# A GUIDE TO DESIGN FOR MANUFACTURING AND ASSEMBLY (DfMA) IN PRECAST CONCRETE SYSTEM

CIDB Technical Publication No.: 2113

CIDB MALAYSIA

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A Guide to Design for Manufacturing and Assembly (DfMA) in Precast Concrete System
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# PREFACE

The guide to Design for Manufacturing and Assembly (DFMA) in precast concrete system is an introduction towards adopting the DfMA in Malaysia construction industries.  While the precast concrete system has been widely used in Malaysia over the past years and CIDB has classified it to be one of the IBS system, but it should not stop there as the construction industry towards transformation and the demand on affordable housing keep on rising which DfMA is the solution.

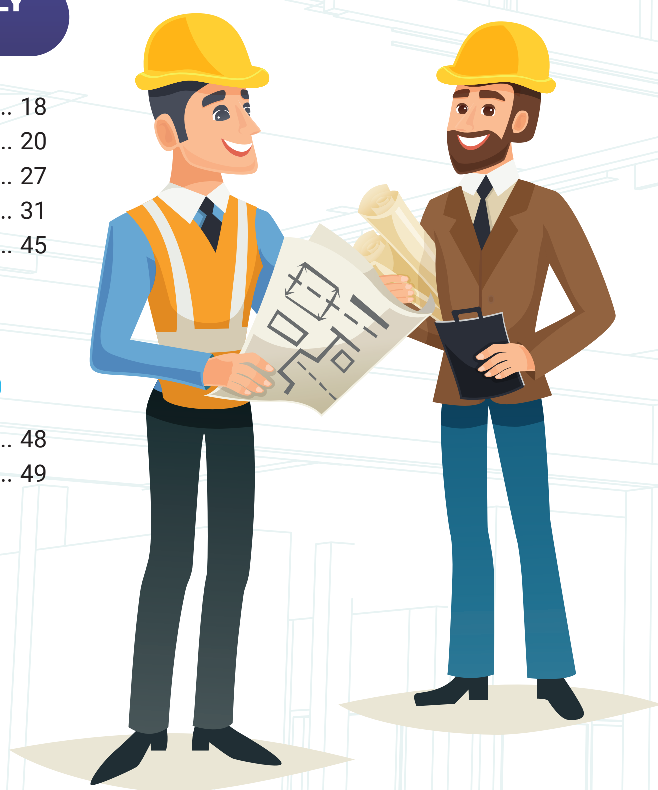
DfMA is an engineering methodology focuses on ease of manufacture and efficiency of assembly. This approach comprises a continuum of various technologies and methodologies that promote offsite fabrication from prefabricated components to fully integrated assemblies across the structural, architectural and MEP disciplines. DfMA is combination of two methodologies – Design for Manufacturing and Design for Assembly.

In this document will be used as a reference in order to understand DfMA from aspect consideration during design stage, types of production during manufacturing and things to consider on the physical works during assembly. This documents also aims to provide a comprehensive guide with the help of previous publication as a normative reference which include standard specification, guidelines and affordable housing standard design. Furthermore, the content of this guide is intent to give a better understanding on DfMA for all level of professional in various parties.

CIDB wish to express their gratitude and appreciation to all the professional industry from developer, architects, IBS manufacturers, consultants, contractors and all industry players involved in development of this guide. This guide 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.

# CONTENT





# Disclaimer

The guide to Design for Manufacturing and Assembly (DfMA) is to assist construction industries on how to adopt and what to consider if one should participate in DfMA. This guide is a graphical guide that shows some examples using an affordable housing standard design developed by CIDB.

The concept of DfMA emphasises on the use of Industrialised Building System (IBS) components which were widely used by the construction industry in recent years. The underlying principle of DfMA is to have more efficient construction method in a more controlled environment.

This is a general document that may cover a few typical scenarios but not to the extent of covering all scenarios that might arise during actual construction project.

# Normative Reference

BIM Guide 5 – BIM Project Guide – A Guide to Enabling BIM in Projects – Construction Industry Development Board Malaysia (CIDB)

CIDB Affordable Housing Design Standard for Malaysia – Construction Industry Development Board Malaysia (CIDB)

DeLIGHT Homes – A Sustainable and Innovative Affordable Housing Design Handbook – Construction Industry Development Board Malaysia (CIDB)

Guideline for Volumetric Module House Manufacturing Design and Construction for Malaysia – Construction Industry Development Board Malaysia (CIDB)

IHSAN Homes – Innovative Affordable Housing Design for Tropical Climate Through Technology – Construction Industry Development Board Malaysia (CIDB)

Specification for the Design, Manufacture & Construction of Precast Concrete Structures – Construction Research Institute of Malaysia (CREAM)

# Editorial

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# List of Abbreviation

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| BIM | Building Information Modelling |
| BS | British Standard |
| CIDB | Construction Industry Development Board |
| CIS | Construction Industry Standard |
| DfA | Design for Assembly |
| DfM | Design for Manufacture |
| DfMA | Design for Manufacturing and Assembly |
| DOE | Department of Environment |
| IBS | Industrialised Building Systems |
| JBPM | Fire and Rescue Department of Malaysia |
| JKT | Local Government Department |
| JKPP/DOSH | Department of Occupational Safety and Health |
| JPJ | Road Transport Department |
| JPK/DSD | Department of Skills Development |
| JPN | National Housing Department |
| JPP | Sewerage Services Department |
| JTK | Department of Manpower |
| MC | Modular Coordination |
| MEP | Mechanical, Electrical and Plumbing |
| MS | Malaysian Standard |
| SPAN | National Water Services Commission |
| SWCorp | Solid Waste Management and Public Cleansing Corporation |

# INTRODUCTION

## Overview

Industrialised Building Systems (IBS) can be defined as a construction technique in which the components are manufactured in a controlled environment before being transported, positioned, and assembled into a structure with minimal additional site work. In addition to this, the Construction Industry Development Board (CIDB) has defined and categorised IBS as having six characteristics that are equally important in ensuring the realisation of the claimed benefits, which are as follows:

- Industrial production of components through prefabrication
- Highly mechanised in-situ processes (i.e., slip-forms, post-tensioning, and tunnel shutters)
- Reduced labour during prefabrication of components and site works
- Modern design and manufacturing methods.
- Systematic Quality Control.
- Open Building Concept (i.e., permitting hybrid applications, adaptable to standardisation, and Modular Coordination (MC)).

Based on the structural classification by CIDB, the following six main IBS groups are widely used in Malaysia:

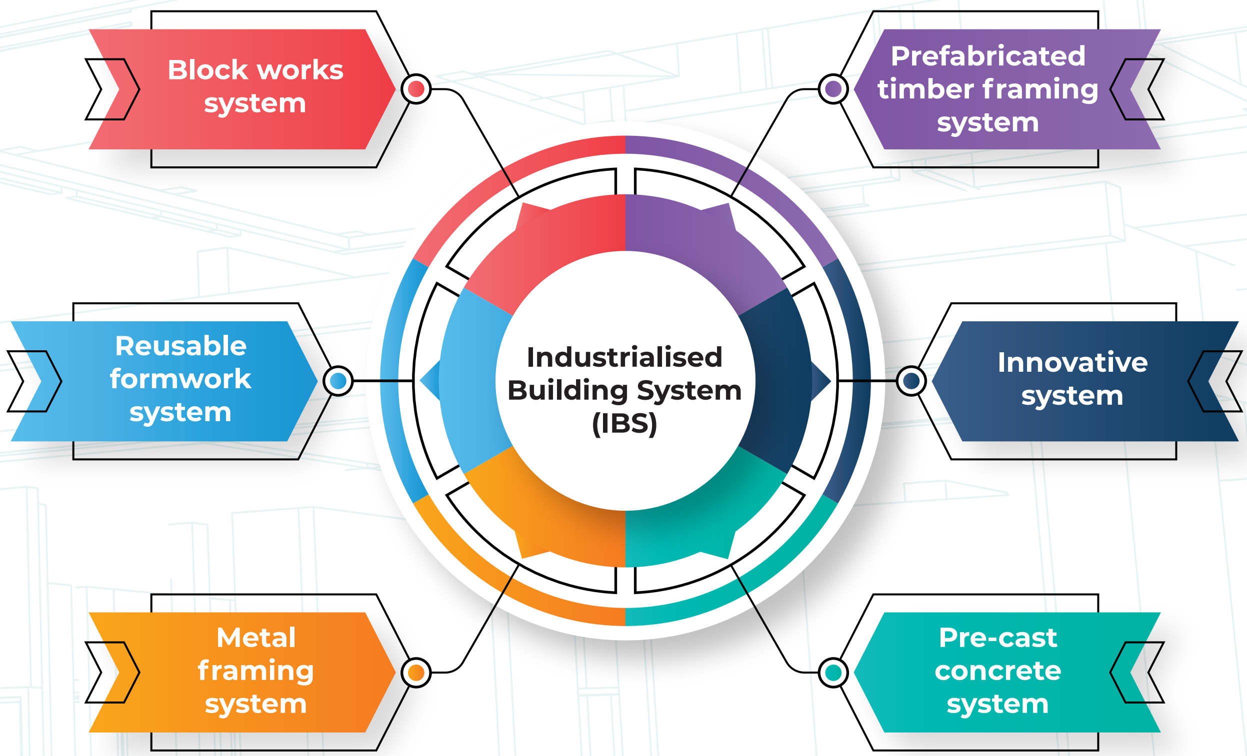



Figure 1. IBS Classification in Malaysia Context (CIDB, 2017)

In this sense, IBS can be defined as a construction method established based on innovation and rethinking of the best techniques in construction, therefore some IBS may not best to use the term Design for Manufacturing and Assembly (DfMA), for example reusable formwork system that is made up of tunnel forms, beams and columns moulding forms, as well as permanent steel formworks, after which concrete is poured at site. One of the most significant aspects of DfMA is the design stage, in which at this early stage of construction one should predetermine the production, logistic, assembly technique and facility management. As a result, some may use IBS in building, yet fail to properly utilise the DfMA concept.

## What is DfMA

Design for manufacture and assembly (DfMA) is a manufacturing phrase that emphasises two practical design aspects – how a component is manufactured and how it will be integrated into a product – that when combined, there will be potential to improve production efficiency. The emphasis is useful and welcomed because these factors are typically disregarded in favour of design for use, especially in building. The term originally applied to factory-made, mass-produced components that would be assembled into larger mass-produced products destined for an end-user, all in a factory. With advancements in manufacturing technology, it is now routinely used to create products that can be customised to various degrees in a process known as customisation. The ability to mass customise has broadened the scope of DfMA's use to cover the design of more sophisticated, higher-ticket, lower-sales-volume products, such as buildings.

The Overlay's consultees were quick to point out that, while DfMA is a technical process, it is also a philosophy that should be viewed as an extension or evolution of the designer's typical working methods. After all, designers have always strived to do the best they could for their clients, the people who utilise their structures, and society as a whole. This procedure just facilitates their progress. The consultees want to dispel the idea that DfMA is a roadblock towards excellent design or that it is only applicable to a few new-built sectoral building types. Furthermore, DfMA can result in outstanding, award-winning architecture with minimal limitations. It is applicable to all types of projects, including smaller ones and work on existing structures, and should be used by all types of organisations, including microbusinesses.

The DfMA Overlay is a companion to the Construction Strategy and an additional Project Strategy within the RIBA Plan of Work. It lays out the activities that must be completed in order to have a successful DfMA approach in a project and to effectively implement the numerous modern building methods. After being distributed among the client team, design team, or construction team as applicable under professional services or building contracts, the tasks are to be completed by the project team (Cross et al., 2021).

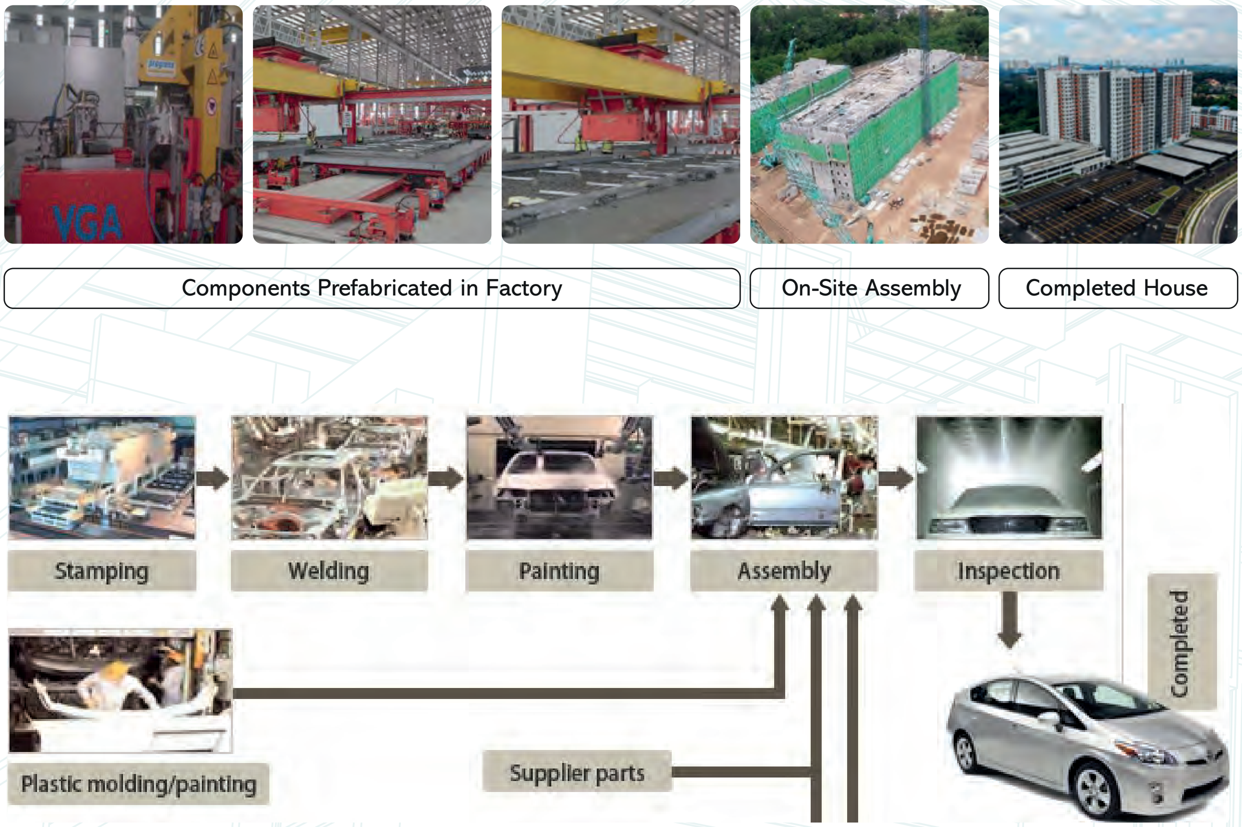
DfMA is a combination between Design for Manufacture (DfM) and Design for Assembly (DfA), and it is executed through design principles with the goal of making product manufacturing, delivery, and assembly easier (Staub-french et al., 2018). Both approaches respond to a number of different conditions as laid out in Table 1. The implementation of DfA and DfM can potentially bring considerable benefits, including reducing assembly and manufacturing costs, improving quality, and reducing production time through simplified products.

**Table 1. Conditions and considerations for DfM and DfA**

| Design for Manufacture | Design for Assembly |
|---|---|
| Design for productivity | Minimise and manage interfaces including templates / jigs |
| Design for logistics | Simplify and reduce sub-assemblies and component parts |
| Design to be modular | Reduced assembly risks |
| Design to facilitate manufacturing | Make sub-assembly easy |
| Optimised design for supplier capabilities | Designed for easy handling |
| Use common parts and materials | Use efficient methods of joining |
| | Prototype and perform first run studies |

*(Sources: Fraser, Kelly and Schock (2018))*

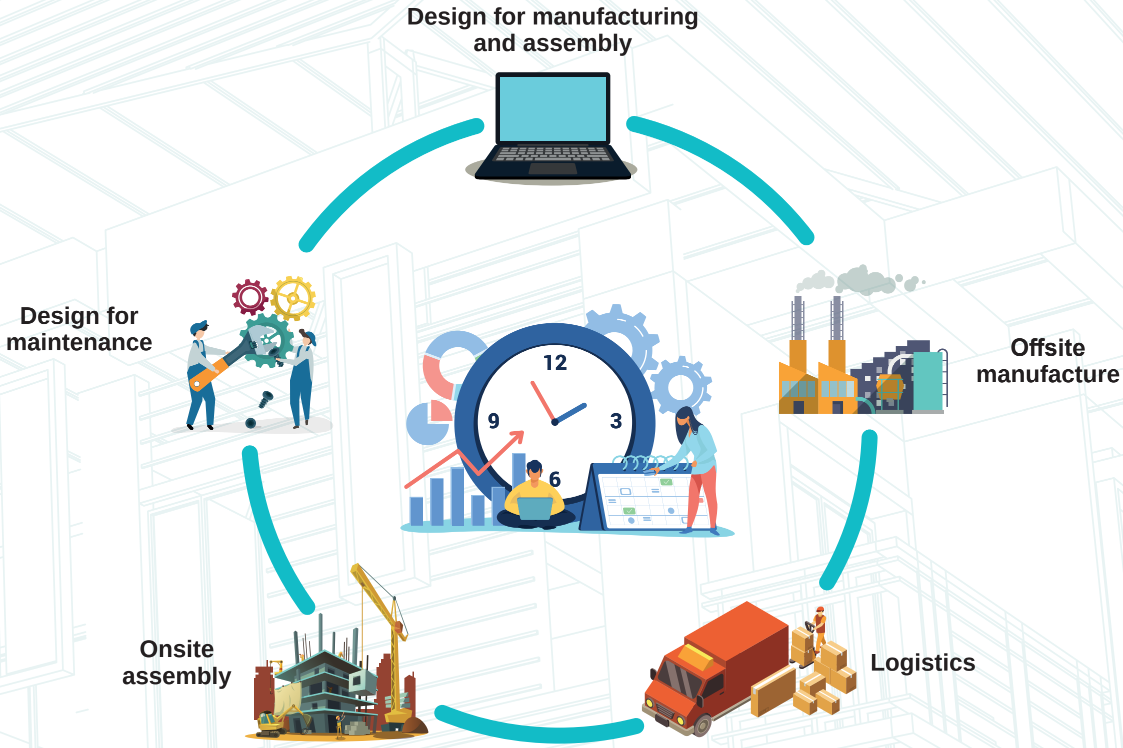
Therefore, DfMA emphasises the importance of design for ease of manufacturing and assembling of components that will form the final product. When applied to the building and construction industry, the DfMA approach necessitates a smooth transition between design and construction. The design should concentrate on the techniques for delivering the project, utilising off-site manufactured components whenever possible and arranging for effective logistics and assembly of these components on-site. It is a game-changing method of construction that also includes off-site manufacturing carried out in a controlled environment, before being assembled on-site. DfMA has been widely used in the automotive industry over the years and has proven to be productive and cost effective, therefore construction industry should implement DfMA to improve the current situation. Figure 2 shows the comparison between automotive industry and construction industry.




*(Source: Gamuda IBS and Toyota Motor Corporation)*

**Figure 2. Comparison between automotive industry and construction industry**

DfMA can also be referred as a design philosophy that emphasised on a holistic view of the design process. In this overarching view, 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 individual parts are to be fabricated and connected as part of the design process, rather than as an after-thought (Monash University, 2017).




*(Source: CIDB, (2020). Revaluing Affordable Housing in Malaysia Through Advanced Technology and Innovation)*

**Figure 3. DfMA mindset: through the stages of offsite manufacturing**

## Why adopt to DfMA

To improve construction productivity and fundamentally alter the design and construction processes, the industry is encouraged to embrace the concept of Design for Manufacturing and Assembly (DfMA), in which a significant portion of the work is designed and detailed to be completed off-site in a controlled manufacturing environment.

DfMA is a new approach in the construction industry. Manpower and time required to construct structures are minimised by planning more work offsite, while ensuring that work sites are safe, conducive, and minimally influence the surrounding living environment. The use of prefabrication methods in construction has been promoted as a way to improve productivity in the traditionally manpower-intensive industry.

There is no doubt that there are impressive projects being delivered using DfMA approaches, and major contractors and housebuilders are making huge investments in developing their own systems and factories. According to early indications, adoption is unlikely to spread beyond the projects in which these companies are directly involved, and the fact that less than ten percent of projects awarded in this manner are unlikely to change anytime soon.

## Benefits of DfMA

The key benefits of adopting DfMA compared to conventional construction are shown in Figure 4.

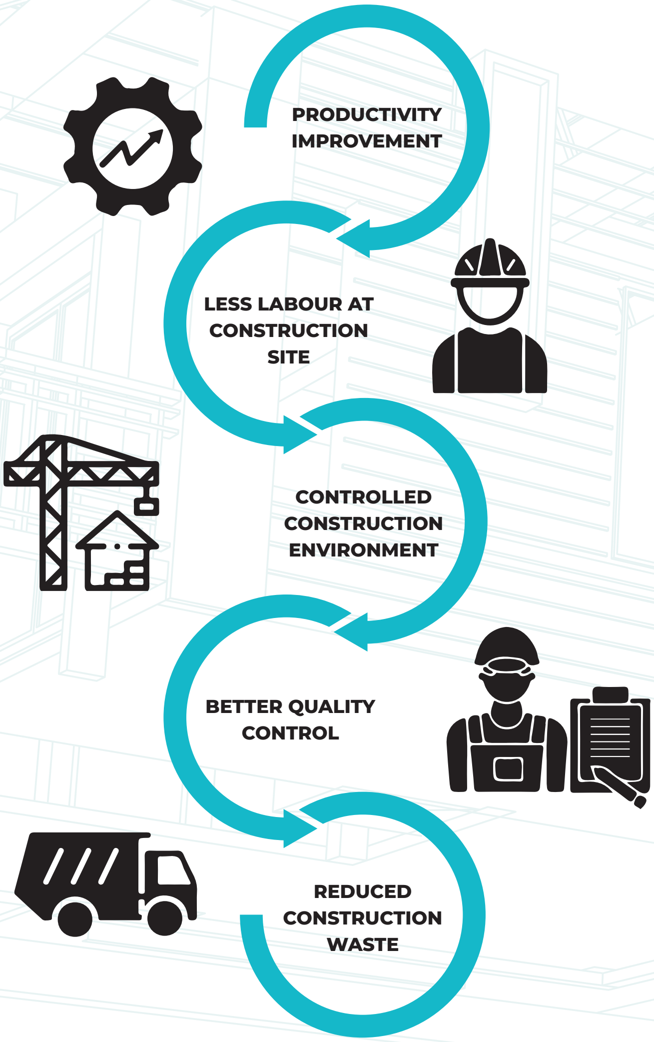



Figure 4. The key benefits of DfMA

**Productivity improvement**

The interactive participation in the design and planning stage by all stakeholders can lead to optimum solutions in the early stage which can reduce any upcoming problems during fabrication or assembly stage thus translate into having more productive construction.

**Less labour at construction site**

The conventional construction is known to be labour intensive process compared to DfMA, having a precast component delivered to construction site and then assembled at site will reduce the amount of labour used at site.

**Controlled construction environment**

Having a controlled construction environment can improve health and safety performance at site and can reduce the impact of noise, vibration, dust and air pollution at site.

**Better quality control**

Higher quality assurance can be achieved as the precast components are being manufactured in a controlled environment.

**Reduced construction waste**

When compared to conventional construction, the amount of timber as formwork at site can be reduced when using DfMA.

## Challenges in adopting DfMA

Several companies have adopted DfMA, but the challenges that impede wider acceptance of DfMA in the construction industry include the following:

- Public's negative perception related to "pre-fabricated" structures.
- Reluctance of the wider industry to adopt DfMA and off-site manufacturing.
- High start-up cost which leads to high risk for financial and investment institutions.
- Conventional procurement process discourages DfMA
- Slow acceptance by the market for new technologies. In particular, design standards and statutory approval processes do not necessarily keep pace or fully integrate with new construction methodology.

Probably the biggest challenge to widespread use of DfMA in the construction industry is the conventional procurement process.

## Studies on DfMA Principle and Strategies

DfMA signifies a shift in tradition, from sequential design thinking to a non-linear, reiterative methodology by actively considering the downstream processes in the upfront design stage. Key principle for the application of DfMA in manufacturing had been highlighted by Swift and Brown (2013), Bogue (2012), and Emmatty and Sarmah (2012) as shown in Table 2.

Table 2. A non-exhaustive list of DfMA key principle

| No. | Principle | Benefits |
|---|---|---|
| 1 | Aim for mistake-proof design | Avoids unnecessary re-work, improve quality, reduce time and costs |
| 2 | Design for ease of fabrication | Reduces time and costs by eliminating complex fixtures and tooling |
| 3 | Design for simple part orientation and handling | Reduces time and costs by avoiding non-value adding manual effort |
| 4 | Design with a predetermined assembly technique in mind | Reduces time and costs when assembling |
| 5 | Design multifunctional and multi-use parts | Reduces time with fewer manufacturing processes and simplified jointing |
| 6 | Consider modular designs | Reduces time and costs due to simplified design and assembly |
| 7 | Consider design for mechanised or automated assembly | Improves assembly efficiency, quality, and security |
| 8 | Use standard and off-the-shelf components | Reduces purchasing lead time and costs |
| 9 | Use similar materials as possible | Reduces time with fewer manufacturing processes and simplified jointing |
| 10 | Use environmentally friendly materials as possible | Reduces harm to the environment and residents |
| 11 | Minimise the part count | Reduces time and costs with simplified design, manufacture, and assembly |
| 12 | Minimise and standardise connector types and quantity | Reduces time and costs with simplified design,manufacture, assembly, repair and maintenance |
| 13 | Minimise the use of fragile parts | Reduces costs due to fewer part failures, and easier handling and assembly |
| 14 | Do not over-specify tolerances or surface finish | Reduces time and costs with easier manufacture |

*(Sources: Swift and Brown (2013), Bogue (2012), and Emmatty and Sarmah (2012))*

A few empirical studies have begun to investigate the implementation of DfMA, mainly in offsite prefabrication and modular construction projects. As summarised in Table 3, DfMA principles have been applied to various types of construction projects for various components. For example, Kim et al. (2016) reported the use of DfMA in the selection of suitable precast beams for a highway bridge in the UK; Gerth et al. (2013) reported its application in detailing the design of light walls for two four-story houses in Sweden. These studies reveal common practices in applying DfMA, such as identifying its driver, developing criteria for 'manufacturability' and 'constructability', investigating specific difficulties to address in design, involving different professionals in the design group, and optimising design through various principles.

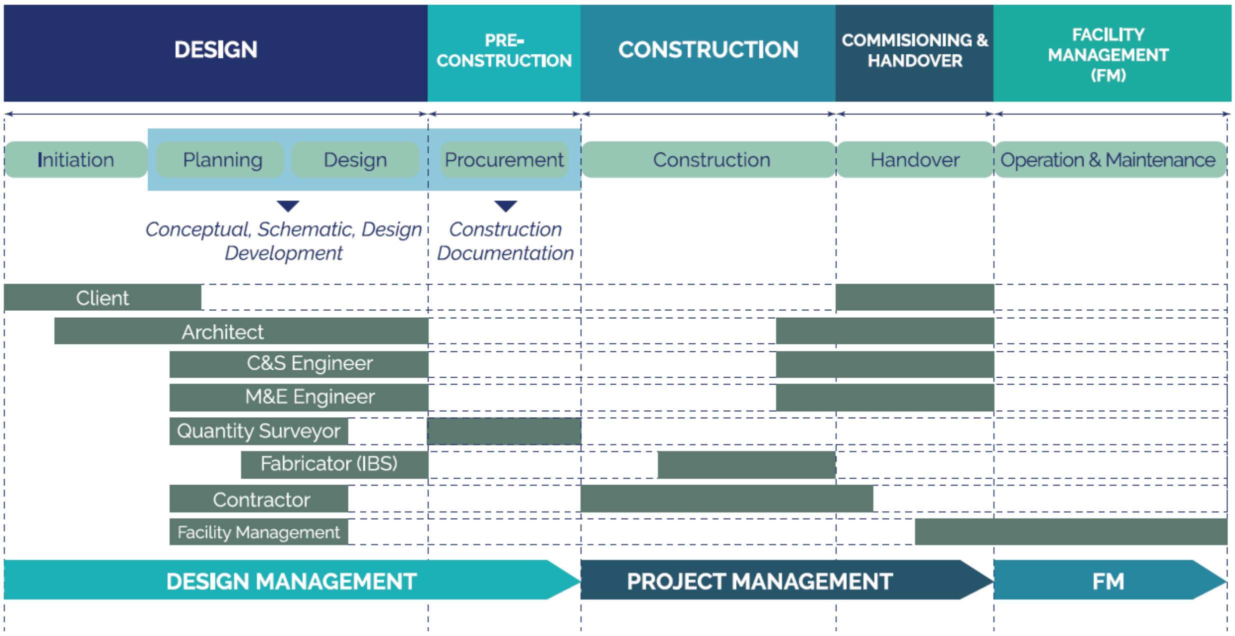
Table 3. A summary of construction projects applying DfMA principles

| Principle | Project type | Related components | DfMA strategies |
|---|---|---|---|
| Gerth et al. (2013) | four-storey houses | lightweight wall | 1. detail the joint design<br>2. minimise assembly operation |
| Kim et al. (2016) | highway bridge | precast beam | 1. minimise the number of parts<br>2. simplify the operation<br>3. choose of material and components |
| Chen and Lu (2018) | high-rise commercial building | curtain wall system | 1. coordinate the design of LED tubes and electric wires in the curtain wall system |
| Banks et al. (2018) | high-rise residential and commercial tower | modularised facade, MEP system, structure, etc | 1. coordinate the facade, MEP system, and structure |
| Peterseim et al. (2016) | new solar tower | modules of cable-stay solar tower | 1. select optimal components and materials |
| Ramaji et al. (2017) | student dormitory | modules | 1. optimise the size and geometry of parts |
| Machado et al. (2016) | student accommodation | fittings and furnishings | 1. implement BIM as a catalyst for a lean transformation, streamlining process and operations |

*(Source: Design for Manufacture and Assembly (DfMA) in Construction: the Old and the New, (Lu et al., 2021))*

## Integration of BIM in DfMA implementation

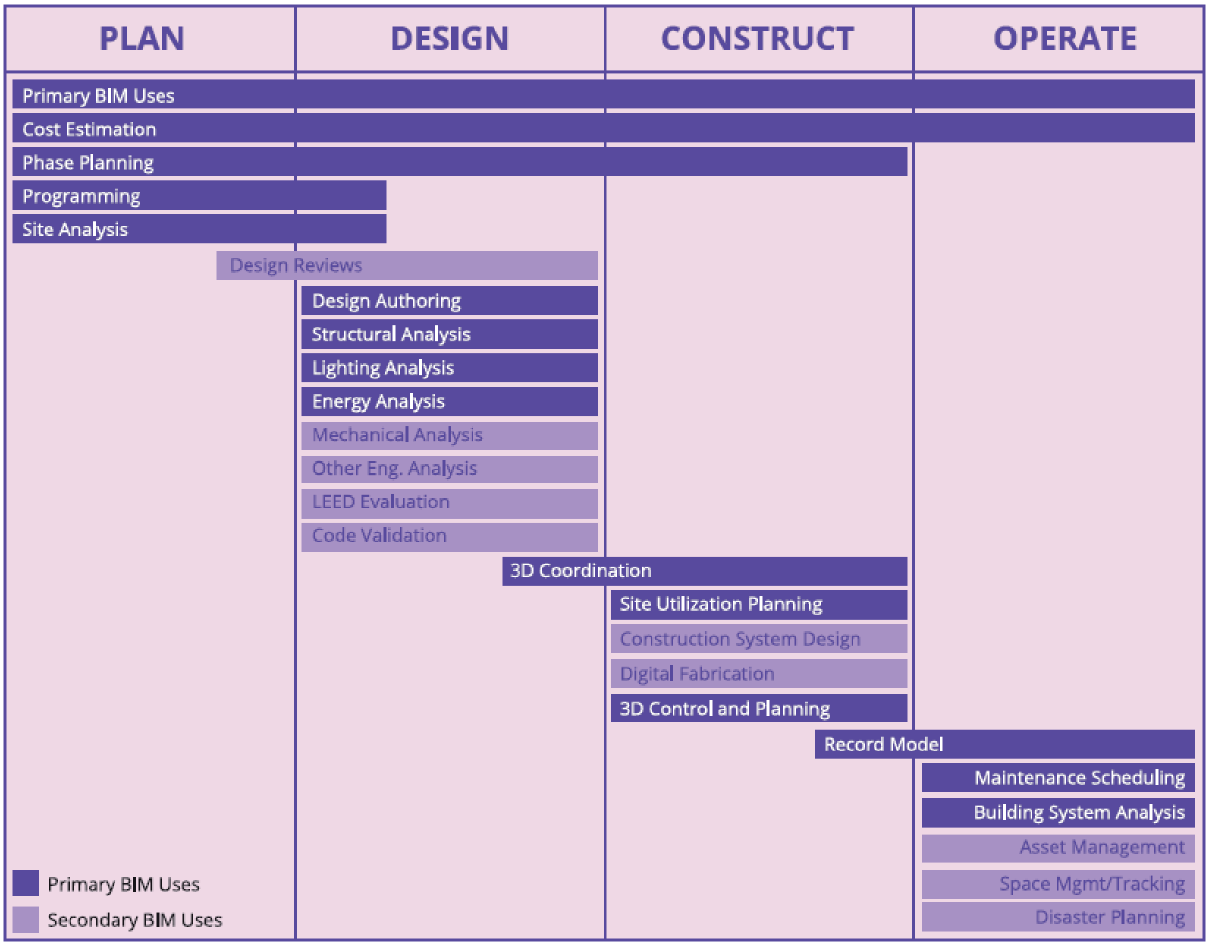
Building Information Modelling (BIM) and advanced modelling support the IBS process through synchronisation in design, manufacturing, and construction. The construction supply chain is complex and originates from a large number of participants of the project (organisational complexity), fragmentation, and ramifications in the delivery (operational complexity), which increase the challenges of building projects (technical complexity) and external environmental factors (contextual complexity) (Winch, 2010). In order to support the implementation of DfMA, cooperation among various parties through the implementation of integrated approach in the construction supply chain. Indeed, BIM-based technology supports the integration process. Basically, BIM, as collaborative work platform, is a major key enabler in improving collaboration and integration process of DfMA in the construction supply chain.




*(Source: Rethinking Affordable Housing in Malaysia (CIDB, 2019))*

**Figure 5. Proposed Framework for Integration of DfMA and BIM in the Construction Supply Chain**

Essentially, BIM Uses refer to how BIM can be utilised in a project. Specifically, BIM Use is defined as "a method of applying BIM during a facility's life-cycle to achieve one or more specific objectives". In this guide, BIM Uses have been referred to as the "Penn State BIM Execution Planning Guide". Therefore, a BEP is required to clearly state BIM Uses according to the project objectives. Figure 6 illustrates BIM Uses in the project life-cycle.




*(Source: BIM PROJECT GUIDE A Guide to Enabling BIM in Projects (CIDB, 2019))*

Figure 6. BIM Uses in project life-cycle

# ROLES AND RESPONSIBILITIES

## Developer

The developer shall define the project to be developed according to DfMA concept. This should be based on the specific objective e.g., costing, sales and marketing, return of investment.

The developer shall make use of BIM as a platform throughout the project. This will provide details of the relationships between various parties involved in the project.

The developer shall administer early involvement of all parties to fully utilise the potential for construction efficiencies through DfMA.

The developer is responsible for consulting the designers and main contractors to make sure health and safety matters are considered in all aspects.

To ensure that competent people are engaged to carry out the work, the developer will often engage consultant team and main contractor to manage a construction project.

## Designer/Consultant

To ensure the design and specification are consistent with the client's brief in terms of function, cost and sustainability.

To ensure the DfMA approach been considered and predetermined e.g., supply chain capability, site constraint and limitation, and logistic constraint.

To design and predetermine the construction process accordingly e.g., crane capacity, load of precast component, and sequence of works.

For a reasonably practicable design, it is pertinent to ensure that precast concrete elements and supporting structures are able to resist any reasonably foreseeable static, dynamic and impact loads. Appropriate safety factor needs to be applied when specifying any cast-in components that may be used for lifting precast concrete elements.

Precast concrete works involving, but is not limited to, structural designer, as well as other people responsible for erection design and temporary works. For example:

- Designer of a system that provides safe temporary support of precast concrete elements until they are fully supported by the completed works.
- Designer who contributes to the development of a safe system of work for erecting precast or tilt panel concrete elements.
- Economical design utilising standardised concept but not limiting any creativity in using suitable systems with upfront coordination thoroughly carried out with all trades.

## Manufacturer

Precast manufacturer involved in the design, transport and erection processes should work together to plan the intended construction and erection sequences before manufacturing the precast concrete elements.

The manufacturer must provide adequate information and any potential issues about the purpose for which the elements were manufactured, and any particular conditions related to their use.
As part of their internal quality assurance processes, manufacturers must carry out whatever tests they consider appropriate to meet their duty. A competent construction personnel must take part in the inspection for quality assurance.

The precast manufacturer needs to know the client's requirements. The main contractor gives the precast manufacturer all the relevant drawings, specifications and work programme. These include any amendments, notices to tenderers, agreed variations and all other information.

The precast manufacturer will then manufacture the precast concrete element once a competent person has approved the shop drawings.

The precast manufacturer:

- Confirm the appropriate concrete strength is achieved before demoulding and lifting.
- Ensures all lifting anchors (including those with special designs) have been installed in
- accordance with the manufacturer's installation instructions and in compliance with the approved shop drawings.
- Determines and ensures safe lifting and handling of precast concrete elements in the precast yard.
- Provides relevant paperwork to the main contractor prior to the precast concrete element leaving the precast yard or offloaded at site; this may include a Manufacturer's Statement of Compliance.

## Contractor

Managing a construction project and responsible for on-site coordination and monitoring and liaising with key parties during construction.

Contractor's role includes:

- Sharing information about the site and a proper planning.
- Reviewing site-specific documentation, such as shop drawings.
- Making sure that adequate training and communication practices are in place.
- Ensuring that health and safety procedures or processes are in place, including for emergency scenarios.

- Planning all aspects of the site work to ensure deliveries, handling and temporary works are carried out safely.
- Advising sub-contractors of specific requirements for handling, transport, and erection
- Ensuring that sub-contractors develop and put in place safe work practices.
- Consulting and coordinating with designers, precast concrete manufacturers, transport contractors and crane contracting businesses throughout the duration of the project.

A GUIDE TO DESIGN FOR MANUFACTURING AND ASSEMBLY (DfMA) IN PRECAST CONCRETE SYSTEM

# DESIGN FOR MANUFACTURING AND ASSEMBLY (DfMA) FOR PRECAST CONCRETE SYSTEM

## Overview

In developing a building using DfMA concept, the functional consideration, building aesthetics and design approach must first be understood before conceptual determination and commencing design development to meet the project specifications.

The use of BIM in DfMA should be implemented from 2D until 7D in order to fully utilise the DfMA concept. In general, 2D construction model constitutes in a simple x-axis and y-axis. 3D represents the 3-dimensional geographical structures of a building, which is the X-axis, the Y-axis, and the Z-axis of a building. It is also referred to as a coordinated model. 4D helps in planning the building site properly, including the schedule of all the construction stages. 5D BIM modelling is to integrate cost, schedule, and design in a 3D output. This model is charged with forecasting/predicting the flow of finance for a project and visualising the progress they have made concerning the project. 6D BIM involves the addition of other relevant information that supports the facility' management and operation in the hope that it will bring about a better business outcome. 7D BIM helps to monitor the management of the facility or asset right from the design stage to the demolition stage.

The structural design must be coordinated with the specification for precast components, in reference to Specification for the Design, Manufacture & Construction of Precast Concrete Structures (CREAM). In addition, the connections design should adopt high degree of component repetitions with optimal standardisation as this can ease site assembly work. Higher productivity can be achieved through design standardisation in component type, as indicated in IBS catalogue for precast concrete building system (CIDB,2017).

In the early concept design stage, architectural design must consider few aspects as mentioned below in order to accomplish the DfMA concept. In the manufacturing phase, this guide shows the types of production and typical production process. Meanwhile in assembly phase, this guide will emphasise on the physical works involved in handling the precast components.

# The DfMA process for precast concrete system

Design Consideration

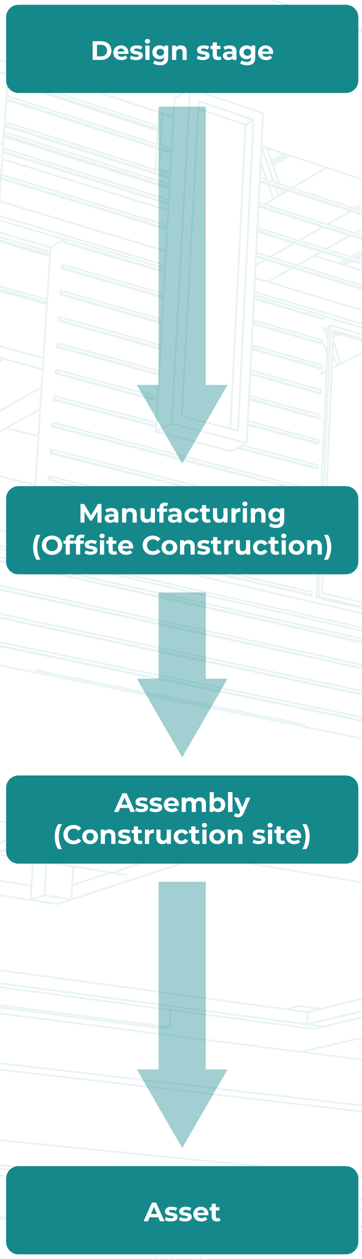
- Standardisation
- Simplification
- Modularity
- Flexibility
- BIM Integration

Manufacturing

- Production

Assembly

- Transportation
- Lifting
- Installation
- Quality assurance & Quality control



# PART 1: Design Consideration

## 1.1 Standardisation

The use of manufactured construction is needed to accelerate the construction process. This leads to dependability on the principle of standardisation and the principle of dimensional co-ordination, see example for DeLIGHT Homes (Figure 7).

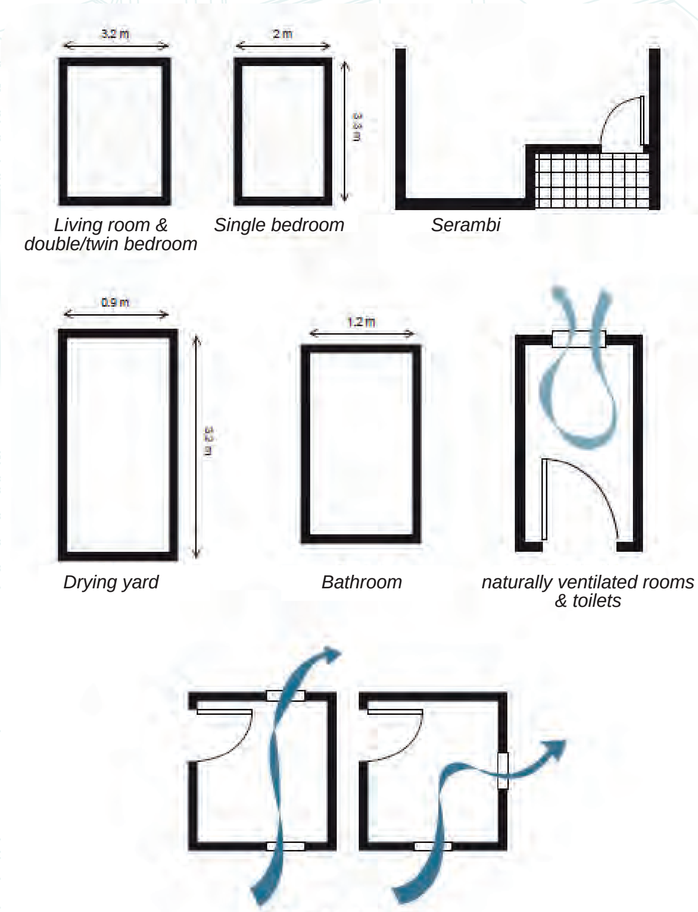



**Figure 7. DeLIGHT Homes space consideration**

The implementation of guideline, rules, and specification for repeated use, aimed at achieving optimum degree of order or uniformity to maximise the use of moulds. Standardisation can also offer a solution for any coordination problem.

## 1.2 Simplification

The aim of simplification in design is to make sure that there will be minimal complication during fabrication as well to provide ease of orientation, handling and assembly of components during assembly phase. This can be achieved by making sure that the size and weight of components are easy to handle. An example is the use of precast components in DeLIGHT Homes and D3 as shown in Figure 8.

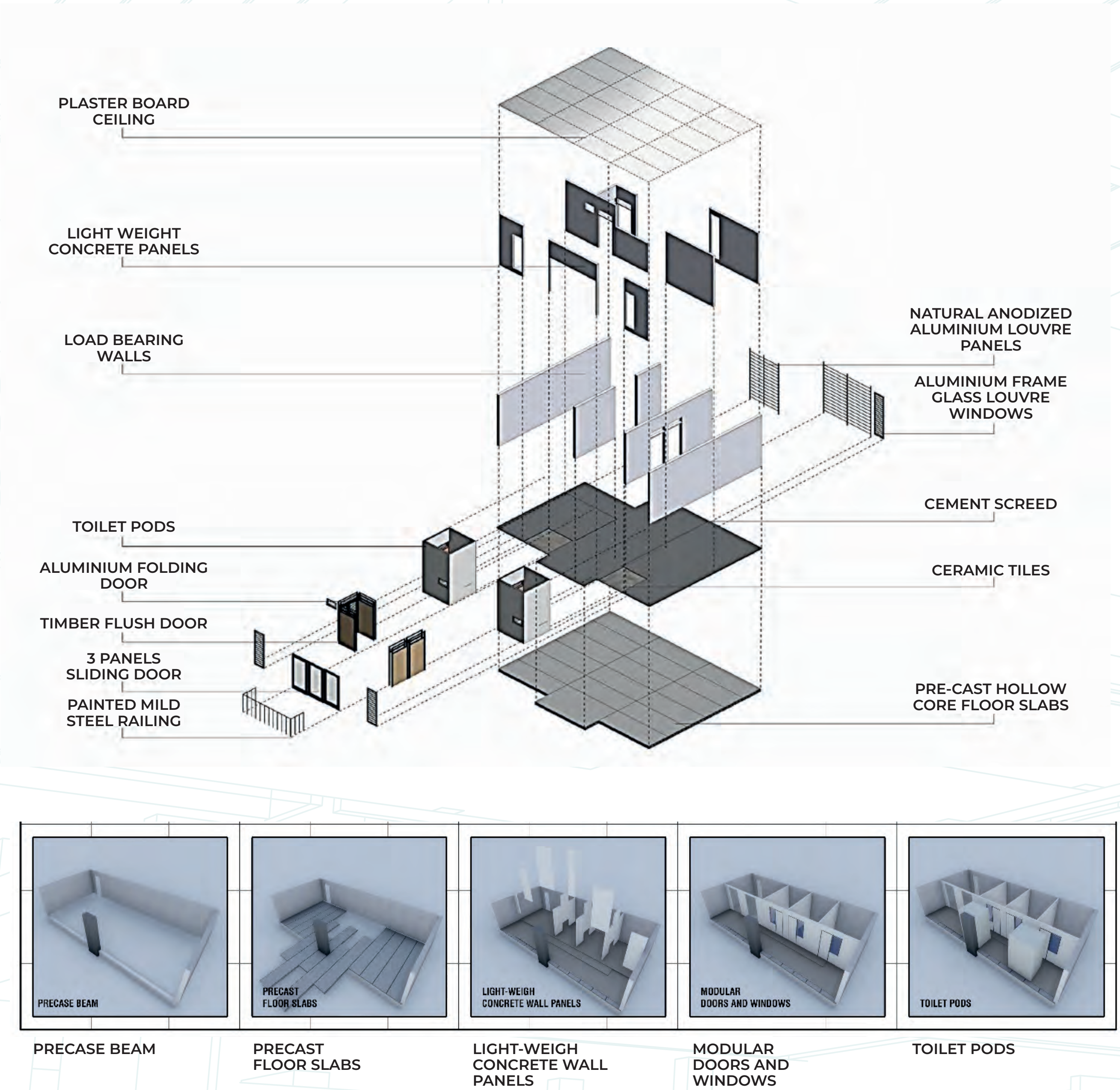



Figure 8. DeLIGHT Homes and D3 precast component

Besides that, Mechanical, Electrical and Plumbing (MEP) works in DeLIGHT Homes also took into consideration the aspect of simplification as shown in Figure 9.

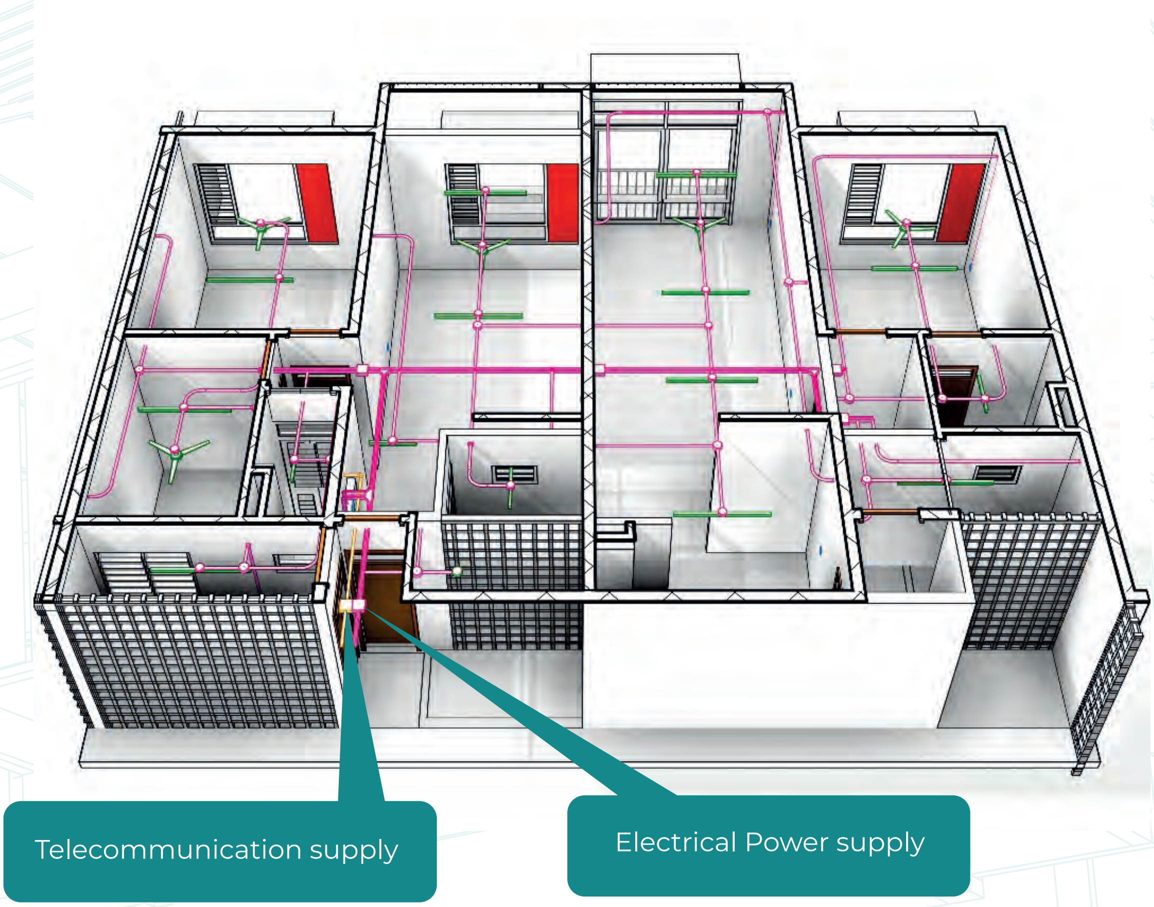


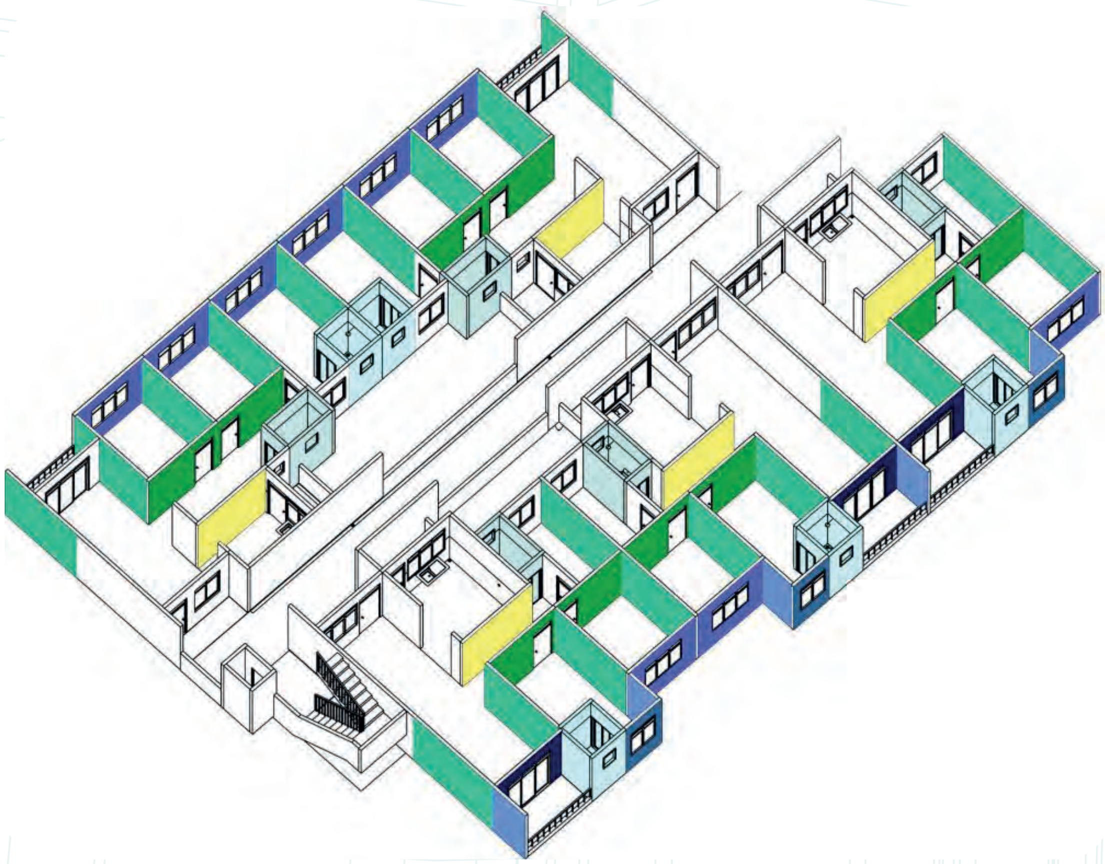

Figure 9. Electrical design in DeLIGHT Homes

## 1.3 Modularity

Consideration in using modular designs can offer benefit through reduction of time and costs due to simplified design and assembly. DeLIGHT Homes units are designed in such a way that allows them to be modularised. Modularity allows standard sections to be fabricated off-site while the main structure is being simultaneously erected at the site, thus speeding up the whole construction process as shown in Figure 10.


Figure 10. DeLIGHT Homes modular units

The modularity in IHSAN Homes allows it to be fully prefabricated within an economy of scale. The strategy for the development is to ensure the design is ready for the adoption of faster design coordination as shown in Figure 11.



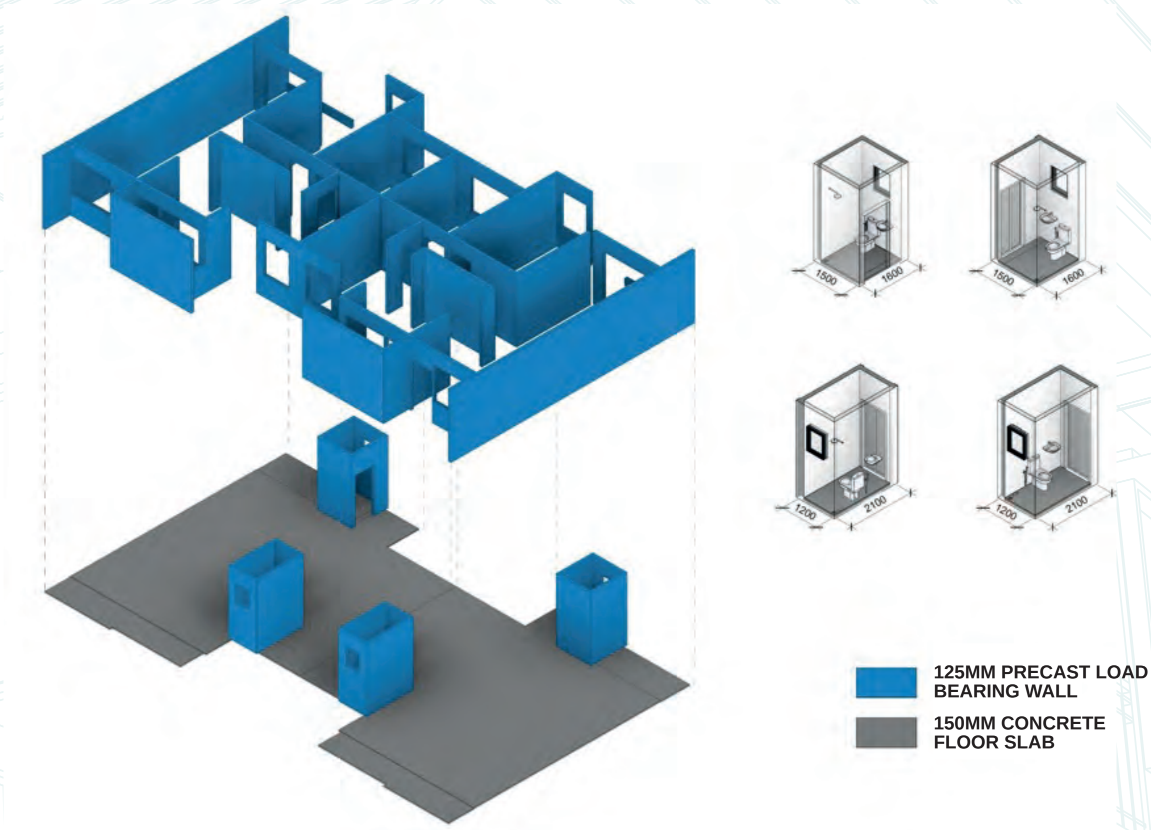



Figure 11. IHSAN Homes modular concept

## 1.4 Flexibility

Design with a predetermined assembly technique in mind can lead to reduced time and costs during assembly process. Not over-specifying tolerances or surface finish can benefit in reduced time and costs, and ease manufacturing works.

D3 combines an open plan design concept with the use of lightweight wall to produce a variety of housing design options that meet possible user requirements. With the built-in architectural flexibility, D3 basic dwelling unit can be divided into more than one plan, in which the occupant can choose the floor plan they want to live before moving in, thereby achieving harmony between the basic structure and the various sizes of dwellings in the long term.


Figure 12. D3 open plan concept

## 1.5 BIM Integration

The importance of design stage in DfMA is to predetermine the design for all disciplines to avoid any discrepancy so that the next stage can carry on without any problems. Thus, BIM is important to focus on coordination and communication among members of the project. Example of IHSAN Homes MEP integration is shown in Figure 13.

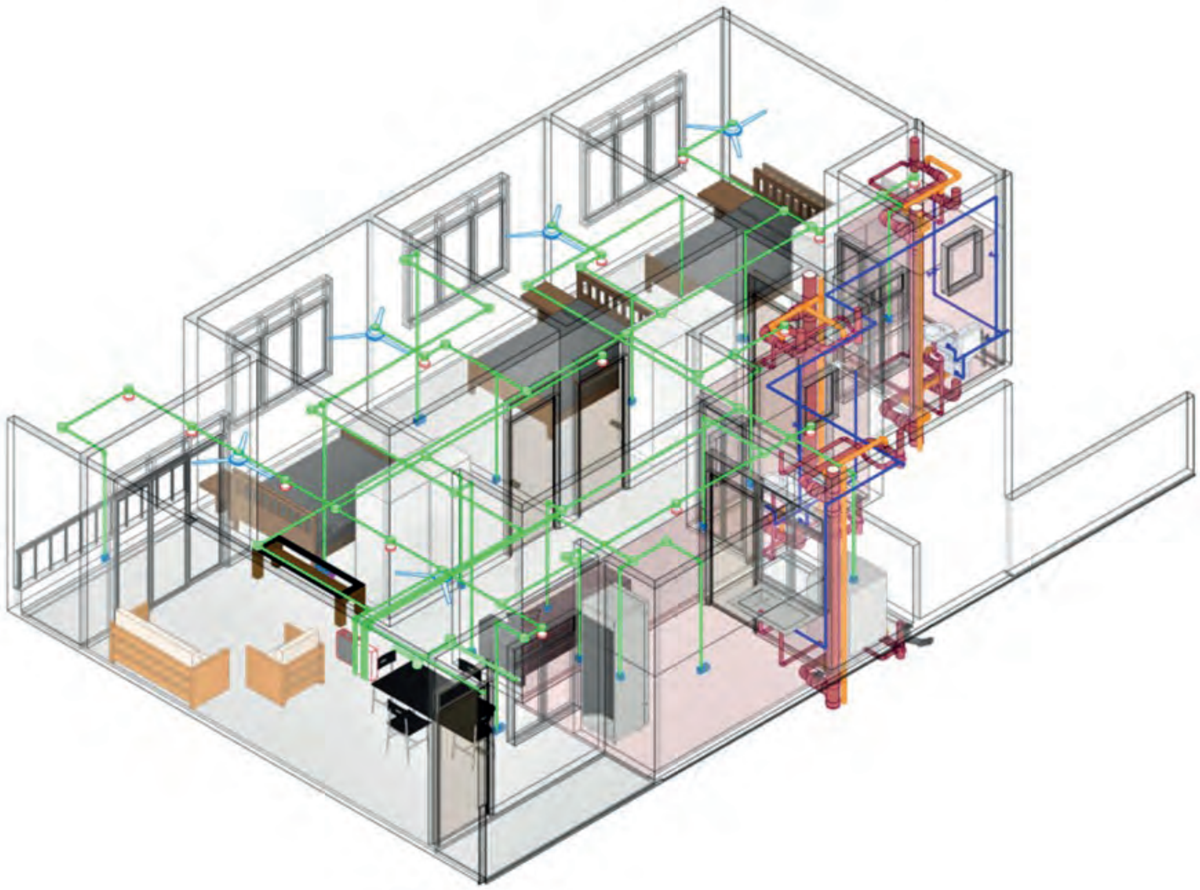


**Figure 13. IHSAN Homes MEP layout.**

An analysis in BIM is to identify and resolve major clashes by utilising clash detection tools through combined model from all disciplines. This can avoid unnecessary re-work or any modification during manufacturing or assembly. Example on the use of clash detection in IHSAN Homes is shown in Figure 14.

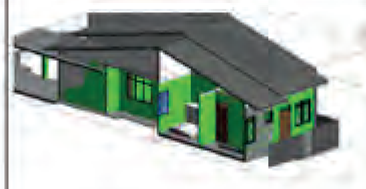
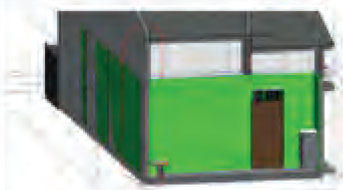
| Issue No. | Location | Issue | Model Snapshot (Before) | Model Snapshot (After) | Attention to | Status | |
|---|---|---|---|---|---|---|---|
| | | | | | | Open | Closed |
| Terrace | | | | | | | |
| xx14 | Terrace All Unit | Overlapping Wall element in the model |  | | NSP | 08/09/2020 | |
| xx15 | Terrace All Unit | Archi elements (Roof) in the atructure model |  | | NSP | 08/09/2020 | |
| xx16 | Terrace All Unit | Wall opening mismatch with archi windows / doors |  | | NSP | 08/09/2020 | |
| xx17 | Terrace All Unit | Wall thinkness missmatch |  | | NSP | 08/09/2020 | |

**Figure 14. Clash report in IHSAN Homes during design stage**

# PART 2: Manufacturing

## 2.1 Production

### Static Production

Static production refers to the production of DfMA at a centralised location with materials, services, and employees brought in. Although a steel-framed jig is commonly utilised to ensure the accuracy of the vertical placement of the walls, the geometry of the DfMA must be properly controlled using manual methods.

Importantly, the area surrounding the DfMA must be large enough to accommodate temporary storage of materials and prefinished components such as windows that are handled or lifted by an overhead crane. The availability of employees to complete the essential specialised activities within the required time determines the construction rate. As a result, the process may be slow, but the critical path is not dependent on the execution of any single task in this situation. When the DfMA is finished, it is hoisted using an overhead crane for storage or transferred to the project site.

*(Source : Satow (2013))*

**Figure 15. Example of Static Production**

## Linear production

Linear production refers to a consecutive manufacturing process that is carried out in a definite number of distinct stages, similar to an automotive production line. The DfMA 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 main difference between this and static production is that the DfMA are transferred between dedicated stations rather than the production teams needing to move from one component to another.

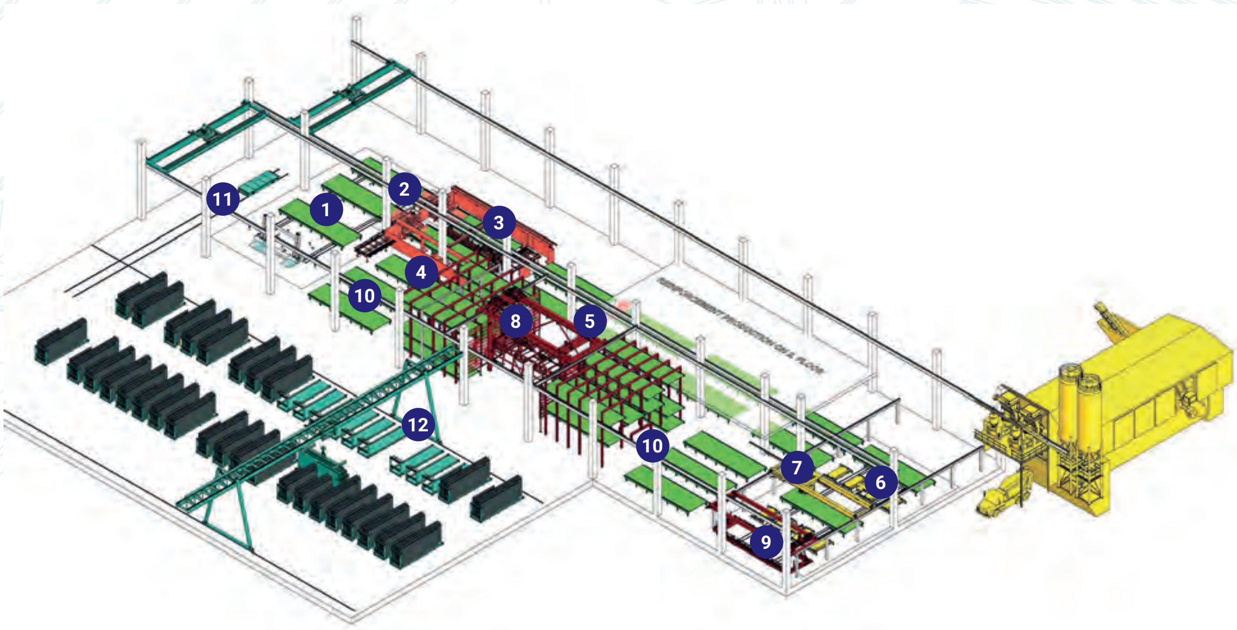
*(Source: Forta Pro)*

**Figure 16. Example of Linear Production Line**

## Semi-automated Linear Production

Modern semi-automated factories for modular production emulate the same concepts of non-automated lines, but with 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 panel type. Automated lines commonly include facilities for fabricating window and door openings (often by the incorporation of subassemblies) and installing insulation and inbuilt services such as cabling and telecoms. However, since bathroom pods are sometimes manufactured off-line or transported in, they do not normally feature automated systems for bathroom fit-out and installation of fitted furnishings. Furnishings is more difficult to automate and turn into a follow-on operation.

Therefore, semi-automated production lines tend to comprise of a highly automated series of operations requiring specialised equipment, followed by a series of relatively conventional manual operations.

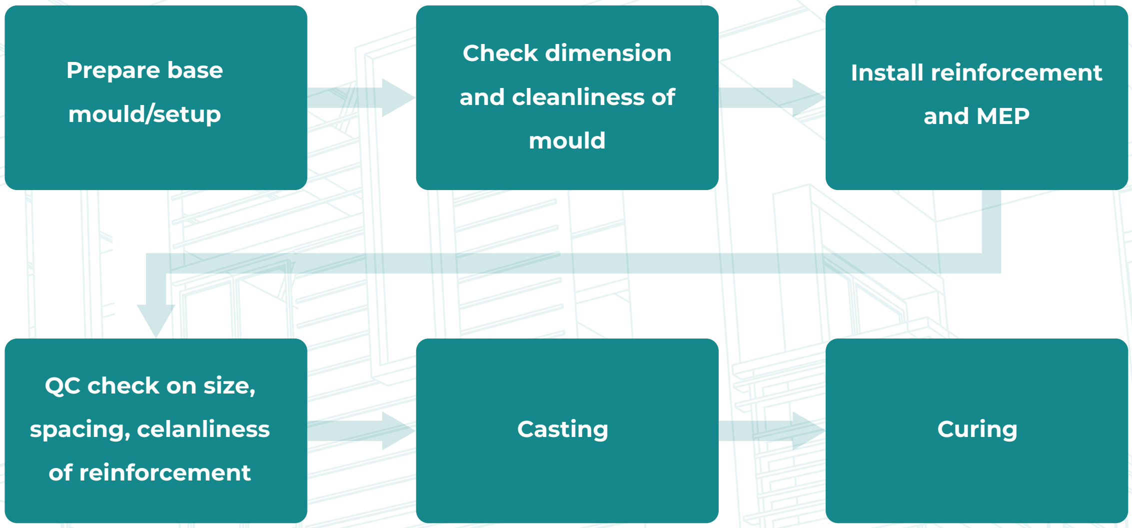


- 01 Pallet transport on roller conveyor and with transverse units
- 02 Cleaning machine for pallets
- 03 Shuttering robots
- 04 Cleaning machine for formwork elements
- 05 Lubrication machine for pallets
- 06 Concrete compaction with oscillating compressor
- 07 Bridge-design concreting apparatus
- 08 Pallet storage technology with storage and retrieval unit and curing chambers
- 09 Turning device
- 10 Tilting station
- 11 Carriage
- 12 Transport frame for concrete components (specialised machinery)
- 13 Circulation pallet

*(Source: Averman (2018))*

Figure 17. Example of semi-automated linear production

## Typical production process of prefabrication concrete



# PART 3: Assembly

## 3.1 Transportation

Before assembly can take place, it is important to take into consideration the transportation as stated below:

- Planning the delivery route
- Planning for contingencies
- Obtaining any permits needed
- Communicating with the supplier and delivery site
- Safely securing the load for transportation
- Transporting the precast concrete element from the precast yard to the delivery site.

The following factors need to be taken into consideration to ensure the stability of the load on the vehicle:

- Mass
- Mass distribution (that is, the location of the centre of mass)
- Height
- Width
- Length

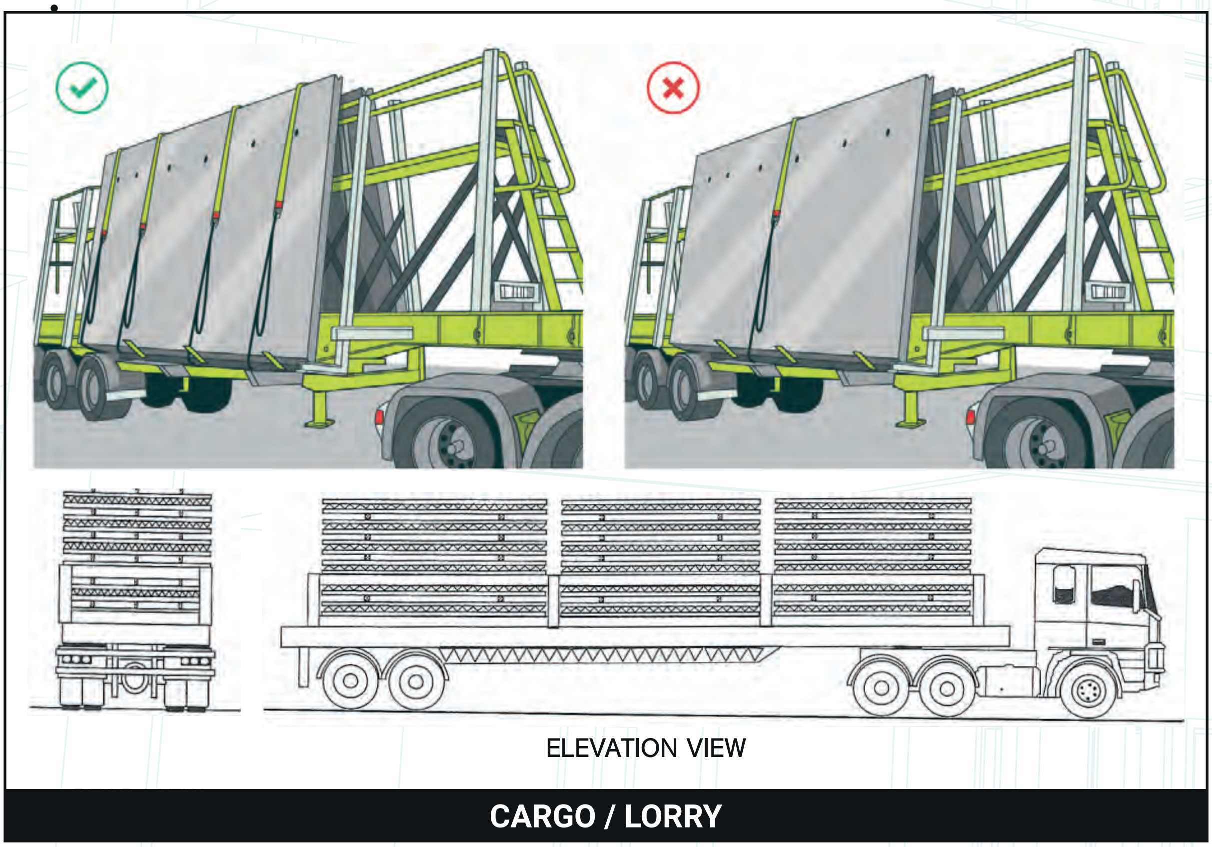



Figure 18. Transporting precast components stacked horizontally into a lorry

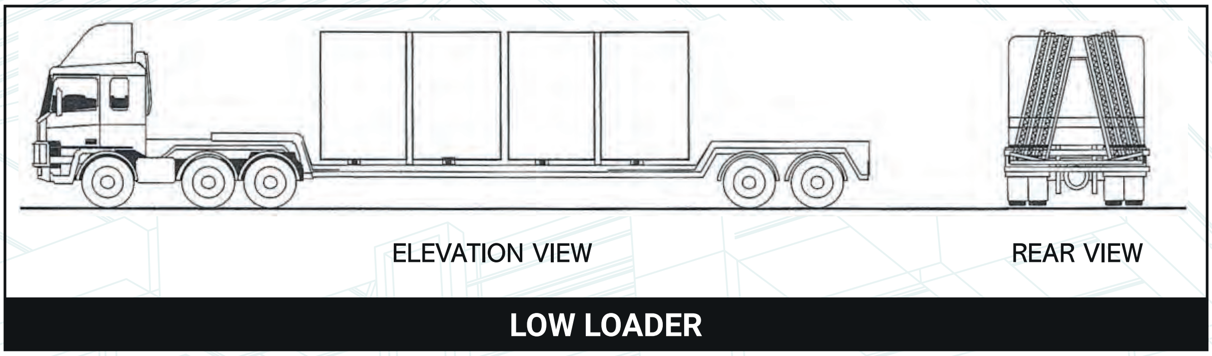



**Figure 19. Transporting precast components stacked in an A-frame position into a low loader**

Workers handling precast concrete are required to be adequately trained or supervised to carry out all required tasks. This may include:

- Slinging
- Using any lifting devices (e.g., gantry cranes)
- Moving precast concrete elements without causing harm or injury to themselves or others.

The handling process depends on the:

- Position of the casting mould (i.e., vertical vs. horizontal casting)
- Minimum concrete strength for demoulding, delivery, and erection
- Adequacy of the design reinforcement to resist handling stresses
- Size and weight of the precast concrete element
- Number, size and location of lifting points and type of anchors
- Lifting method, type of lifting equipment and crane capacity
- Support points for storage and transportation.

## 3.2 Storage/stacking

Generally, the sequence of erection should be in such a way that storage and multiple handling of precast components at site are minimised or avoided if possible.

The required work method must be clearly documented.

The general requirements for handling and storage of elements at site are as follows:

a) Precast components must only be stored in a position approved by the project design engineer;
b) Ground conditions must be checked to ensure that the mass of the element can be supported;
c) Where an element is to be stored on a suspended floor slab, approval and written instructions must be obtained from the project design engineer before proceeding;
d) Wall panels may be stored in a suitable 'A–frame' or stood and braced in a vertical position. Bracing should be in accordance with the general requirements of this code; and

e) Wall panels may only be stored horizontally in accordance with a written instruction from the erection design engineer or project design engineer.

Wall panels should preferably be stored in a vertical position. Where edge-lifted panels are horizontally stored, they must be placed is such a way that reinforcement component around lifting edge inserts is correctly orientated for re–lifting.

Precast concrete components should be separated by suitable dunnage to:

- Keep elements off the ground.
- Allow access between units to fit lifting forks or strops.
- Prevent damage from concrete-to-concrete contact.

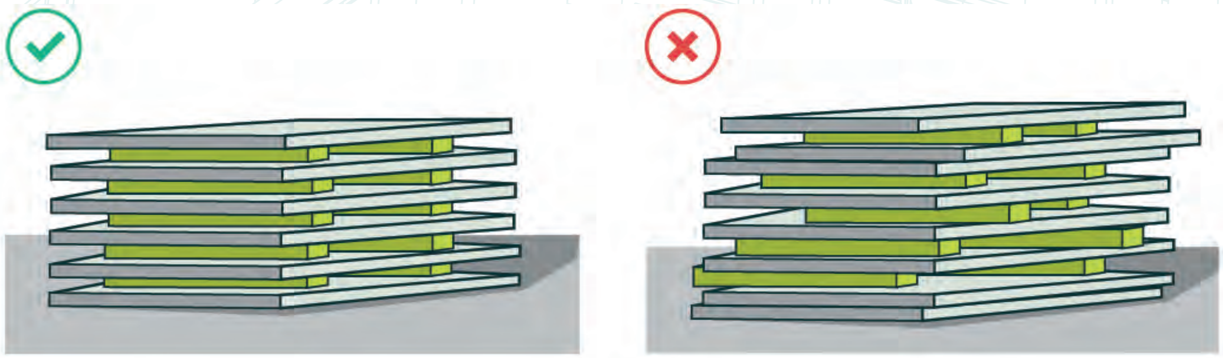


Figure 20. Proper stacking for precast panel

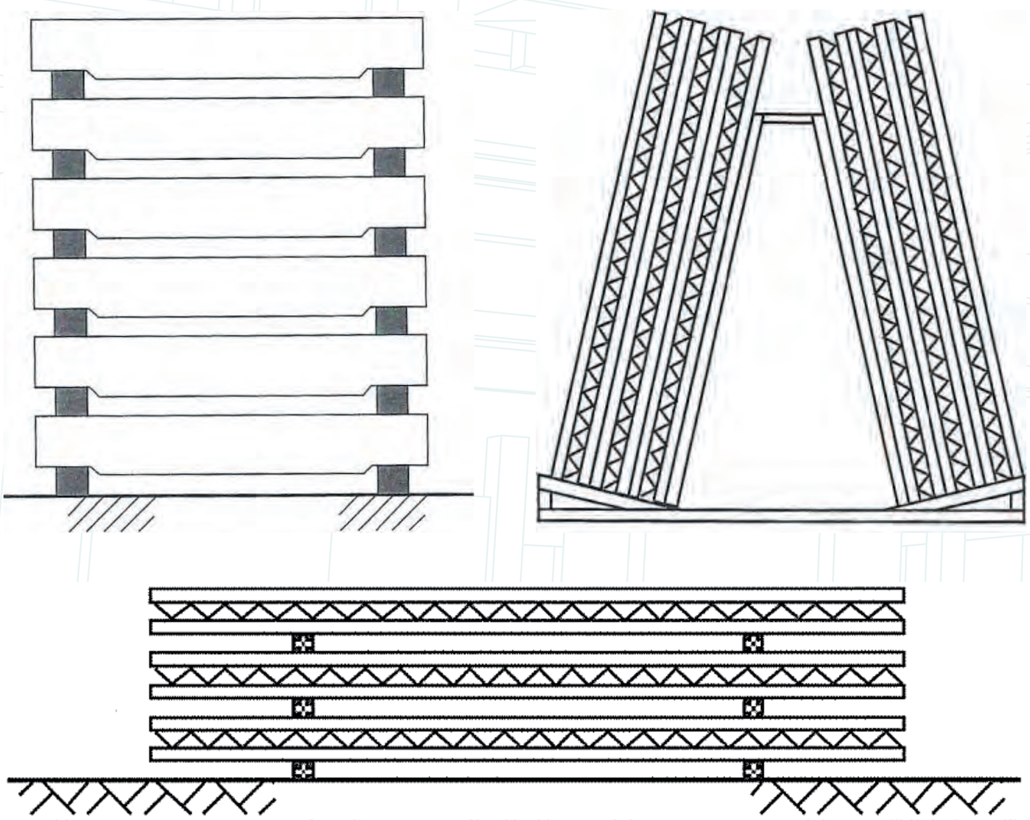


Figure 21. Proper storage for precast component

## 3.3 Lifting

Before attaching lifting equipment to a precast concrete element, check the lifting anchors to ensure that they are undamaged and compatible with the proposed lifting equipment.

The correct lifting equipment should be on-site to unload precast concrete elements. Equipment should be inspected before use.

A tag line (see Figure 22) is ideal for guiding precast concrete elements during light winds. In any case of strong wind that a worker needs to lean and lug then the lifting should not proceed.

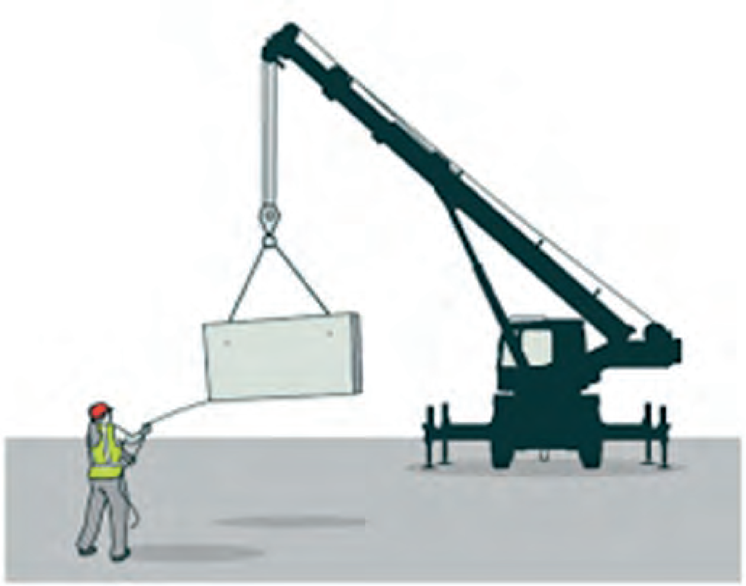


**Figure 22. Lifting precast component**

Take special care with rigging arrangements where load equalisation measures are required. Decide whether to equalise loads between lifting points on precast concrete elements such as beams or flat slabs.

To provide stability, the precast concrete element centre of gravity should be below the lifting points, as shown in Figure 26.

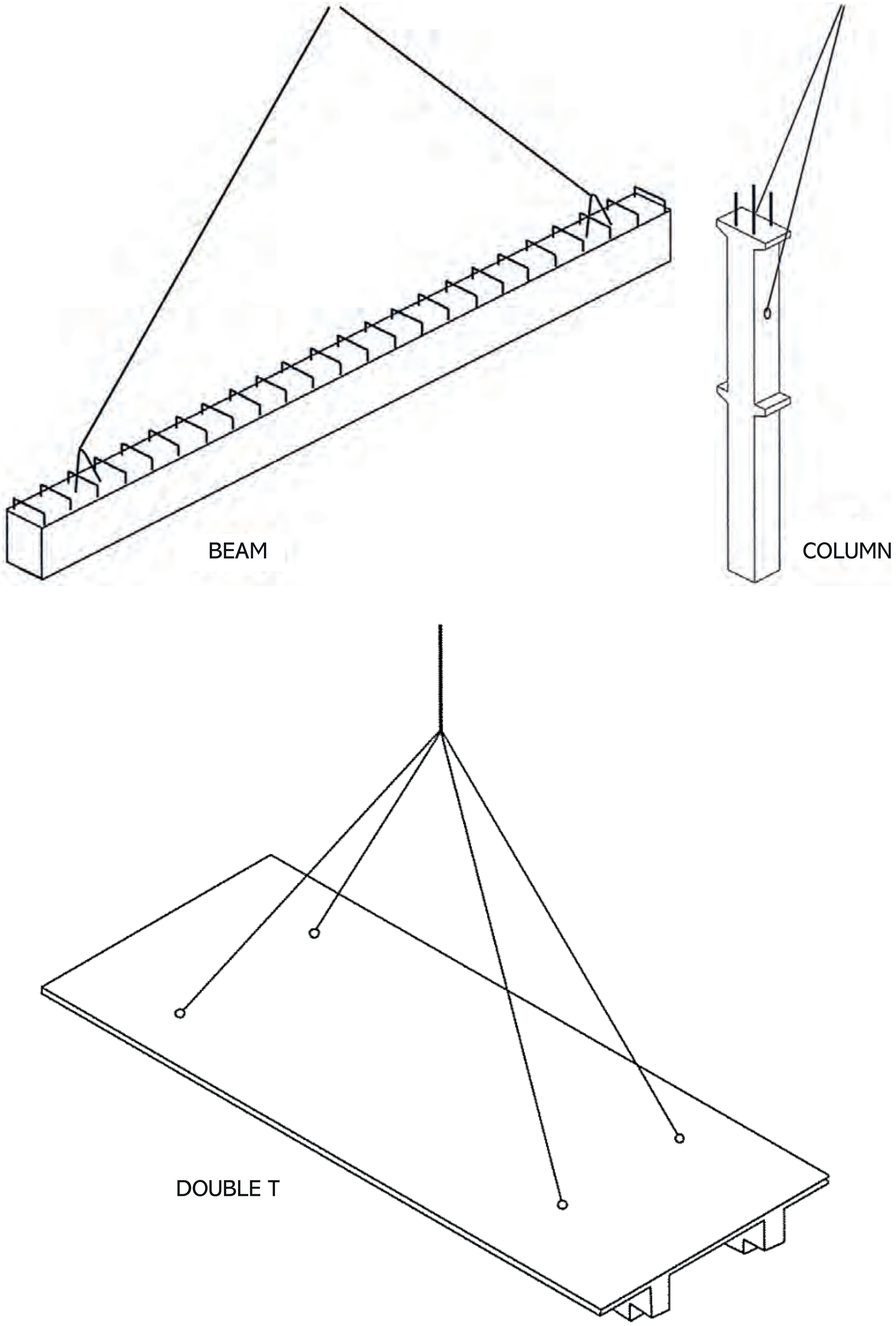



Figure 23. Lifting of precast beam, column and slab (CIS 9: CIDB)

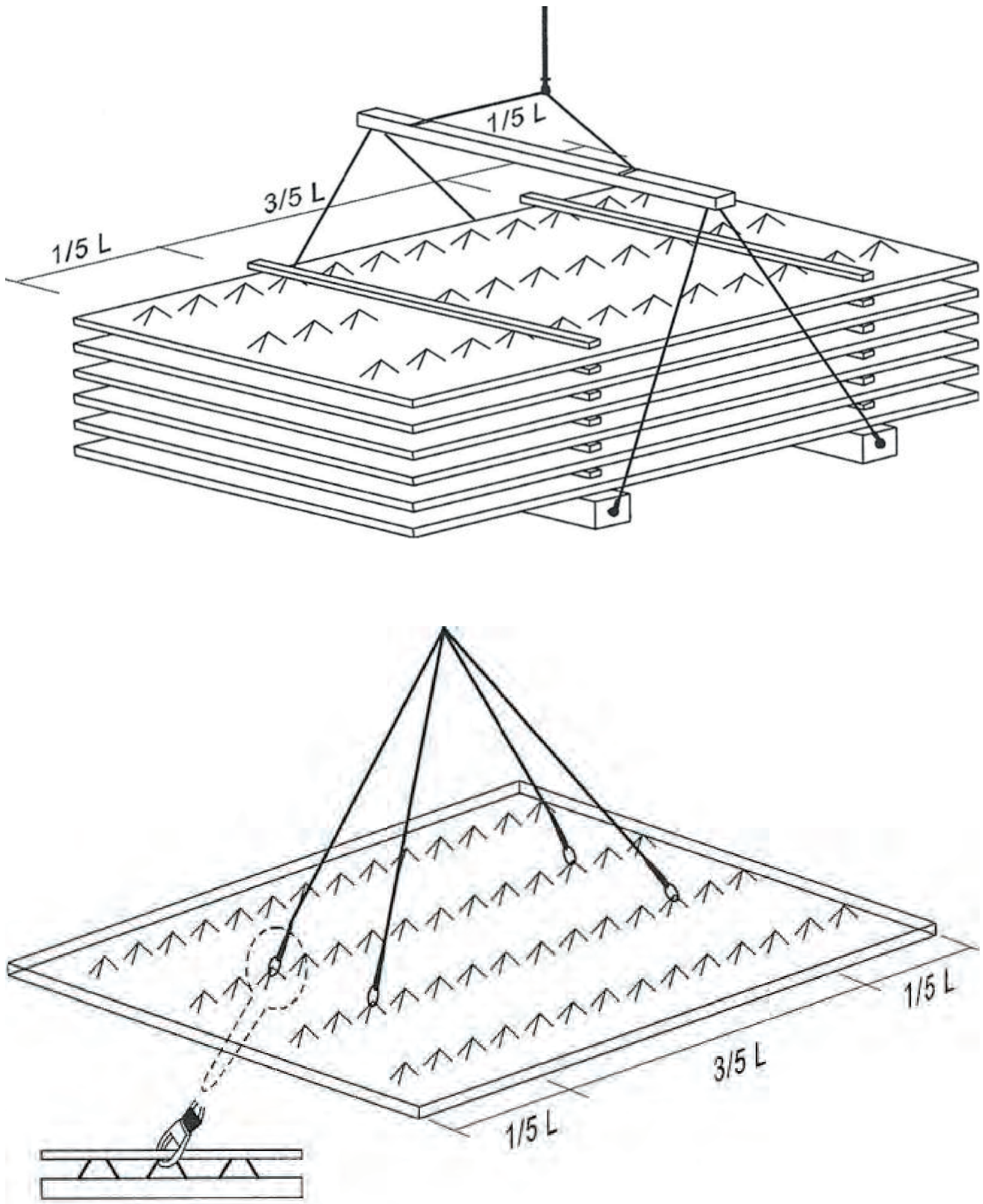
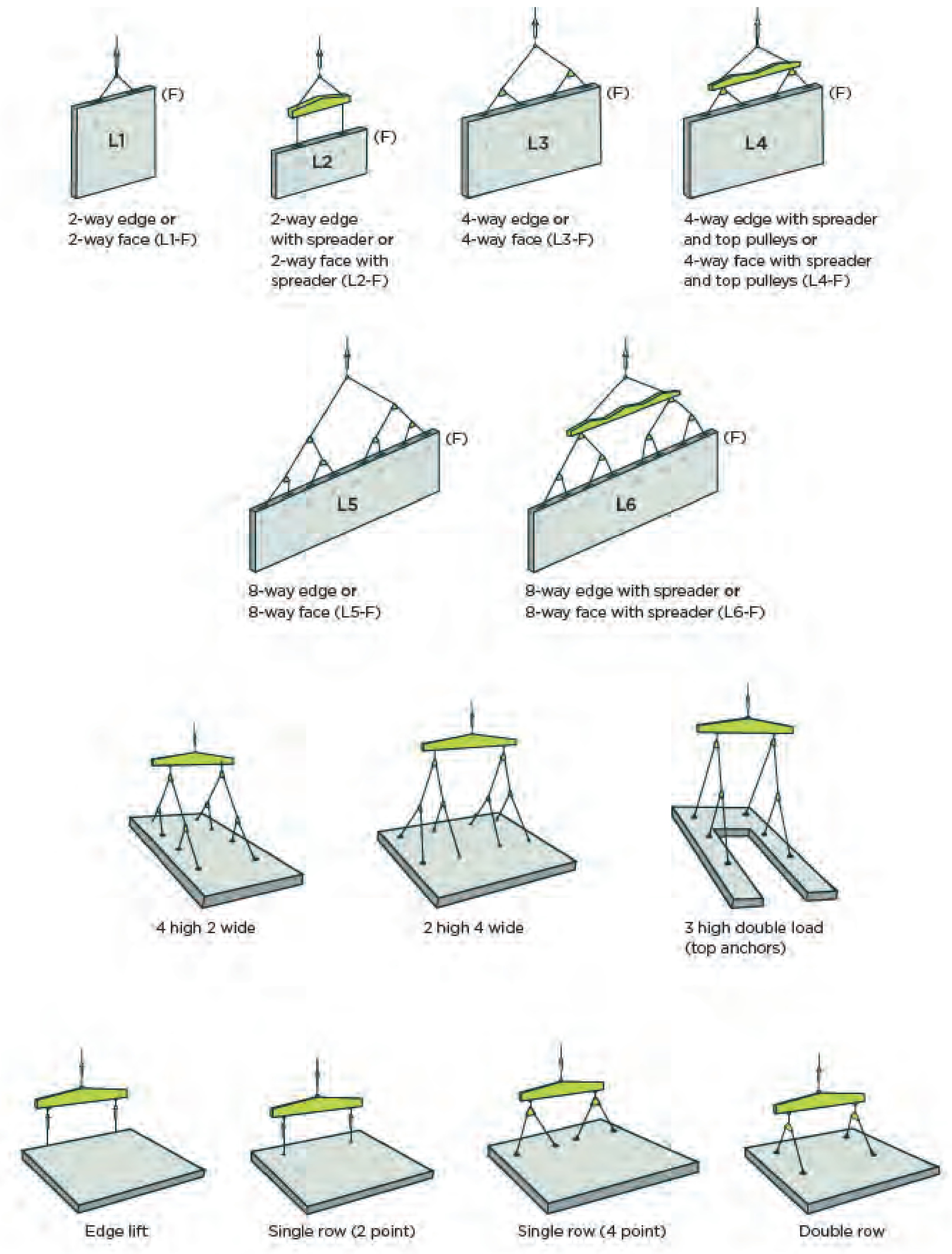
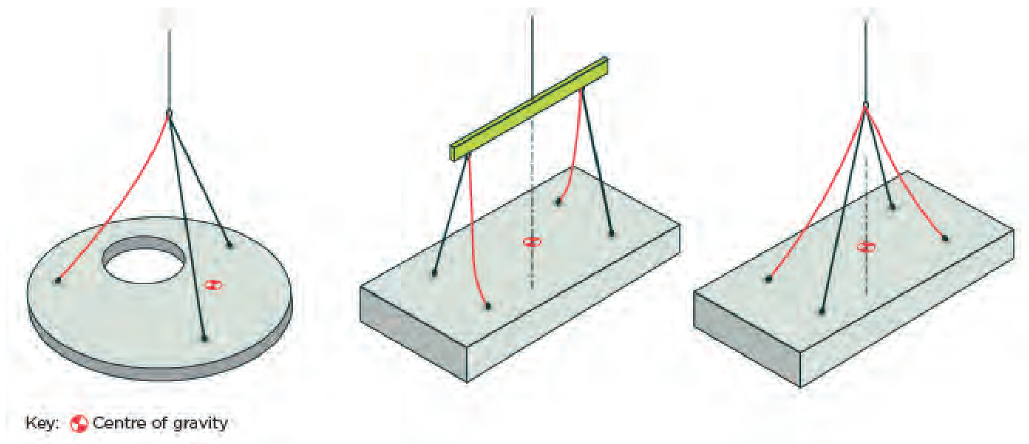


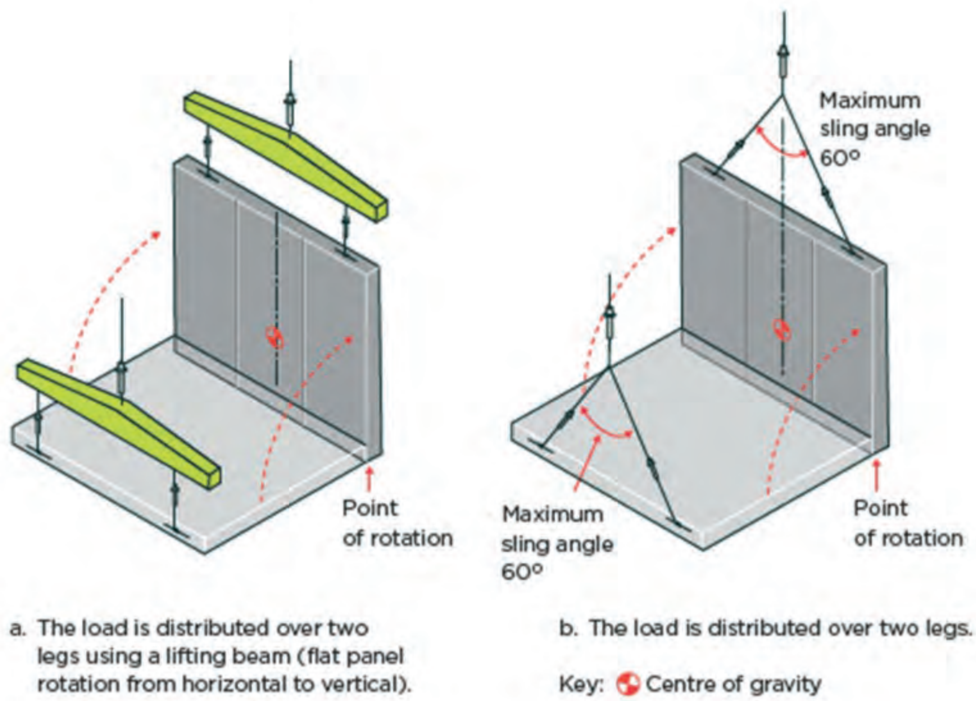

Figure 24. Lifting of multiple and single precast half slab (CIS 9: CIDB)




*(Source: Safe work with precast concrete, Worksafe New Zealand (2018))*

**Figure 25. Example of lifting precast panel using spreader**




*(Source: Safe work with precast concrete, WorkSafe New Zealand (2018))*

Figure 26. Example of lifting precast component by considering the centre of gravity

## 3.4 Installation

The installation workers need to be briefed on how the precast concrete elements will be handled on-site, including special rigging requirements, temporary propping requirements, and any handling restrictions.

Planning for safe installation of precast concrete elements should include, but not be limited to:

- Hazards, risks, and control measures
- Method of statement
- Casting and delivery sequence
- Erection sequence
- Lifting plan
- Site limitations and features.
- Compaction of site surface areas
- Precast concrete element sizes
- Crane size, configuration, mobility, and access
- Working radius of the crane (shown on a crane layout drawing)
- Sign-off for shore loading by a competent person.
- Visual inspection of rigging and all associated equipment
- Height access equipment appropriates to the construction methods
- Structural stability during erection, including propping and bracing requirements (e.g., length)
- Transport requirements.

### What to consider

Erection plan coverage

- Does the erection plan address all aspects of the erection procedure?

Site conditions

- Is the site clear and safe for all vehicles (including counterweight trucks) and crane/s access and assembly?
- Is there a compacted hard-fill ramp with a suitable gradient?
- Is a traffic management plan in place?
- Are the weather conditions suitable for erection?

Crane operating area

- Has the crane operating area been cleared to provide enough room for swing while lifting?
- Can the crane platform support the loads exerted by the crane during operation?
- Has an exclusion zone been set up?

Supports, props, braces, and restraints.

- Are support methods, including falsework has been design.
- Is there enough clear space to safely prop and brace precast concrete elements?
- Have locating dowels/other horizontal restraints been fitted before final placement of elements?
- Are the recommended braces fitted to the precast concrete elements?
- Have brace foundations reached their required strength before precast concrete panels are erected?
- If strong backs are required, are they correctly installed?

Other

- Are control measures in place for safely working at height?
- Are there enough properly trained erection crew members?
- Is a Manufacturer's Statement of Compliance required?

## Props

A prop, whether custom-made or generic, is used to temporarily support a precast concrete element. Props are commonly used to support floors and beams.

Props may be needed to:

- Provide temporary gravity load support during construction.
- Reduce the self-weight deflection of precast concrete flooring systems while the cast-in-place topping concrete is poured and cured.
- Prevent torsional instability or rotation of beams loaded along one edge.
- Provide fine adjustment of the precast concrete element to the correct level while freeing the crane for the next lift.
- Support temporary construction loads that exceed the design capacity of any part of the structure.

Unless specifically noted otherwise, all temporary propping should:

- Be in place, adjusted to the correct levels allowing for any required cambers, and fully braced before beginning erection.
- Fully support all construction loads including the full self-weight of the completed floor system and possible local concentrations of load during construction.

Propping for beams should allow possible changes to the load distribution during the construction process.

Permanent grouting or mortar packing of precast concrete element support points needs care and supervision to ensure that the requirements for strength and durability are met.

## Braces

Braces are usually placed diagonally and firmly attached to provide stability and resist lateral loads. Lateral bracing is sometimes used to resist panel base movement, wind, and other lateral forces. Braces may take the form of proprietary props (often adjustable), scaffolding, or specially designed components. If braces are to be connected to piles, then the piles should be designed to ensure the loads can be safely transferred to the soil. The dimensions are designed to cater for the connection of all anchor points and appropriate edge distances.

Other engineered systems, such as screw anchors, are also available. Any proprietary system has to be designed to ensure the loads can be safely transferred to the soil.

Braces:

- May act in compression and in tension.
- May have flexible end connections to adjust to different angles.
- May or may not be adjustable in length.
- Are required to cope with cyclic loads.
- Are not generally used vertically.
- Prevent overturning and resist horizontal movement.

Braces should be designed, manufactured, inspected, and maintained to a recognised standard, as stated in CIS 23: 2018, CIDB.

Braces are commonly used when erecting precast concrete panels to resist wind and other loads until panels are permanently fixed. Adjustable props are another form of support, typically used to support beams and floors.

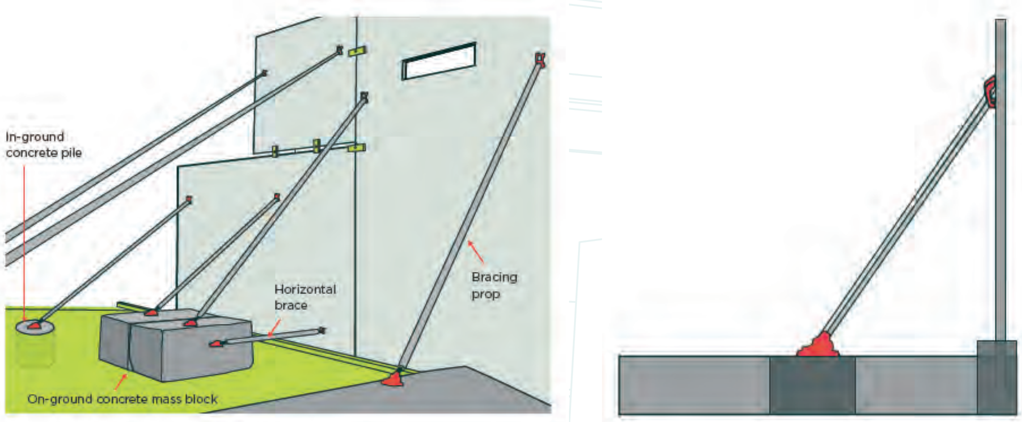



Figure 27. Example of using braces

## Levelling shims

Levelling shims carry the load of the precast concrete element that must be adequately supported to prevent movement until it is incorporated in the main structure.

Levelling shims are to be manufactured from a suitable durable material and shall have adequate strength to sustain the full imposed loads.

Note: Direct concrete to concrete, or concrete to steel bearing should be avoided unless some edge spalling and cracking is acceptable.

Shimming should be limited to a maximum thickness of 50 mm and a minimum width of 100 mm unless specifically designed otherwise. Where the total shim thickness is greater than 50 mm, extra care must be taken to ensure stability.

Shims should be located at least 300 mm in, from the ends of the element and bearing support, unless otherwise specified. This is particularly relevant for thin wall panels where edge breakout can occur if shims are placed too close to bottom corners (refer Figure 28).

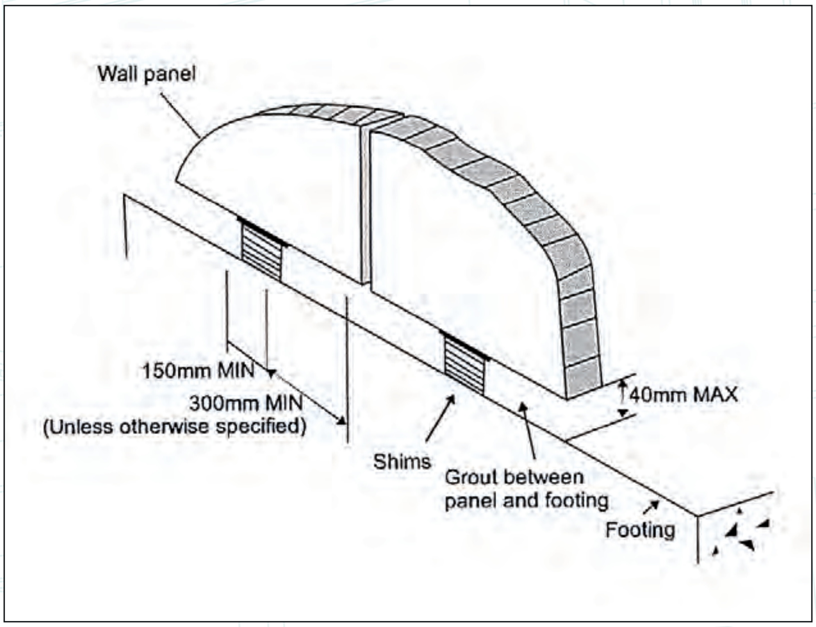



**Figure 28. Leveling shims**

Direct concrete-to-concrete, or concrete-to-steel bearing should be avoided unless some edge spalling and cracking is acceptable to the builder and project design engineer.

The gap between the bottom of the element and the footing must ultimately be grouted or dry packed, to transfer the load to the footings.

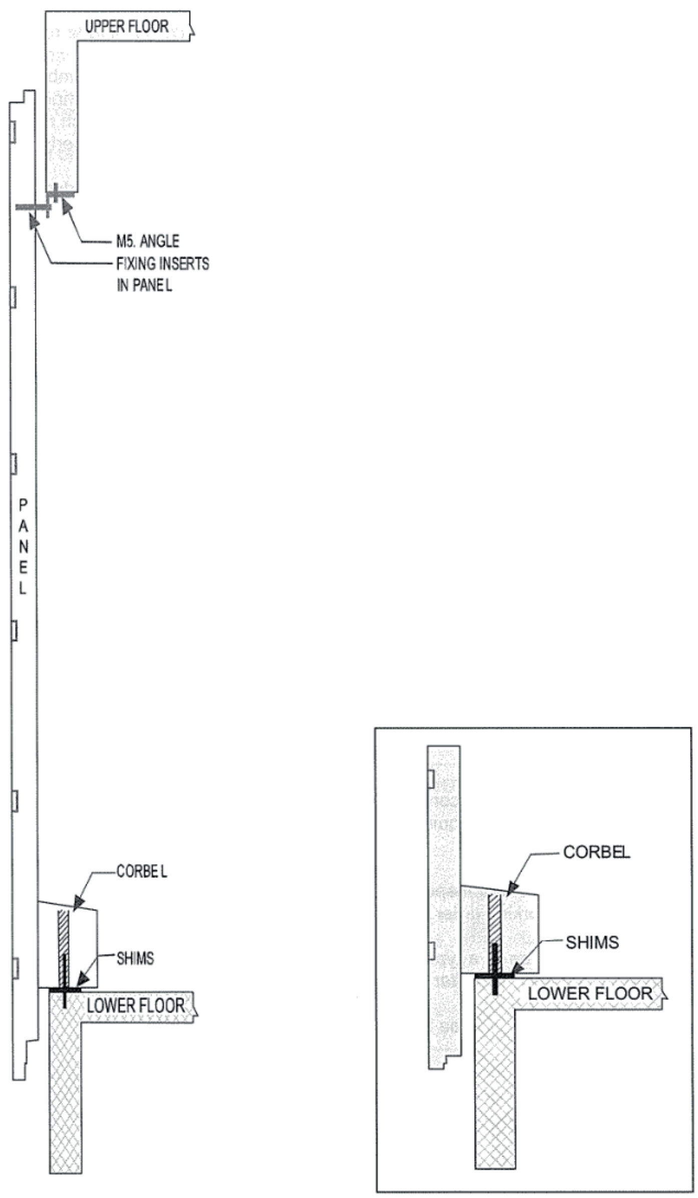



Figure 29. Section view of the use of shims

## Access and Egress

As part of the design review, the entire process of which the components are to be installed should be reviewed. This should also include how workers would gain access to and egress, this consideration should has been predetermined during early stage of the DfMA prosses.

Precast concrete members shall be erected according to pre-planned sequence. The erection plan is commonly prepared in the form of drawings hence it is important for structural stability and access to connections to be indicated at specific location. The erection sequence shall avoid multiple handling of elements. Finally, a trial erection operation should be considered to identify any unforeseen erection difficulties.

Likewise, any open area should be covered with a safety barricade to prevent workers from falling down (Figure 30). A demarcated egress should be provided as well to allow workers to exit the work area in case of an emergency.

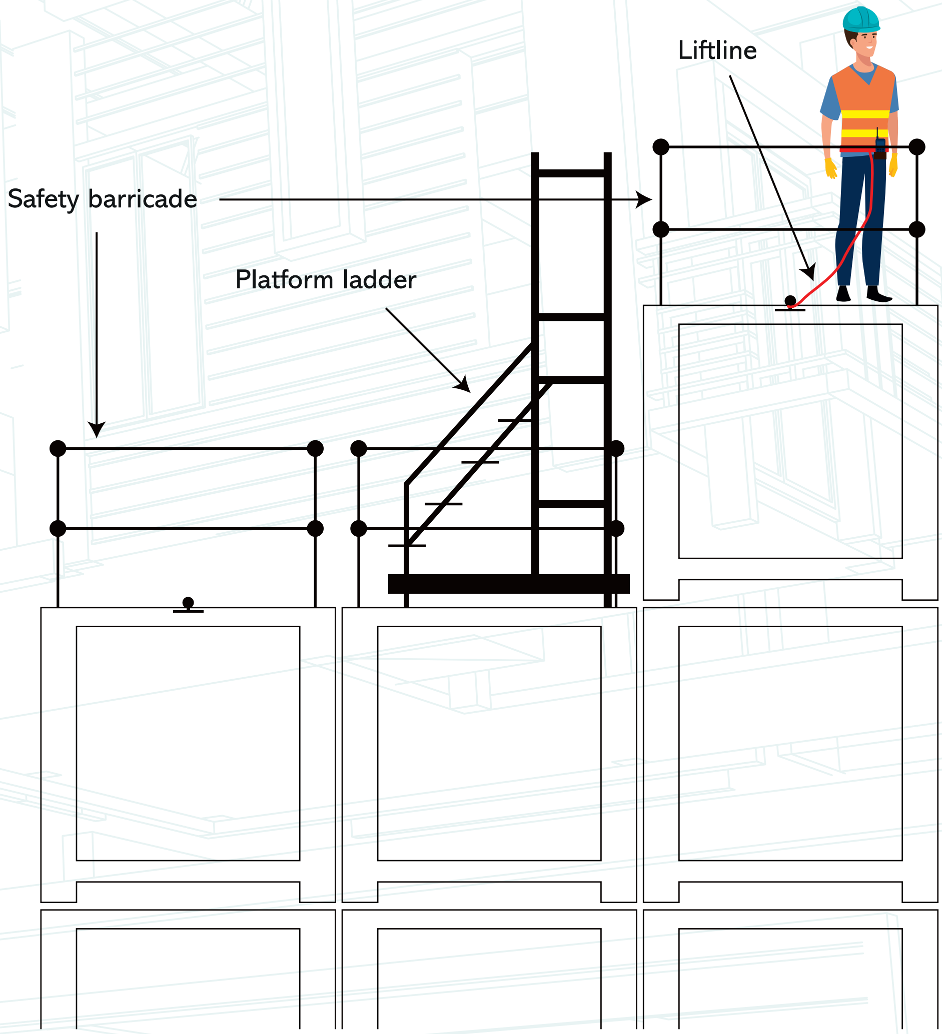



Figure 30. Example of Safety Measure during Installation Process

# PART 4: Quality assurance and quality control

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 from materials up to delivery as listed below that should take into consideration throughout the DfMA process. In addition, a competent person should be appointed to oversee the quality aspects.

**Raw Materials**

- Reinforcement bar (tensile strength)
- Cement (Cert from factory)
- Aggregate (sieve analysis, moisture content)
- Admixture (Cert from factory)

**Concreting**

- Check the dimension of the mould according to drawing.
- Check the reinforcement according to detailed drawing.
- Check on the installation of MEP according to drawing.
- Check on the size of concrete cover.

**Concrete**

- Slump test
- Compression test

**Storage**

- Visual check on any defects, crack, and honeycomb.
- Tag the product with its own identification.

**Delivery**

- Check the product delivered to site to ensure the correct product is delivered (DO)
- Visual check on any defects and cracks after unloading is done.

A GUIDE TO DESIGN FOR MANUFACTURING AND ASSEMBLY (DfMA)
IN PRECAST CONCRETE SYSTEM

# REGULATION AND STANDARD REFERENCES

## Regulation

The related regulations, acts and policies:

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

## Related Standards, Guidelines and References

The related standards, guidelines and references:

| Standard | Malaysian Standard (MS): |
|---|---|
| Malaysian Standard (MS) | • MS EN 1990:2010 - Eurocode - Basis of Structural Design<br>• MS EN 1992-1-1:2010 - Eurocode 2: Design of Concrete Structures - Part 1-1: General Rules and Rules for Buildings<br>• MS EN 1993-1-1:2010 - Eurocode 3: Design of Steel Structures - Part 1-1: General Rules and Rules for Building<br>• MS EN 12390-3:2012 - Testing hardened concrete - Part 3: Compressive strength of test specimens (Second revision)<br>• MS 1064-1: 2001 (Confirmed 2009) - Guide to modular coordination in buildings – Part 1: General Principle<br>• MS 1064-2: 2001 (Confirmed 2009) - Guide to modular coordination in buildings – Part 2: Storey heights and room heights<br>• MS 1064-10: 2018 - Guide to modular coordination in buildings - Part 10: Coordinating sizes and preferred sizes for reinforced concrete components (First revision)<br>• MS 1525:2014 - Energy efficiency and use of renewable energy for non-residential buildings - Code of practice (Second revision)<br>• MS 1183:2015 - Fire safety in the design, management and use of buildings - Code of practice (First revision)<br>• MS 1600-1:2013 - Fire resistance tests - Part 1: General requirements<br>• MS 1979: 2015 – Electrical installation of buildings – code of practice<br>• 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<br>• MS IEC 60364 Electrical installations of buildings MS 1936, Electrical installations of buildings - Guide to MS IEC 60364<br>• MS IEC 62305 Protection Against Lightning<br>• MS 1979:2015, Electrical installations of buildings - Code of practice |

| Standard | Construction Industry Standard (CIS) |
| --- | --- |
| Construction Industry Standard (CIS) | • CIS 1:1998 - Standard Perumahan Kebangsaan Bagi Perumahan Kos Rendah - Satu dan Dua Tingkat<br>• CIS 2:1998 - Standard Perumahan Kebangsaan Bagi Perumahan Kos Rendah - Rumah Pangsa<br>• CIS 3:2005 - Standard Perumahan Kebangsaan Bagi Perumahan Kos Sederhana Rendah Selain Rumah<br>• CIS 4:2005 - Standard Perumahan Kebangsaan Bagi Perumahan Kos Sederhana Rendah Rumah Pangsa<br>• CIS 5:2004 - Quality Assurance for Prefabricated Timber Truss Systems<br>• CIS 7:2014 - Quality Assessment System for Building Construction Work (QLASSIC)<br>• CIS 9:2008 - Guideline on Handling, Transportation, Stacking and Installation of Precast Concrete Components<br>• CIS 10:2008 - Safety and Health Assessment System in Construction (SHASSIC)<br>• CIS 12:2009 - Quality Assurance for Prefabricated Light Weight Steel Roof Truss<br>• CIS 13:2009 Guideline on Handling, Transportation, Stacking and Installation of Structural Steel<br>• CIS 15:2009 Guideline on Prevention of Fall at Construction Site<br>• CIS 18:2018 Manual for IBS Content Scoring System (IBS Score)<br>• CIS 20:2013 Manual Tatacara Penilaian Pengeluar Berstatus IBS (AIS)<br>• CIS 21:2018 Ready-Mixed Concrete: Production, Conformity, Transportation and Delivery criteria for Producers<br>• CIS 22:2017 Safe Use of Scaffolding in Construction<br>• CIS 23:2018 Safe Use of Falsework and Formwork in Construction<br>• CIS 26:2019 Standard Perumahan Kebangsaan |

| Standard | British Standard (BS) |
|---|---|
| British Standard (BS) | • BS EN 13369:2018 - Common rules for precast concrete products<br>• BS EN 13693:2004+A1:2009 - Precast concrete products. Special roof elements<br>• BS EN 14843:2007 - Precast concrete products. Stairs<br>• BS EN 14992:2007+A1:2012 - Precast concrete products. Wall elements<br>• BS EN UBB47:2005+A2:2010 - Precast concrete products. Floor plates for floor systems<br>• BS EN 1168:2005+A3:2011 - Precast concrete products. Hollow core slabs<br>• BS EN 15050:2007+A1:2012 - Precast concrete products. Bridge elements<br>• BS EN 13225:2013 - Precast concrete products. Bridge elements<br>• BS EN 14991:2007 - Precast concrete products. Foundation elements<br>• BS EN 13224:2011 - Precast concrete products. Ribbed floor elements<br>• BS EN 1253-1:2015 – Gullies for buildings. Trapped floor gullies with a depth water seal of at least 50 mm<br>• BS EN 1253-3:2016 - Gullies for buildings. Evaluation of conformity<br>• BS EN ISO 12572:2016 - Hygrothermal performance of building materials and products. Determination of water vapour transmission properties. Cup method<br>• BS 476-21/22:1987 - Fire tests on building materials and structures. Methods for determination of the fire resistance of loadbearing elements of construction<br>• BS EN 1991-1-2, Eurocode I -Actions on structures -Section 1-2: General actions - Actions on structures exposed to fire<br>• BS EN 1993-1-2, Eurocode 3 - Design of steel structures -Section 1-2: General rules - Structural fire design |

| Standard | American Society for Testing and Materials (ASTM) |
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| American Society for Testing and Materials (ASTM) | • ASTM D5957 - 98(2013) - Standard Guide for Flood Testing Horizontal Waterproofing Installations<br>• ASTM D7832 / D7832M – 14 - Standard Guide for Performance Attributes of Waterproofing Membranes Applied to Below-Grade Walls / Vertical Surfaces (Enclosing Interior Spaces) |

| Standard | Guidelines/ Specifications/ References |
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| Guidelines/ Specifications/ References | • Guideline on Geometric Design of Roads - Road Engineering Association of Malaysia (REAM)<br>• Guideline for Public Safety and Health at Construction Sites (1st Revision) 2007 - Department of Occupational Safety and Health (DOSH)<br>• Arahan Teknik (Jalan) ATJ. 8/86: A Guide on Geometric Design of Roads (Pindaan 2015) – Public Work Department (PWD)<br>• Garis Panduan BIM 2014 - Public Work Department (PWD)<br>• A Reference Guide to Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST) – Construction Industry Development Board (CIDB)<br>• Green Building Index (GBI) – Board of Architect Malaysia (BAM)<br>• Green Real Estate (GreenRE) - Real Estate Housing Developers' Association Malaysia (REHDA)<br>• Specification for the Design, Manufacture & Construction of Precast Concrete Structures – Construction Research Institute of Malaysia (CREAM)<br>• Construction Quality Assessment System (CONQUAS) – Building and Construction Authority (BCA), Singapore<br>• Handbook for the Design of Modular Structures – Monash University, Australia<br>• Design in Modular Construction – CRC Press, United Kingdom<br>• Design for Manufacturing and Assembly (DfMA): Prefabricated Prefinished Volumetric Construction - Building and Construction Authority (BCA), Singapore<br>• BIM for DfMA Essential Guide - Building and Construction Authority (BCA), Singapore<br>• Safe work with precast concrete, WorkSafe, New Zealand, 2018 |

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