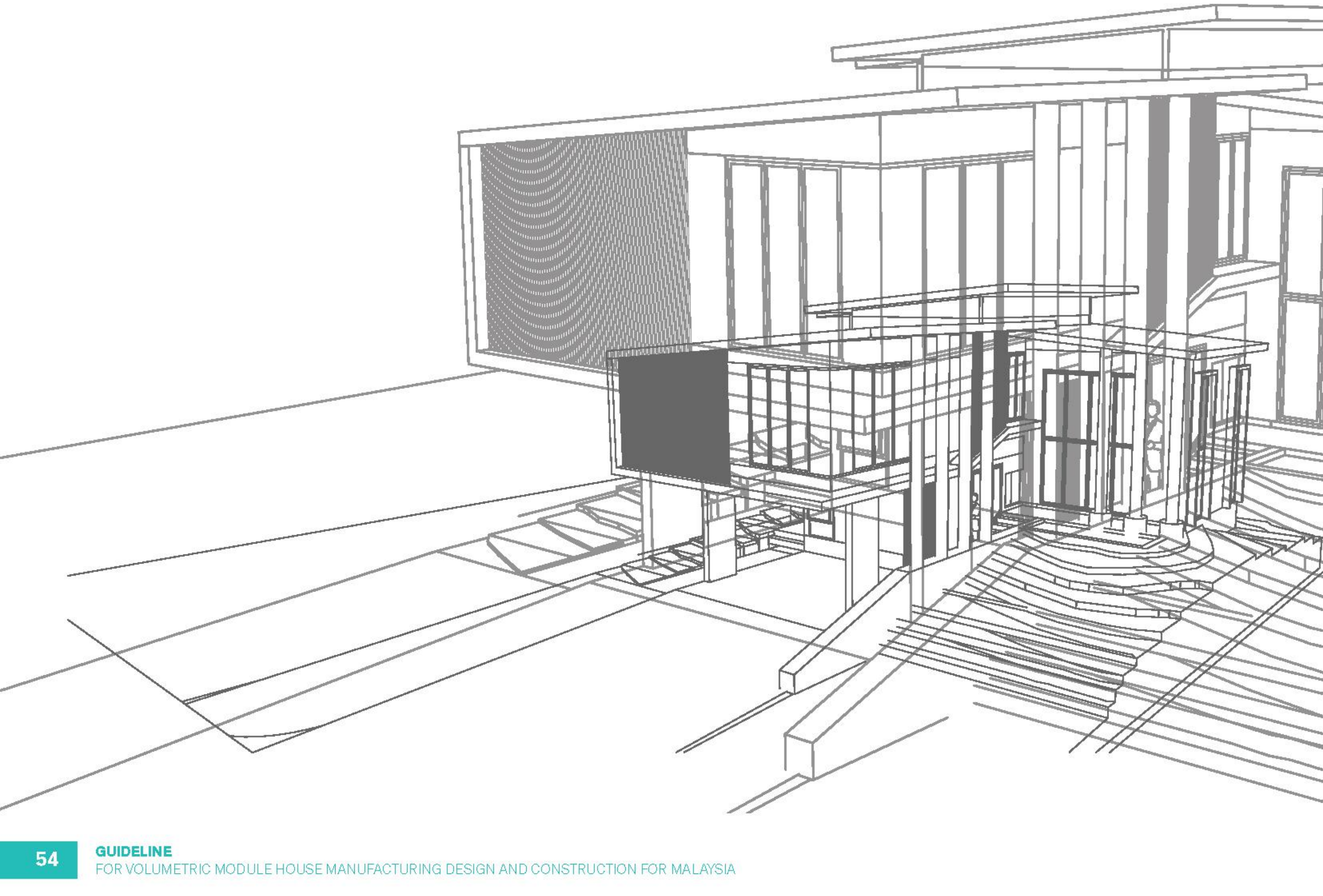
e) Alteration, Repair and Replacement Works

- Replacement of accessories/ installation of additional fittings
- Availability and supply of spare parts
- Instruction, drilling and fixing
- Instructions for tile replacement
- Instructions for grab bars installation

9.3 Reuse and Recyclability

While modular construction presents an opportunity to achieve a higher degree of reusability and recycling, likewise, the capacity of VMs for disassembly removes the need for demolition which facilitates potential reuse. Furthermore, disassembly accommodates a much more orderly, systematic and thorough segregation of preassemblies, products and materials. Accordingly, this alleviates certain environmental and human health concerns related to demolition, such as dust production, noise and contamination from the uncontrolled transportation of materials. This results in a much cleaner and a less environmental impact decommissioning phase that benefits both the local and broader community.

Also, it is important to prepare for disassembly since this process requires much more planning and coordination. Without a simple demolition strategy, the risks might be more significant compared to traditional demolition methods. Traditional on-site demolition typically uses large machinery that disassociates workers from large quantities of waste that is generated, essentially "bulldozing" large developments. This demolition method results in mixed, damaged and a contaminated waste stream that immediately downgrades the material to a lower level in the waste hierarchy.



CHAPTER 10: COMPLIANCE WITH BUILDING CODES AND REGULATION

10.1 Compliance with Safety Regulation

10.1.1 Fire Safety Requirement

The fire resistance rate for building structures such as compartments between the floor to floor levels, and the compartments between the walls segregating the dwelling units, should comply with fire regulations and other requirements. Documentary proof and detailed drawings should be available to illustrate the level of compliance with the fire rating requirements of the proposed system regarding compartmentation, material usage and so forth.

Also, the materials used for the building elements should be considered to ensure the integrity of the VMs. The use of building products/materials/systems should comply with the fire test performance requirements stipulated in the regulated fire safety products/materials. Additionally, fire test performance reports from accredited test laboratories should be provided to support compliance of the proposed products/materials/systems.

10.1.2 Risk Assessment and Safety at Work

To identify all potential hazards, a comprehensive risk assessment should be conducted. Appropriate control measures must then be established, communicated and implemented before the commencement of works. A comprehensive Fall Prevention Plan with Safe Work Procedures and appropriate control measures should also be established. Control measures such as safety barricades should be provided for all open sides where a person may fall. Such barricades can only be removed during installation when the VM is hoisted near its designated position.

Similarly, all workers performing work at height should be provided with appropriate Personal Protective Equipment (PPE) such as a personal fall arrest system. Accordingly, they should be formally trained in the proper use of the system and to ensure that the system is always in place. All lifting gears and equipment are to be in serviceable condition at all times.

a) Elimination of Work at Height

All work that may involve the risk of falling should be eliminated at the design stage. For example, a Design Engineer proposes the connection of the two-high floor VMs using bolts, nuts and a linkage plate. As the connection work can only be carried out externally from the building façade, it would mean that workers will need to extend themselves outside the VM in order to reach the connections thereby exposing themselves to the risk of falling. Following the design review, the Design Engineer should redesign the connections to connect with the safety of the VM unit and successfully eliminate the risk of falling.

b) Substitution of a Safer Work-at-Height Method

If the risks cannot be eliminated by design, the Design Engineer should investigate safer working methods in order to minimise the risk, (e.g. use of a mobile elevating work platform (MEWP), scaffold or step platform ladder instead of an A-frame ladder placed beside the VM).

c) Engineering Control – Fall Prevention

Where workers are required to work on top of a VM or at any location where there is a risk of falling, the open sides of the VM or location should be appropriately barricaded or physically guarded (e.g. Engineering Control measure). The connections for the barricades or guardrails should be built into the VM wherever possible and feasible. A fall prevention system such as using barricades is preferred over fall restraints and fall arrest systems as barricades provide a high level of protection once correctly installed.

d) Personal Protection Equipment (PPE)

Where barricades or guardrails cannot be provided, anchorage points and/or lifelines should be provided to ensure that workers are protected from falling from a height. Anchorage points, anchorage lines, safety harnesses etc., should be planned beforehand, taking into consideration the zone of which the workers will be required to operate for rigging/unrigging operations and other work, (e.g. grouting work at the top of the VM or the working level).

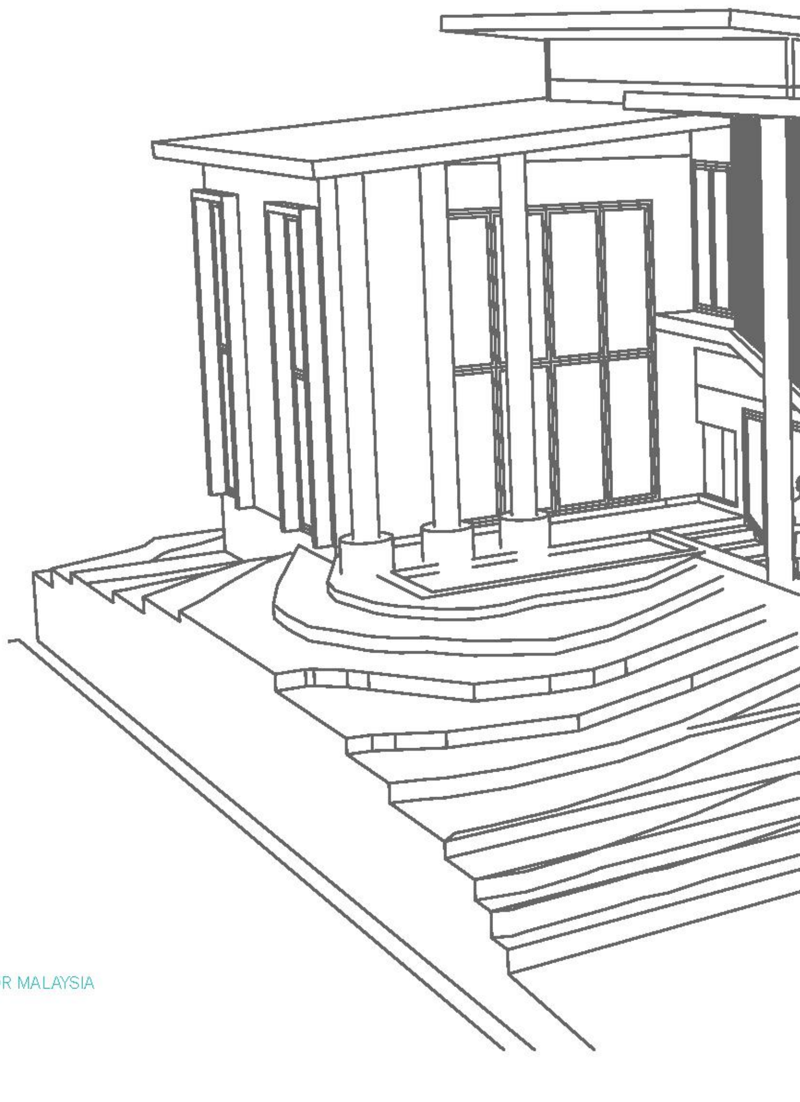
Generally, there are two types of fall protection or prevention systems: fall restraint and fall arrest systems, of which the former is preferred over the latter.

Fall restraint systems (FRS) prevent a person from falling and includes the use of:

i. Work-Positioning; and
ii. Travel Restraint systems.

Whereas, fall arrest systems (FAS) protect a person after falling to a certain distance by stopping the fall before the person hits the surface below and includes the use of:

i. A full body harness, shock absorber and anchor; and
ii. Safety nets.



10.2 Authorities Involved

The list of authorities involved include:

	Federal Ministry	Federal Agency
i.	**Ministry of Works**	• Construction Industry Development Board (CIDB) • Public Works Department (JKR) • Board of Engineers of Malaysia (BEM) • Board of Architects, Malaysia (LAM) • Board of Surveyors of Malaysia (LJT)
ii.	**Ministry of Transport**	• Road Safety Department (JKJR) • Road Transport Department (JPJ)
iii.	**Ministry of Housing and Local Government**	• Local Government Department (JKT) • Fire and Rescue Department of Malaysia (JBPM) • National Housing Department (JPN) • National Solid Waste Management Department (JPSPN) • Solid Waste Management and Public Cleansing Corporation (SWCorp)
iv.	**Ministry of Human Resources**	• Department of Manpower (JTK) • Department of Occupational Safety and Health (JKKP /DOSH) • Department of Skills Development (JPK/DSD) • National Institute of Occupational Safety and Health (NIOSH)
v.	**Ministry of International Trade and Industry**	• Malaysian Steel Institute (MSI) • Malaysian Investment Development Authority (MIDA) • Malaysian Productivity Corporation (MPC)
vi.	**Ministry of Economic Affairs**	• Economic Planning Unit (EPU)
vii.	**Ministry of Water, Land and Natural Resources**	• Department of Irrigation and Drainage (JPS/DID) • National Water Services Commission (SPAN) • Sewerage Services Department (JPP)
viii.	**Ministry of Energy, Technology, Science, Environment and Climate Change**	• SIRIM Berhad • Malaysian Sustainable Energy Development Authority (SEDA) • Malaysia Green Technology Corporation (GreenTech Malaysia) • Energy Commission
ix.	**Ministry of Education**	• Technical and Vocational Education and Training (TVET)
x.	**Ministry of Rural Development**	• Institut Kemahiran MARA (IKM) • Kolej Kemahiran Tinggi MARA (KKTM)

10.3 Related Regulations, Act and Policies

The related regulations, acts and policies:

	Federal Ministry	Federal Agency
i.	Construction Industry Development Board (CIDB)	• Act 520 - Akta Lembaga Pembangunan Industri Pembinaan Malaysia 1994 (Pindaan 2011)
ii.	Road Transport Department (JPJ)	• Act 333 - Road Transport Act 1987
iii.	Fire and Rescue Department of Malaysia (JBPM)	• Act 341 - Fire Services 1998
iv.	National Housing Department (JPN)	• National Housing Policy • Act 118 - Akta Pemajuan Perumahan
v.	Local Government Department (JKT)	• Act 133 - Street, Drainage and Building Act 1974 (Pindaan 1978) • Uniform Building By-Laws (UBBL) 1984
vi.	Solid Waste Management and Public Cleansing Corporation (SWCorp)	• Solid Waste and Public Cleansing Management Act 2007 (Act 672 & Act 673)
vii.	Sewerage Services Department (JPP)	• Act 508 - Akta Perkhidmatan Pembetungan 1993
viii.	Department of Occupational Safety and Health (JKKP/DOSH)	• Act 139 - Factories and Machinery Act 1967 (Pindaan 2006) • Act 514 - Occupational Safety and Health Act 1994 • Factories and Machinery (Building Operations and Works of Engineering Construction) (Safety) Regulations 1986) • Factory and Machinery (Safety, Health & Welfare) Regulation 1970
ix.	Department of Skills Development (JPK/DSD)	• Pembangunan Sumber Manusia Berhad Act 2001 • Skills Development Fund Act 2004 • National Skills Development Act 2006
x.	Department of Manpower (JTK)	• Act 446 - Workers' Minimum Standards of Housing and Amenities Act 1990
xi.	Department of Environment (DOE)	• Act 127 - Environmental Quality Act 1974
xii.	National Water Services Commission (SPAN)	• Water Services Industry (Water Reticulation and Plumbing) (Amendment) Rules 2015 • Water Services Industry (Water Reticulation and Plumbing) (Amendment) (No. 2) Rules 2015 • Water Services Industry (Planning, Design and Construction of Sewerage System and Septic Tank) Rules 2013 • Act 654 - Suruhanjaya Perkhidmatan Air Negara Act 2006 • Act 655 - Water Services Industry Act 2006
xiii.	Energy Commission	• ACT 447 - Electricity Supply Act 1990

10.4 Related Standards, Guidelines and References

The related standards, guidelines and references:

i.	**Malaysian Standard (MS)**	• MS EN 1990:2010 - Eurocode - Basis of Structural Design • MS EN 1992-1-1:2010 - Eurocode 2: Design of Concrete Structures - Part 1-1: General Rules and Rules for Buildings • MS EN 1993-1-1:2010 - Eurocode 3: Design of Steel Structures - Part 1-1: General Rules and Rules for Building • MS EN 12390-3:2012 - Testing hardened concrete - Part 3: Compressive strength of test specimens (Second revision) • MS 1064-1: 2001 (Confirmed 2009) - Guide to modular coordination in buildings – Part 1: General Principle • MS 1064-2: 2001 (Confirmed 2009) - Guide to modular coordination in buildings – Part 2: Storey heights and room heights • MS 1064-10: 2018 - Guide to modular coordination in buildings - Part 10: Coordinating sizes and preferred sizes for reinforced concrete components (First revision) • MS 1525:2014 - Energy efficiency and use of renewable energy for non-residential buildings - Code of practice (Second revision) • MS 1183:2015 - Fire safety in the design, management and use of buildings - Code of practice (First revision) • MS 1600-1:2013 - Fire resistance tests - Part 1: General requirements • MS 1979: 2015 – Electrical installation of buildings – code of practice • MS EN 1998-1:2015 (National Annex: 2017) - Malaysia National Annex to Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings
ii.	**Construction Industry Standard (CIS)**	• CIS 1:1998 - Standard Perumahan Kebangsaan Bagi Perumahan Kos Rendah - Satu dan Dua Tingkat • CIS 2:1998 - Standard Perumahan Kebangsaan Bagi Perumahan Kos Rendah - Rumah Pangsa • CIS 3:2005 - Standard Perumahan Kebangsaan Bagi Perumahan Kos Sederhana Rendah Selain Rumah • CIS 4:2005 - Standard Perumahan Kebangsaan Bagi Perumahan Kos Sederhana Rendah Rumah Pangsa • CIS 5:2004 - Quality Assurance for Prefabricated Timber Truss Systems • CIS 7:2014 - Quality Assessment System for Building Construction Work (QLASSIC) • CIS 9:2008 - Guideline on Handling, Transportation, Stacking and Installation of Precast Concrete Components • CIS 10:2008 - Safety and Health Assessment System in • Construction (SHASSIC) • CIS 12:2009 - Quality Assurance for Prefabricated Light Weight Steel Roof Truss • CIS 13:2009 Guideline on Handling, Transportation, Stacking and Installation of Structural Steel • CIS 15:2009 Guideline on Prevention of Fall at Construction Site • CIS 18:2018 Manual for IBS Content Scoring System (IBS Score) • CIS 20:2013 Manual Tatacara Penilaian Pengeluar Berstatus IBS (AIS) • CIS 21:2018 Ready-Mixed Concrete: Production, Conformity, Transportation and Delivery criteria for Producers • CIS 22:2017 Safe Use of Scaffolding in Construction • CIS 23:2018 Safe Use of Falsework and Formwork in Construction

iii.	**British Standard (BS)**	• BS EN 13369:2018 - Common rules for precast concrete products • BS EN 13693:2004+A1:2009 - Precast concrete products. Special roof elements • BS EN 14843:2007 - Precast concrete products. Stairs BS EN 14992:2007+A1:2012 - Precast concrete products. • Wall elements • BS EN UBB47:2005+A2:2010 - Precast concrete products. Floor plates for floor systems • BS EN 1168:2005+A3:2011 - Precast concrete products. Hollow core slabs • BS EN 15050:2007+A1:2012 - Precast concrete products. Bridge elements • BS EN 13225:2013 - Precast concrete products. Bridge elements • BS EN 14991:2007 - Precast concrete products. Foundation elements • BS EN 13224:2011 - Precast concrete products. Ribbed floor elements • BS EN 1253-1:2015 – Gullies for buildings. Trapped floor gullies with a depth water seal of at least 50 mm • BS EN 1253-3:2016 - Gullies for buildings. Evaluation of conformity • BS EN ISO 12572:2016 - Hygrothermal performance of building materials and products. Determination of water vapour transmission properties. Cup method • BS 476-21/22:1987 - Fire tests on building materials and structures. Methods for determination of the fire resistance of loadbearing elements of construction • BS EN 1991-1-2, Eurocode I -Actions on structures -Section 1-2: General actions - Actions on structures exposed to fire • BS EN 1993-1-2, Eurocode 3 - Design of steel structures-Section 1-2: General rules - Structural fire design
iv.	**American Society for Testing and Materials (ASTM)**	• ASTM D5957 - 98(2013) - Standard Guide for Flood Testing Horizontal Waterproofing Installations • ASTM D7832 / D7832M – 14 - Standard Guide for Performance Attributes of Waterproofing Membranes Applied to Below-Grade Walls / Vertical Surfaces (Enclosing Interior Spaces)
v.	**Guidelines/ Specifications/ References**	• Guideline on Geometric Design of Roads - Road Engineering Association of Malaysia (REAM) • Guideline for Public Safety and Health at Construction Sites (1st Revision) 2007 - Department of Occupational Safety and Health (DOSH) • Arahan Teknik (Jalan) ATJ. 8/86: A Guide on Geometric Design of Roads (Pindaan 2015) – Public Work Department (PWD) • Garis Panduan BIM 2014 - Public Work Department (PWD) • A Reference Guide to Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST) – Construction Industry Development Board (CIDB) • Green Building Index (GBI) – Board of Architect Malaysia (BAM) • Green Real Estate (GreenRE) - Real Estate Housing Developers' Association Malaysia (REHDA) • Specification for the Design, Manufacture & Construction of Precast Concrete Structures – Construction Research Institute of Malaysia (CREAM) • Construction Quality Assessment System (CONQUAS) – Building and Construction Authority (BCA), Singapore • Handbook for the Design of Modular Structures – Monash University, Australia • Design in Modular Construction – CRC Press, United Kingdom • Design for Manufacturing and Assembly (DfMA): Prefabricated Prefinished Volumetric Construction - Building and Construction Authority (BCA), Singapore • BIM for DfMA Essential Guide - Building and Construction Authority (BCA), Singapore

CHAPTER 11: CASE STUDY

11.1 Case Study: Projects in Malaysia

11.1.1 Office Building at University of Malaysia Pahang

Descriptions	
Contractor	Portland Arena Sdn Bhd
Application	Office
Year of construction	2014
Project period	5 months
Cost of project	RM3.5 million (including internal M&E works, air conditioning and furniture).
No. of modular units	72 units
Additional structural framework	-Steel framing for supporting the structure (staircases, floor joists and walkways) -Only used pad footings and ground beams for the substructure.

11.1.2 Central Labour Quarters (CLQ) at Pengerang Integrated Complex

Descriptions	
Contractor	Castwell Industries (M) Sdn Bhd
Application	Workers Quarters
Year of construction	2015
Project period	6 months
No. of storey	6 blocks with 4 storeys 14 blocks single storey
IBS System	3D Modular System
IBS Product/Component	3D Modular Building (wall, concrete slab, ceiling etc.), 3D Modular Roof, 3D Modular Staircase.

11.2 Case Study: Projects Worldwide

11.2.1 Crowne Plaza Extension Hotel, Singapore

Descriptions	
Structure Material	Modular Steel Container
Application	Hotel
Year of construction	2015
Project period	Manufacture Period: 155 days Construction Period: 26 days
No. of storey	10 storeys and 243 hotel rooms
Features	• Steel container construction • 100% off site construction manufacturing • 9.0 magnitude earthquake and typhoon resistant • All building materials BCA Green Mark Certified

11.2.2 The Clement Canopy, Singapore

Descriptions	
Structure Material	Concrete modules
Application	Residential
Year of construction	2016
No. of storey	40 storeys and 505 apartment units
Features	• The first PPVC project using entirely concrete modules • 1,866 modules in total • The heaviest module weighs 29 tons • The lightest module weighs 17 tons • Aims to lift an average of 8 modules per day

REFERENCES

ACT 333. (1987). Weight Restrictions (Federal Roads) (Amendment) Order 2017. Malaysia: ATTORNEY GENERAL'S CHAMBERS.

Almeida, S. J., & Wei, H. S. (2017). Affordable Housing: Challenges and the Way Forward, (2011), 19–26.

Alter, L. (2014). Modular construction and cross-laminated timber, together at last! | TreeHugger. Retrieved September 26, 2018, from https://www.treehugger.com/modular-design/modular-construction-and-cross-laminated-timber-together-last.html

Alter, L. (2016). In Sweden they are building high quality multifamily wood prefabs that we can only dream about here | TreeHugger. Retrieved October 2, 2018, from https://www.treehugger.com/modular-design/sweden-they-are-building-high-quality-multifamily-wood-prefabs-we-can-only-dream-about-here.html

ATJ. (2015). A Guide on Geometric Design of Roads (Arahan Tek). Jabatan Kerja Raya Malaysia. Retrieved from https://www.scribd.com/document/73094454/Arahan-Teknik-Jalan-8-86-A-Guide-on-Geometric-Design-of-Roads

Aurélie Cléraux. (2018). Modular construction - Bouygues Innovation. Retrieved September 26, 2018, from https://blog.bouygues-construction.com/en/dossier-special/construction-modulaire/

Azman, M. N. A., Ahamad, M. S. S., Majid, T. A., & Hanafi, M. H. (2011). Status of Industrialized Building System Manufacturing Plant in Malaysia. UNIMAS E-Journal of Civil Engineering, 2(2), 8–16. Retrieved from http://www.feng.unimas.my/JCEST/images/article/Volume2Issue2Disember2011/2Vol2Issue2.pdf

BCA. (2017). Design for Manufacturing and Assembly (DfMA) - Prefabricated Prefinished Volumetric Construction. Retrieved February 12, 2018, from https://www.bca.gov.sg/Professionals/Technology/others/PPVC_Guidebook.pdf

BFT International. (2015, April). Concrete Plant Precast Technology. BFT Magazine. Retrieved from http://www.bft-international.com/en/artikel/bft_Modular_Housing_System_for_earthquake-proof_living_space_in_Peru_2313177.html

Bridgette Meinhold. (2010). Stacked Shipping Containers Create Smart Green Homes in Malaysia | Inhabitat - Green Design, Innovation, Architecture, Green Building. Retrieved September 25, 2018, from https://inhabitat.com/stacked-shipping-containers-create-smart-green-homes-in-malaysia/

CIDB. (2017). The Way Forward for IBS: Modular Construction. IBS Digest: Degree of Industrialisation, (3), 18–22.

CIDB Malaysia. (2015). Construction Industry Transformation Programme 2016-2020. https://doi.org/10.1007/s13398-014-0173-7.2

Demographia. (2015). 11 th Annual Demographia International Housing Affordability Survey: 2015. Retrieved from http://www.demographia.com/dhi2015.pdf

Elliott, K. . (1996). Multi-storey Precast Concrete Framed Structures. Blackwell Science, Oxford.

Forta PRO. (n.d.). About Forta PRO | Modular Construction Company. Retrieved October 2, 2018, from http://www.fortapro.com/about-company/

Gass, M. S. (1989). A Quality Control Program Analysis for Modular Housing. The Pennsylvania State University. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a221025.pdf

K-Structures. (2015). Modular Toilet Pod. Retrieved September 26, 2018, from http://www.k-structures.com/product/modular-toilet-pod

Lawson, R. M., & Ogden, R. G. (2010). Sustainability and Process Benefits of Modular Construction. 8th CIB World Building Congress, 38.

Lawson, R. M., Ogden, R., & Goodier, C. (2014). Design in Modular Construction. Taylor & Francis Group.

MBI. (2018). What is Modular Construction?, 1–4. Retrieved from http://www.modular.org/HtmlPage.aspx?name=why_modular

Mcfarlane, A., Leader, S. E., Rourke, L. O., Stehle, J., Leader, S. E., & Rourke, L. O. (2014). DfMA: Engineering the Future.

Monash University. (2017). Handbook for the Design of Modular Structures.

MS1064-2. (2001). Guide to Modular Coordination in Buildings: Part 2: Storey Heights and Room Heights (First Revision). Department of Standards Malaysia.

Musa, M. F., Yusof, M. R., Mohammad, M. F., & Mahbub, R. (2014). Characteristics of Modular Construction: Meeting the Needs of Sustainability and Innovation. 2014 IEEE Colloquium on Humanities, Science and Engineering, (Chuser 2014), 216–221.

PCE Ltd. (2017). Modular Core Construction from PCE Ltd. Retrieved September 25, 2018, from https://pceltd.co.uk/wp-content/uploads/2017/02/PreFastCore-Feb_2017.pdf

REAM. (2002). Guide on Geometric Design of Roads. Road Engineering Association of Malaysia (REAM). Retrieved from https://www.scribd.com/doc/74757659/REAM-Guidelines-On-Geometric-Design-of-Roads

Richard, R. B. (2005). Industrialised building systems: Reproduction before automation and robotics. Automation in Construction, 14(4), 442–451. https://doi.org/10.1016/j.autcon.2004.09.009

Ross, K., Cartwright, P., & Novakovic, O. (2006). A guide to modern methods of construction. Amersham: National House Building Council.

Satow, J. (2013, March 8). More Units Going Up in a Snap. The New York Times. Retrieved from https://www.nytimes.com/2013/03/10/realestate/inwood-prefab-homes-win-converts-in-new-york.html

Shift Modular. (2014). Modular Philosophy - Modular Construction & Prefab Buildings | Shift Modular. Retrieved September 25, 2018, from http://www.shiftmodular.com/modular-philosophy/

Sinclair, D., Johnson, J., Heptonstall, I., Francis, R., Fraser, N., Mccarthy, S., … Stacey, S. (2016). RIBA Plan of Work 2013 Designing for Manufacture and Assembly. Retrieved from https://www.architecture.com/RIBA/Professionalsupport/Assets/Files/RibaPlanofWorkDfMaOverlay2016.pdf

AKNOWLEDGEMENT

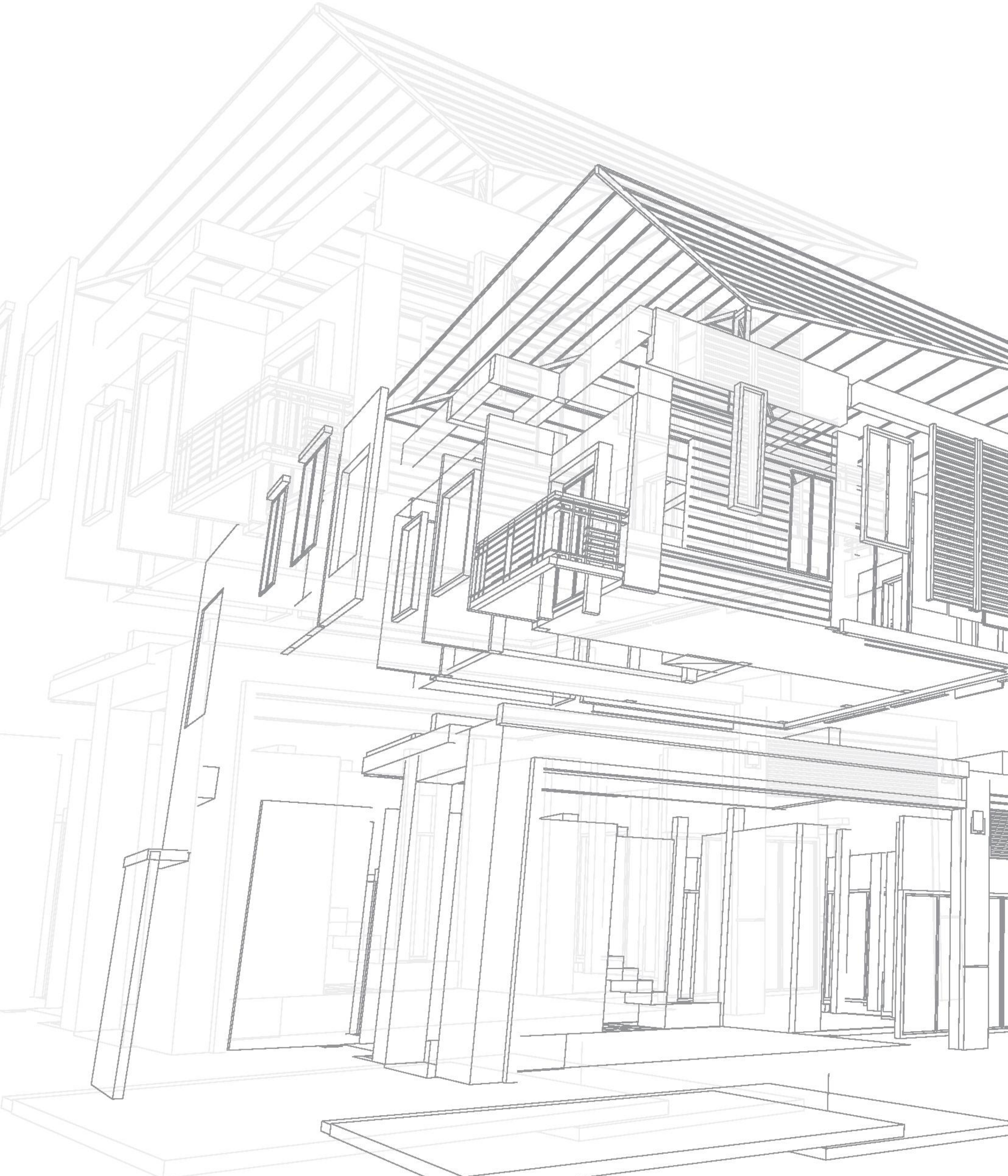
The Construction Industry Development Board (CIDB) Malaysia would like to acknowledge the individuals and organisations for their valuable contributions and insights during the development of the **Guideline for Volumetric Module House Manufacturing Design and Construction for Malaysia.**

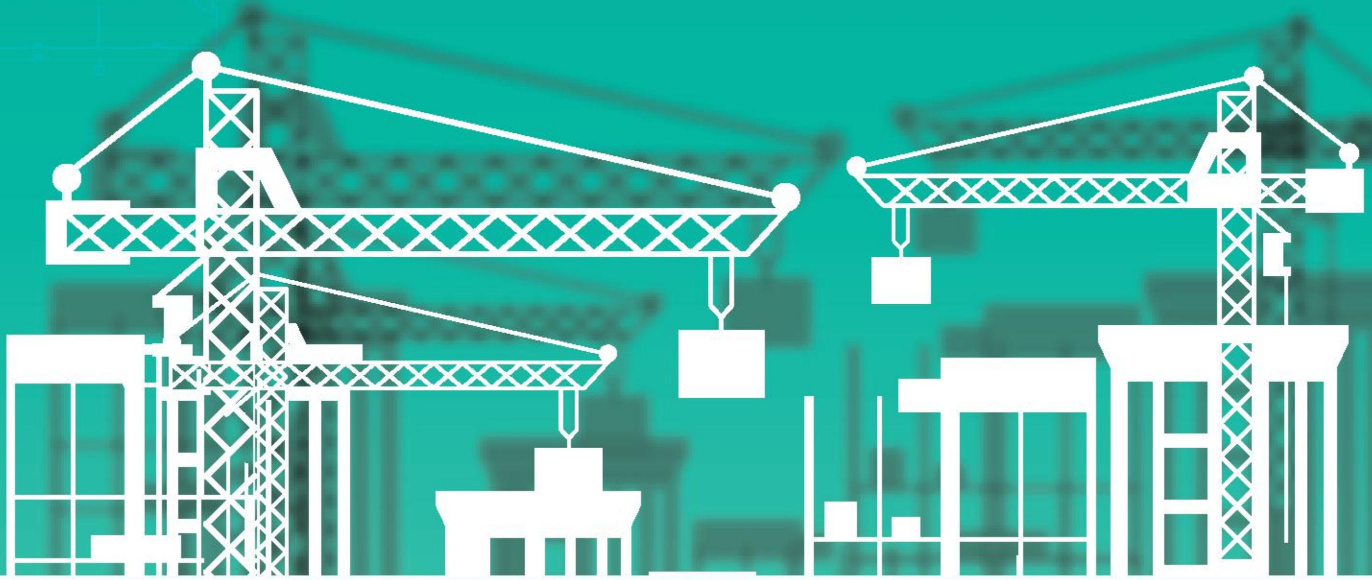
TECHNICAL COMMITTEE

Mr. Aw Jewee Chin	Associated Concrete Products (M) Sdn. Bhd
Mr. Md Zon bin Haron	Castwell Industries (M) Sdn Bhd
Ms. Nadiah binti Musa	Central Cables Berhad
Mr. Zani bin Kassim	Central Cables Berhad
Mr. Muhammad Faiz Musa	CIDB Selangor
Ar. Dr. Eleena Jamil	Eleena Jamil Architect (EJA)
Ir. Thoo Hoi Hian	GAMUDA IBS
Ir. Shahrul Nizar Shaari	Innovacia Sdn Bhd
Ir. K.Gunasagaran	Institute of Engineers Malaysia (IEM)
Ar. Sharina Intan Binti Abdullah	Jabatan Kerajaan Tempatan (JKT)
Ir. Zul Amri bin Abu Bakar	Jabatan Kerja Raya (JKR)
Mr. Mohd Noor Nasriq Bin Mohd Hudal	Jabatan Perumahan Negara (JPN)
Mr. Nikan Anak Remang	Jabatan Perumahan Negara (JPN)
YBhg. Dato' Massuan bin Ahamad	Kementerian Kerja Raya (KKR)
Mr. Yeap Chin Seong	Kimlun Sdn Bhd
Mr. Rozaiman Hassan	MyIBS
Mr. Saiful Adli Abdul Karim	NS Prefab Consultancy
Mr. Hj. Jasmin Dato'Hj. Jamil	Oxford Thinkers
Mr. Mohamed Asyraff bin Husin	Oxford Thinkers
Mr. Nazmi Kashful Anuar	Oxford Thinkers
Ar. Abu Zarim bin Abu Bakar	Persatuan Arkitek Malaysia (PAM)
Mr. Foong Fatt Kee	Setia Precast Sdn Bhd
Ms. Maureena Jurliel Abdullah	Setia Precast Sdn Bhd
Ir. Kamal Pasha bin Mokhtar	Sime Darby Property Bhd
Mr. Azlan Azri Zainal Abidin	Strand Malaysia
Mr. Engku Afif Engku Zam	TXMR Sdn Bhd
Mr. Safwan Salim	TXMR Sdn Bhd
Ir. Dr. Kamarul Anuar Mohamad Kamar	UEM Group Berhad
Dr. Mohd Shuisma Mohd Ismail	Universiti Teknologi Malaysia (UTM)

CONTRIBUTORS AND REVIEWERS

Ir. Siow Jat Shern	Alliance MEP Sdn Bhd
Mr. Chia Soon Yoon	Alliance MEP Sdn Bhd
Ir. Ng Kok Peng	Eastern Pretech (Malaysia) Sdn Bhd
Mr. Mohd Hafiz bin Mohd Ameran	Gamuda IBS Sdn Bhd
Ir. Sanisah binti Hj. Sulaiman	Jabatan Kerja Raya (JKR)
Mr. BK Sinha	Malaysia Green Building Confederation (MGBC)
Mr. Febriyanshah Musazumu bin Saad	Numaginelab Sdn Bhd
Mr. Vadivelu A/L Jeyaraman	Ranhill Bersekutu Sdn Bhd
Mr. Abdul Majid bin Moideen	TK Modular Pte Ltd
Mr. Mohd Saifuddin Hassin	UAC Berhad





CIDB
MALAYSIA

9 789670 997582