DeLIGHT Homes

A SUSTAINABLE AND INNOVATIVE AFFORDABLE HOUSING DESIGN HANDBOOK

CIDB TECHNICAL PUBLICATION NO: 204

CIDB MALAYSIA



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Research Collaboration

CREAM CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA · ELEENA JAMIL architect · NS PREFAB CONSULTANCY · SIRIM · GREENIBS

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Published in 2020 by
CONSTRUCTION INDUSTRY DEVELOPMENT BOARD MALAYSIA (CIDB)
IBS Centre, CIDB Malaysia,
Level 11, Sunway Putra Tower,
No. 100, Jalan Putra,
50350 Kuala Lumpur
MALAYSIA

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ISBN 978 967 0997 90 2

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Preface

The Malaysian government aims to deliver affordable housing in its effort to provide decent, liveable, and quality housing to the people. In line with the Dasar Perumahan Mampu Milik (DRMM) and Construction Industry Standard, CIS 26: 2019 Standard Perumahan Kebangsaan, the government aims to provide an adequate supply of affordable housing to the target receivers consisting of middle- and low-income groups to ensure their wellbeing, raise their quality of life to good levels, and humanise residents and communities.

This handbook is a continuation of the first and second books in the publication series themed **Humanising Low-Income Group's Housing Through Technology and Innovation**, which aims to provide guidance to housing players in the technical aspect of delivery and construction of affordable housing. *DeLIGHT Homes: A Sustainable and Innovative Affordable Housing Design Handbook* is intended to encourage the industry players to renew and improve affordable housing – both existing and under construction – by leveraging on technology and innovation.

Based on the simulation of typical floors of high-rise strata flats, this handbook is composed of a book collection that provides a comprehensive manual on architectural, civil, and structural aspects, as well as mechanical, electrical, and plumbing in designing quality affordable homes for the low-income group in Malaysia. This handbook also offers extensive guidance on construction cost calculations to inspire housing industry players that it is possible to build affordable housing for the low-income group without sacrificing the necessary features for a good quality of life.

This handbook adds value by providing an output in the form of a pre-approved plan as a reference for the housing players for their affordable housing projects. Local authorities and policymakers may also use this handbook as a basis to encourage the housing industry players to use technology and innovation as a game changer for the industry.



Editorial

This project was funded by the Construction Industry Development Board (CIDB) Malaysia and executed by the Construction Research Institute of Malaysia (CREAM) since January 2018 until March 2019. We would like to thank the following members for their contribution and support.

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This project is a collaboration effort between CREAM and the industry players. We would like to thank the following members for their contribution and support.

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Contents



DeLIGHT Homes
A Sustainable and Innovative Affordable Housing Design Handbook

PREFACE i
EDITORIAL ii
ABBREVIATIONS vi

INTRODUCTION 03
TO DELIGHT HOMES HANDBOOK

SECTION A: 07
HANDBOOK FOR ARCHITECTS

SECTION B: 93
HANDBOOK FOR STRUCTURAL ENGINEERS

SECTION C: 129
HANDBOOK FOR MECHANICAL ELECTRICAL AND PLUMBING ENGINEERS

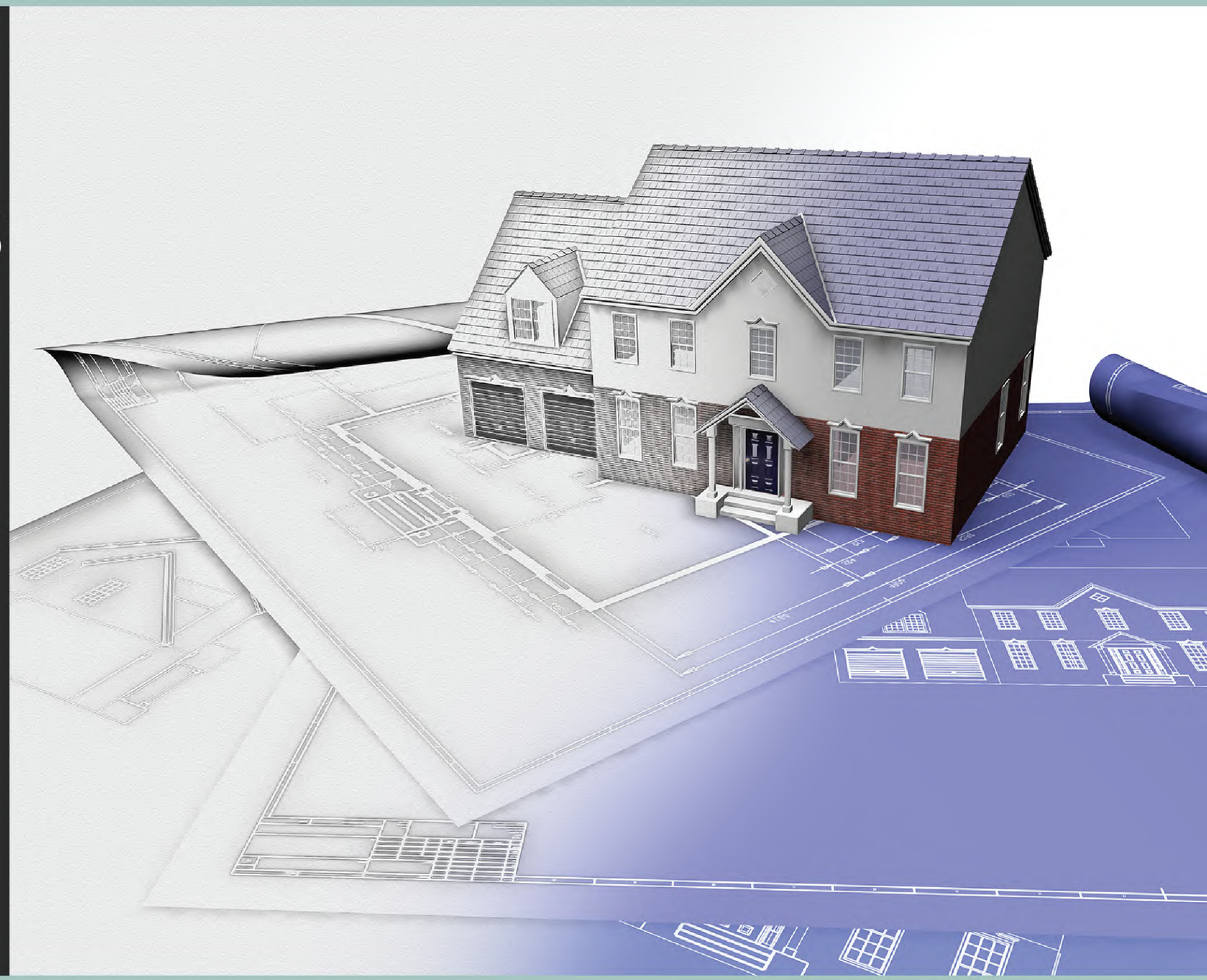
SECTION D: 157
HANDBOOK FOR QUANTITY SURVEYORS

SECTION E: 205
HANDBOOK FOR CFD SIMULATION AND ANALYSIS

BIBLIOGRAPHY 219
ACKNOWLEDGEMENT 221

List of Abbreviations

BEP	Building Execution Plan
BIM	Building Information Modelling
CFD	Computational Fluid Dynamics
CIDB	Construction Industry Development Board
CIS 26: 2019	Standard Perumahan Kebangsaan
CREAM	Construction Research Institute of Malaysia
DRMM	Dasar Perumahan Mampu Milik
ECI	Early Contractor Involvement
EIR	Employer's Information Requirements
IBS	Industrialised Building System
LBS	Location-based sectioning
LOD 300	BIM Level of Development as per Consultant Documentation
LOD 400	BIM Level of Development as per Contractor Documentation
LOD 500	BIM Level of Development as per As-Built Documentation / Facility Management
M&E	Mechanical and Electrical
MEP	Mechanical Electrical Plumbing
PPR	Projek Perumahan Rakyat
Prefab	Prefabrication
RMR	Rumah Mesra Rakyat
SIRIM	Standard and Industrial Research Institute of Malaysia
SKMM	Suruhanjaya Komunikasi dan Multimedia Malaysia
SPAN	Suruhanjaya Perkhidmatan Air Negara
ST	Suruhanjaya Tenaga



DeLIGHT Homes
A Sustainable and Innovative Affordable Housing Design Handbook



INTRODUCTION

To DeLIGHT Homes Handbook

INTRODUCTION TO DELIGHT HOMES HANDBOOK

In the face of the issues concerning housing demand as well as sustainable and affordable housing in Malaysia, it seems that our plastered-on, short-term quick-fixes are starting to burst through the seams. The availability of affordable housing is essential for all countries, including Malaysia, in ensuring socioeconomic stability and promoting national development. Affordable housing provides a platform that creates strong and stable communities by accelerating economic, education, and health outcomes while ensuring the safety of individuals, families, and communities. Hence, the government continues to provide good quality affordable housing for the poor, low- and middle-income groups with varying levels of support based on need.

To achieve the objective of providing sustainable and affordable housing, the government has initiated various housing policies and programmes focusing on economic viability, social acceptability, and technical feasibility. One of the essential industries for the delivery of affordable housing is the construction industry. This industry is the foundation that affects all the economic sectors, influences productivity and wellbeing, and creates homes, hospitals, schools, workplaces, and infrastructures that are most needed for a good quality of life. Hence, it is unsurprising that when construction goes wrong, communities will suffer (CBI, 2020).

The handbook and case study presented focus on delivering affordable housing, especially to the low-income group communities, taking into consideration the aspects of technical viability, satisfactory social habitability, and cost effectiveness. This handbook demonstrates that technology and innovation can serve as catalysts that boost the effectiveness and productivity of housing players.

The purpose of DeLIGHT Homes: A Sustainable and Innovative Affordable Housing Design Handbook is to provide a reference for housing players, designers, and the government as well as assist developers and policymakers in delivering affordable housing to the people. This handbook serves as a manual and guideline based on the simulation of the affordable housing project, DeLIGHT Homes. DeLIGHT Homes is a product of the research conducted on Humanising Low-Income Group's Housing Through Technology and Innovation to deliver a set of new housing designs. Sustainable and inclusive design elements, capability in technological advancement and innovation, integrated process designing, and planning of affordable housing will increase the likelihood of the success of a project.

Inputs for this handbook were compiled from architects; structural engineers; mechanical, electrical, and plumbing engineers; and quantity surveyors.This handbook contains five sections, namely Handbook for Architects; Handbook for Structural Engineers; Handbook for Mechanical, Electrical, and Plumbing Engineers; Handbook for Quantity Surveyors; and Handbook for Computational Fluid Dynamics (CFD) and Simulation Analysis.

All the handbooks were derived from a case study that involved simulating the strata design of DeLIGHT Homes. Additionally, the Handbook for Architects provides a guide on a wide range of housing design issues and housing proposal outlines for the design of strata (high-rise), terrace home, townhouse, and rural bungalow homes for the low-income group. The case study emphasises on Building Information Modelling (BIM) as a platform in a project's lifecycle, modularity-based design, and Industrialised Building System (IBS) in simulating a construction project.

It is recognised that there is no perfect answer to the issues and problems associated with housing for the low-income group. Nevertheless, this handbook can be used as a guide in searching for possible solutions and effective design strategies. Furthermore, this handbook provides practical information that can help the reader formulate an approach and make informed decisions concerning low-income housing. How a project will respond is based on the complexity of each project in varying contexts and precedents for designs (Matuke, 2016). The determination of the overall success of the project is in the hands of the reader in using this handbook as a guide and recognising the immense responsibility that comes with managing a public good.

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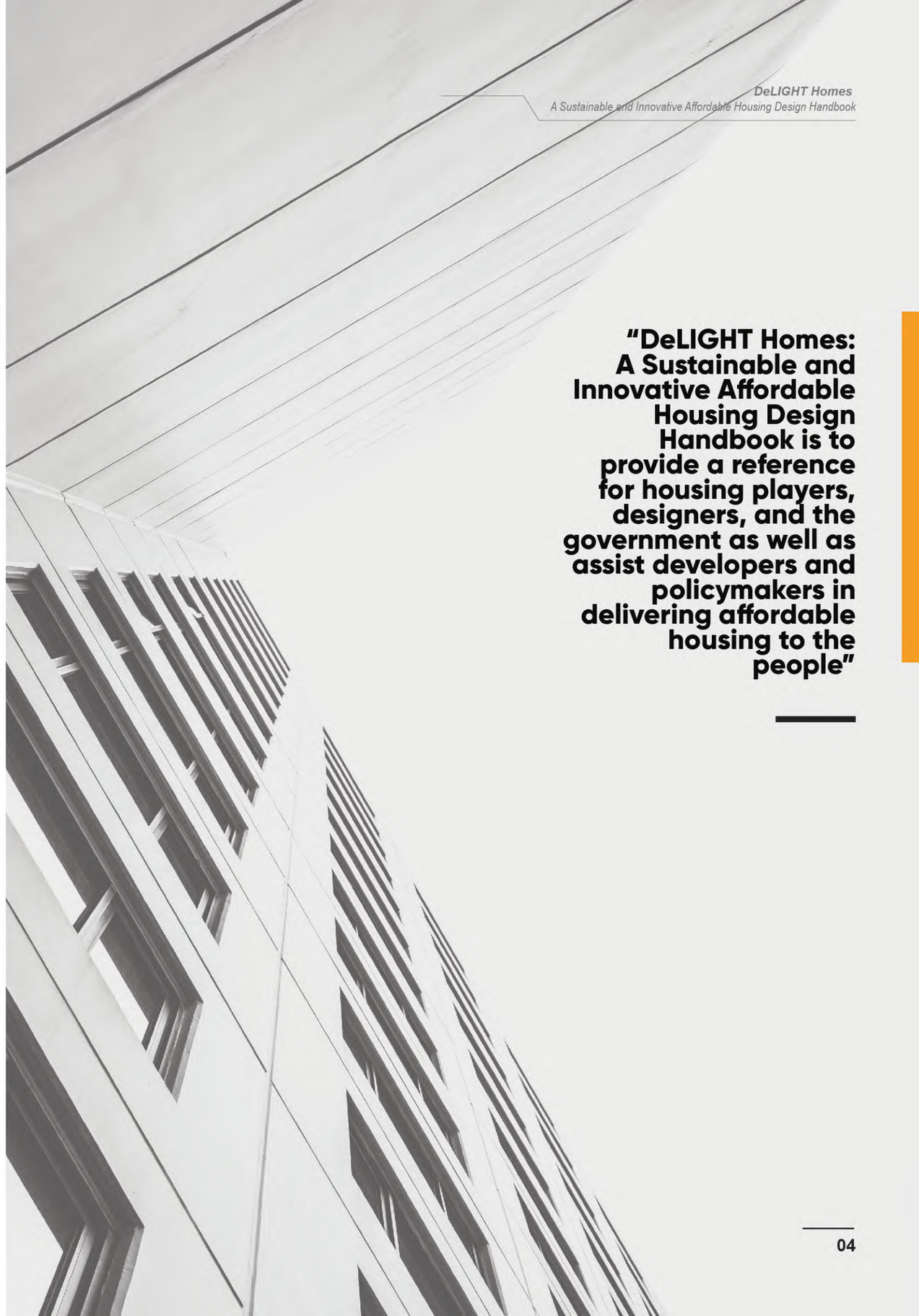
A Sustainable and Innovative Affordable Housing Design Handbook



"DeLIGHT Homes: A Sustainable and Innovative Affordable Housing Design Handbook is to provide a reference for housing players, designers, and the government as well as assist developers and policymakers in delivering affordable housing to the people"



SECTION A:
HANDBOOK FOR ARCHITECTS

A1 **Brief Introduction**

A2 **Low-Income Housing Issues**
2.1 Low-Income Housing in Malaysia
2.2 Low-Income Housing in Malaysia – Design Issues
2.3 Humanising Qualities in a Home

A3 **Housing Proposal**
3.1 High-Rise Flats
3.2 Rural Bungalows
3.3 Terrace Homes
3.4 Townhouses
3.5 Terrace Homes and Townhouses (Mixed Development)

Written by:

ELEENA JAMIL
architect



A1 BRIEF INTRODUCTION

This handbook forms part of continuing studies and interests to encourage renewals and improvements of mass housing architecture through a long cycle of critiques, reassessments, and interventions. The handbook looks at ways on how to humanise low-income housing using design as a tool in the context of Malaysia. Rather than prescribing a specific approach, it works as a design primer that helps in understanding the complexities of designing housing and the issues that need to be addressed. The fundamental aim of this guide is to promote more liveable, viable, and adaptable public housing over the life of a building.

In developing cities like Kuala Lumpur, housing is one of the most important built-forms in the urban landscape. Its success ensures that the city thrives economically and socially. Nevertheless, the need to provide housing in unit numbers with a commercial focus has led to compromises on design and quality. A typical housing estate for the low-income group accommodates thousands of families crammed in box-like units within a small plot of land. Moreover, in most countries, social housing is structurally tied to institutions and authorities that are themselves conservative and slow to change. Thus, a timely discussion is required to ensure that we do not lose sight of providing dignified housing for those most in need.

This Handbook for Architects is divided into two parts: housing design issues and housing proposals. The first part discusses and illustrates the different aspects of design and approaches that could help in providing homes that are better for the environment and community. Case studies from various sources facilitate focus on different issues in realised projects and illustrate the different approaches to specific design aspects. This part of the handbook is designed to provide practical information to help the reader formulate an approach and make informed decisions concerning low-income housing.

The second part outlines the design proposals for high-rise, terrace home, townhouse, and rural bungalow homes, which were produced by Eleena Jamil Architect to demonstrate the possible solutions to housing design. This section is further divided into multiple parts: built-form, technical, ventilation, and lighting issues. The proposals do not claim to provide answers to all problems associated with low-income housing. Instead, they seek to illustrate how sustainable and dignified housing design may be achieved in basic built-forms using simple yet effective design strategies.

A2 LOW-INCOME HOUSING ISSUES

2.1. Low-Income Housing in Malaysia

Generally, low-income housing in Malaysia refers to housing built for people in the "B40 group", i.e., the bottom 40% income group according to the Department of Statistics Malaysia. The building of low-income housing units is not centralised but carried out by different governmental agencies throughout the country, ranging from initiatives such as "Projek Perumahan Rakyat" (PPR) (People's Housing Projects) to Rumah Mesra Rakyat (RMR). In such cases, low-income housing units are not necessarily low-cost housing as they are heavily subsidised despite the tremendous efforts made to reduce prices by offering a very basic design. These housing initiatives have focused on increasing borrowing or subsidising the cost of purchasing a house for home buyers, particularly those buying homes for the first time.



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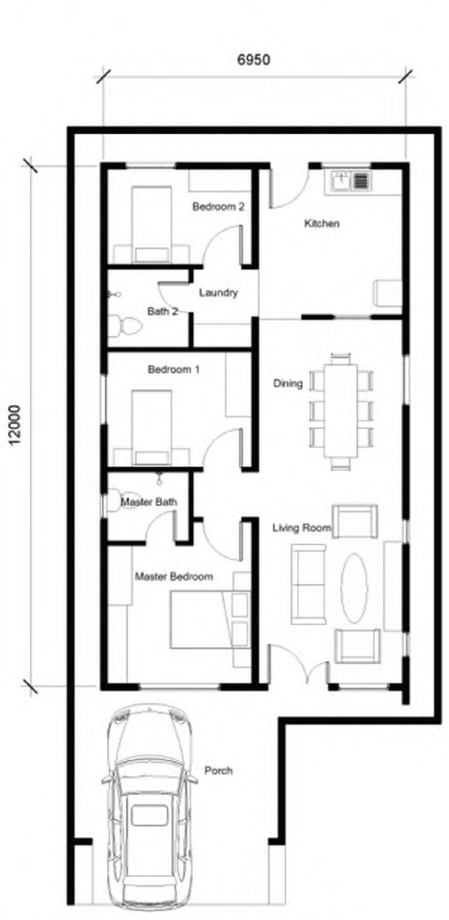


Rural bungalows like those built under RMR



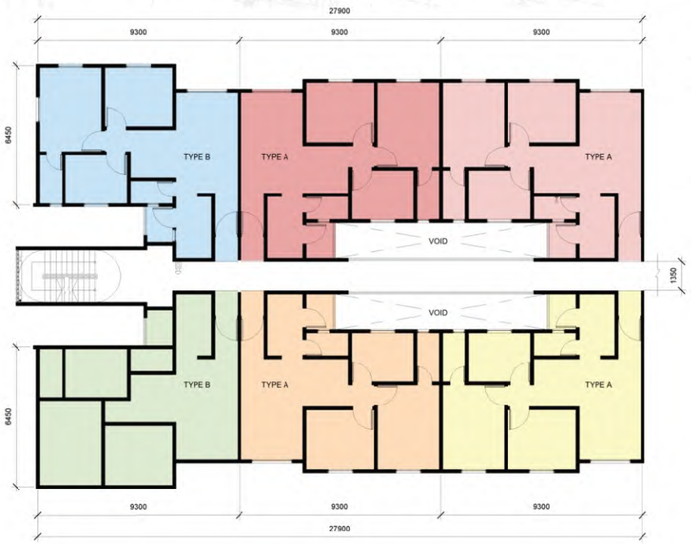
700 ft² PPR

700 ft² PPR

Above are some examples of the standard plans of low-income housing built across Malaysia. Low-income housing in the form of PPR flats consists of 3-bedroom, 700 square feet flats arranged in towers that can be as high as 24 storeys. A single PPR development in an urban area can accommodate up to 1500 units of identical flats complemented by amenities such as shops, kindergartens, prayer rooms, community halls, and shops. RMR houses, on the other hand, offer rural landowners the opportunity to build detached homes at minimal costs. These houses are also 3-bedroom houses with sizes ranging from 700 to 1000 square feet.



2.2. Low-Income Housing in Malaysia – Design Issues



A typical PPR block plan

Government-led low-income housing such as PPR and RMR has seen some improvements over the years, but they tend to be more resistant to design innovation in comparison to affordable homes built by private developers, which have seen more architectural breakthroughs in producing more well-designed, energy-efficient homes.

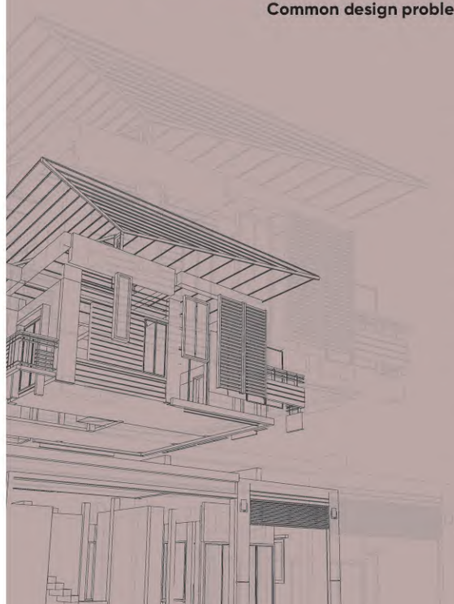
In terms of planning low-income housing estates, more consideration can be given to the way spaces are used, particularly by children. A children's playground is very often located across the road from the tower block along the rear of the development, exposing children to danger when they cross the road to get there. The play area tends to be very small. Its proximity to the foot of the tower block also means children are exposed to the danger of being hit by items thrown from the windows of the flats.

There have been attempts to foster a community spirit by providing a multitude of amenities, which are often located around the ground floor in a smaller block. However, apart from the size of the spaces, there is no differentiation in design between rooms such as nursery, kindergarten, library, and smart class or computer room. They all have the same simple and bare design with standard casement windows.

Soft landscaping is minimal in this type of development. Most of the open spaces on the ground floor are dominated by tarmac in the form of roads and car parks, while greenery is limited to the edges of the site. There is no green landscape on either the tower blocks or the amenities block.



Common design problems in low-income housing in Malaysia



The tendency to build tall at the lowest cost possible could lead to some design problems. For example, building 500 home units of the same size and design within a block that soars between 18 and 25 storeys offers very little flexibility to meet the occupants' different needs. In the tower block, corridors leading to individual homes are dark, necessitating the use of artificial lighting throughout the day. A small entrance foyer (the width of a door) is provided outside the house to allow the occupants to add a grill if needed.

In most housing units, the drying yard, kitchen, and third bedroom open out to air wells. Hence, there are multiple air wells in a block, but being 18 to 25 storeys high, they offer inadequate ventilation and very little daylight except to the top two floors. Casement windows are often used throughout the development, which means that the occupants need to add additional grill openings to safeguard from falls or to provide added security. Some of the visited PPR in this study have windows that are designed to open at a maximum of 30-degree swing, which is still large enough for a child's body to pass through.

DeLIGHT Homes
A Sustainable and Innovative Affordable Housing Design Handbook

2.3. Humanising Qualities in a Home

Having an outdoor private space



Spacious, bright and well-ventilated kitchen



Homes that overlook play areas and public areas increase natural surveillance for safety



Green open public spaces around the housing estate



Tall, bright and airy internal spaces



Views out



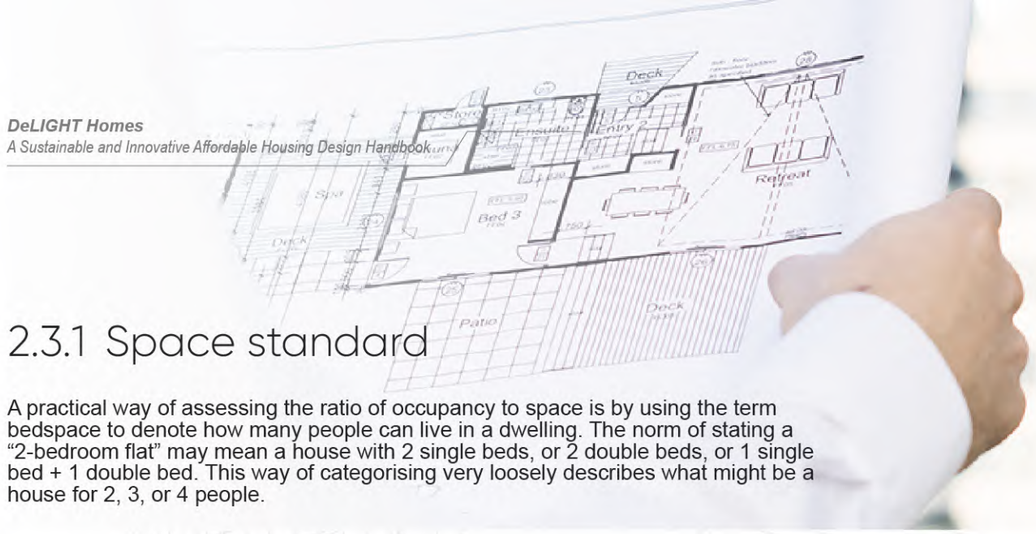
Adequate well-ventilated space for clothes drying



Private, defensible space outside one's door



Sources: CIDB Malaysia (2019)



2.3.1 Space standard

A practical way of assessing the ratio of occupancy to space is by using the term bedspace to denote how many people can live in a dwelling. The norm of stating a "2-bedroom flat" may mean a house with 2 single beds, or 2 double beds, or 1 single bed + 1 double bed. This way of categorising very loosely describes what might be a house for 2, 3, or 4 people.

Comparison between standards in the UK and Singapore for social housing

Bed space	UK GLA (m^2)	Singapore HDB (m^2)	Proposed for PPR (m^2)
2	44	36	57
3	57	-	57
4	67	60	-
5	81	-	82
6	92	90	110
7	105	-	-

Proposed prototype for PPR housing area

House Type	Bed Space	Area (ft^2)	Area (m^2)
1-Bedroom Flat	2	614	57
2-Bedroom Flat	3	614	57
3-Bedroom Flat	5	882	82
3-Bedroom Flat Type A	6	1184	110
3-Bedroom Flat Type B	5	1184	110
4-Bedroom Flat	6	1184	110

Sources: http://www.hatc.co.uk/knowledge/publications/housing-space-standards-gla-2006
http://www.hdb.gov.sg/cs/infoweb/residential/buying-a-flat/new/types-of-flats
Laws of Malaysia: Uniform Building By-Lays 1984 [G.N. 5178/85]

Area for each room with introduced new standards including a drying yard and storage

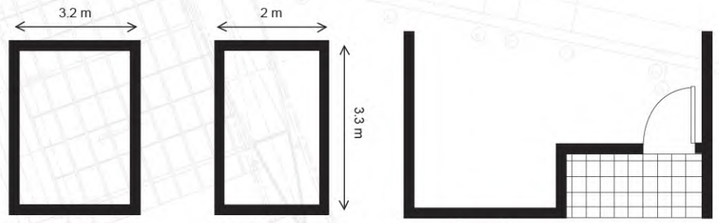
Bed space	Malaysia UBBL (m^2)	UK GLA (m^2)	Proposed for PPR (m^2)
Double-bed Room	9.3	10	13.4
Single Room	6.5	6.5	6.6
Bedroom Ratio	-	2:1	2:1
Kitchen	4.5	space determined according to no of occupants	Refer to table below
Living Room	11		
Bathroom	2	-	2.5
Balcony	-	3	-
Store	-	1	0/3
Drying Yard	-	-	3

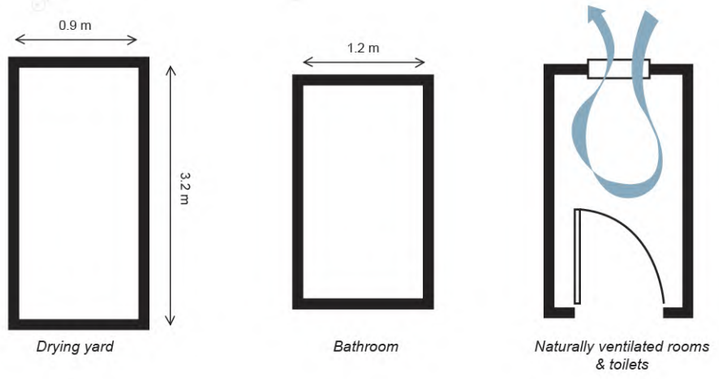
Minimum floor area for general areas (cooking, eating, and living)

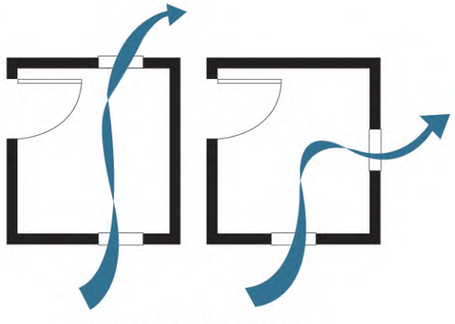
House Type	Bed space	UK GLA (m^2)	Proposed PPR Area (m^2)	Area (ft^2)
1-Bedroom Flat	2	22	30.3	237
2-Bedroom Flat	3	24	30.3	-
3-Bedroom Flat	5	30	30.3	291
3-Bedroom Flat Type A	3	33	30.3	323
3-Bedroom Flat Type B	5	30	30.3	-
4-Bedroom Flat	6	33	30.3	355

2.3.2 Space considerations

Efforts to improve low-income homes are usually hampered by space constraints. A minimum requirement has been developed to ensure that the humanising qualities in a home are not compromised.







2.3.3 Designing for all

DeLIGHT Homes considers designing flexible homes to meet the needs of different demographic groups, family units, and living challenges. Design strategies that include modularity, adaptability, and universality add to the comfort and convenience of the homes and support the changing needs of individuals and families at different stages of life.



Demographics	House Type
Single Person	- 1-Bedroom Home
Young Couple	- 1-Bedroom Home - 2-Bedroom Home
Nuclear Family	- 2-bedroom Home - 3-bedroom Home
Extended Family	- 3-Bedroom Home - 4-Bedroom Home -universal plan
Elderly Couple	- 1-Bedroom Home - 2-Bedroom Home -universal plan
Living with a Disabled Person	- 2-Bedroom Home - 3-Bedroom Home -universal plan
Elderly Couple with one Adult	- 2-Bedroom Home - 3-Bedroom Home -universal plan

Offering homes that can meet the demands of various demographic groups is a significant step towards humanising low-income housing. The relationship between demographic factors, house prices, and housing affordability needs to be understood in the context of designing homes for the masses. Offering different house types provides flexibility to potential homeowners in choosing according to their income, needs, and preference.



Single Person/ Young Couple/ Elderly Couple

- Live/Workspace
- Generous Storage for one
- Living Area separated from the Kitchen



Nuclear Family

- Accommodates wheelchair users
- Living Area separated from the Kitchen
- 3 Bedrooms



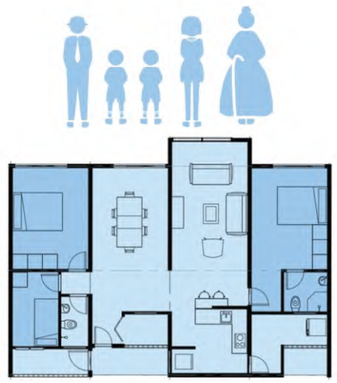
Living with the Disabled

- Accommodates wheelchair users
- 2 Master Bedrooms with 1 Normal Bedroom
- Kitchen separated from the Living Area



Nuclear Family

- Separated Bedrooms
- Bunk beds
- Study & Homework Area
- Generous Storage Area



Extended Family

- Accommodates wheelchair users
- Generous Storage Area
- Kitchen separated from the Living Area
- Large Drying Yard Area
- Study & Homework Area



SECTION A

A3 HOUSING PROPOSAL

3.1. High-Rise Flats

3.1.1. Introduction



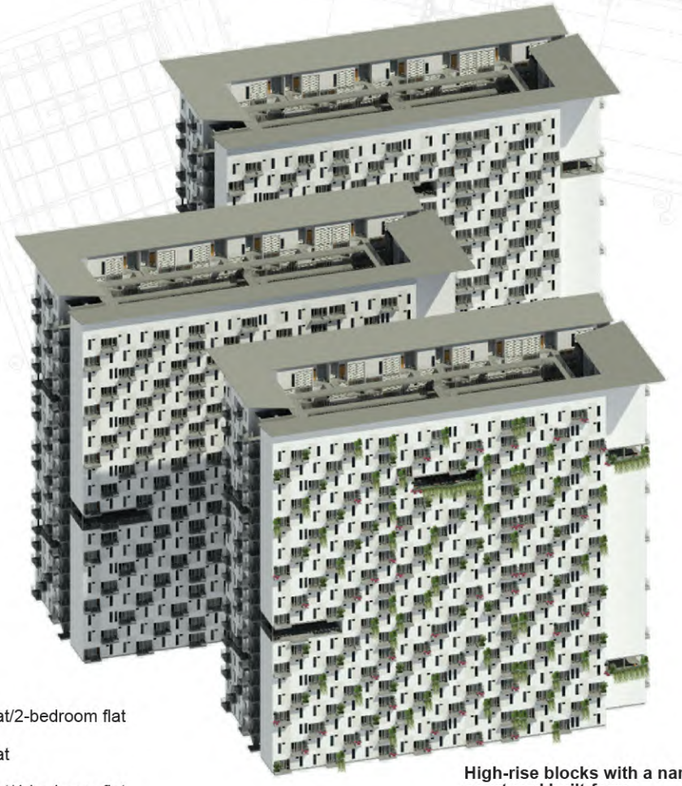
High-rise homes have always been a feature of Malaysia's urban landscape in providing a solution to the problem of housing the urban poor. Among the earliest high-rise housing developments in the country are Rifle Range Flats in Penang and Jalan Pekeliling Flats along Jalan Tun Razak in Kuala Lumpur in which industrialised or prefabricated building systems were used under the initiative by the Ministry of Housing and Local Government.

Our proposal for high-rise homes explores built forms to improve ventilation, lighting, and privacy, which can be challenging when the towers soar to between 17 and 20 storeys.

Passive solar strategies are used throughout the design as a means of achieving comfortable living conditions.

Like their predecessors, industrialised building systems and modular forms are used to ensure high standards of construction and to keep costs within an acceptable range. Here, the concept of modularity is explored as a way of offering various house types in the industrialised production of high-quality homes.

3.1.2. Built form of high-rise flats



1-bedroom flat/2-bedroom flat
3-bedroom flat
3-bedroom flat/4-bedroom flat
Public space

High-rise blocks with a narrow courtyard built-form



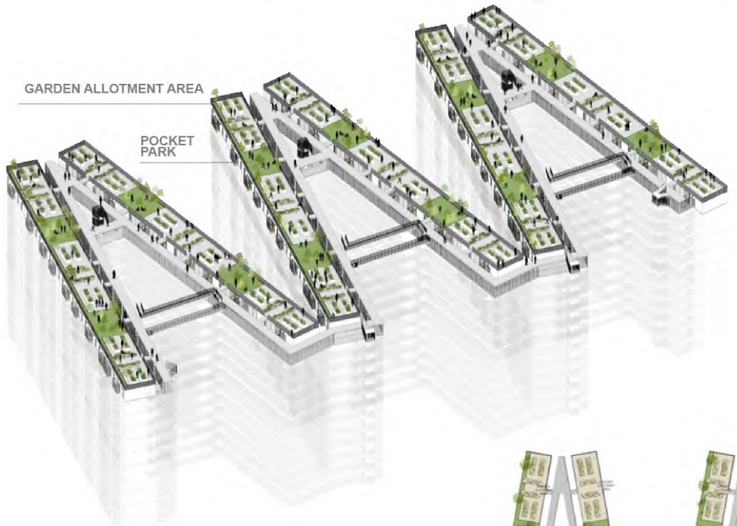
Typical Floor Plan

The narrow courtyard built-form allows some cross ventilation to occur and natural light to stream down, day lighting mainly the homes at the top levels.

Further attempts to improve day lighting and ventilation can be seen in the following pages with different courtyard proportions and shapes.



High-rise blocks in a zig-zag form



The zig-zag built-form offers a better view out while maintaining natural lighting and cross ventilation.

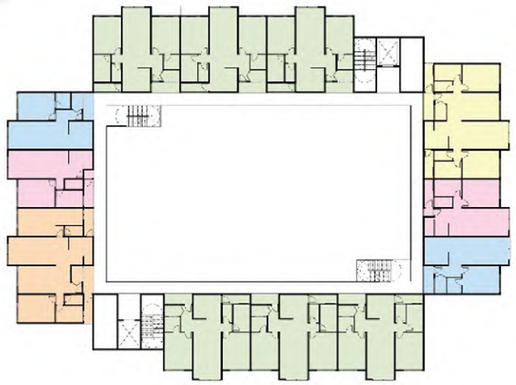


Typical Floor Plan



High-rise block with a wider courtyard built-form

The high-rise with a wider courtyard built-form is further developed as a basis of study as it potentially offers the highest opportunities for ventilation, day lighting, and privacy to occupants of the home units.



Typical Floor Plan

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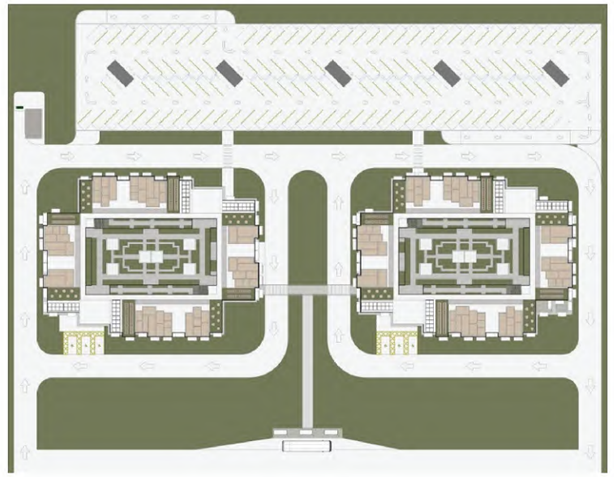
Potential arrangement of tower blocks



Tower blocks may be arranged in such a way that the car park is placed at the rear, making the front part of the development a car-free open space with footpaths, green fields, and recreation zones.

Potential site plan of tower blocks

3.1.3. Design layout of high-rise flats

House Type	Area (sqft)	Units (per floor) 16 Floors	Units (per block)	Percentage (%)	Units (for 2 blocks)
1-Bedroom Flat	614	1/2/4	27	17%	54
2-Bedroom Flat	614	2/3/8	53	17%	106
3-Bedroom Flat	904	0/3/6	45	27%	90
3-Bedroom Flat Type A	1195	1	14	8%	28
3-Bedroom Flat Type B	1195	0/2	14	8%	28
4-Bedroom Flat	1195	1	14	8%	28
	Total	11/12/14	167	~100%	334



A practical way assessing the ratio of occupancy

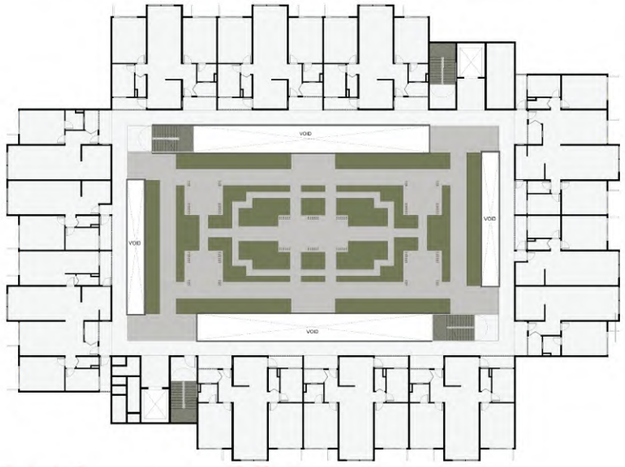
No. of storeys: 16
No. of flats per block: 167 units
Total built-up area: 22 096 m²
Total footprint: 1 953 m²



High-rise flats – Ground floor plan

Amenities/Facilities:

- Multipurpose/ Community Hall
- Stalls and Shops
- Kindergarten & Nursery
- Restrooms



High-rise flats (garden podium) – Level 1



High-rise flats (void level) – Level 8

Amenities/Facilities:

- Pocket Gardens
- Playgrounds
- Common Rooms
- Meeting Room
- Restrooms

SECTION A

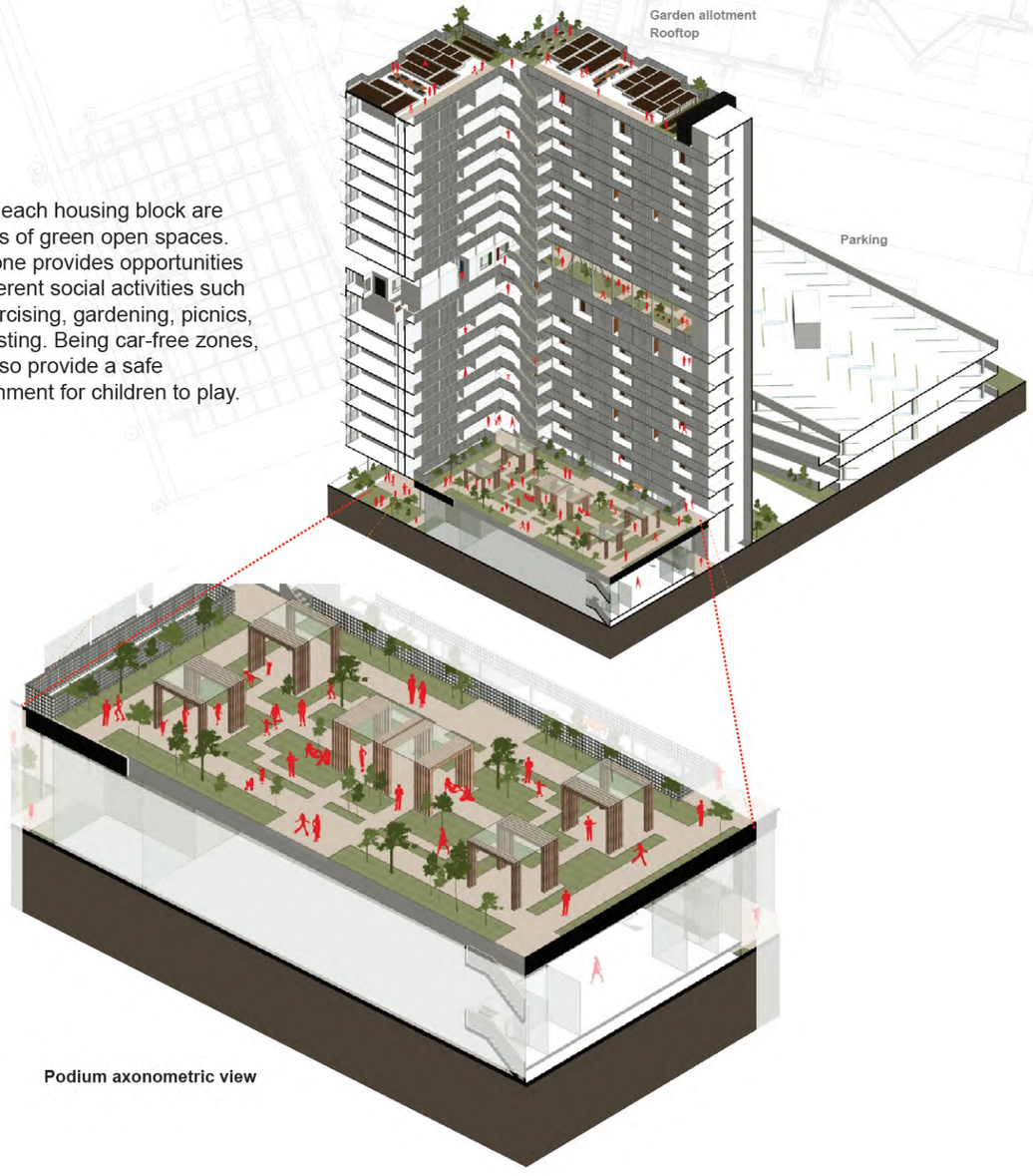


High-rise flats – Roof plan

Amenities/Facilities:

- Pocket Gardens
- Water Tank Area
- 4 different types of Garden Allotments
- Public Seating

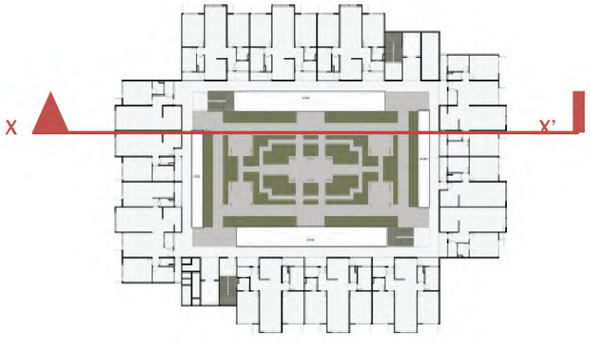
Within each housing block are 3-levels of green open spaces. Each one provides opportunities for different social activities such as exercising, gardening, picnics, and resting. Being car-free zones, they also provide a safe environment for children to play.



Podium axonometric view



Typical floor layouts

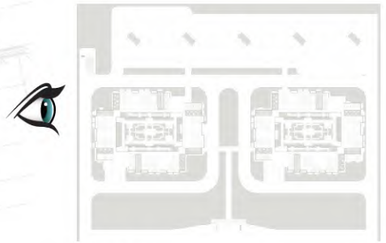


Garden allotment-Roof plan



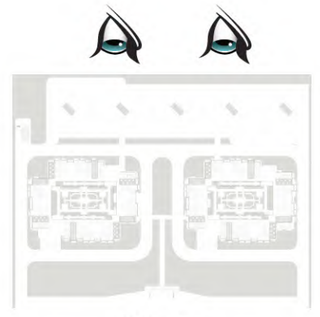
Section through high-rise flats

SECTION A



Site plan

Elevation A

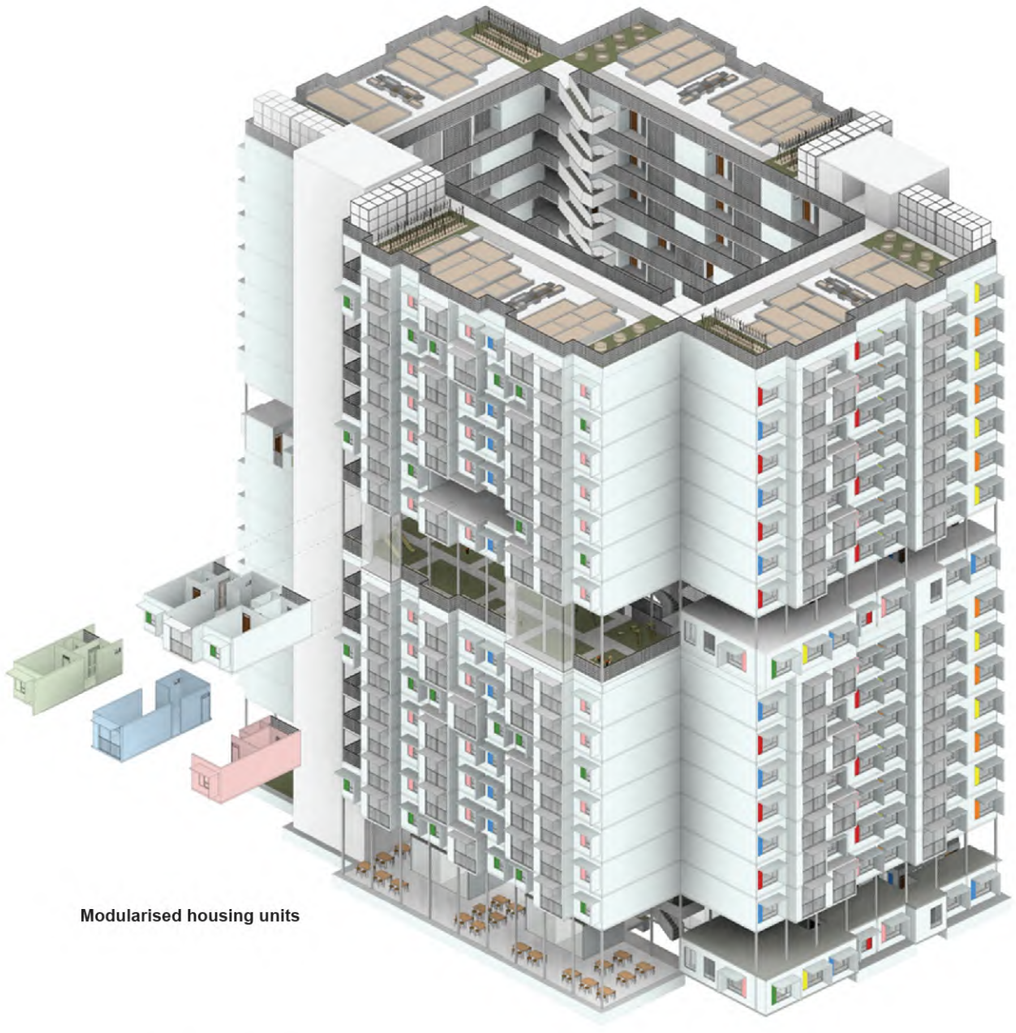


Site plan



Elevation B **Elevation C**

3.1.4. Modular design of high-rise flats



Modularised housing units

The home units are designed in a way that allows them to be modularised. Modularity allows standard sections to be fabricated off-site while the main structure is being erected at the site, thus speeding up the whole construction process.

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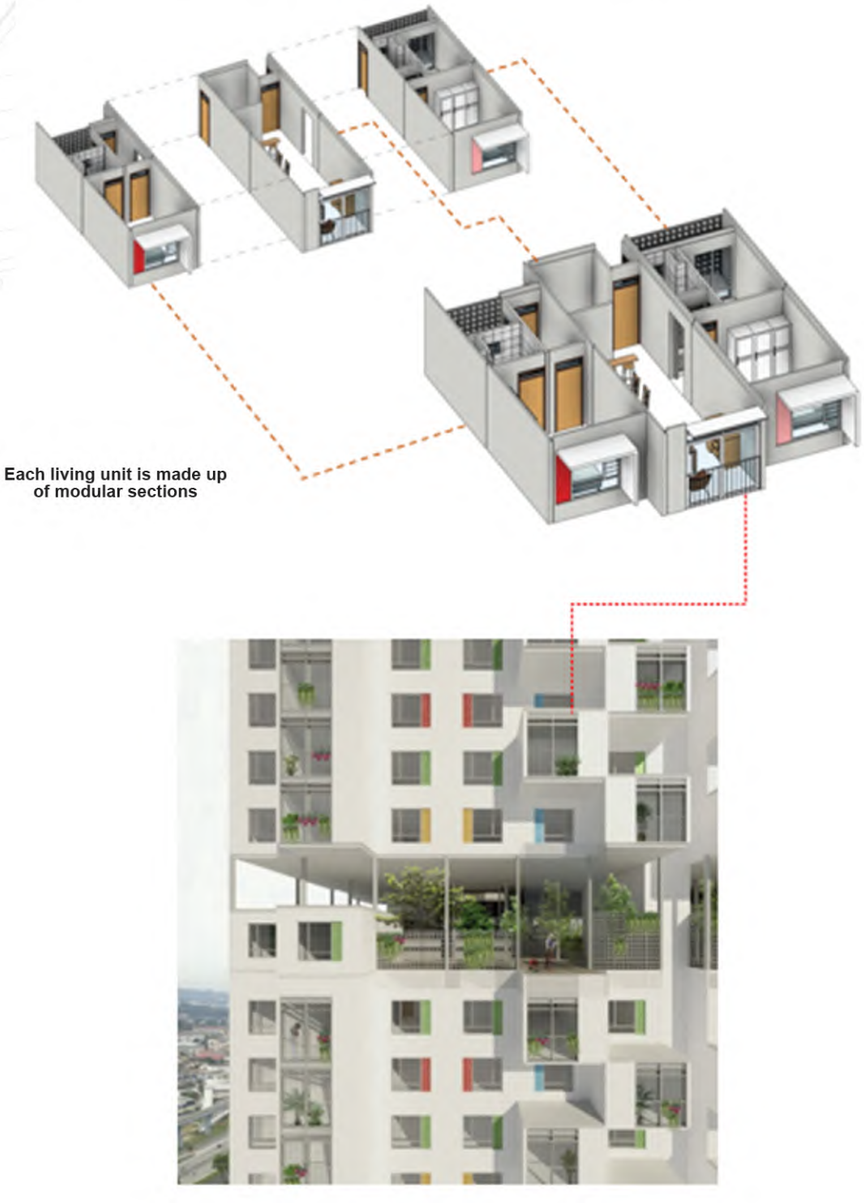
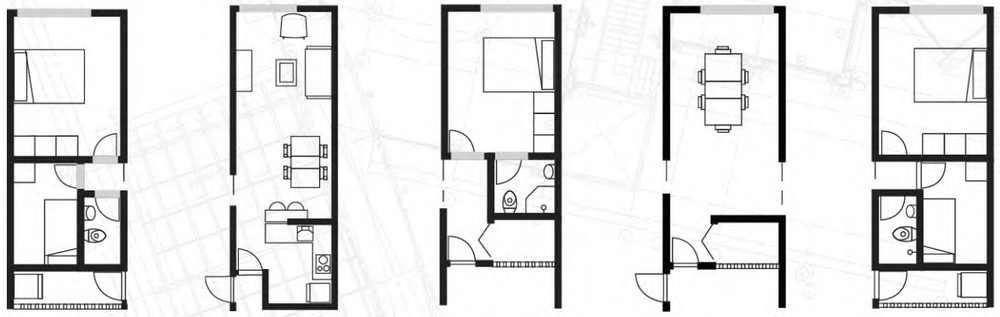
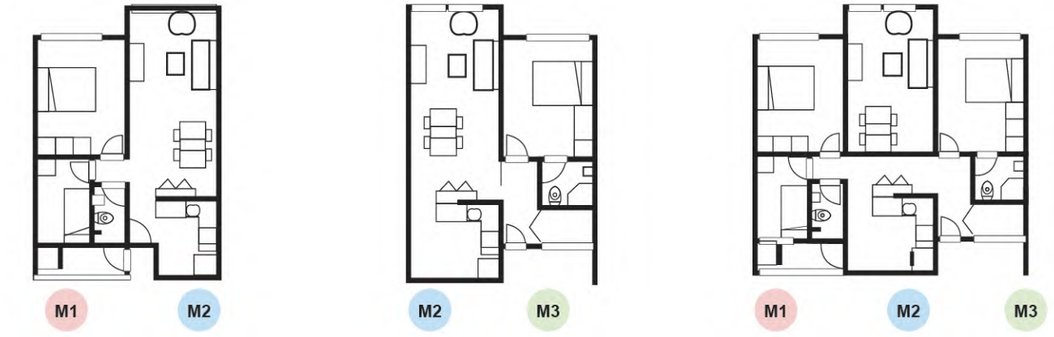


Each living unit is made up of modular sections

Standard modules are mixed and matched to form living units of different sizes and layouts.



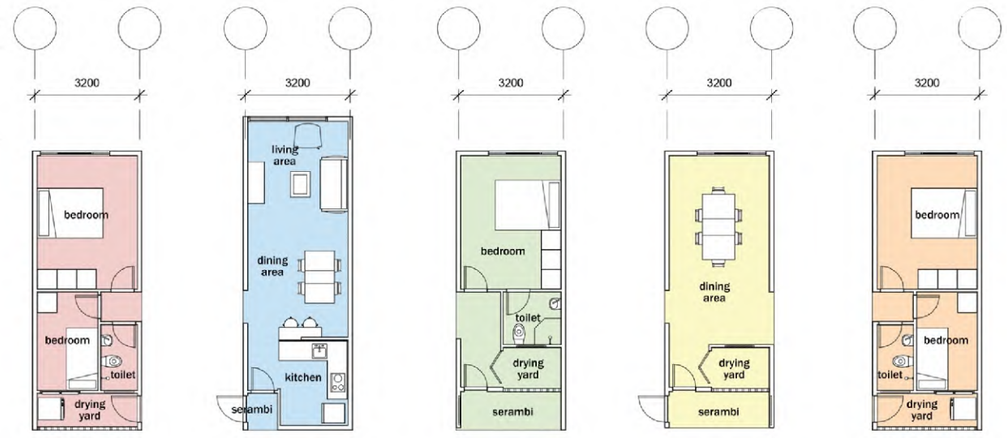
Example of Modules



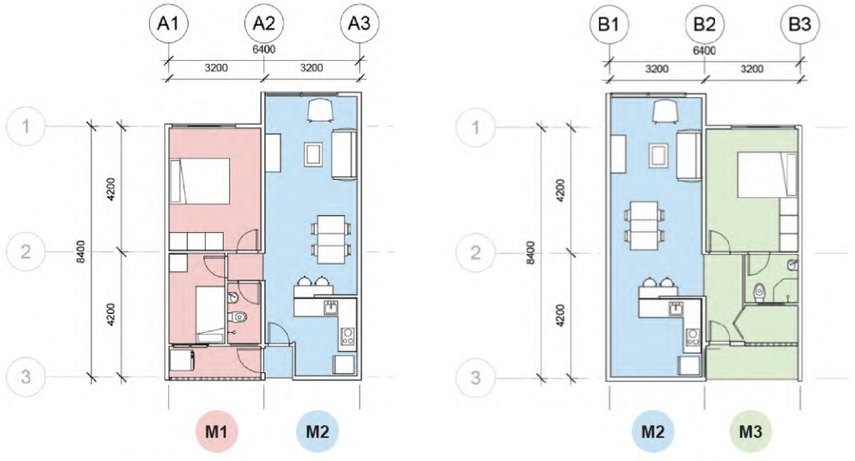


Example of Living units

3.1.5. Modular living units



Standard modules

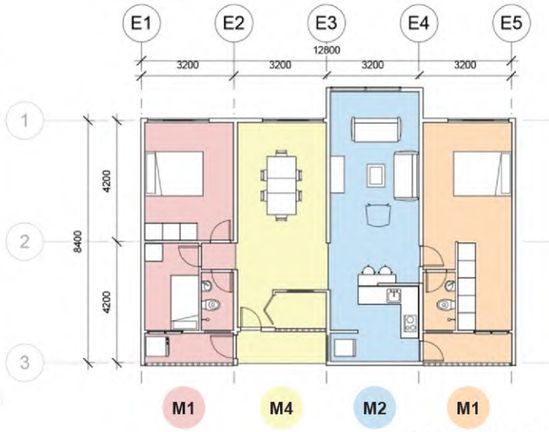


2-Bedroom Flat
57.1 sqm/614 sqft

1-Bedroom Flat
57.1 sqm/614 sqft

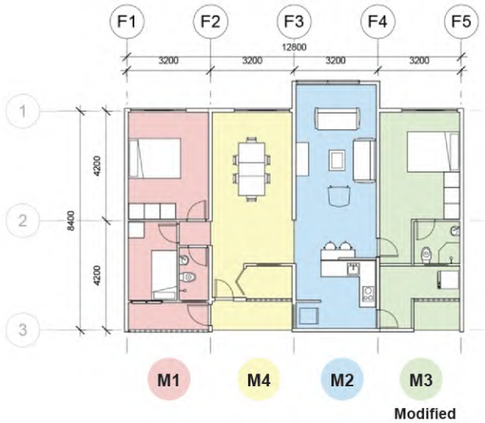


3-Bedroom Flat
84 sqm/904 sqft



Reversed & Modified

3-Bedroom Flat Type A
111 sqm/1195 sqft



Modified

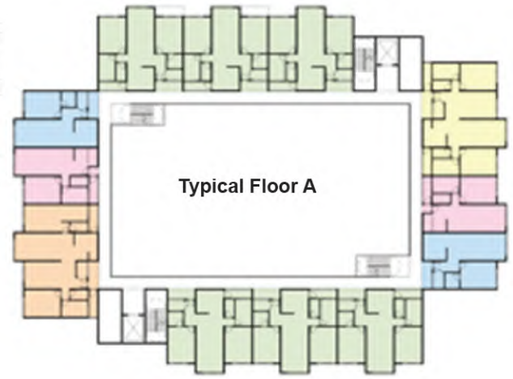
3-Bedroom Flat Type B
111 sqm/1195 sqft



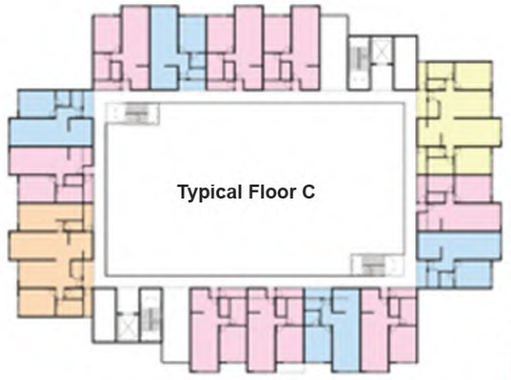
Reserved

4-Bedroom Flat
111 sqm/ 195 sqft

SECTION A







Each tower block will be a mix of 3 typical floor plate plans. The floor plates are arranged alternately to effectively create less monotony and regularity on the facades and housing environment.



Distribution of home types within a tower block

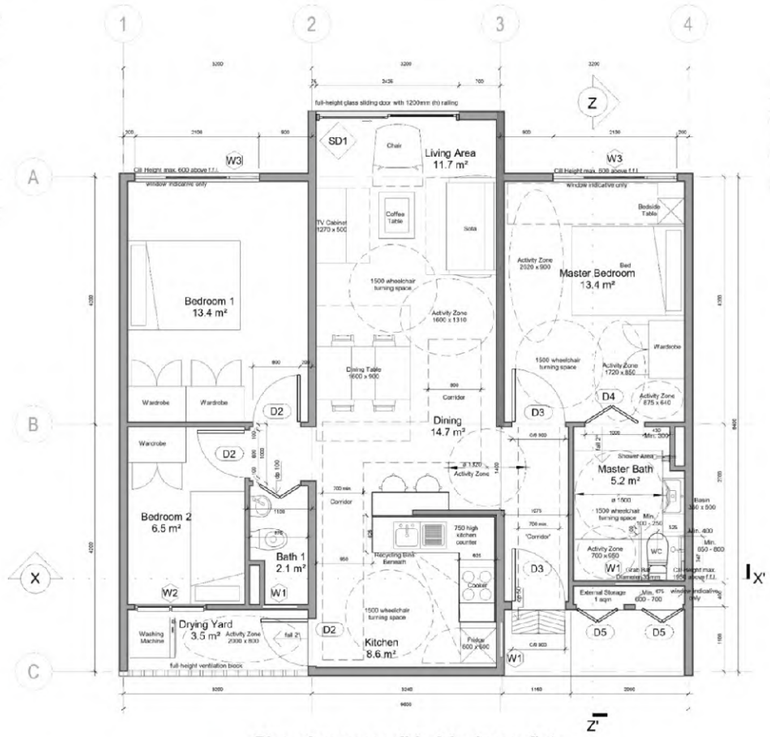
House Type	Area (sqft)	Units (per floor) 16 Floors	Units (1 block)	Percentage (%)	Units (2 blocks)
1-Bedroom Flat	614	1/2/4	27	17%	54
2-Bedroom Flat	614	2/3/8	53	32%	106
3-Bedroom Flat	904	0/3/6	45	27%	90
3-Bedroom Flat Type A	1195	1	14	8%	28
3-Bedroom Flat Type B	1195	0/2	14	8%	28
4-Bedroom Flat	1195	1	14	8%	28
	Total	11/12/14	167	~100%	334

A total of 167 home units are provided within a single 16-storey tower block.



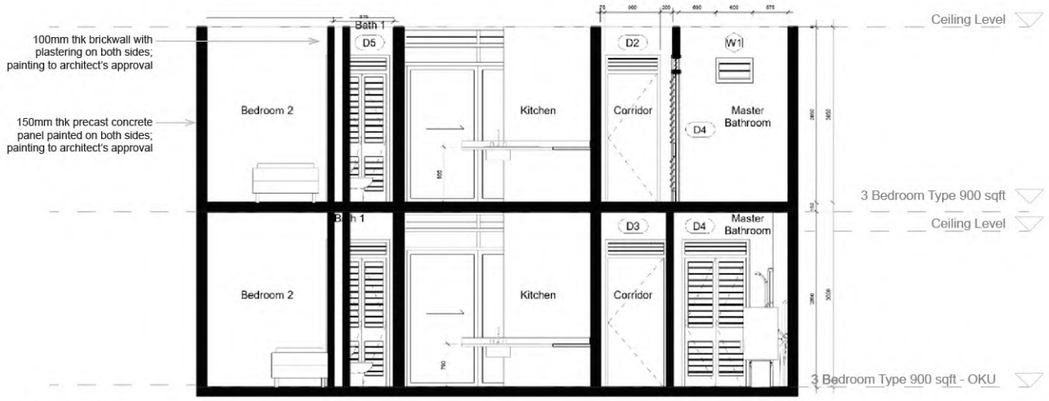
Cross section through a tower block

3.1.6. Accessibility of high-rise flats

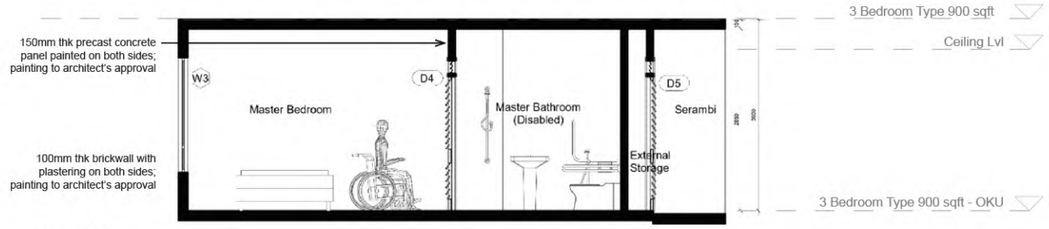


Plan of an accessible 3-bedroom flat

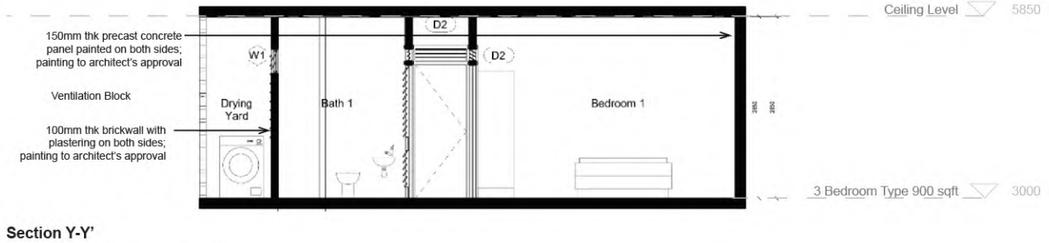
Area	De-Program House (sqm)	UBBL (sqm)	UK Standard (sqm)
Bedroom 1	13.4	6.5<	10.0<
Bedroom 2	6.5	6.5<	6.5<
Master Bedroom	13.4	9.3<	10.0<
Kitchen	8.6	4.5<	24<
Living Area	11.7	11<	24<
Dining	14.7	-	24<
Bath 1	2.3	1.5<	-
Master Bathroom (Disabled)	5.3	1.5<	-
Dry Yard	3.5	-	-



Section X-X'



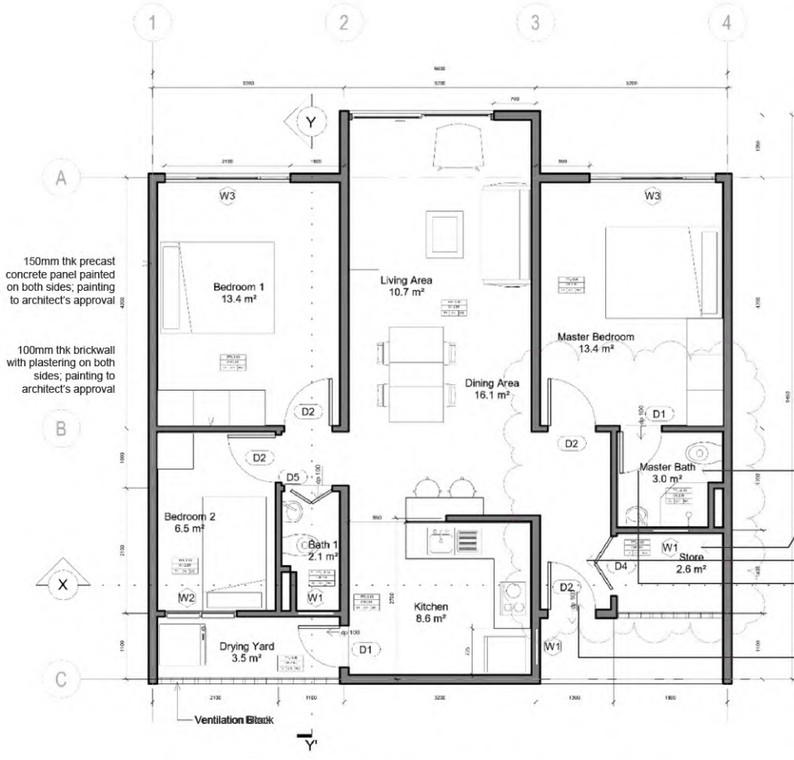
Section Z-Z'



Section Y-Y'

Sections through an accessible 3-bedroom flat

SECTION A



FFL 0.000			FLOOR, WALL AND CEILING SPECIFICATION
CEILING HEIGHT			
FLOOR	WALL	CEILING	
FLOOR			
T1			HOMOGENOUS TILES (600x1200mm) Niro Bloomsbury-Code:LIGNITE GBB03
T2			HOMOGENOUS TILES (200x230mm) Musha Series from Terracota
T3			CEMENT RENDERED
WALL			
W1			CERAMIC WALL TILES (200x230mm) Musha Series from Terracota
W2			PLASTERED AND PAINT
CEILING			
C1			PAINT ON SLAB

CHANGES FOR OKU

1. Wider bathroom area
2. Store area changed to external storage
3. Corridor in front of entrance dimension's widen
4. Door type from bedroom to bathroom changed to store door type
5. Door size changed from 900 mm to 1000 mm (W)

Modifications to a standard 3-bedroom flat to transform it into an accessible flat



3.1.7. Natural ventilation and natural daylighting of high-rise flats



Building proportion and orientation are two of the main criteria in designing buildings in the tropics. Facades that face north and south are the most shaded from direct sunlight, keeping spaces cool throughout the day.



LOUVRE WINDOWS | VENTILATION BLOCKS | LOUVRE PANELS WITH SLIDING DOOR | LOUVRE PANEL WITH FIXED-PANEL WINDOW | LOUVRE PANEL ABOVE DOOR | LOUVRE PANEL STORE DOOR

SECTION A

a) Natural Ventilation

Each flat has a layout that allows cross ventilation to occur throughout the spaces. The use of ventilation blocks and louvred panels encourages ventilation while maintaining security and safety. Rooms with single window openings are complemented with louvred panels above the doors to help circulate air within the rooms. Ceiling fans are extensively used in all rooms to bolster air circulation.



1-bedroom Flat



2-bedroom Flat



3-bedroom Flat



4-bedroom Flat



3-bedroom Flat Type A



3-bedroom Flat Type B

b) Natural daylighting

Each flat is designed with high levels of natural daylighting in all the rooms. Louvred panels, sliding glass panels, and ventilation blocks are used to allow natural light to emit deep into the internal spaces.



1-bedroom Flat



2-bedroom Flat



3-bedroom Flat



4-bedroom Flat

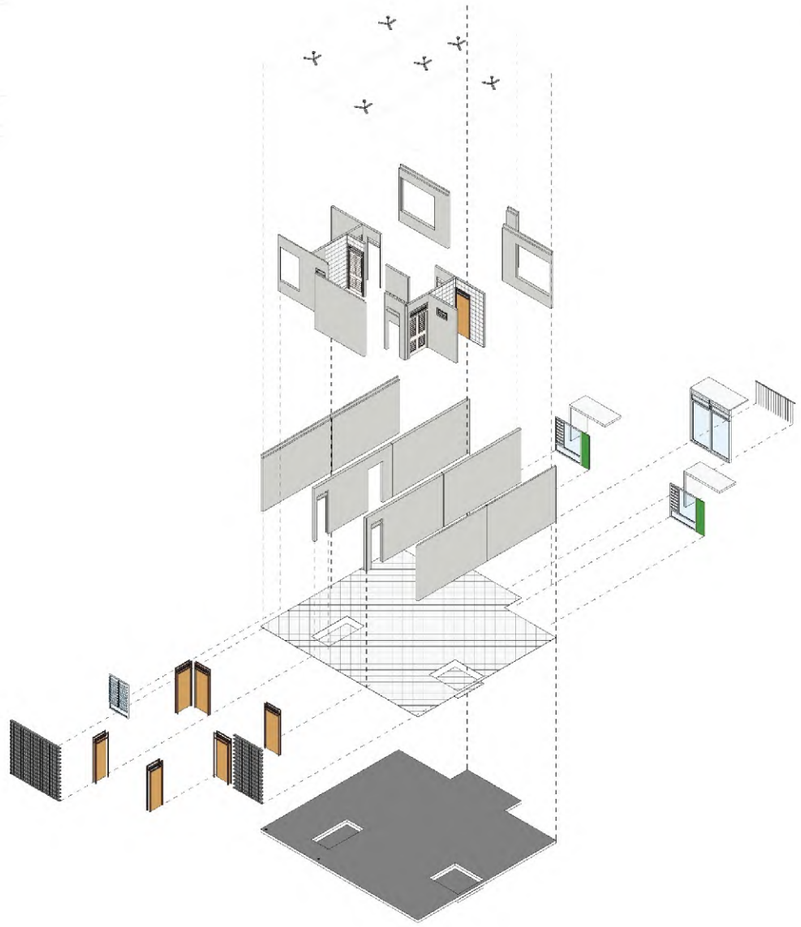


3-bedroom Flat Type A



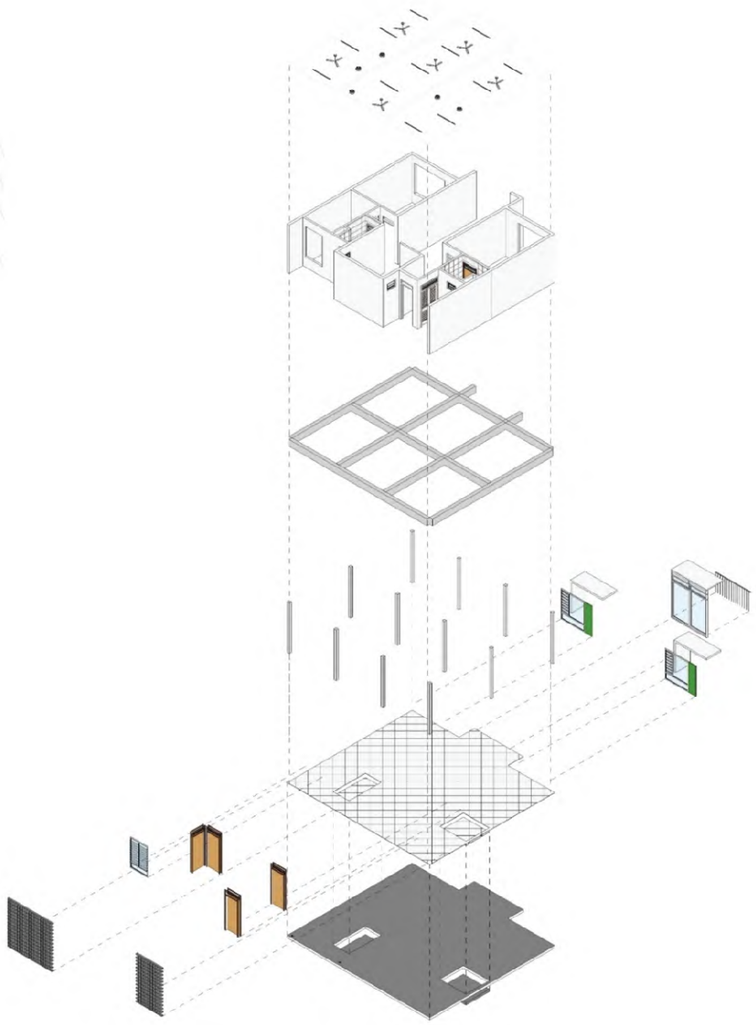
3-bedroom Flat Type B

3.1.8. Industrialised building system (IBS) of high-rise flats



Precast Wall and Precast Slab

The use of precast walls and modular elements such as doors, windows, and vent-block panels can produce more economical design while maintaining high levels of workmanship and speed of delivery.



Precast Column and Beam Structural System

The use of precast IBS column, beam, and wall system along with modular elements such as doors, windows, and vent-block panels can produce more economical design while maintaining high levels of workmanship and speed of delivery.

3.1.9. Visuals of high-rise flats

View of the Podium Level



View of the Corridors



Ground Level View



Podium Level View



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Roof Garden & Allotment View

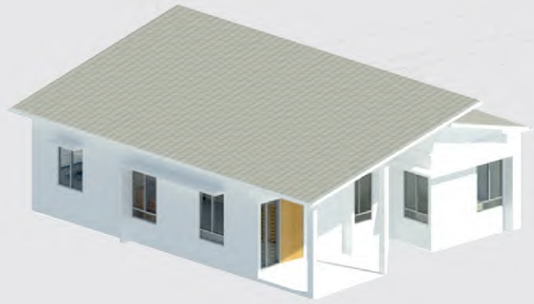




SECTION A

3.2. Rural Bungalows

3.2.1. Introduction



A standard roof type



A butterfly roof type

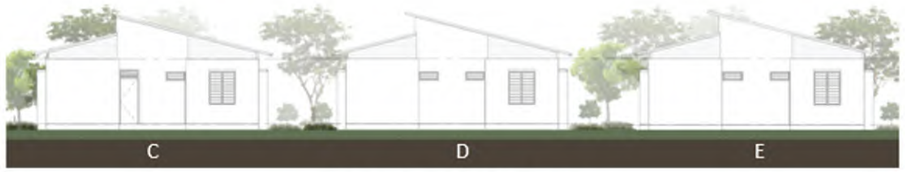
Rural bungalows are designed to cater to rural landowners who receive subsidised incentives to build their own homes. Mainly single-storey structures, the proposal features simple 3-bedroom homes with an improved layout that bolters natural ventilation and lighting. The proposed design also features modularity and IBS.



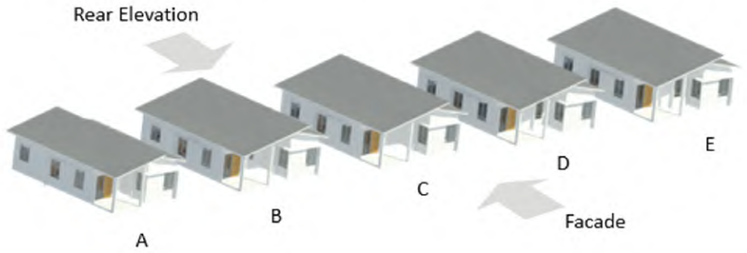
A typical 3-bedroom rural bungalow

3.2.2. Design features of rural bungalows

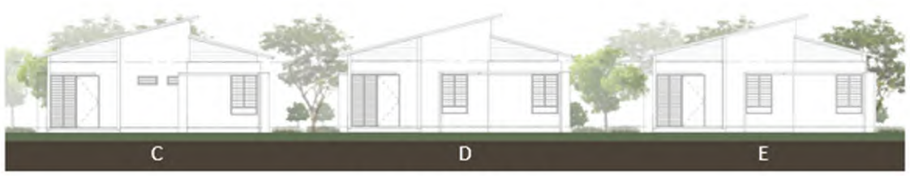




Rear elevation (standard roof)

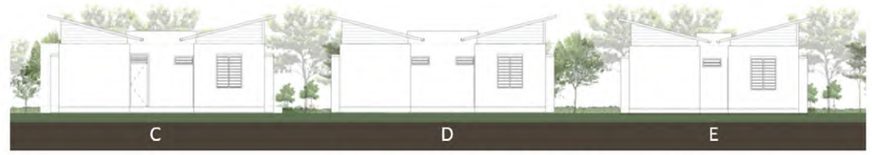




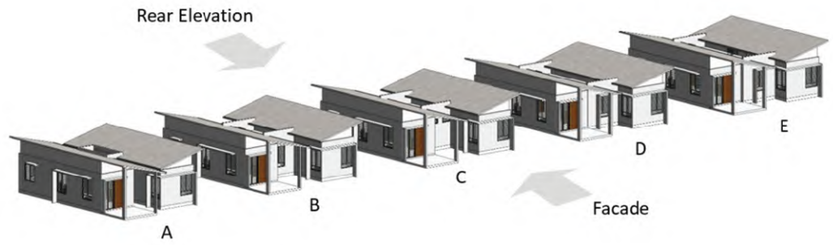


Façade (standard roof)





Rear elevation (butterfly roof)

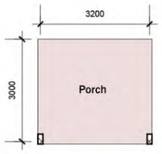






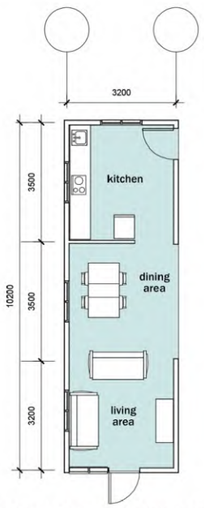
Façade (butterfly roof)

3.2.3. Modular design of rural bungalows



PORCH

FM1



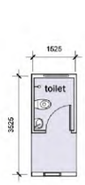
KITCHEN/DINING/LIVING

FM2



3 BEDROOM

FM3



BATH

A



FAMILY AREA

B



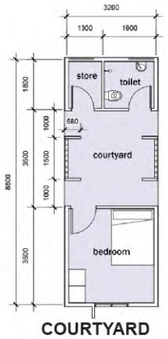
BATH/STORE

C



BEDROOM

D



COURTYARD

E

The design features a kit of modular volumes that could be mixed and matched to provide different layout variations to suit new homeowners' needs.

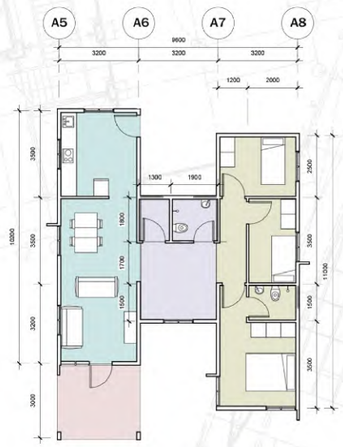
SECTION A



FM2 A FM3

FM1

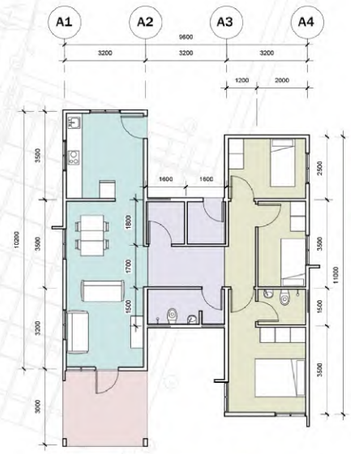
TYPE A
73sqm/785sqft



FM2 B FM3

FM1

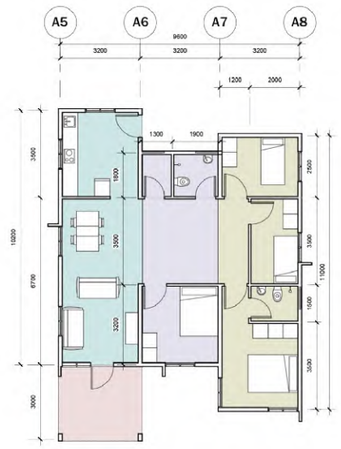
TYPE B
83.6sqm/900sqft



FM2 C FM3

FM1

TYPE C
83.6sqm/900sqft



FM2 D FM3

FM1

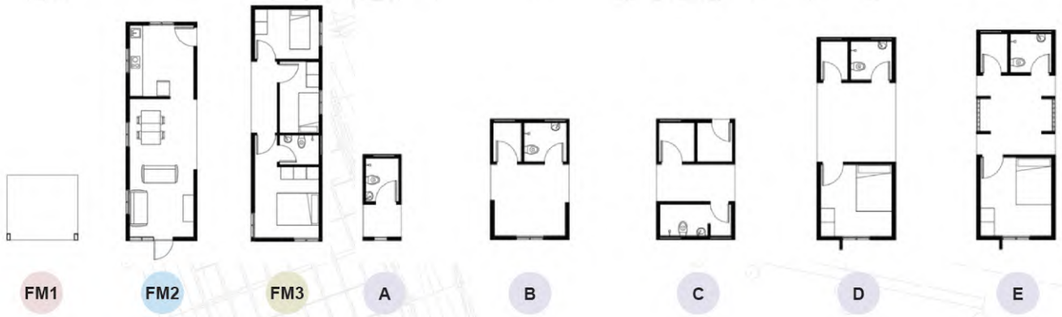
TYPE D
95sqm/1023sqft



FM2 E FM3

FM1

TYPE E
96qm/1033sqft





SECTION A

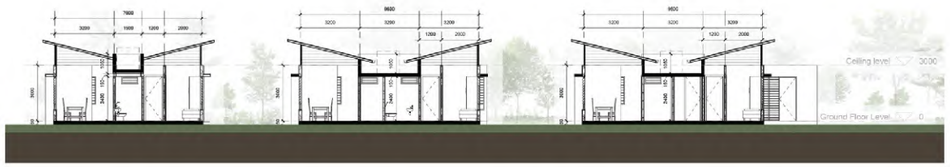


Plan View: Type A, Type B, Type C, Type D, Type E





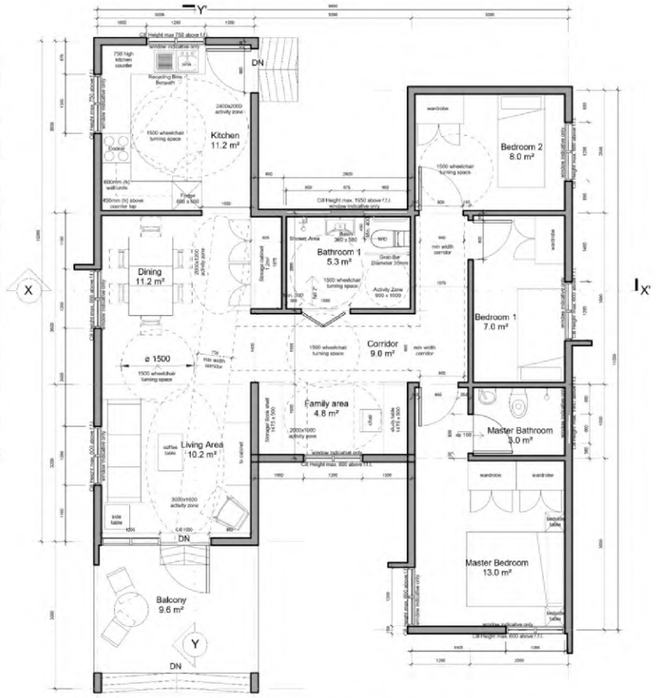
Cross-section (standard roof)





Cross-section (butterfly roof)

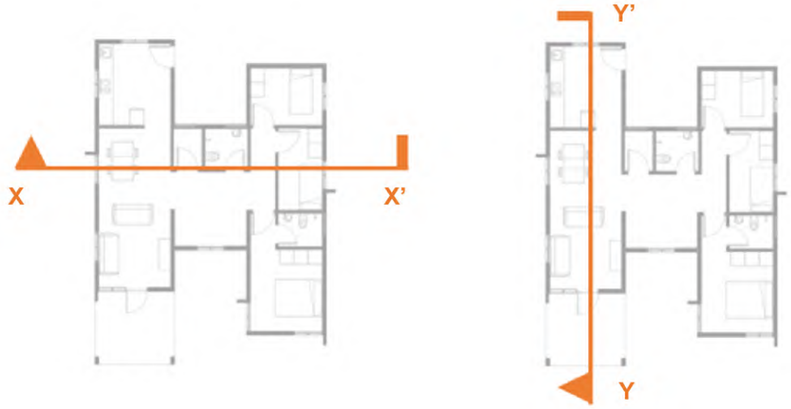
3.2.4. Accessibility of rural bungalows

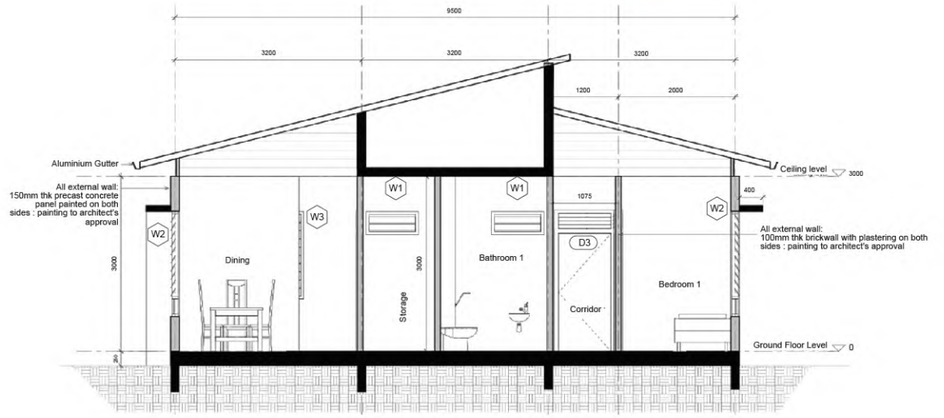


Rural Bungalow Type B

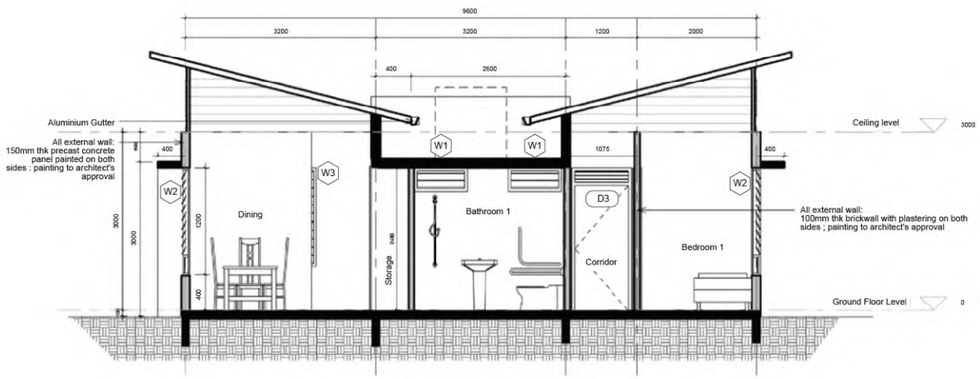
Area	De-Program House (sqm)	UBBL (sqm)	UK Standard (sqm)
Bedroom 1	13.4	6.5<	10.0<
Bedroom 2	6.5	6.5<	6.5<
Master Bedroom	13.4	9.3<	10.0<
Kitchen	8.6	4.5<	24<
Living Area	11.7	11<	24<
Dining	14.7	-	24<
Bath 1	2.3	1.5<	-
Master Bathroom (Disabled)	5.3	1.5<	-
Dry Yard	3.5	-	-

SECTION A



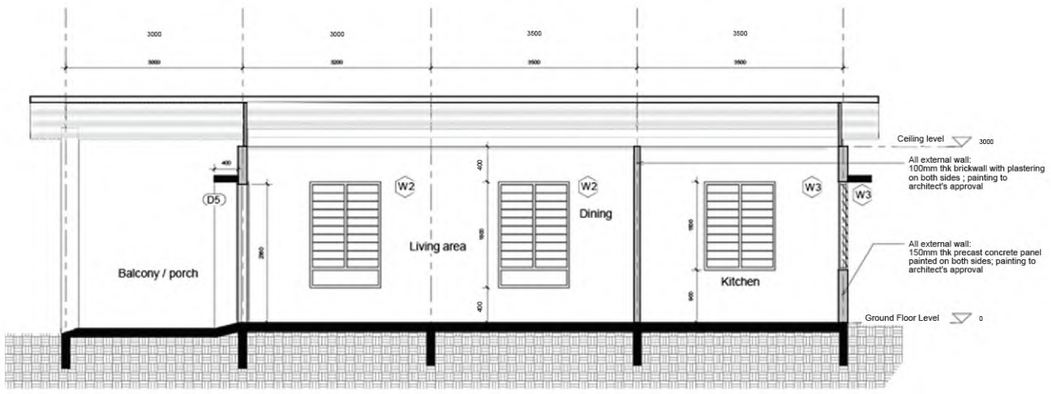


Section X-X' (standard roof)

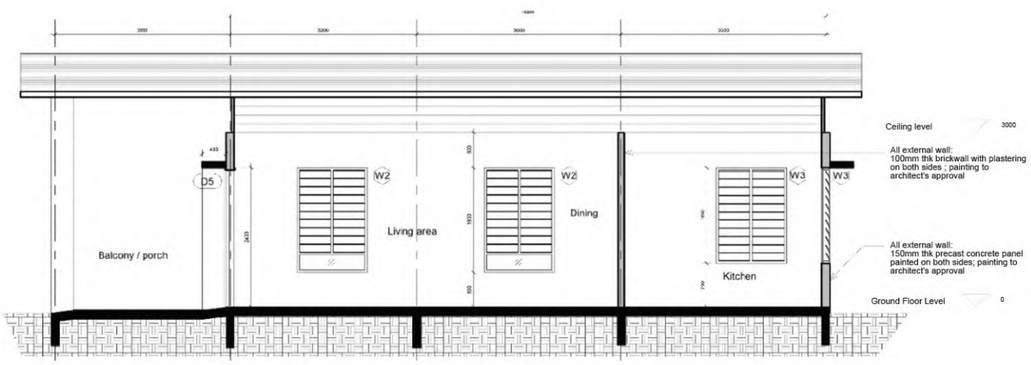


Section X-X' (butterfly roof)





Section Y-Y' (standard roof)



Section Y-Y' (butterfly roof)

SECTION A

3.2.5. Natural ventilation and natural daylighting of rural bungalows

Each rural bungalow is designed to encourage cross ventilation and high levels of natural daylighting in all the rooms. Louvred panels, sliding glass panels, and ventilation blocks are used to allow natural lighting to emit deep into the internal spaces. High-level louvred openings above doors encourage ventilation further.



Type A



Type B



Type C









Type D



Type E





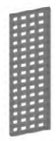
LOUVRE WINDOWS







LOUVRE PANELS BESIDE DOOR



VENTILATION BLOCKS

3.2.6. Design visuals of rural bungalows

View of the Courtyard



View of Living & Dining



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External View (front)







External View (side)



SECTION A

3.3. Terrace Homes

3.3.1. Introduction



Façade



Rear View

3.3.2. Design features of terrace home



Ground Floor
66sqm/710sqft

First Floor
60sqm/646sqft

Total Floor Area
126sqm/1356sqft



Ground Floor Plan

SECTION A





A practical way of assessing the ratio of occupancy



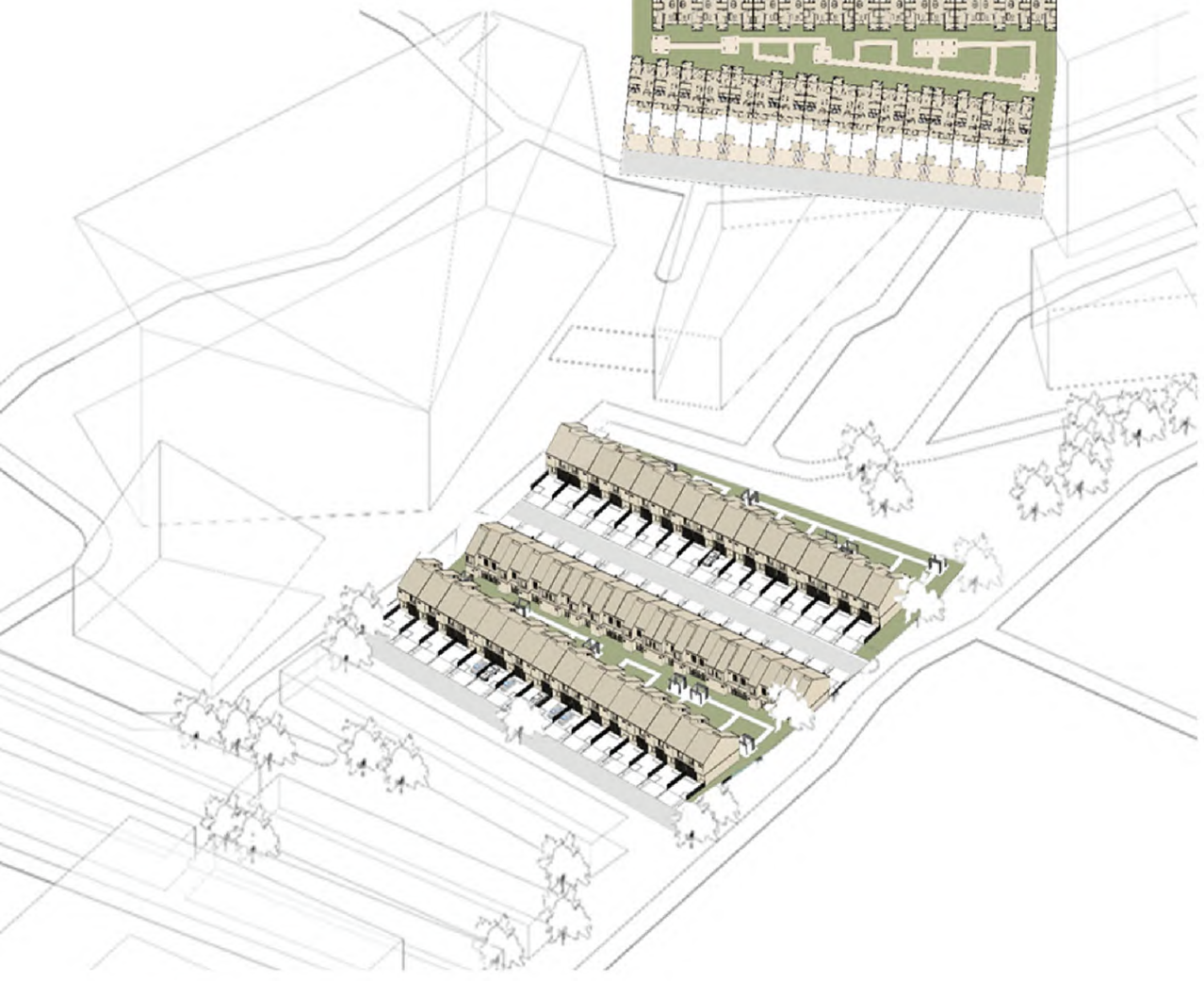
Façade



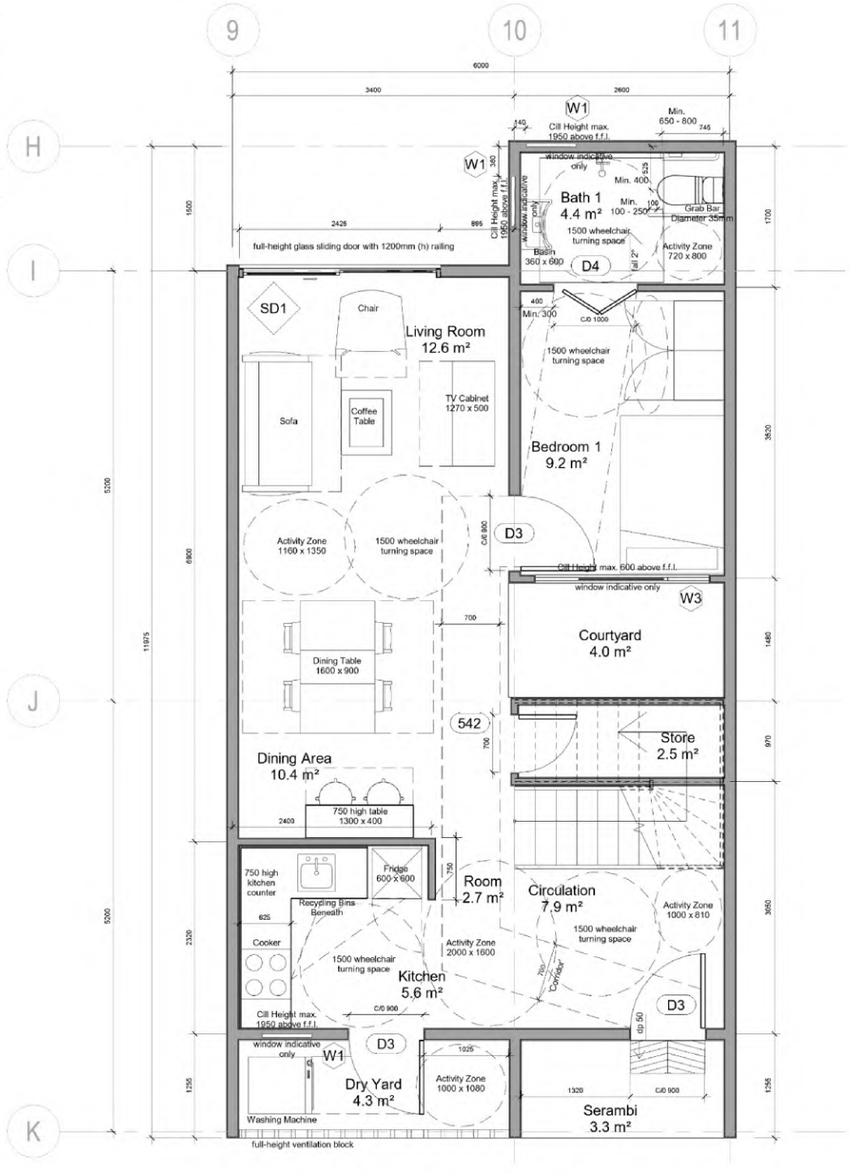
Rear Elevation

A view of a typical development of terrace homes

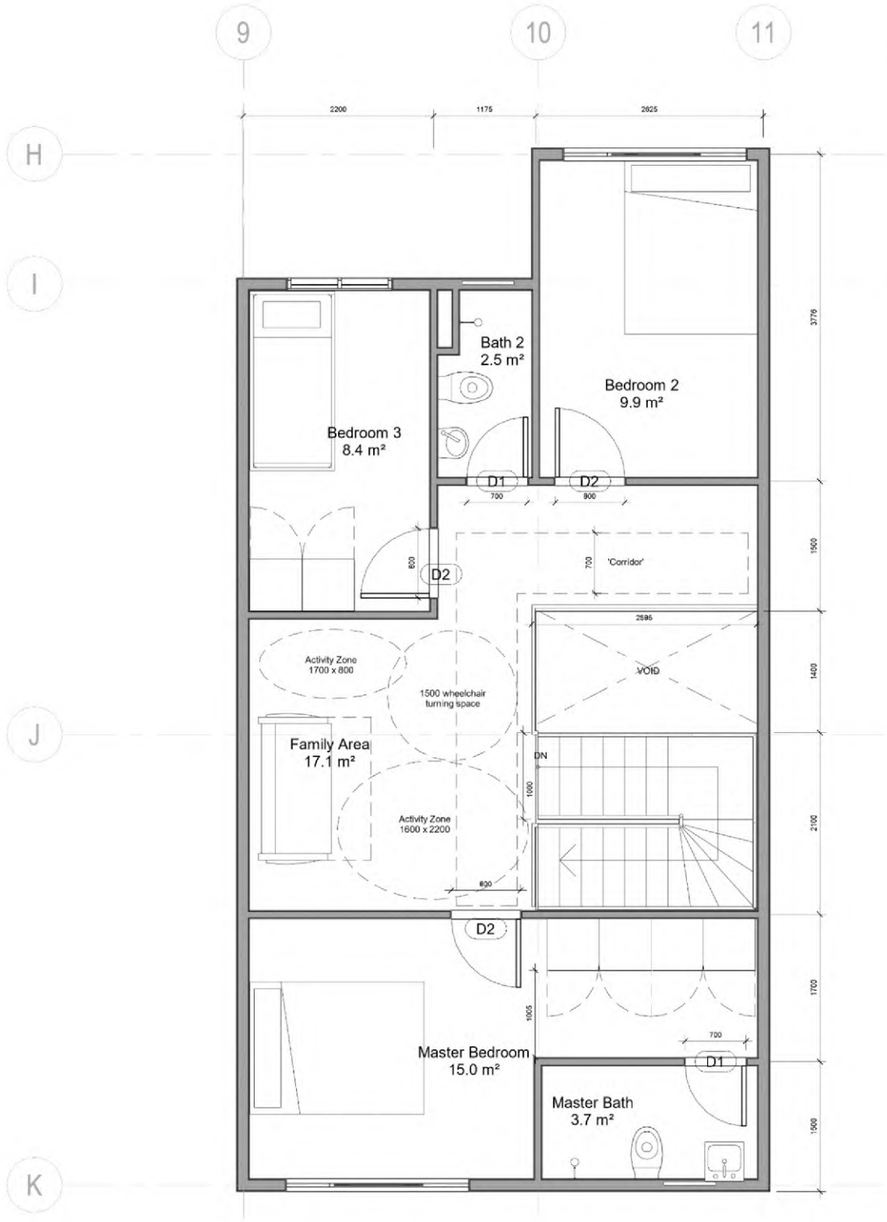




3.3.3. Accessibility of terrace home



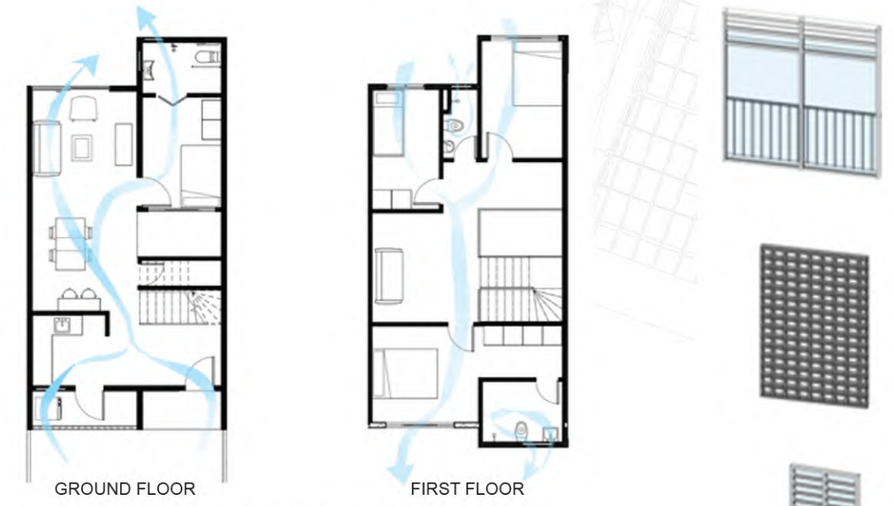
Terrace Home – Ground Floor



Terrace Home– First Floor

SECTION A

3.3.4. Natural ventilation and natural daylighting of terrace home



Natural cross ventilation



Natural daylighting

3.3.5. Design visuals of terrace homes

Street View



Back Lane View





Bird's Eye View

Back Lane View



3.4. Townhouses

3.4.1. Introduction



Façade



Rear View

3.4.2. Design features of townhouses



Ground Floor



First Floor

LEGEND

1. Car porch
2. Serambi
3. Store
4. Bathroom 1
5. Corridor
6. Bedroom 1
7. Living area
8. Bedroom 2
9. Bathroom 2
10. Dining area
11. Kitchen
12. Bedroom 3
13. Drying yard
14. Study room
15. Roof terrace

TOTAL FLOOR AREA:

Type A: 184sqm/1981sqft
Type B: 175sqm/1884sqft



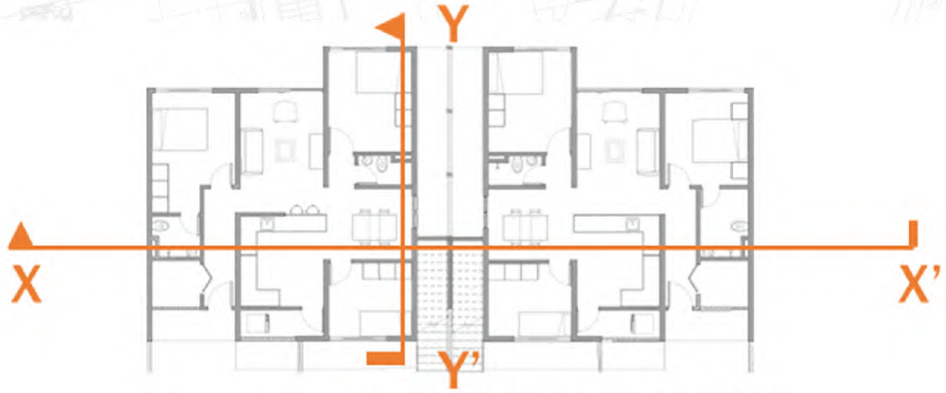
Ground Floor



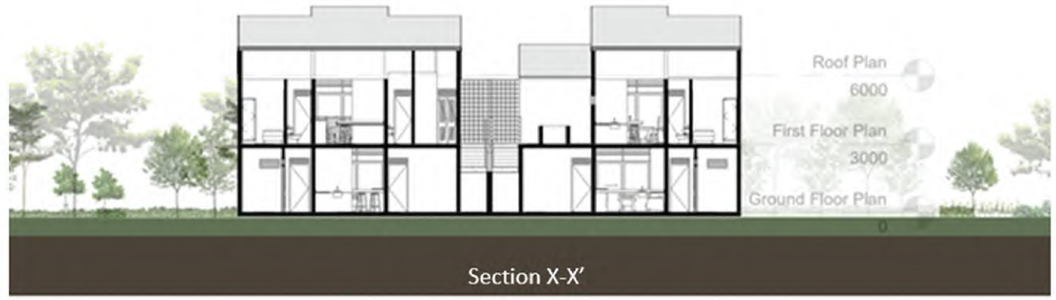
First Floor

TOWNHOUSE TYPE A (G)
TOWNHOUSE TYPE B (G)
TOWNHOUSE TYPE A (1)
TOWNHOUSE TYPE B (1)

SECTION A



Ground Floor Plan : Townhouse Type A, Townhouse Type B





A practical way of assessing the ratio of occupancy



Façade

From Left (Ground Floor) : Townhouse Type A(G), Townhouse Type B(G)
(First Floor) : Townhouse Type B(1), Townhouse Type B(2)



Rear Elevation

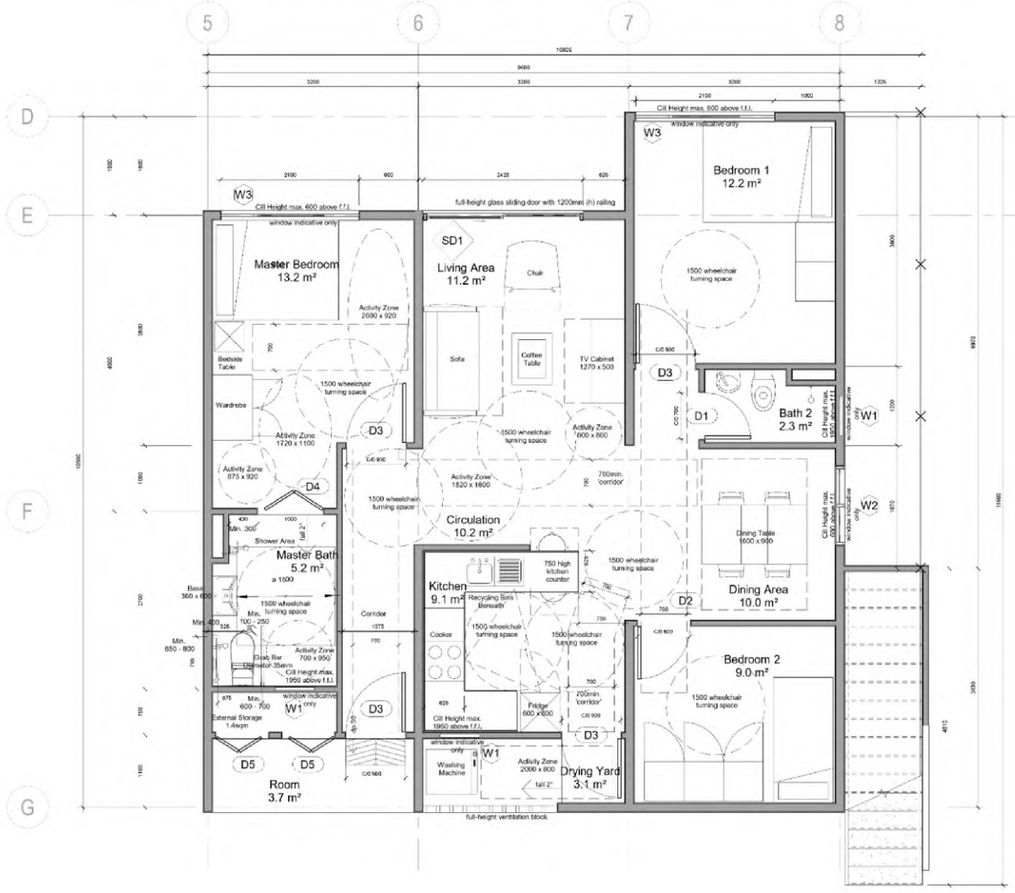
From Right (Ground Floor) : Townhouse Type A(G), Townhouse Type B(G)
(First Floor) : Townhouse Type A(1), Townhouse Type B(1)

SECTION A

A view of a typical development with a housing mix consisting of terrace homes and townhouses types A and B. The mix encourages more diversity within a development.



3.4.3. Accessibility of townhouses



Townhouse Type A – Ground Floor Unit

SECTION A

3.4.4. Natural ventilation and natural daylighting of townhouses



Natural cross ventilation



Natural daylighting

3.4.3. Accessibility of townhouses



Street View



Back Lane View

SECTION A

3.5. Terrace Homes and Townhouses

3.5.1. Introduction

In this section, terraced homes and townhouses are proposed to combined to create a dynamic housing development that caters to the multiple requirements of homeowners.



Façade



Rear view

3.5.2. Design features of terrace homes and townhouses

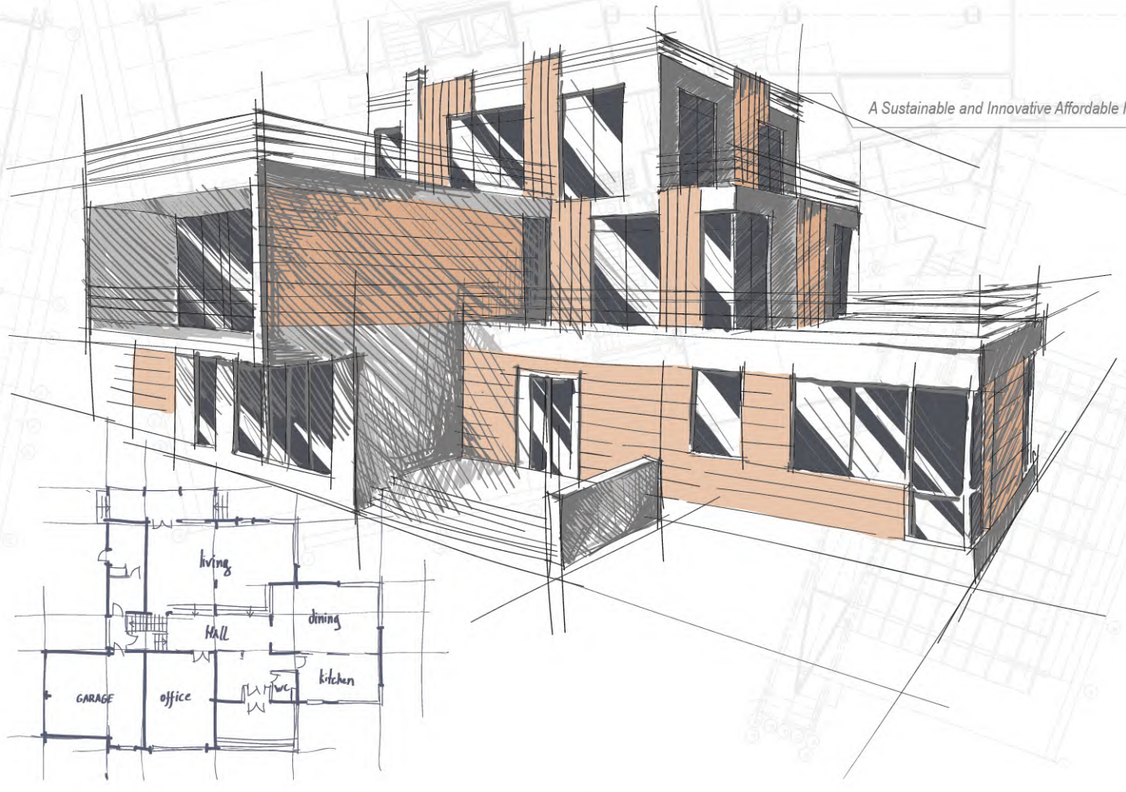


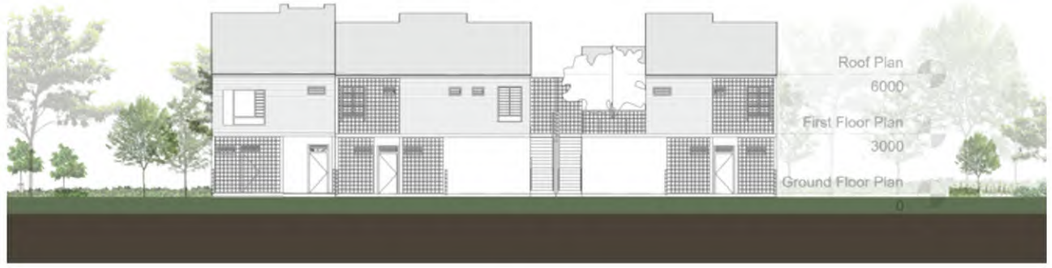
Ground Floor Plan : Terrace Home (TR), Townhouse Type A, Townhouse Type B,





A practical way of assessing the ratio of occupancy





Façade

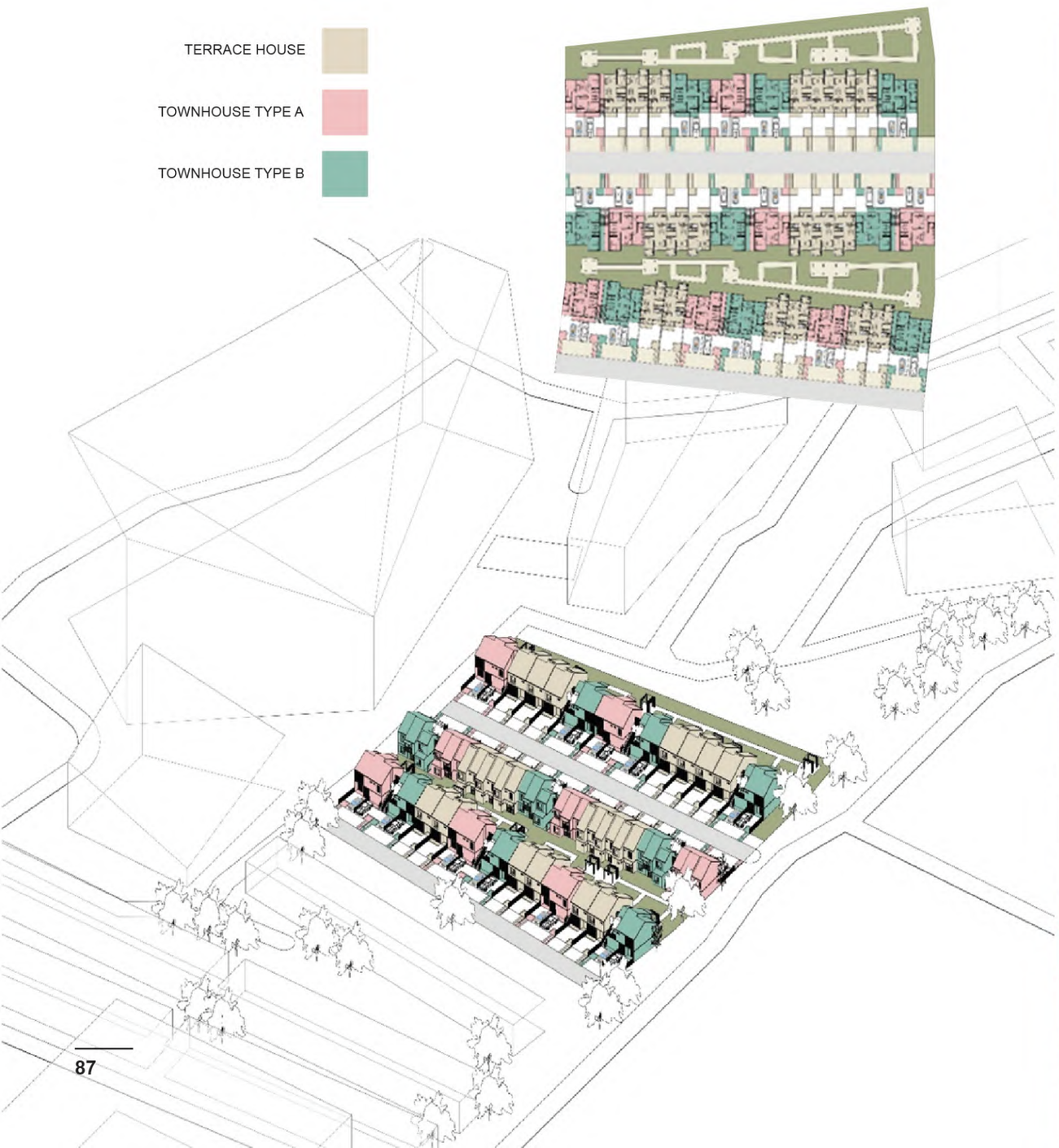
From Left : Terrace House, Townhouse Type A, Townhouse Type B



Rear Elevation

From Right : Terrace House, Townhouse Type A, Townhouse Type B

A view of a typical development with a housing mix consisting of terrace houses and townhouses types A and B. The mix encourages more diversity within a development.



3.5.3. Design visuals of terrace homes and townhouses

Street View



Back Lane View

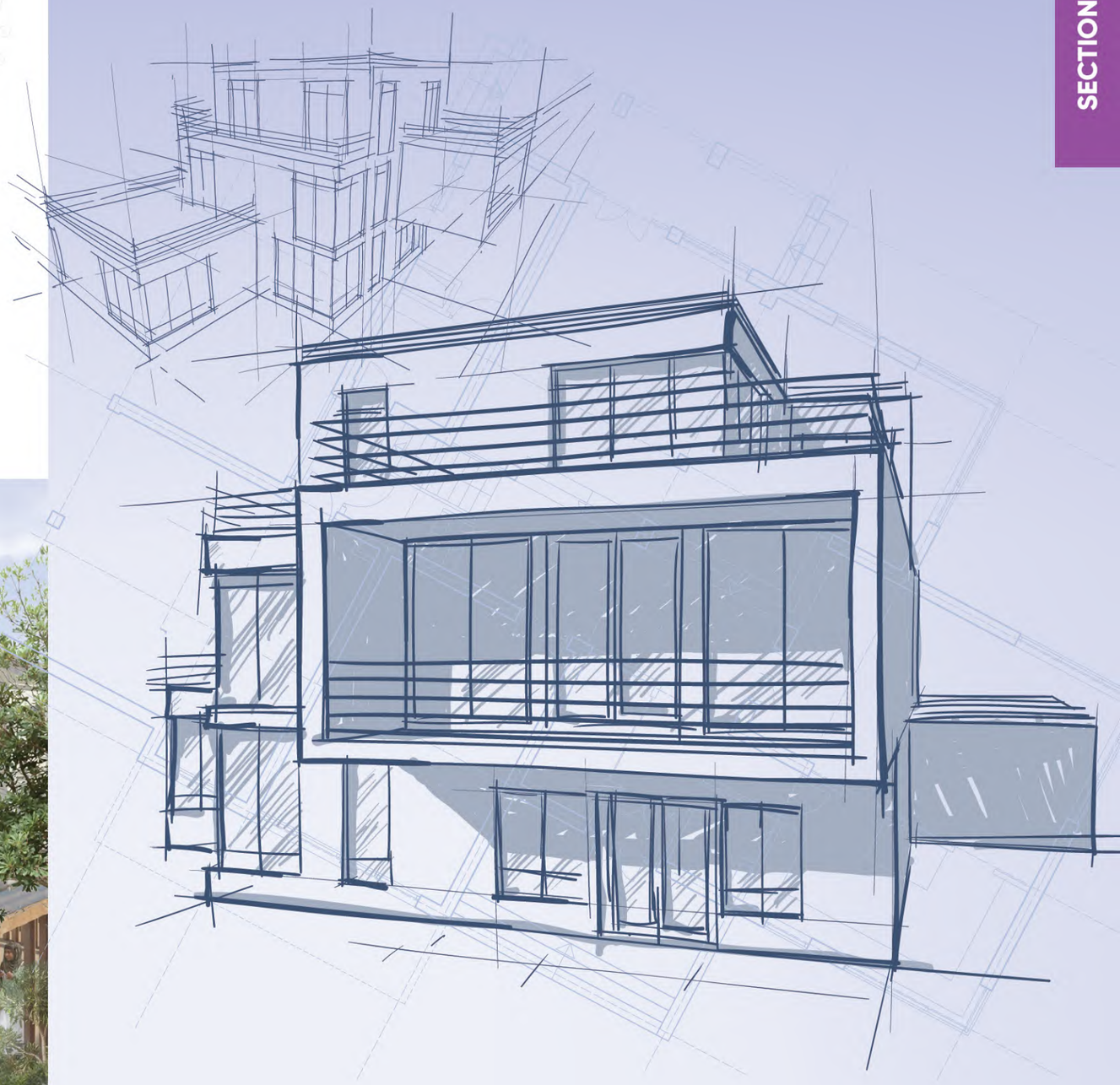




Bird's Eye View

Back Lane View







SECTION B:

HANDBOOK FOR STRUCTURAL ENGINEERS

B1 **Brief Introduction**

B2 **Advantages of Precast Homes**

B3 **Design Approach**
3.1 Precast Concrete Wall
3.2 Precast Concrete Slab

B4 **Design Consideration**
4.1 Precast Load Bearing Wall Design
4.2 Precast Half Slab Design
4.3 Precast Connection

B5 **Method of Installation**
5.1 Starter Bar and Level Setting Out
5.2 Precast Wall Panel Installation
5.3 Precast Slab Installation

B6 **Precast Concrete Production Process**

Written by:

NS PREFAB CONSULTANCY

GREENIBS CONSULT



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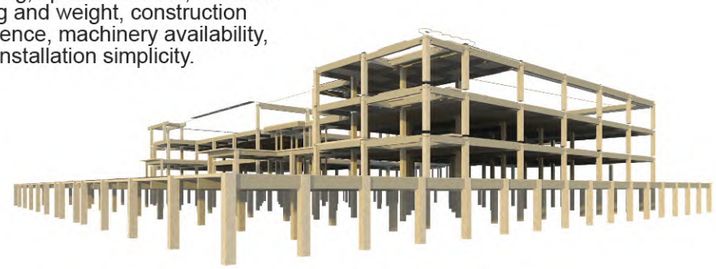
B1 BRIEF INTRODUCTION

Precast technology is widely regarded as an economical, durable, environmentally friendly, structurally sound, and architecturally versatile form of construction. The precast concrete industry is continuously making efforts to develop in tandem with the demands of modern society in economic, efficiency, technical performance, safety, labour circumstances, and environmental friendliness aspects.

Engineers and other industry players often view precast construction as a mere improvisation of the cast-in-situ traditional execution method whereby prefabrication means the structure and architectural elements are pre-fabricated at a specialised yard, transported, and installed at the designated position at the site, as the same concept of cast-in-situ structure is achieved again. This view is somewhat inaccurate as every construction method has its unique characteristics, and the efficiency of a precast system is always at the highest level in terms of structural layout, grid spacing, span and width, element sizing and weight, construction sequence, machinery availability, and installation simplicity.

The success stories of precast buildings always entail detailed pre-planning from the preliminary stage until the building completion including the design stage (before tender), shop-drawings preparation, production of elements, installation stage, as well as coordination with other architectural elements.

A precast concrete structure consists of an assemblage of precast elements which, when suitably connected, form 3D frames to satisfy both vertical and horizontal loads. Two of the most familiar precast systems are precast frame system and precast load-bearing wall system.
The existence of the precast concrete industry and the numerous successful building projects achieved using precast concrete either as a whole structure or just as a part of it is proof of the practicality and economic viability of the technique.



Typical precast concrete structures

B2 ADVANTAGES OF PRECAST HOMES

Precast home building provides an excellent way to control costs while ensuring the process moves along more quickly. Its advantages and disadvantages vary according to the particular situation, budget, preferences, and timeline.

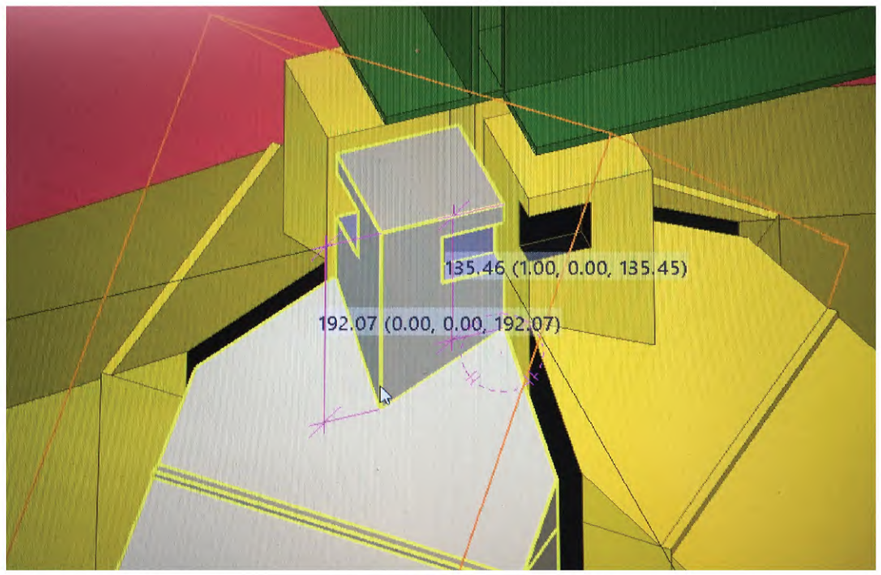
Less Expensive than Traditional Home Builds	• Building component cost per-structural capacity is comparable to other materials • The overall building costs, inclusive of transport, fixing finishing, maintenance and repair are competitive with the right economies of scale
Faster than Traditional Construction	• Construction sequence is sensible, enabling other trades to dovetail into programmes • Construction is safe and temporary stability is guaranteed • Economic cranes are used • Minimum numbers of skilled labour are engaged • The installation of building services can be integrated into the precast elements (variety of holes, fixing, conduits, piping, etc.)
Flexible Size and Aesthetic	• Standardised elements can adopt flexible shapes to adhere to architectural creativity • A wide variety of surface appearances and finishes can be produced
Optimum use of materials	• Reduce timber formwork at the site • Reduce material wastage as detailed planning is done at an early stage
Fast to erect	• Clear heights and floor zones are satisfied • Following trades (brick-layers, electricians, joiners) can move in quickly • Decorative, both internally and externally may be exploited
Factory-made products	• Better quality control • Pre-stressing element can be employed

B3 DESIGN APPROACH

Under the traditional approach, the architect's main role is to satisfy the functional and aesthetic requirements of the user (client), while the engineer prepares and designs the structural members to suit the architectural plans and elevation. The design for precast construction should go beyond that by considering architectural and structural particularities of the precast production methodology. This should lead to full coordination of the final design (shop drawings preparation) incorporating all the mechanical and electrical (M&E) services and architectural features before proceeding to the production work stage at the precast yard.

The key aspect towards achieving an efficient and economical precast design is by simplifying the structure through uniformity and regularity of the geometrical configuration both in plan and elevation. The configuration should allow for a standardised, clear, and simple load path to enable the utilisation of standard elements that require minimal or no special treatments.

The precast designer should approach the structural frame as a whole rather than as an arbitrary set of elements, as the designer needs to analyse the component design and structural stability for all different stages simultaneously.



Precast slanting beam connection

The preliminary design stage should include but not limited to the following aspects:

a) Skeletal structure for horizontal and vertical load transfer

b) Frame stability

c) Frame integrity

d) Type of component selection

e) Connection design

f) Sequence of the installation process

g) Machinery limitation (crane and transporter)



Crane reach & capacity

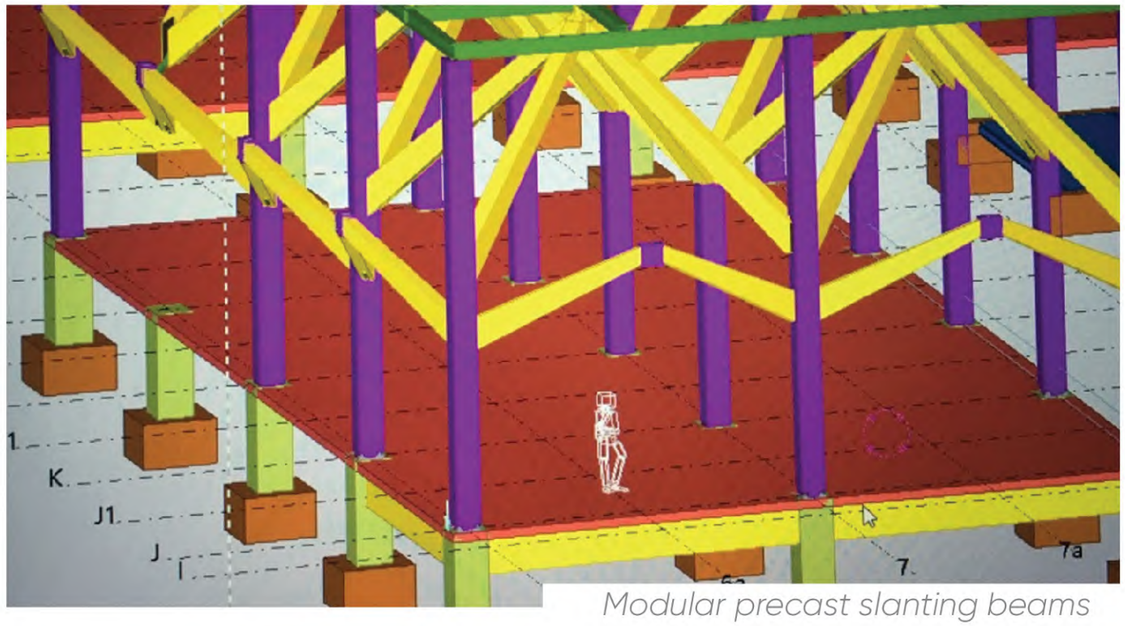


Propping requirement for installation

All of these aspects need to be dealt with comprehensively as they have major implications on the feasibility of the proposed design. For example, the continuity of adjacent elements based on the selected type of connection is one of the factors that determine the prop and material to use for installation to provide stability at the temporary stage. Logistic planning (crane reach and capacity, site access) is important for the designer in determining the component sizes that ensure the practicability of a design.

The use of standardised solutions, whenever possible, can facilitate the production of economical yet flexible designs. Standard modules would allow the use of standard components that are available in the market, while ample numbers of repetitive elements would enable economic fabrication of new moulds. As the industry shifts towards a higher degree of industrialisation, design flexibility can be enhanced by utilising the latest fabrication technology machines.

A standard approach also reduces the need for complex details, which can affect the speed of work during the design, manufacturing, or installation stage at the site. A good design should always use details that are as simple as possible.



Modular precast slanting beams

3.1. Precast Concrete Wall

Precast wall systems are mostly used in the construction of residential buildings for both landed housing and apartments. The advantages of these systems include prefinished products, speedy installation, embedded mechanical services, preinstalled door and window frames, and better quality control.

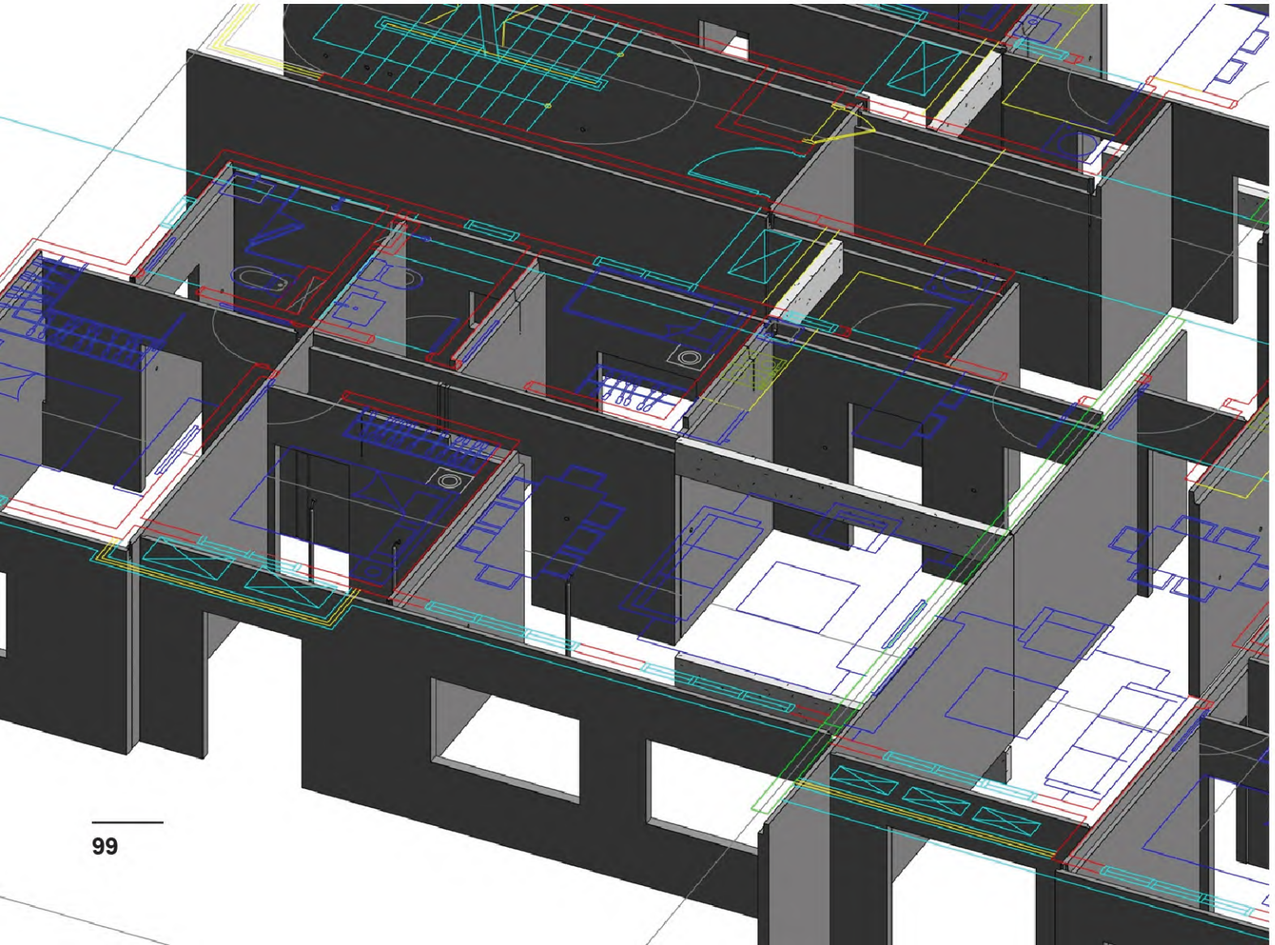
Precast wall frames consisting of vertical load-bearing and horizontal slab units are designed to sustain the vertically and uniformly distributed loads transmitted from the roof and respective floors and to cater to the horizontal force, respectively, in order to provide overall building stability.

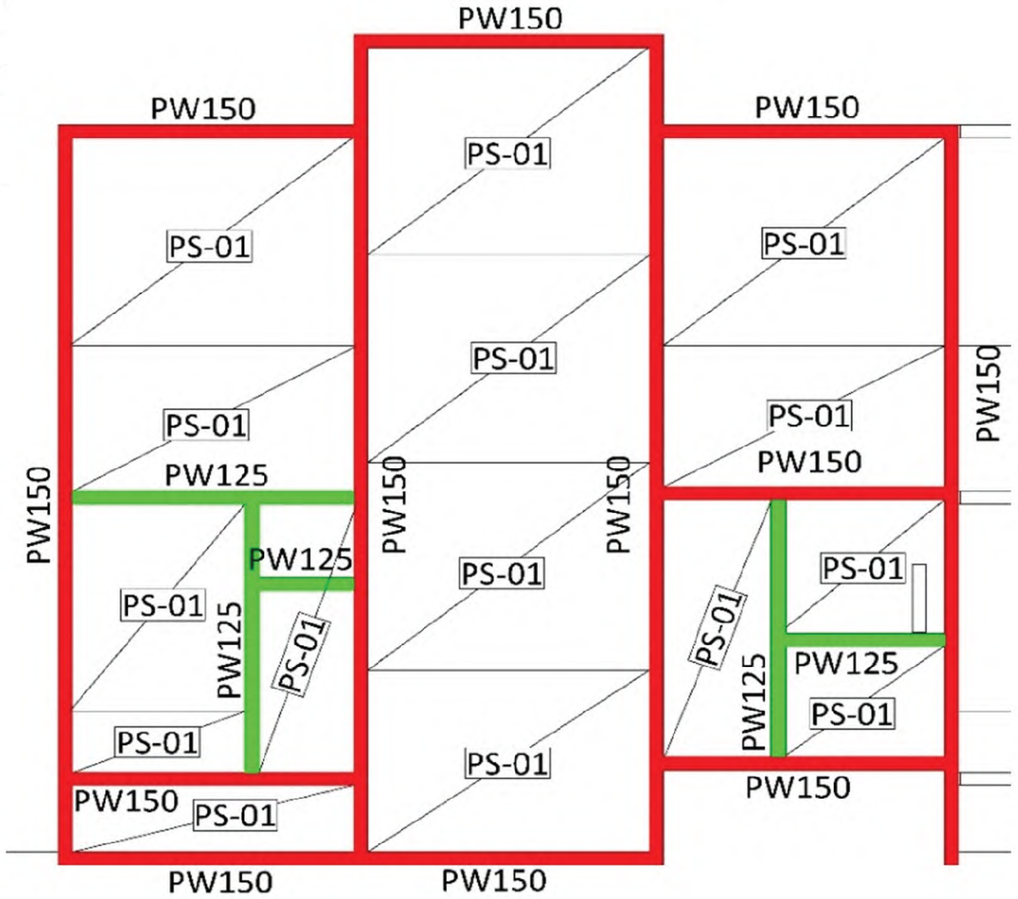
These precast walls are subsequently supported by cast-in-situ transfer beams on the first floor or ground floor with cast-in-situ columns and stumps to the foundation.

Wall frames would be the obvious choice, as the walls are all load-bearing and they support one-way spanning floor slabs. Walls should preferably be arranged in a rectangular grid at a fixed modular distance for better economic advantages.

Wall frames may be more economical and are often faster to build, especially the external walls with pre-decorative finishing at the factory. The walls are pre-casted together with a doorframe, window frames, conduit, and piping to accelerate works at the site.

For better logistic planning, the self-weight of precast concrete wall units are limited to less than 5 tonnes per unit. The precast walls are designed with a maximum length of 4.8 m so that they can be easily stacked together on a trailer.

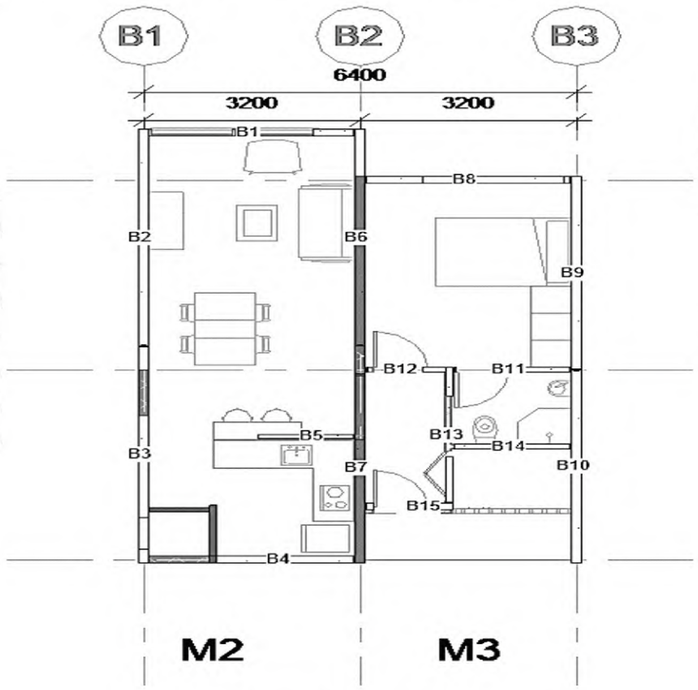




Legend:

1. *PW150 – Denotes a 150 mm thick precast wall*
2. *PW125 – Denotes a 125 mm thick precast wall*
3. *PS-01 – Denotes a 75 mm thick precast slab*

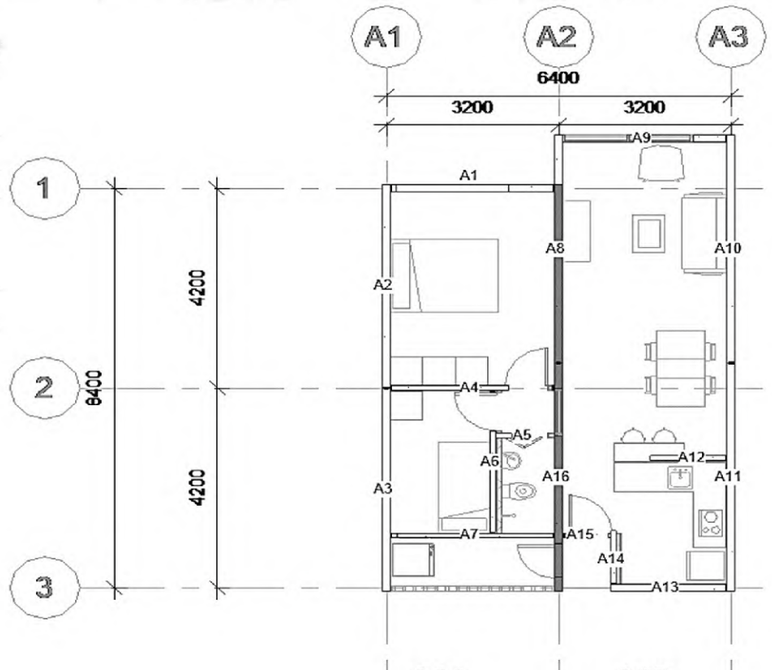
A typical precast design layout (3D & 2D layout)



A typical precast wall layout (1-Bedroom Flat)

Precast wall schedule (1-Bedroom Flat)

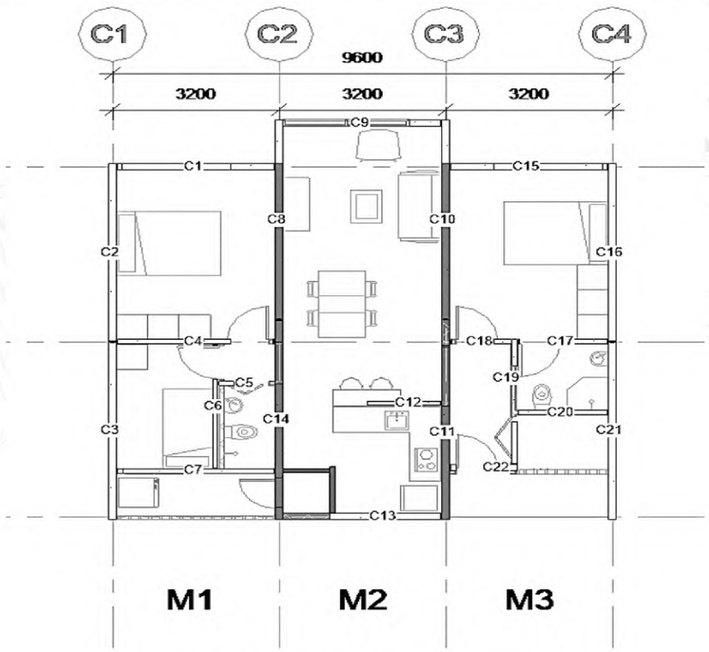
Panel Mark	Thickness (mm)	Length (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
NSP B1	150	3020	3000	0.26	0.62
B2	150	4795	3000	2.08	4.99
B3	150	4795	3000	1.47	3.54
B4	150	2135	3000	0.93	2.23
B5	125	1410	3000	0.40	0.95
B6	150	4795	3000	2.08	4.99
B7	150	4195	3000	1.26	3.02
B8	150	3020	3000	0.75	1.80
B9	150	4270	3000	1.85	4.44
B10	150	4270	3000	1.85	4.44
B11	125	1720	3000	0.31	0.75
B12	125	1170	3000	0.16	0.39
B13	125	2985	3000	0.56	1.34
B14	125	1720	3000	0.45	1.08
B15	150	1285	3000	0.30	0.72



A typical precast wall layout (2-Bedroom Flat)

Precast wall schedule (2-Bedroom Flat)

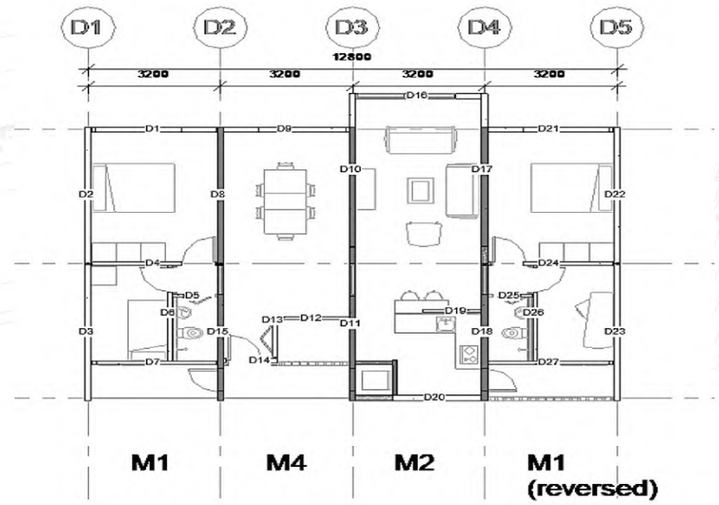
Panel Mark	Thickness (mm)	Length (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
A1	150	3020	3000	0.75	1.80
A2	150	4270	3000	1.85	4.44
A3	150	4270	3000	1.85	4.44
A4	125	3020	3000	0.68	1.64
A5	125	1070	3000	0.14	0.33
A6	125	2975	3000	0.67	1.61
A7	125	3020	3000	0.62	1.50
A8	150	4795	3000	2.08	4.99
A9	150	3020	3000	0.26	0.62
A10	150	4795	3000	2.08	4.99
A11	150	4795	3000	2.08	4.99
A12	125	1410	3000	0.40	0.95
A13	150	2135	3000	0.93	2.23
A14	125	1110	3000	0.31	0.75
A15	125	870	3000	0.08	0.18
A16	150	4795	3000	1.47	3.54



A typical precast wall layout (3-Bedroom Flat)

Precast wall schedule (3-Bedroom Flat)

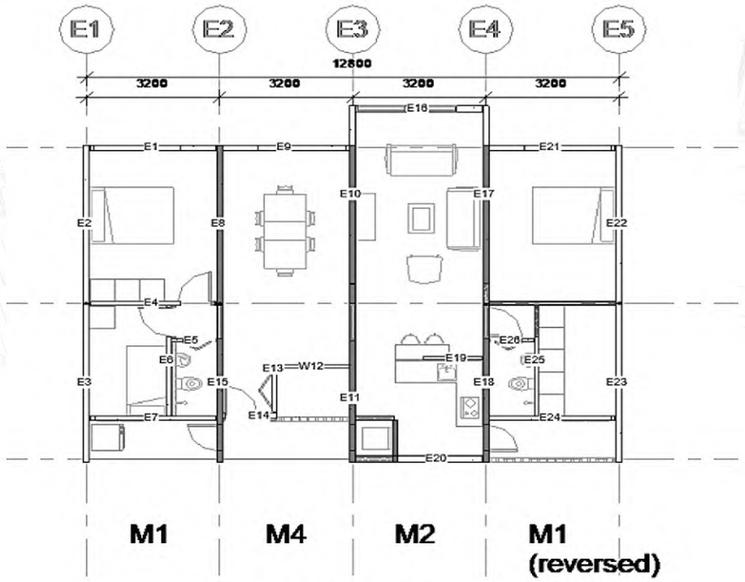
Panel Mark	Thickness (mm)	Length (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
C1	150	3020	3000	0.75	1.80
C2	150	4270	3000	1.85	4.44
C3	150	4270	3000	1.85	4.44
C4	125	3020	3000	0.68	1.64
C5	125	1070	3000	0.14	0.33
C6	125	2975	3000	0.67	1.61
C7	100	3020	3000	0.62	1.50
C8	150	4795	3000	2.08	4.99
C9	150	3020	3000	0.26	0.62
C10	150	4795	3000	2.08	4.99
C11	150	4195	3000	1.26	3.02
C12	125	1410	3000	0.40	0.95
C13	150	2135	3000	0.93	2.23
C14	150	4795	3000	1.47	3.54
C15	150	3020	3000	0.75	1.80
C16	150	4270	3000	1.85	4.44
C17	125	1720	3000	0.31	0.75
C18	125	1170	3000	0.16	0.39
C19	125	2985	3000	0.56	1.34
C20	125	1720	3000	0.45	1.08
C21	150	4270	3000	1.85	4.44
C22	150	1285	3000	0.30	0.72



A typical precast wall layout (4-Bedroom Flat)

Precast wall schedule (4-Bedroom Flat)

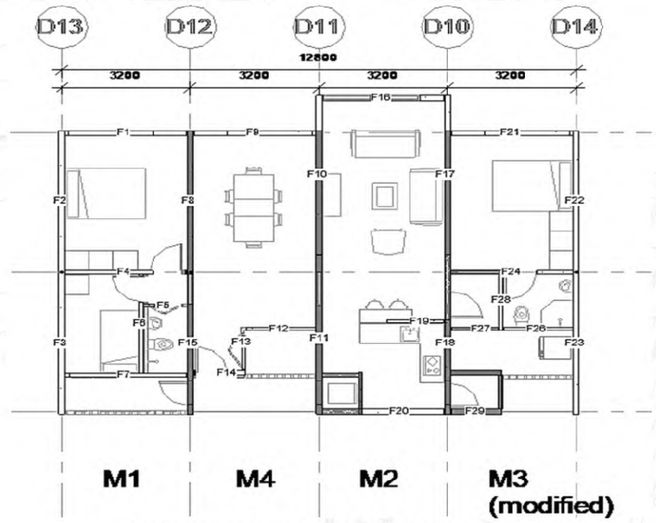
Panel Mark	Thickness (mm)	Length (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
D1	150	3020	3000	0.75	1.80
D2	150	4270	3000	1.85	4.44
D3	150	4270	3000	1.85	4.44
D4	125	3020	3000	0.68	1.64
D5	125	1070	3000	0.14	0.33
D6	125	2975	3000	0.67	1.61
D7	100	3020	3000	0.62	1.50
D8	150	4270	3000	1.85	4.44
D9	150	3020	3000	0.75	1.80
D10	150	4795	3000	2.08	4.99
D11	150	4795	3000	1.47	3.54
D12	125	1720	3000	0.45	1.08
D13	125	1285	3000	0.30	0.72
D14	150	1285	3000	0.27	0.65
D15	150	4270	3000	1.28	3.07
D16	150	3020	3000	0.26	0.62
D17	150	4795	3000	2.08	4.99
D18	150	4270	3000	1.28	3.07
D19	125	1410	3000	0.40	0.95
D20	150	2135	3000	0.93	2.23
D21	150	3020	3000	0.75	1.80
D22	150	4270	3000	1.85	4.44
D23	150	4270	3000	1.85	4.44
D24	125	3020	3000	0.68	1.64
D25	125	1070	3000	0.14	0.33
D26	125	2975	3000	0.67	1.61
D27	100	3020	3000	0.62	1.50



A typical precast wall layout (3-Bedroom Flat Type A)

Precast Wall Schedule (3-Bedroom Flat Type A)

Panel Mark	Thickness (mm)	Length (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
E1	150	3020	3000	0.75	1.80
E2	150	4270	3000	1.85	4.44
E3	150	4270	3000	1.85	4.44
E4	125	3020	3000	0.68	1.64
E5	125	1070	3000	0.14	0.33
E6	125	2975	3000	0.67	1.61
E7	100	3020	3000	0.62	1.50
E8	150	4270	3000	1.85	4.44
E9	150	3020	3000	0.75	1.80
E10	150	4795	3000	2.08	4.99
E11	150	4795	3000	1.47	3.54
E12	125	1720	3000	0.45	1.08
E13	125	1285	3000	0.30	0.72
E14	150	1285	3000	0.27	0.65
E15	150	4270	3000	1.28	3.07
E16	150	3020	3000	0.26	0.62
E17	150	4795	3000	2.08	4.99
E18	150	4270	3000	1.28	3.07
E19	125	1410	3000	0.40	0.95
E20	150	2135	3000	0.93	2.23
E21	150	3020	3000	0.75	1.80
E22	150	4270	3000	1.85	4.44
E23	150	4270	3000	1.85	4.44
E24	100	3020	3000	0.62	1.50
E25	125	2975	3000	0.67	1.61
E26	125	1070	3000	0.14	0.33



A typical precast wall layout (3-Bedroom Flat Type B)

Precast wall schedule (3-Bedroom Flat Type B)

Panel Mark	Thickness (mm)	Length (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
F1	150	3020	3000	0.75	1.80
F2	150	4270	3000	1.85	4.44
F3	150	4270	3000	1.85	4.44
F4	125	3020	3000	0.68	1.64
F5	125	1070	3000	0.14	0.33
F6	125	2980	3000	0.67	1.61
F7	100	3020	3000	0.62	1.50
F8	150	4270	3000	1.85	4.44
F9	150	3020	3000	0.75	1.80
F10	150	4800	3000	2.08	4.99
F11	150	4800	3000	1.47	3.54
F12	125	1720	3000	0.45	1.08
F13	125	1285	3000	0.30	0.72
F14	150	1285	3000	0.27	0.65
F15	150	4270	3000	1.28	3.07
F16	150	3020	3000	0.26	0.63
F17	150	4800	3000	2.08	4.99
F18	150	4275	3000	1.10	2.63
F19	125	1410	3000	0.40	0.95
F20	150	2135	3000	0.93	2.23
F21	150	3020	3000	0.75	1.80
F22	150	4270	3000	1.85	4.44
F23	150	4270	3000	1.85	4.44
F24	125	1720	3000	0.31	0.75
F26	125	1720	3000	0.45	1.08
F27	125	1170	3000	0.33	0.79
F28	125	4160	3000	0.89	2.14
F29	150	1260	3000	0.54	1.31

3.2. Precast Concrete Slab

Precast concrete flooring offers an economic and versatile solution to the ground and suspended floors in any type of building construction. There is a wide range of flooring types available to give the most economical solution for all loadings and spans. The floor has maximum structural performance with minimum weight and may be used with or without structural toppings, non-structural finishes or with raised timber floors.

There are several types of the precast concrete slab:

a) Hollow-core
b) Double tee slab
c) Waffle slab
d) Plank

Lattice slab is a semi-precast option using a lightweight yet versatile precast soffit in terms of shape, strengthened to span up to about 6 m using top reinforcement in compression.

The advantages of using precast concrete slabs are:

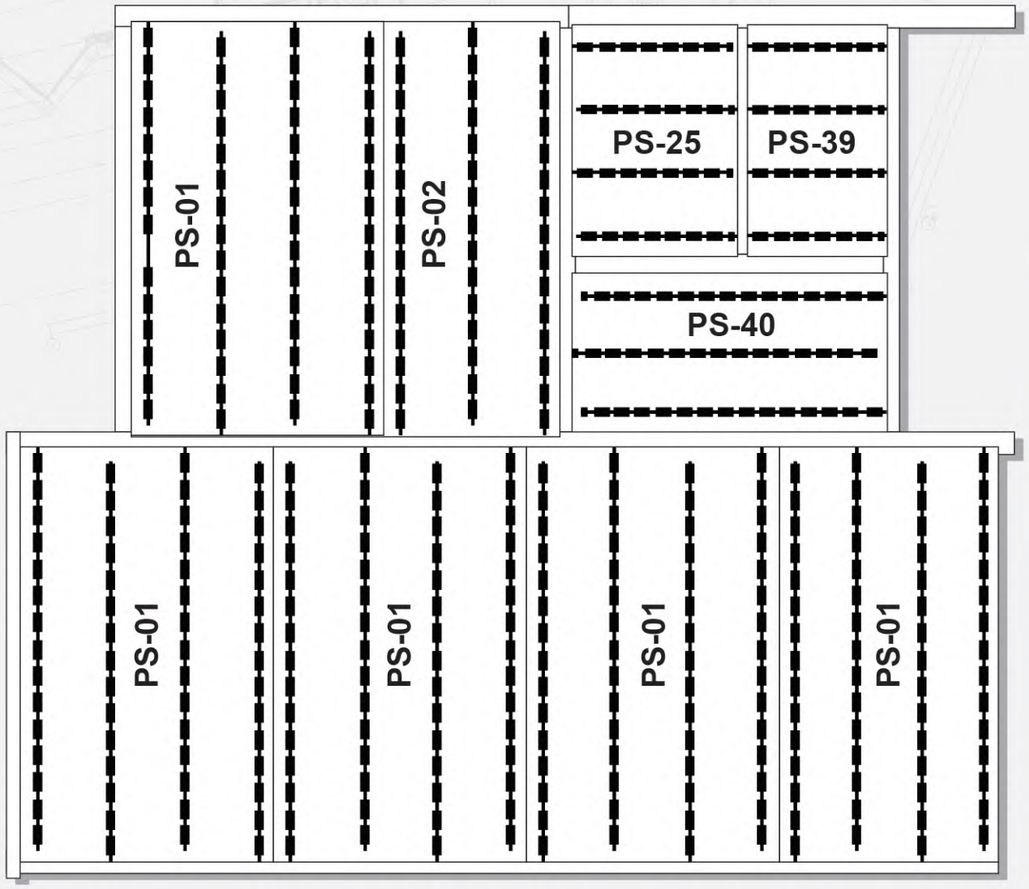
a) Simple and economical manufacturing of units
b) Safe and rapid installation of floors
c) Possible to create a structurally complete precast floor
d) Minimal use of in-situ reinforcement and wet concrete
e) Off-site production of high strength, highly durable units
f) Fast erection of long-span floors on-site

Precast half slabs are to be utilised for this project mainly because of the designated span required to achieve a more economical solution. The installation works are simplified due to the un-prop construction method used during the installation stage. All the mechanical and electrical services are to be laid within the topping for more flexible installation at site. Precast half slabs are widely available in the market as they do not require special machines to produce.



Source: Planning and Design Handbook on Precast Building Structure, fib, 2014

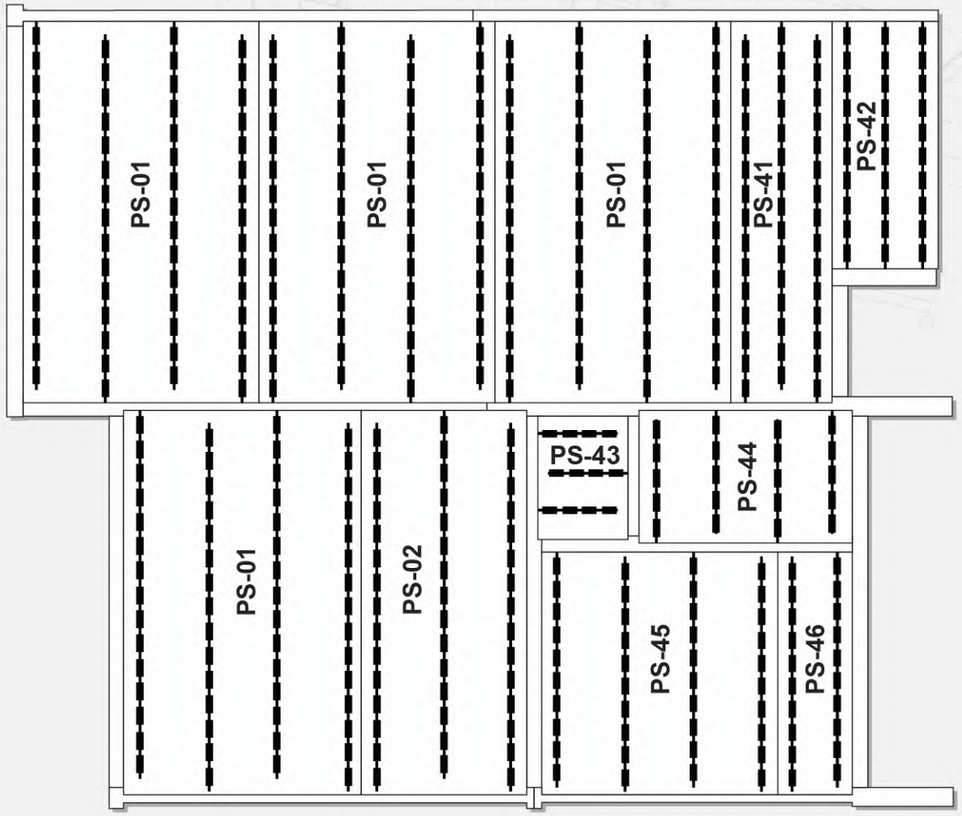
An example of typical precast concrete slabs



Precast concrete slab layout (1-Bedroom Flat)

Precast concrete slab schedule (1-Bedroom Flat)

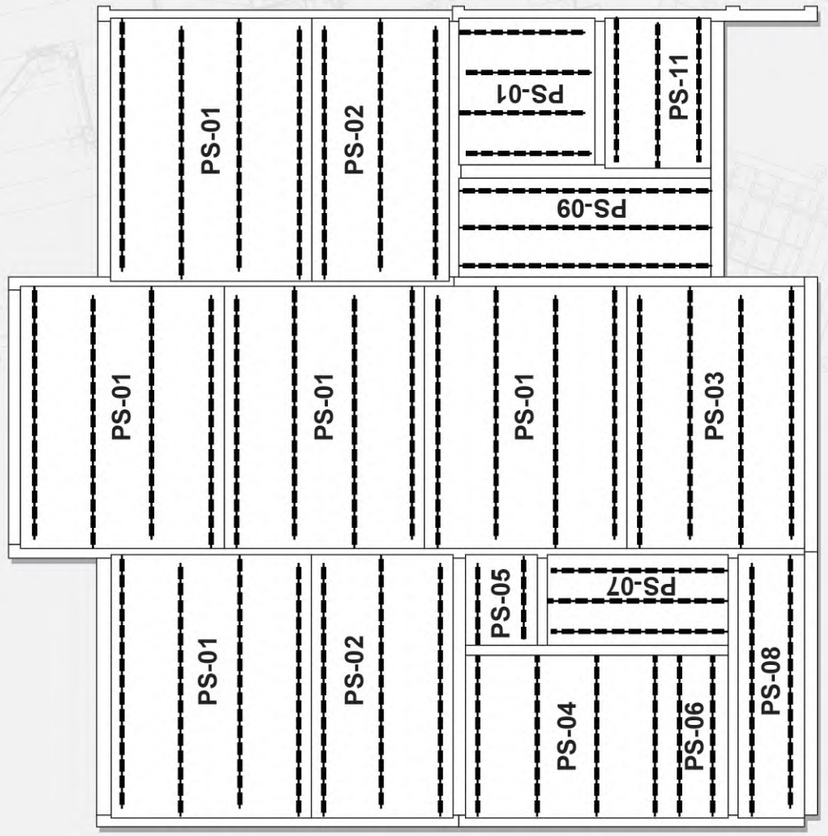
Slab Marking	Length (mm)	Width (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
PS-01	3110	2400	75	0.56	1.34
PS-02	3110	1675	75	0.39	0.94
PS-25	1560	1725	75	0.20	0.48
PS-39	1335	1725	75	0.17	0.41
PS-40	2985	1175	75	0.26	0.62



Precast concrete slab layout (2-Bedroom Flat)

Precast concrete slab schedule (2-Bedroom Flat)

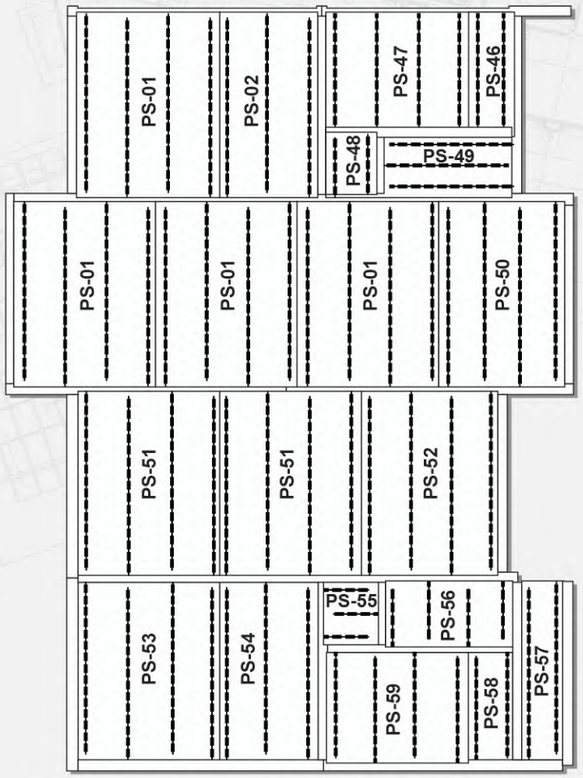
Slab Marking	Length (mm)	Width (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
PS-01	3110	2400	75	0.56	1.34
PS-02	3110	1675	75	0.39	0.95
PS-41	3110	1025	75	0.24	5.76
PS-42	2035	1075	75	0.17	0.41
PS-43	910	1013	75	0.07	0.17
PS-44	1073	2150	75	0.17	0.41
PS-45	1948	2385	75	0.35	0.84
PS-46	1948	750	75	0.11	0.26



Precast concrete slab layout (3-Bedroom Flat)

Precast concrete slab schedule (3-Bedroom Flat)

Slab Marking	Length (mm)	Width (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
PS-01	3110	2400	75	0.56	1.34
PS-02	3110	1675	75	0.39	0.94
PS-03	3110	1025	75	0.24	0.58
PS-04	2035	1075	75	0.16	0.38
PS-05	1013	910	75	0.07	0.17
PS-06	1073	2150	75	0.17	0.41
PS-07	1948	2385	75	0.35	0.84
PS-08	1948	750	75	0.11	0.26
PS-09	1175	3035	75	0.27	0.65
PS-10	1725	1610	75	0.21	0.50
PS-11	1785	1275	75	0.17	0.41



Precast concrete slab layout (4-Bedroom Flat)

Precast concrete slab schedule (4-Bedroom Flat)

Slab Marking	Length (mm)	Width (mm)	Height (mm)	Volume (m^3)	Weight (Tonne)
PS-01	3110	2400	75	0.56	1.34
PS-02	3110	1675	75	0.39	0.94
PS-46	1948	750	75	0.11	0.26
PS-47	1948	2400	75	0.35	0.84
PS-48	1073	850	75	0.07	0.17
PS-49	2210	1013	75	0.17	0.41
PS-50	3110	2100	75	0.49	1.18
PS-51	3123	2400	75	0.56	1.34
PS-52	3123	2350	75	0.55	1.32
PS-53	3098	2400	75	0.56	1.34
PS-54	3098	1675	75	0.39	0.94
PS-55	910	1063	75	0.07	0.17
PS-56	1123	2150	75	0.18	0.43
PS-57	3098	725	75	0.17	0.41
PS-58	1885	750	75	0.11	0.26
PS-59	1885	2400	75	0.34	0.82

SECTION B

B4 DESIGN CONSIDERATION

The precast concrete walls which are under compression are designed to sustain the vertically and uniformly distributed loads transmitted from the roof and respective floors. These precast walls are subsequently supported by cast-in-situ transfer beams on the first floor with cast-in-situ columns and stumps to the foundation.

The design of the proposed building adopts the following design criteria and codes of practice:

a) BS 8110 (1997), "The structural use of concrete"

b) BS 6399 Part 1 1984, "Loadings"

c) CP3 Chapter V, Part 2, 1972, "Wind loading"

Material Data:

a) Concrete grade, fcu	= 35 N/mm^2
b) High tensile steel, fy	= 460 N/mm^2
c) Mild steel, fyv	= 250 N/mm^2
d) Concrete density	= 240 kN/m^3
e) Maximum agg. size	= 20 mm



In the design of the structural elements, the following design criteria/assumptions which are in accordance with BS 8110, Part 1, 1997 have been adopted:

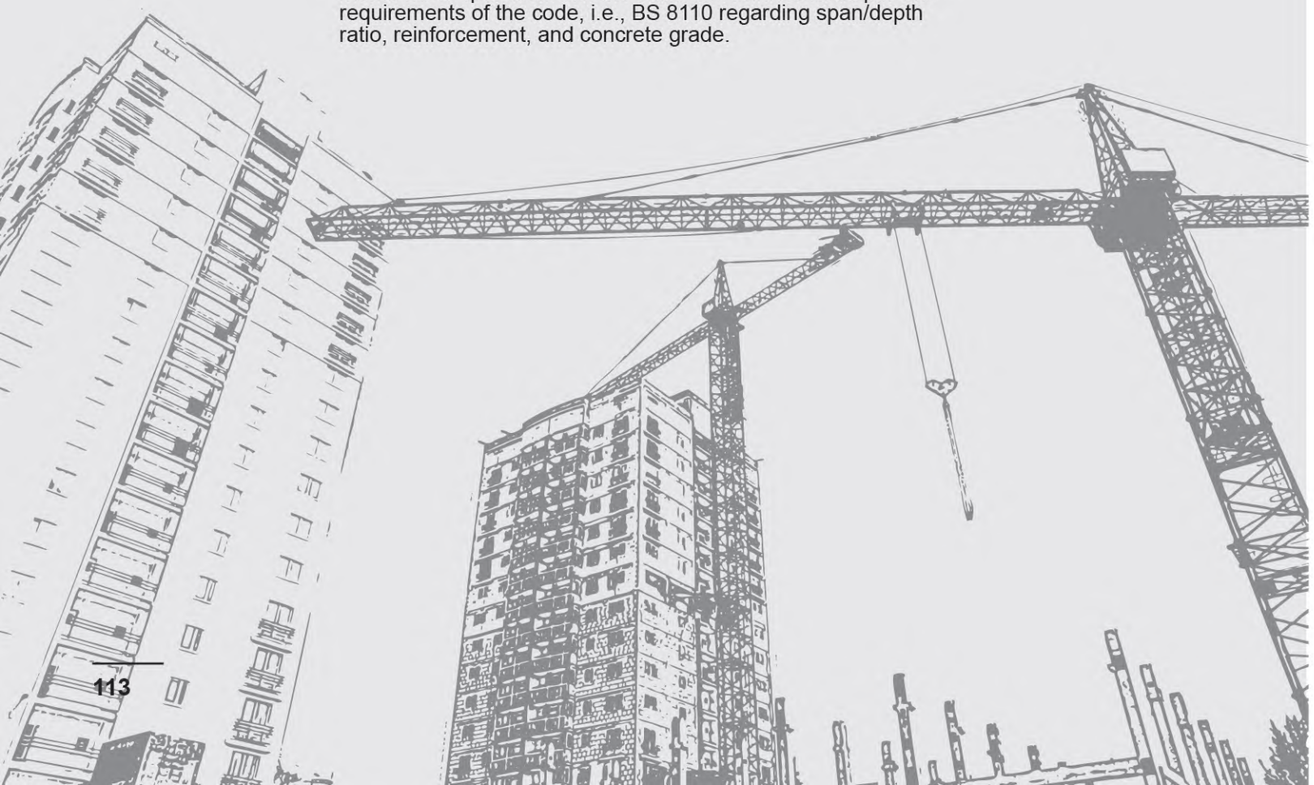
a) **The designed ultimate axial force in the walls is computed on the basis that the concealed beams and slabs transmitting forces on it are simply supported.**

b) **From floor to floor, the walls are braced by floor slabs which are designed as "continuous structural plates" to cater for the dead and imposed loads which simultaneously behave as horizontal diaphragms to withstand lateral forces.**

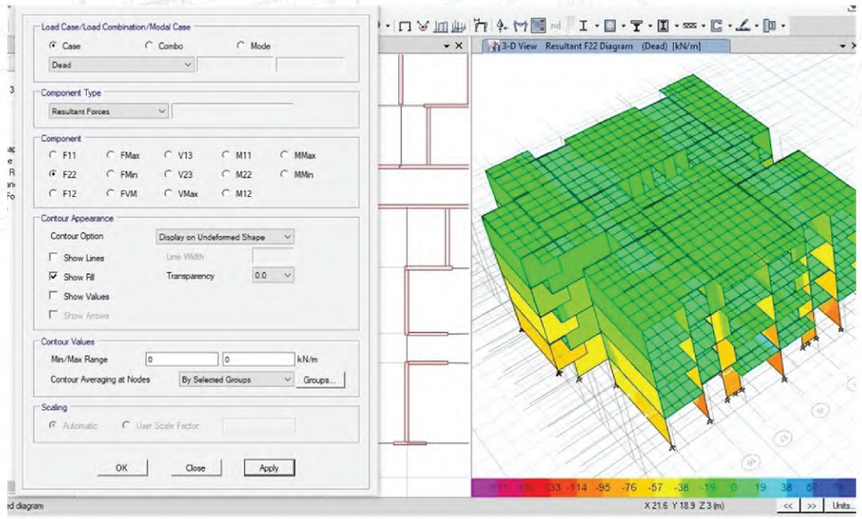
c) **In the design of the precast walls, the effective height between floor levels, limit of slenderness, and transverse eccentricity of forces are taken into consideration which are in accordance with the limitations provided in cl.3.9.4 of BS 8110 (1997).**

Generally, based on the loading of the 16-storey block, the selected wall thickness of 125–150 mm is sufficient. All the respective walls satisfy the uniform building by-laws as regards fire resistance and durability.

The precast slabs are designed as continuous structural members to span between the walls and reinforced as per the requirements of the code, i.e., BS 8110 regarding span/depth ratio, reinforcement, and concrete grade.



4.1. Precast Load Bearing Wall Design



A typical precast load bearing wall design

4.1.1. Precast wall typical layout (3-bedroom flat – type A)

Wall Mark:		**D-8**				
b	**=**	**4268 mm**	**Storey = 16 nos**		f_{cu} =	**35 N/mm²**
le	**=**	**3000 mm**			f_y =	**460 N/mm²**
h_{max}	=	**150 mm**				

Based on the analysis, the maximum vertical load wall capacity for a wall with a 150 mm thickness is N_w = 805 kN/M and moment M_w = 30 KN/m.

For reinforcement details, please refer to Table 38, WB150-02 in IBS Catalogue for Precast Concrete Building System Revision 2017.

4.1.2. Precast wall typical layout (3-bedroom flat – type B)

Wall Mark:		**E-10**				
b	**=**	**4793 mm**	**Storey = 16 nos**	**f_{cu}**	**=**	**35 N/mm²**
le	**=**	**3000 mm**		**f_y**	**=**	**460 N/mm²**
h_{max}	**=**	**150 mm**				

Based on the analysis, the maximum vertical load wall capacity for a wall with a 150 mm thickness is N_w = 950 kN/M and moment M_w = 50 KN/m.

For reinforcement details, please refer to Table 38, WB150-01 in IBS Catalogue for Precast Concrete Building System Revision 2017.

4.2. Precast Half Slab Design

4.2.1. Precast half slab thickness = 75 mm

Length	**=**	**3.2 m**	**Lattice slab thickness**	**=**	**0.075 m**
f_{cu}	**=**	**35 N/mm²**	**Topping thickness**	**=**	**0.075 m**
f_y	**=**	**460 N/mm²**	**Lattice slab width**	**=**	**1200 mm**

a) Analysis – Moment Installation Stage

Midspan Moment = 1.59 kNm **Support Moment @ prop = 2.51 kNm**

b) Analysis – Moment Final Stage

Midspan Moment = 14.64 kNm **Support Moment = 10.70 kNm**

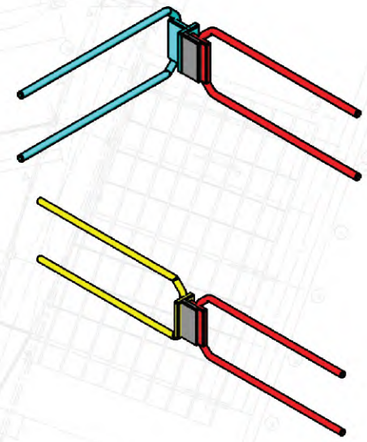
c) Summary of Rebar:

Lattice rebar = T6-28.278 mm² **Lattice girder = 2 nos**
Top bar (@ pc slab) = T12-400 mm² **As = 339.336 mm²/m, or 3T12**
-ve bar (@ top of slab) = T10-200 mm c/c **As = 471.3 mm²/m, or 6T10**
Bottom main bar (in PC) = T12-200 mm c/c **As = 678.672 mm²/m**
Bottom cross bar (in PC) = T10-300 mm c/c **As = 314.2 mm²/m**

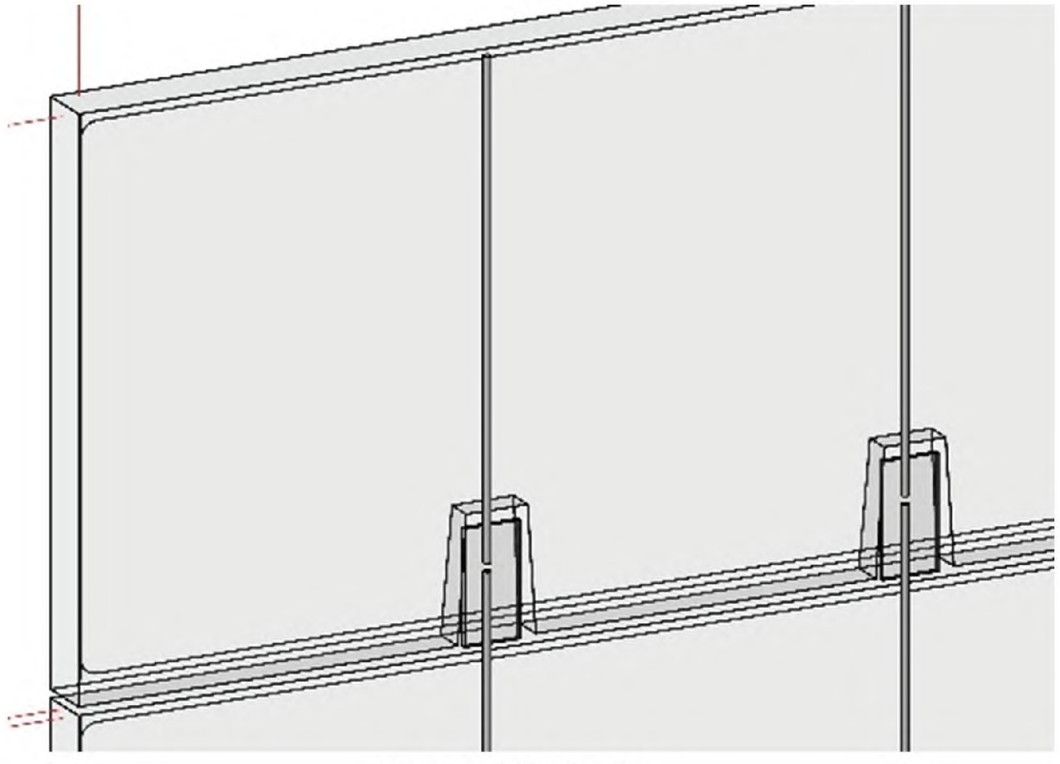
4.3. Precast Connection

Effective design and construction are achieved through the use of suitable connections to cater for all service, environmental, and ultimate load conditions. The structural system is composed of precast concrete elements joined together mechanically using bolts, welds, reinforcing steel, grout, or concrete to form the joints. The joints are important in ensuring the integrity of the whole structure.

Welding plates are used as connections to simplify the installation works so that the desired speed for precast construction can be achieved. The plates between adjacent precast walls are welded at a specified thickness and length to form the vertical joints. The starter bars between two subsequent layers of precast wall panels are welded at a specified thickness and length to form the adequate horizontal joints.



Typical wall horizontal connections



Typical wall vertical connections



B5 METHOD OF INSTALLATION



A typical installation method

5.1. Starter Bar and Level Setting Out

01

Survey reference points will be transferred from lower floors upon the completion of slab concrete casting.

02

The surveyor to set out the grid lines and mark the points of starter bars on floor slabs to ensure precision.

03

The precast installer will then mark the offset lines of panel positions from the gridlines

04

The installer must ensure the positions of starter bars are within tolerance.

05

At the same time, the installer will ensure the level that the panels are to be sat on is within tolerance.



Starter bar location

5.2. Precast Wall Panel Installation

Before the installation work is carried out, the installer needs to prepare the relevant tools such as support, clamps, props, ladders, and other necessary items that are suitable for the designated precast elements of the project.
A crawler crane will be used to lift the panels from the rack stack. The signal man and crane operator will communicate using a walkie-talkie during panel lifting and installation.

The precast installer needs to ensure the slab level is within tolerance and lay shim plates of the necessary thickness to ensure the walls are installed at the right level. The installer will then lay the mortar prior to wall installation to fill the gap between the walls and slabs.

Panels will be hoisted and placed at required positions based on the sequencing numbers labelled on the precast components.

5.2.1. Verticality check

The precast walls then need to be checked for verticality using levelling instrument tools such as a theodolite, levelling tripod, or plumb box. The panels will be temporarily held by props/supports at designated positions until accurate wall verticality is obtained.

5.2.2. Connections/joints

Both vertical and horizontal connection plates/bars are to be welded by a qualified/certified welder. Backer rods are to be installed before pouring non-shrink grout/mortar to secure the joints. Propping as temporary supports of the walls can be removed once the connections for completed typical units are secured.





Precast wall panel lifting (above) and wall panel prop (below)

5.3. Precast Slab Installation

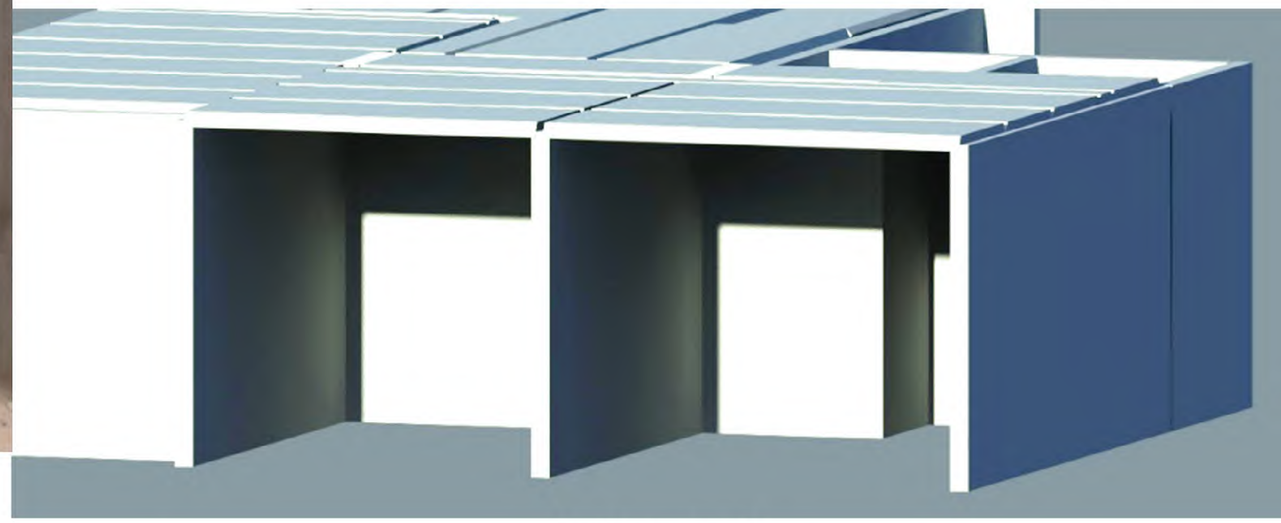
Rubber strips are to be laid on the top of wall panels (steel trowel surface area) to distribute the loads evenly and also to absorb the impact during precast slab installation.

Precast slab components will be lifted and installed as per the marking number labelled on each precast component. The precast slabs must be propped at mid-span using vertical props and supports to control the deflection of slabs during the service stage.

Lay the reinforcement bars with all the mechanical and electrical services embedded within the topping as per the construction drawings for concreting works. Temporary propping for precast slabs can be removed after the concrete topping is cured.

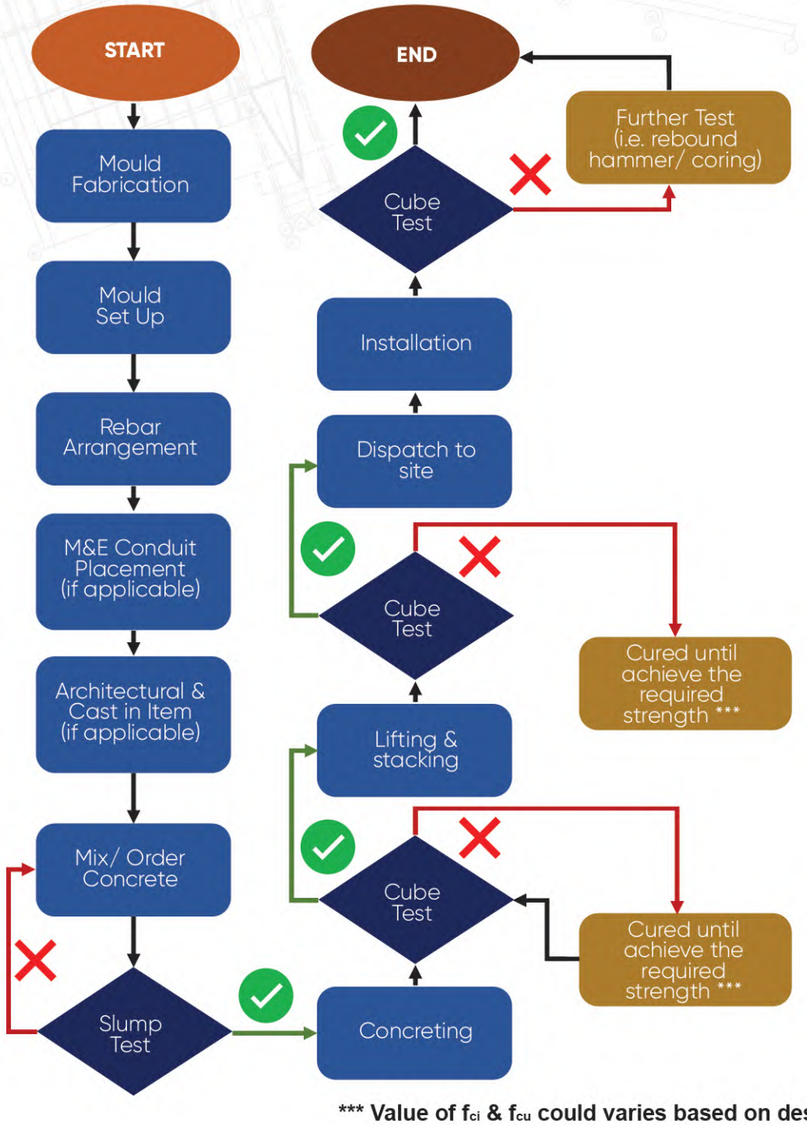


SECTION B



Typical precast floor slabs

B6 PRECAST CONCRETE PRODUCTION PROCESS



*** Value of f_{ci} & f_{cu} could varies based on design







A typical steel bed & side mould set-up



Placing the reinforcement bar



Placing a window and a door frame

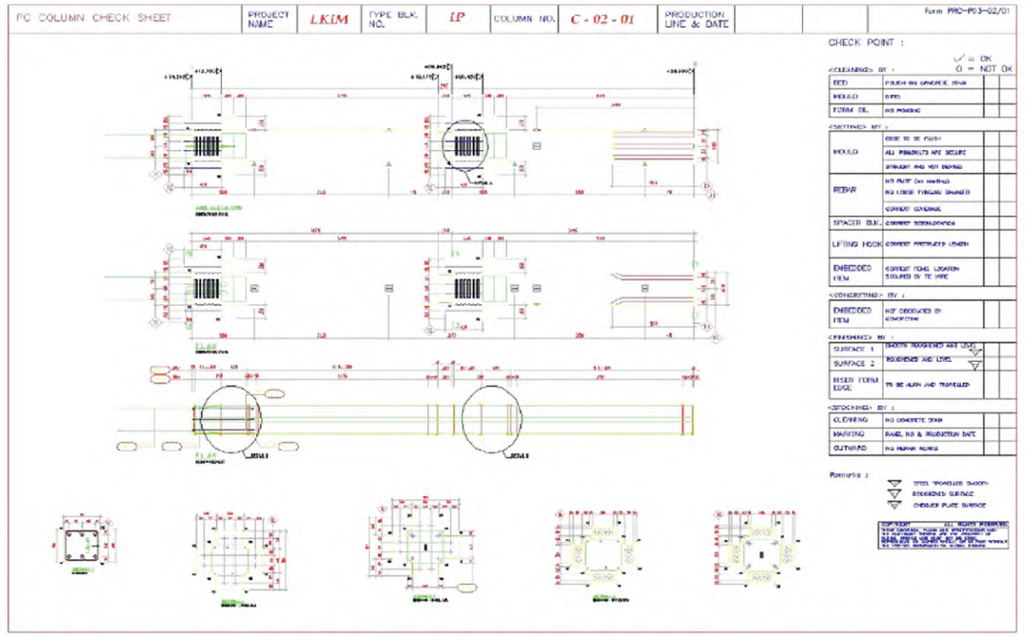


Placing MEP conduit/services

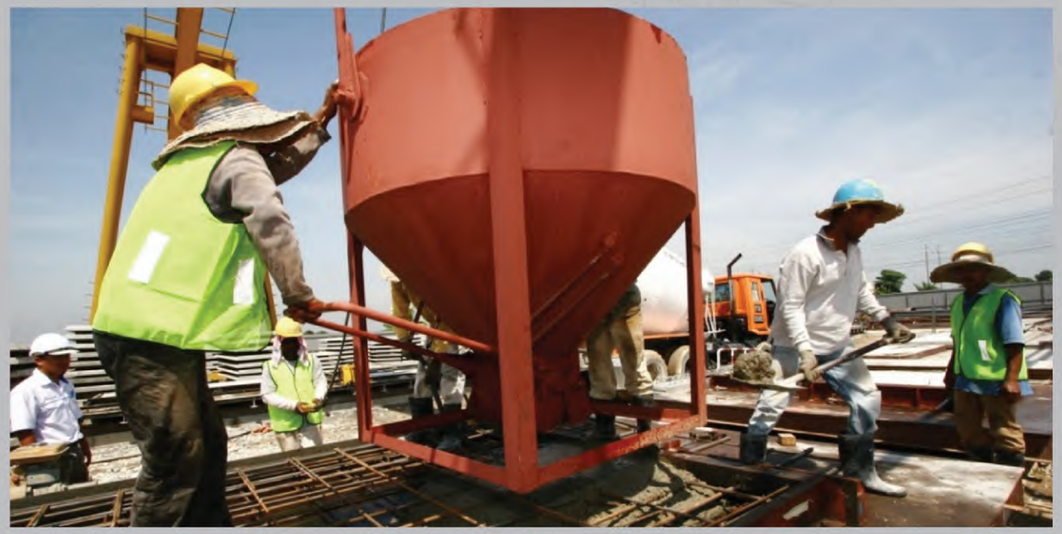


Quality inspection before concreting works

SECTION B



A typical shop drawing for quality inspection







Concreting works



Demoulding works





Quality check on finished products





Logistics – Dispatch to site





Installation works



SECTION C:

HANDBOOK FOR MECHANICAL, ELECTRICAL, AND PLUMBING ENGINEERS

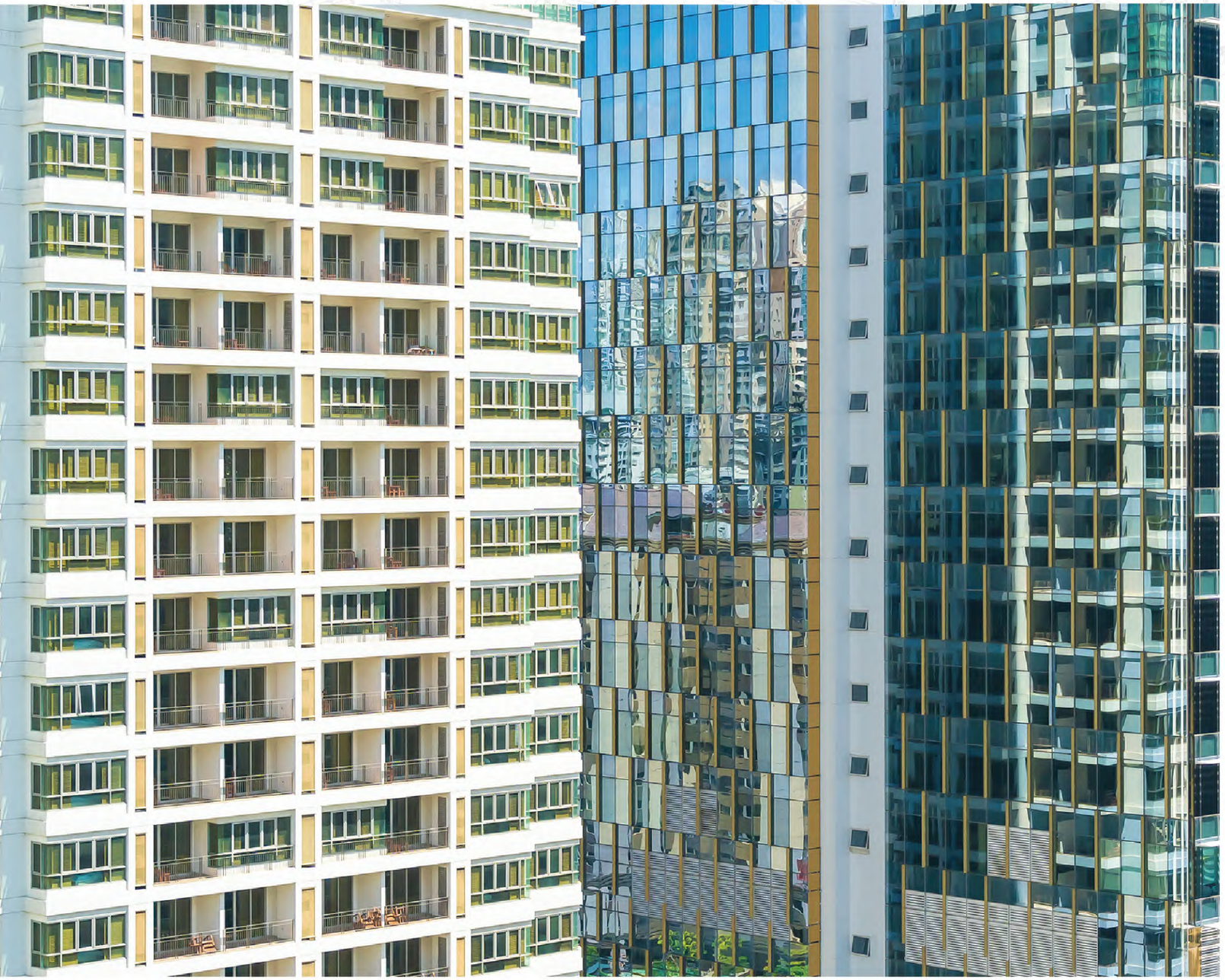
C1 Brief Introduction

C2 MEP Design Considerations
2.1 General Principles of an MEP Design
2.2 MEP Design Considerations
2.3 Electrical and Lighting Protection
2.4 Domestic Water and Sanitary Plumbing Piping
2.5 An Overall MEP Design for a House
2.6 Things to Consider Before the MEP Installation
2.7 Accessibility for Installation and Maintenance

C3 MEP Construction Considerations
3.1 General Principles of Prefab MEP Construction
3.2 Procedures for Prefab MEP Installation

C4 MEP Maintenance Considerations
4.1 Prefab MEP As-Built Drawing

Written by:



DeLIGHT Homes
A Sustainable and Innovative Affordable Housing Design Handbook

C1 BRIEF INTRODUCTION

This handbook is intended to assist construction industry players and stakeholders to advance in the housing manufacturing industry, particularly in Humanising Low-Income Group's Housing in Malaysia.

In line with the DeLIGHT Homes design concept that is aimed at serving the B40 group, this handbook is produced as a reference document for developers, manufacturers, consultants, contractors, and other construction industry players.

Its purpose is to provide a practical overview of the prefabrication construction method in housing manufacturing. Comprehensive information is delivered to assist those engaged in design, manufacturing, installation, construction, and project management.

This handbook is intended to enable and assist the:

Developer	Overall knowledge about the pre-fabrication work method
Consultant	Design considerations on how to use the pre-fabrication work method
Manufacturer	Overview of the manufacturing process
Contractor	Consideration of the safety requirements along the construction process
Building Management	Maintenance after the pre-fabrication construction work

The MEP works in this handbook are divided into three (3) parts:



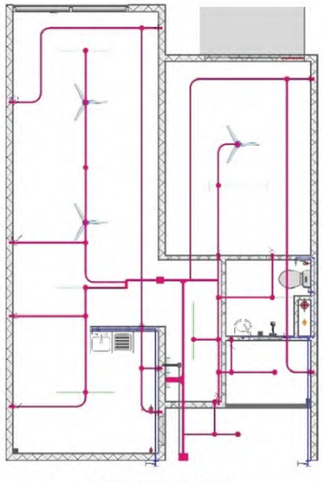
C2 MEP DESIGN CONSIDERATIONS



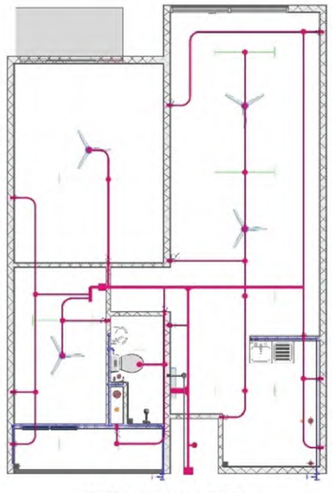
2.1. General Principles of an MEP Design

All MEP materials should comply with the relevant statutory requirements and regulations, including the requirements imposed by local authorities and technical agencies, among others. Examples of the bodies that issue the relevant regulations and standards are Suruhanjaya Tenaga (ST), Suruhanjaya Komunikasi dan Multimedia Malaysia (SKMM), Suruhanjaya Perkhidmatan Air Negara (SPAN), and SIRIM Berhad.

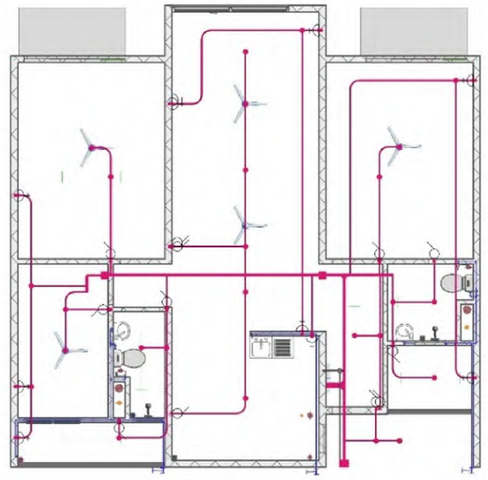
In general, prefab MEP services are installed in every panel in the assembly factory and subsequently mobilised to the site. After all the panels have been put in place, the MEP services shall utilise the plug and play system.



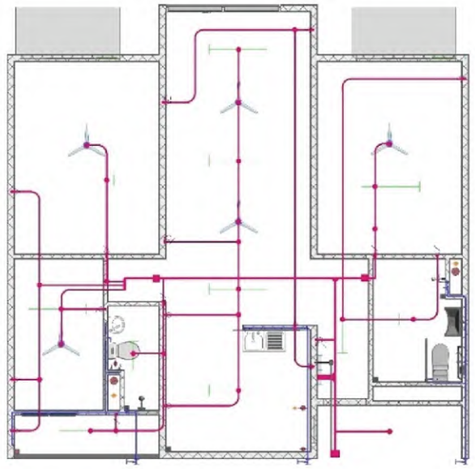
1-Bedroom Flat



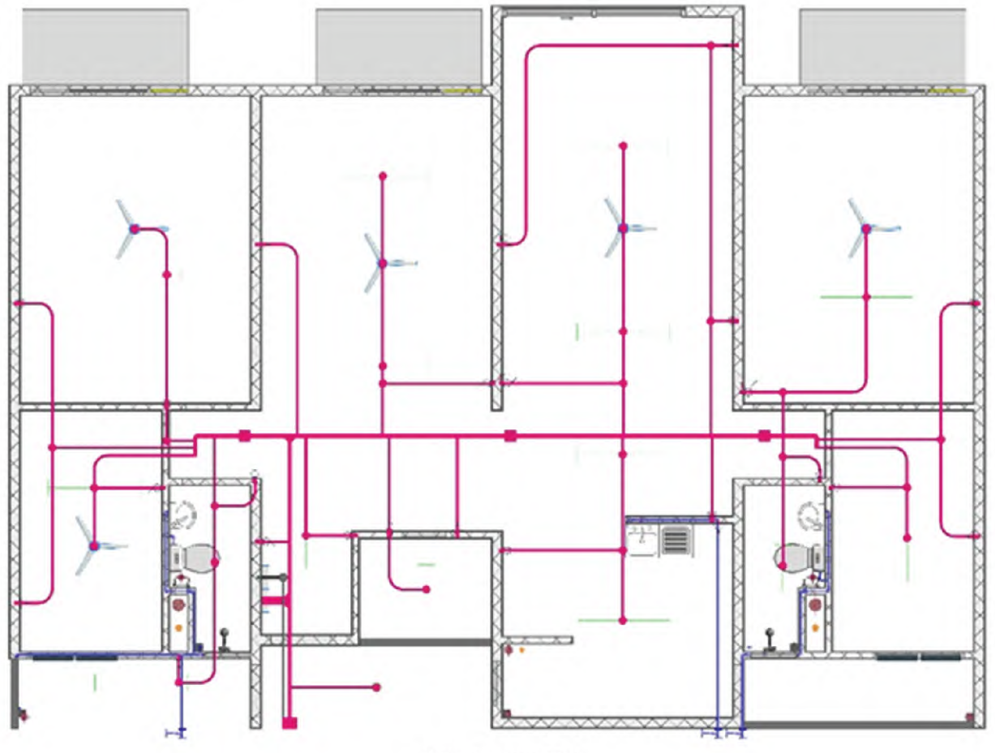
2-Bedrooms Flat



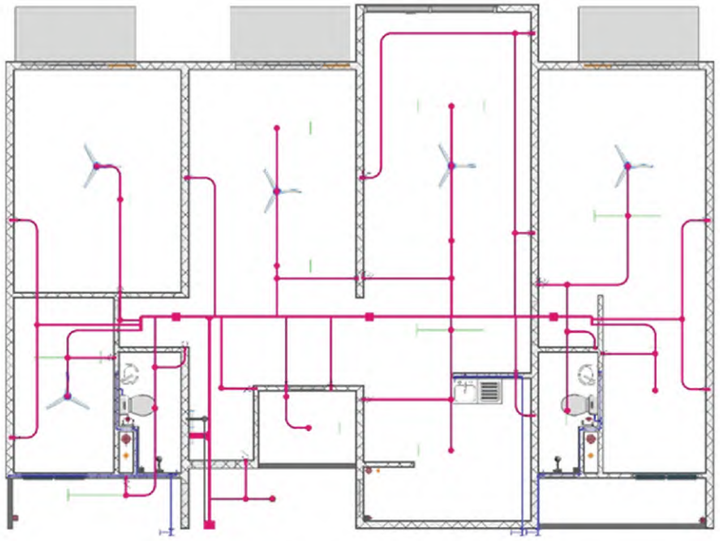
3-Bedrooms Flat



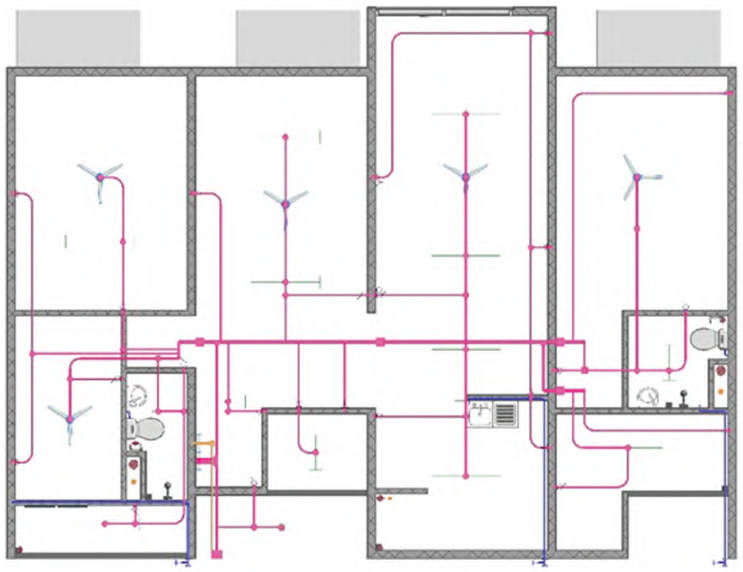
OKU 3-Bedrooms Flat



3-Bedrooms Flat



3-Bedrooms Flat Type B



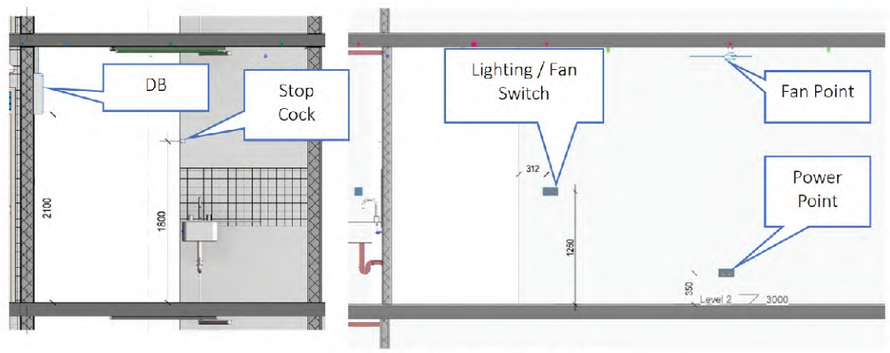
4-Bedrooms Flat

2.1.1. Quantity of MEP points according to house type

The desired numbers of MEP points/fixtures to achieve the target of Humanising Low-Income Group's Housing in Malaysia are shown below according to the house type.

MEP points/fixtures

Description	House Type						
	1 bedroom	2 bedrooms	3 bedrooms	3 bedrooms (OKU)	3 bedrooms (type A)	3 bedrooms (type B)	4 bedrooms
Lighting Points	9	9	13	13	16	16	16
13A Power Points	8	9	10	10	14	14	14
Fan Points	3	4	5	5	5	5	5
Switches	8	8	11	11	13	13	13
Stop Cock Valves	2	2	3	3	3	3	3
Water Closet Angle Valves	1	1	2	2	2	2	2
Sink Angle Valves	1	1	1	1	1	1	1
Basin Angle Valves	1	1	2	2	2	2	2
Shower Stop Cock Valves	1	1	2	2	2	2	2
Water Tap	1	2	3	3	3	3	3

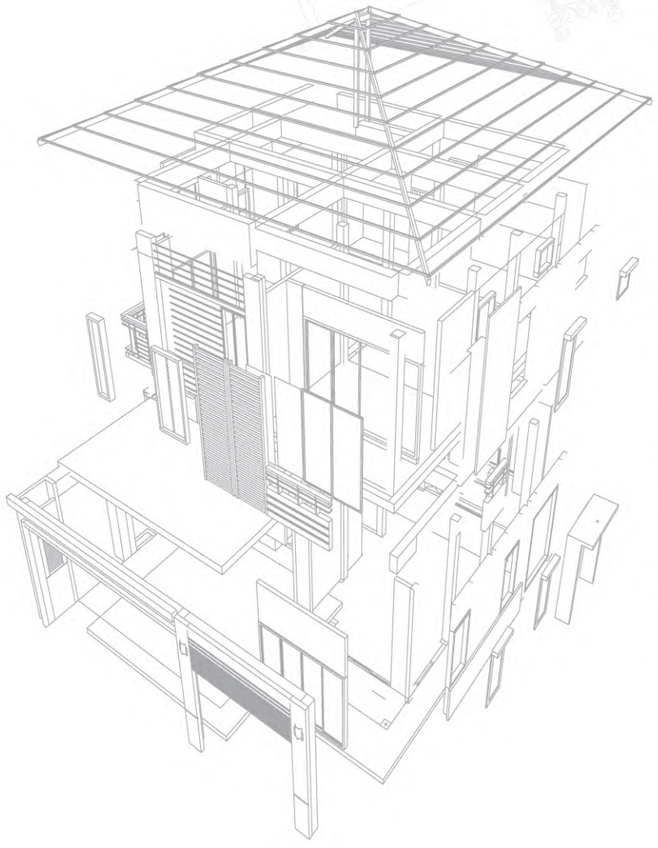


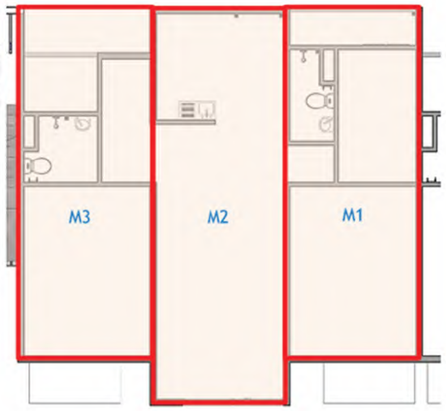
MEP points setting out in prefab panels

2.2. MEP Design Considerations

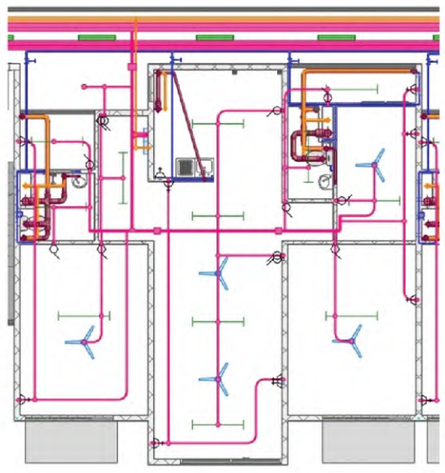
To further explain the prefab MEP system, this handbook provides the sample of 3 modules for an apartment unit. The MEP system shall have a junction box/service accessible area at all connection areas, which will be elaborated in the subsequent subsections.

In designing the prefab MEP system, the designer needs to take into consideration the roles of the contractor, manufacturer, and maintenance team in order to achieve a sustainable building system.

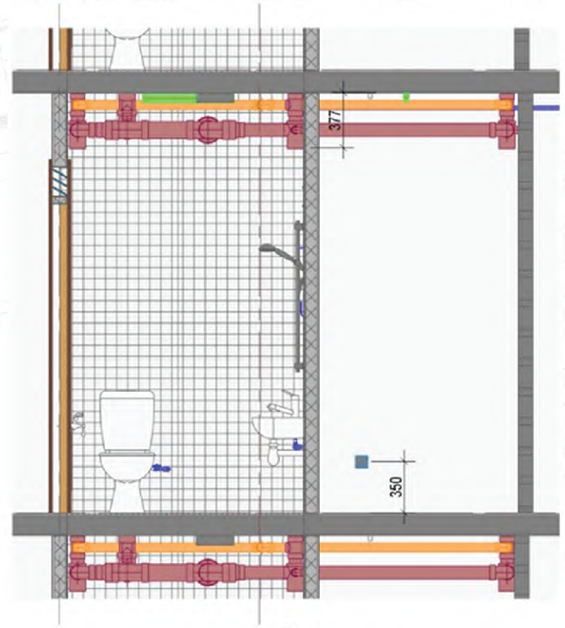


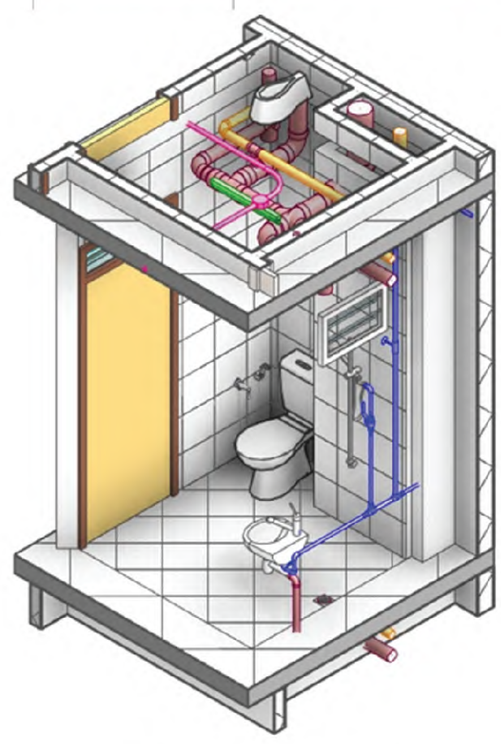


Three modules combined into a house unit



An overall MEP design in three modules combined into a house unit





MEP design for the toilet system



2.2.1. MEP services

The MEP services included in this handbook are electrical, lightning protection, water supply, sanitary, and other systems that are part of the prefab system.

2.2.2. BIM for MEP services coordination

Early coordination of services should be carried out following BIM LOD 300. Constraints in installation and maintenance need to be addressed early to avoid adverse implications on the finished works in later stages. It is imperative to have upfront design coordination that includes structural prefab components.

The BIM shall include structural components and ceiling finishing support components with MEP services for coordination purposes, as BIM coordination facilitates the construction works and shortens the time taken for prefab construction.

BIM coordination shall take into consideration the tolerance and gradient of pipe-work connections, including the flexibility of connections between modules and corridors. These flexible connections include junction boxes, services manholes, stop cocks/valves, and structural openings, among others.

2.2.3. Fire resistance and compliance with building by-laws

Fire resistance and compliance with building by-laws shall be taken into consideration for all openings and access. The finishing method shall be specified and considered during the design stage.

2.2.4. Integration of prefab MEP modules

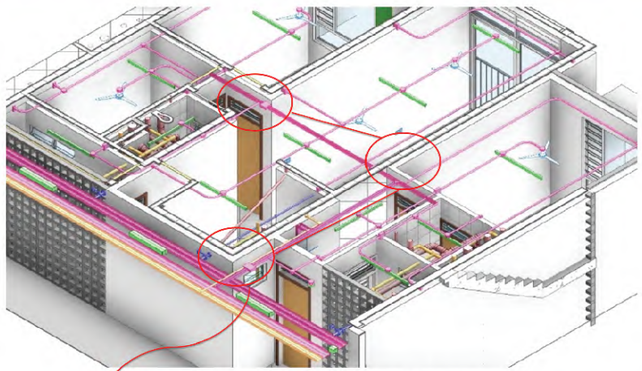
As discussed in subsection 2.1 of this MEP handbook, at the design stage, the method for ensuring the continuity of all the prefab MEP services should be considered. It is recommended to implement a plug and play system for MEP services, if possible. Nevertheless, the plug and play system design should not compromise the safety, performance, and integrity of the prefab MEP services.

2.3. Electrical and Lightning Protection

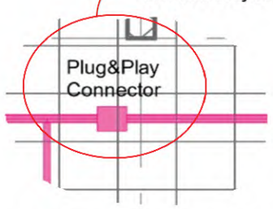
2.3.1. Electrical

The design of MEP services in DeLIGHT Homes should consider the following:

- The electrical design shall not compromise safety and performance.
- The number of circuits within the units should be minimised for ease of construction and integrity of module connections.
- A plug and play cable connector system between MEP modules should be used, if possible, to ensure the integrity of connections.
- All cables and conduits shall not compromise fire safety; as such, proper selection of conduit material is vital for the MEP modules.
- A junction box with a termination bar shall be installed near the joint area between modules and the common corridor for cable connection.



Isometric layout showing an MEP system





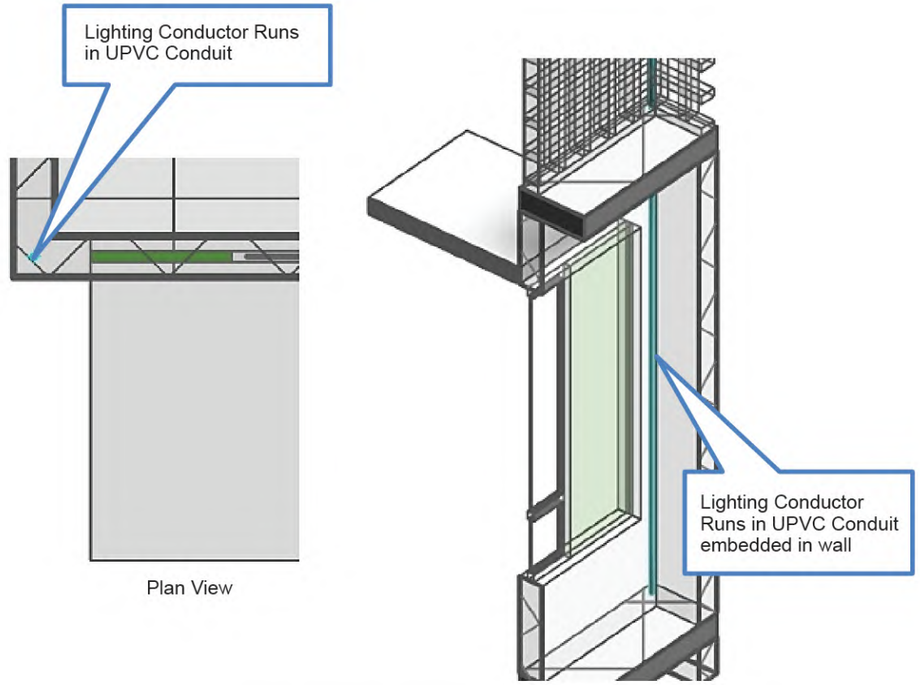
A plug and play cable connector system for connecting electrical wiring

2.3.2. Lightning protection

As discussed in subsection 2.2 of this MEP handbook, MEP is a combination of modules into one house unit. As such, the continuity of the lightning protection system is vital for the system's functionality.

The following factors should be considered in the lightning protection design:

- The lightning conductor selection shall be based on the structural material of the prefab panel modules. For a steel structure, proper selection of the conductor material is critical to prevent the oxidisation of conductors.
- The connection joints should allow proper conductivity with an acceptable methodology.



Lightning conductor connection between modules

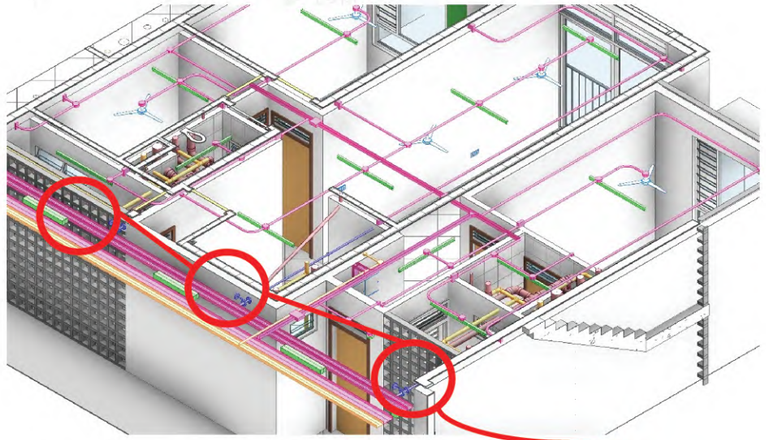
SECTION C

2.4. Domestic Water and Sanitary Plumbing Piping

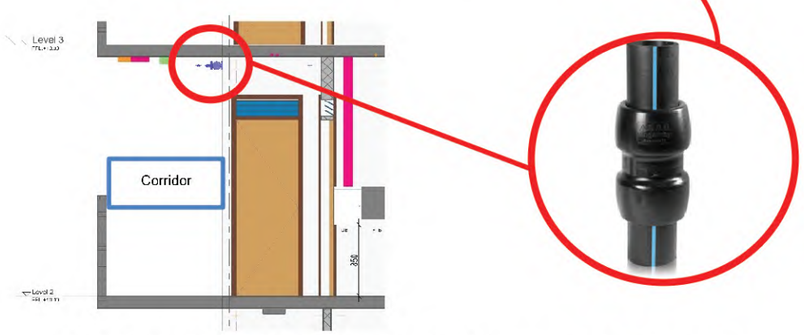
2.4.1. Domestic water plumbing

For domestic water services, each detached toilet shall be considered as a completely separate system from other toilets. As such, all the distribution pipes shall be connected to the main pipe at the top of each toilet with a stop cock.

When the modules are installed on-site, the domestic water pipe shall be connected to the stop cock via connections between modules and the common corridor, as shown in the next figure.



Isometric layout showing cold water entry into a house unit



Cold water stop cock joint system from the corridor/common area to a house unit



Domestic water piping installation in modules

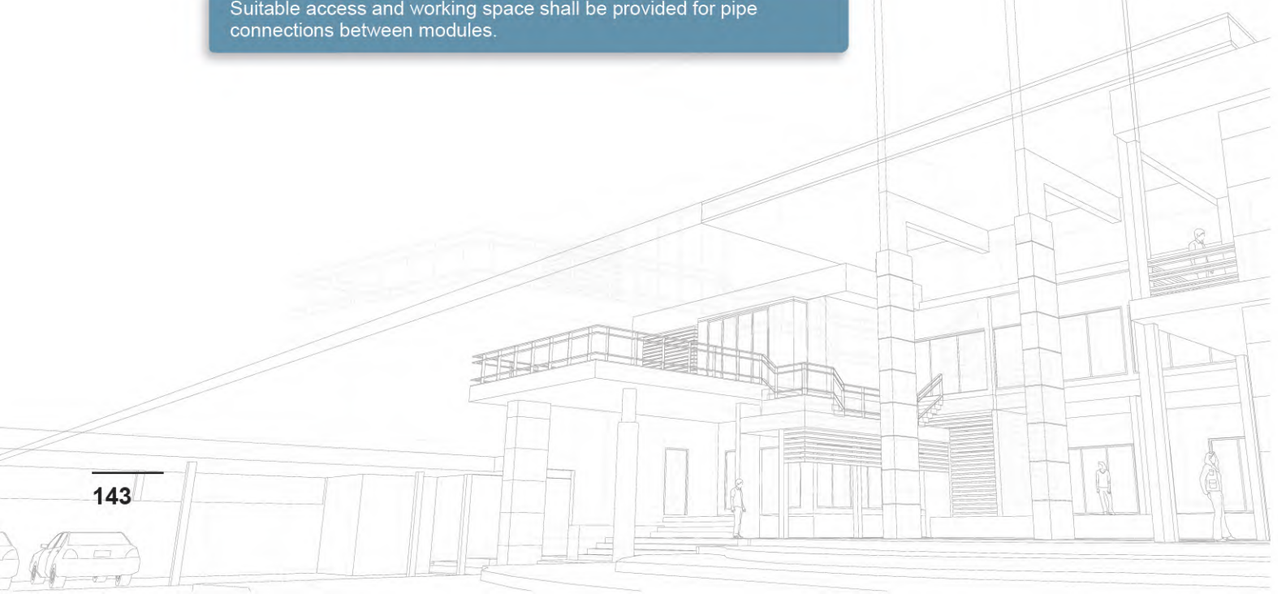
The following should be considered in the design of plumbing services:

- Proper specification of brackets and hangers for all domestic water pipes, taking into consideration the mobilisation of modules from the factory to the site.
- A pressure test shall be conducted for all domestic water pipes prior to delivery to the site.
- Water fittings that are to be concealed should be water-tight and suitable for default conditions (e.g., pressure, temperature, etc.).
- Concealed components embedded in structural elements should be taken into consideration in the structural strength design.

2.4.2. Sanitary plumbing

The following should be considered for the sanitary design:

- The gradient of all sanitary discharge pipes shall be designed by taking into consideration the allowable structural and architecture finishing gaps.
- The design and specifications of support brackets for sanitary pipes are important due to the mobilisation from the factory to the site.
- Conventional P or S trap or top accessed floor trap can be installed in the sanitary system. Its selection depends on the allowable structural and architecture space.
- All pipe sleeves shall be installed with a proper waterproofing system.
- The mounting type of WC should be considered, either floor mounted (S trap) or wall-mounted (P trap). It is recommended to install a P trap WC for ground floor units.
- A BIM coordinated model is vital for the sanitary services system design, as there is a frame structure element immediately after the basin or kitchen sink discharge. As such, proper termination or box up shall be allocated at these areas.
- Concealed components embedded in structural elements should be taken into consideration in the structural strength design.
- Suitable access and working space shall be provided for pipe connections between modules.



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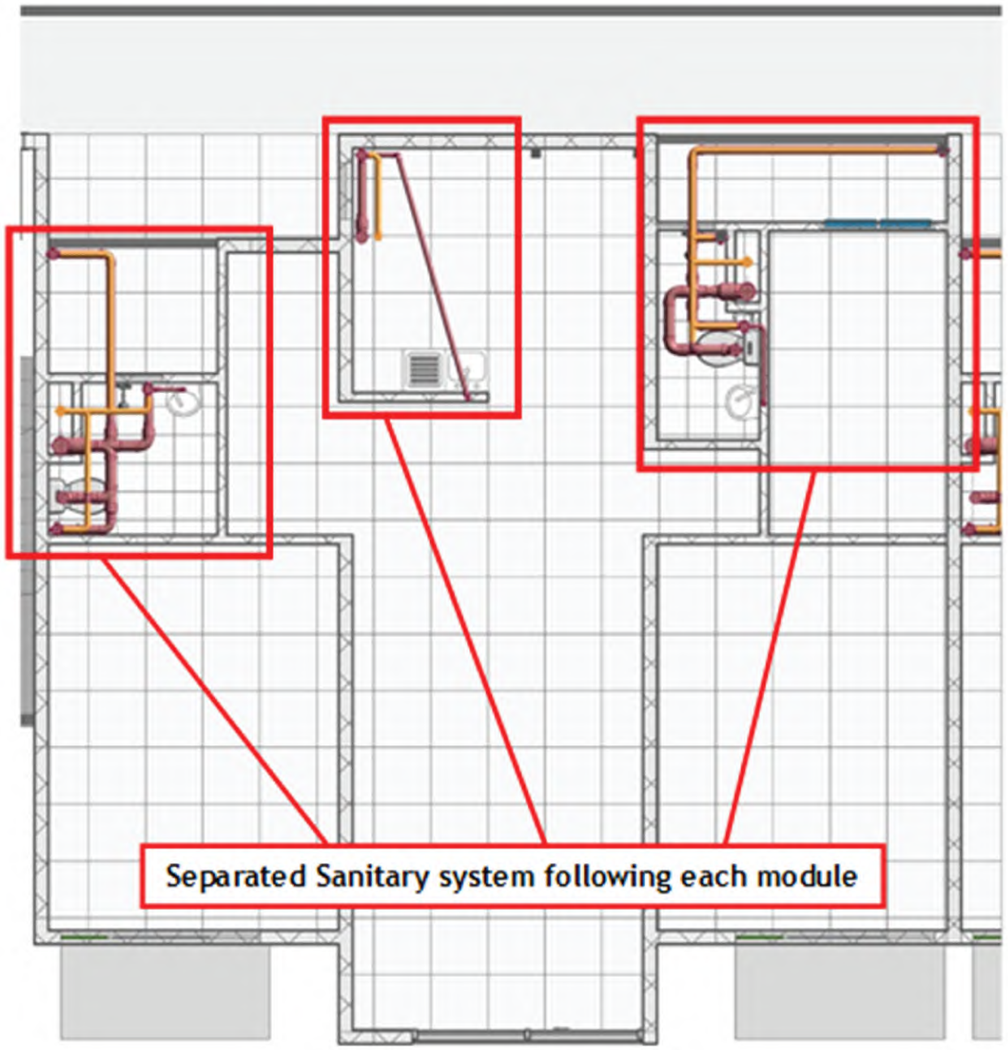
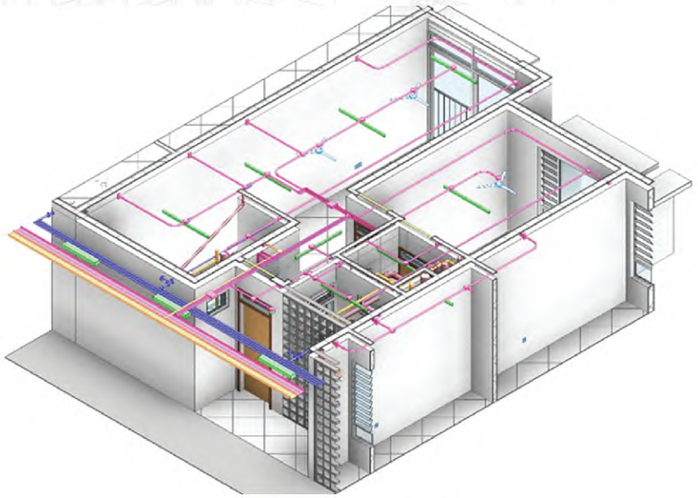
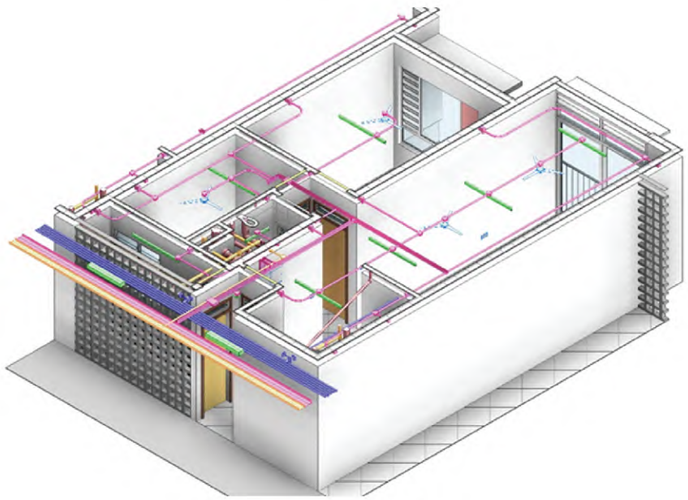


Layout showing a sanitary system between modules

2.5. An Overall MEP Design for DeLIGHT Homes



1-Bedroom Flat



2-Bedroom Flat

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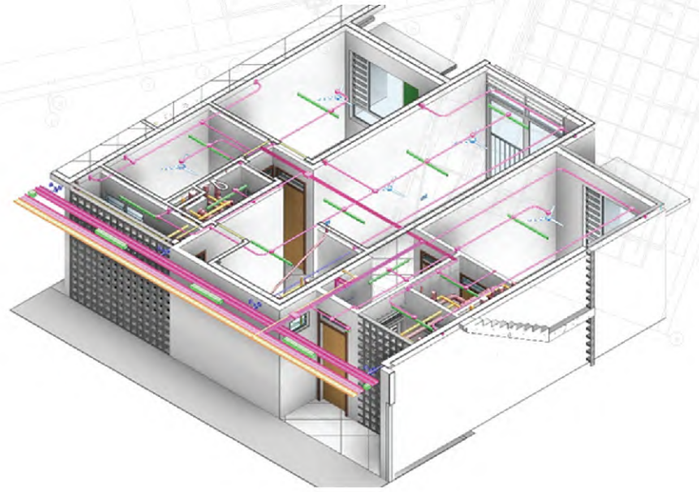
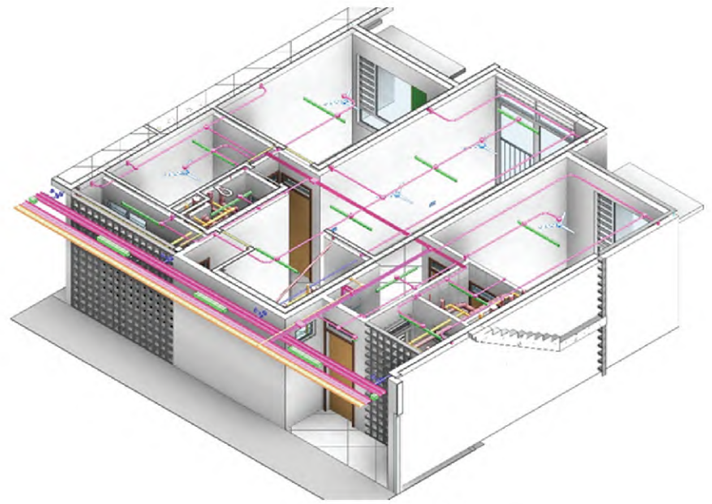
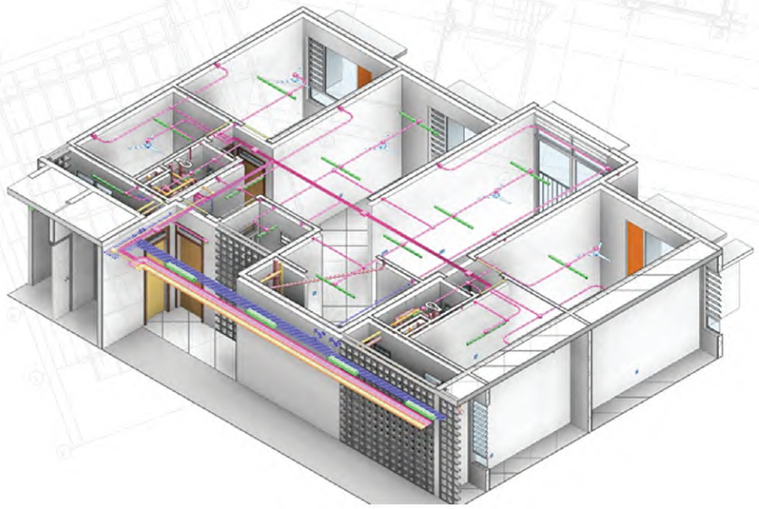


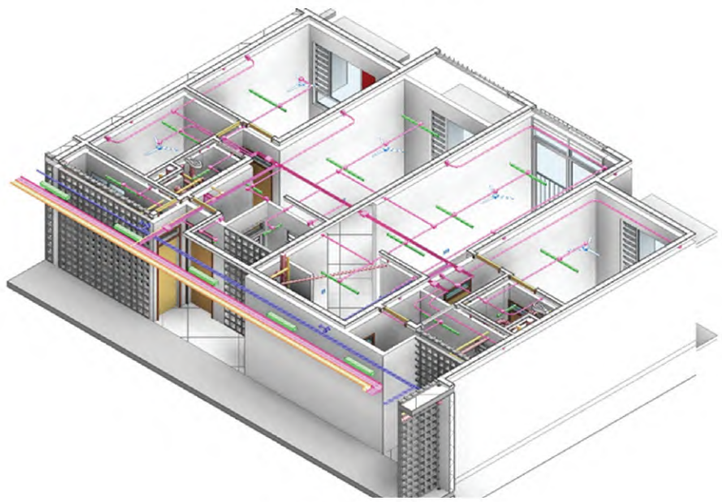
3-Bedroom Flat



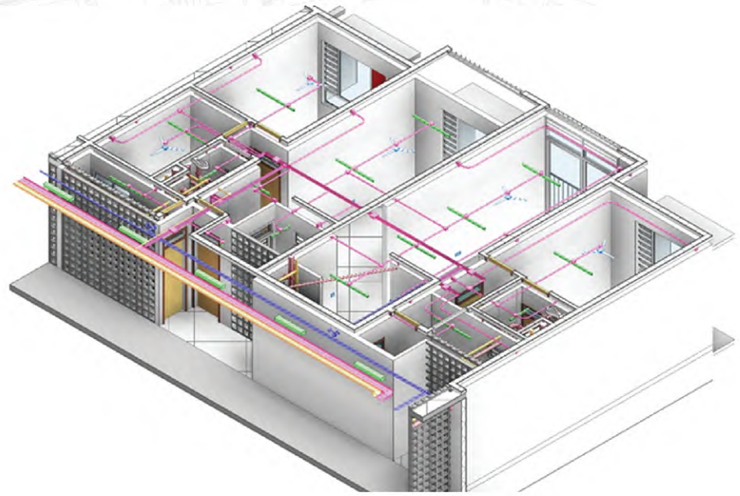
OKU 3-Bedroom Flat



3-Bedroom Flat Type A



3-Bedroom Flat Type B



4-Bedroom Flat

2.6. Things to Consider Before the MEP Installation

Prior to the installation of the MEP conduit and trunking, it is recommended to install MEP services after installing the structural system for the ceiling and walls.

The MEP services access and equipment shall be modelled on BIM LOD 500 for future maintenance works.



2.7. Accessibility for Installation and Maintenance

The means of installation should enable ease of maintenance or future replacement when necessary with adequate space being allocated for installation, maintenance, and future replacement. Pipework enclosures (e.g., ducts, castings, etc.) should be of a suitable size. Sufficient and suitable ready access should be provided for maintenance, inspection, testing and repairing/replacing of the enclosed pipework.



a) Plumbing maintenance



b) Electrical DB troubleshooting



c) Ceiling access to MEP services



d) Lighting point maintenance

Examples of MEP installation & maintenance

C3 MEP CONSTRUCTION CONSIDERATIONS

3.1. General Principles of Prefab MEP Construction

This subsection discusses the prefab MEP construction procedure to ease the works of contractors and give ideas to contractors on the restrictions of the prefab MEP system.

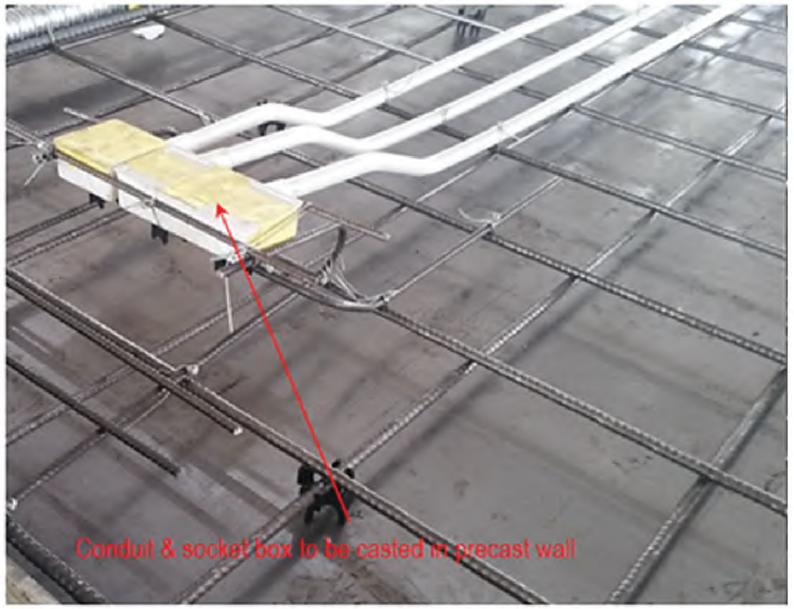
All prefab MEP installation works shall comply with the relevant statutory requirements and regulations, including the requirements imposed by local authorities and technical agencies, among others. Examples of the bodies that issue regulations and standards are Suruhanjaya Tenaga (ST), Suruhanjaya Komunikasi dan Multimedia Malaysia (SKMM), Suruhanjaya Perkhidmatan Air Negara (SPAN), and SIRIM.

3.2. Procedures for Prefab MEP Installation

3.2.1. Electrical installation procedure

- To propose a conduit routing and the maximum number of circuits per conduit.
- To use 25 mm diameter conduits for 3 to 4 circuits taking into consideration the spacing required to comply with the standards and cable size.
- To upgrade all the conduit routing models in BIM to LOD 400.
- All partitions and ceiling structures shall be installed prior to the installation of conduits.
- To install all conduits with proper support brackets.
- To lay cables inside conduits.
- To terminate all electrical cables to the plug and play cable connector system.
- To conduct insulation tests for all circuits prior to the light fitting termination and mobilisation to the site.
- To connect all cables after panels/modules are connected on-site.
- To conduct cable insulation tests before energising the electrical system.





Sample of electrical fixture & conduit laid on prefab panels

3.2.2. Lightning conductor installation procedure

- To allow sufficient installation space for conductor connection in the upper deck and lower deck modules.
- To install all conductors with proper support brackets.
- To connect the upper deck and lower deck conductors with a proper connection system after the modules have been installed on-site.
- To conduct a resistance test and continuity test across the connection area.

3.2.3. Domestic water plumbing installation procedure

- To plan the domestic water supply pipe routing.
- To upgrade all domestic water supply piping models in BIM to LOD 3 400.
- To install all domestic water supply pipes with proper support brackets.
- To conduct pressure tests according to the consultant's specifications prior to mobilising to the site.
- To conduct pressure tests after the modules have been installed on-site.
- To connect domestic water supply pipes from the common corridor to the stop cock of the toilet's main pipe.

3.2.4. Sanitary plumbing installation procedure

For sanitary installation, it is vital to get the structural pivot setting points for the sanitary opening set out.

To upgrade all the sanitary piping models in BIM to LOD 400 with access manhole consideration. These manholes shall not compromise the fire rating criteria.

To mark the sanitary pipe opening required for structural opening.

To install and tie all sanitary pipes to structural elements prior to mobilisation to the site.

To connect all sanitary pipe connections to the main sanitary stack through the access manhole.



Sample of plumbing fixture & piping laid on prefab panels



C4 MEP MAINTENANCE CONSIDERATIONS

4.1. Prefab MEP As-Built Drawings

This subsection discusses the procedure for constructing an MEP system that will ease building maintenance. In prefab MEP, it is important to keep all the MEP systems documented at the BIM LOD 500. As such, the contractor shall produce as-built drawings and the BIM model for future maintenance works at the LOD 500, which is crucial at this stage to allow tenants access to all non-generic information on the MEP components.

Tenants shall be provided with the following documents for renovation purposes:

As-built drawings of prefab MEP services

Renovation handbooks of MEP Services

Prefab MEP connection component list



SECTION D:

HANDBOOK FOR QUANTITY SURVEYORS

D1 Brief Introduction
- 1.1 What is BIM and 5D BIM?
- 1.2 What is Not BIM?
- 1.3 Why is it Important to Adopt BIM?
- 1.4 The Adopted BIM Software
- 1.5 BIM Workflow
- 1.6 Misconceptions About 5D BIM/Quantity Surveyors
- 1.7 Intellectual Property Rights and Reluctance to Share a Model
- 1.8 Verification of the 3D Model – Model Enhancement
- 1.9 Understanding and Knowledge of 5D BIM for the Project
- 1.10 Collaboration – Building Execution Plan (BEP)
- 1.11 Benefits of 5D BIM
- 1.12 Legal Consideration in Using BIM

D2 5D BIM Extraction
- 2.1 DeLIGHT Homes: 5D BIM Extraction
- 2.2 Process and Methodology of 5D BIM
- 2.3 5D BIM Cost Analysis Report

D3 Findings

Written by:

IPM PDMa



DeLIGHT Homes
A Sustainable and Innovative Affordable Housing Design Handbook

D1 BRIEF INTRODUCTION

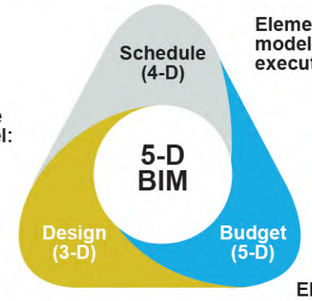
1.1. What Is BIM and 5D BIM?

Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a project, forming a reliable basis for decisions during the project's life cycle.

BIM has become increasingly popular in recent years as digital construction technology is beginning to fundamentally transform the building and construction industry practice in the delivery of the built environment.

Information that can be embedded in 3-D model:

- Geometry
- Spatial data (from geographic information systems/lidar)
- Specifications
- Aesthetics (eg, color)
- Thermal properties
- Acoustic properties



Elements of a 3-D model are linked to the execution schedule

Elements of the 3-D model are used to develop budget and linked to cost heads

BIM is also defined as a modelling technology with an associated set of processes to produce, communicate, analyse, and use digital information models throughout a construction project life cycle (Pemandu Kebangsaan 2013).

The data rich BIM model provides a digital presentation of a building with the 3D design building information data linked to a database, thus enabling easier visualisation.

New technologies will improve construction productivity along with the level of integration and collaboration across various disciplines in the construction value chain. It is therefore important for the industry to embrace the technology with clarity.

1.2. What is Not BIM?

The non-exhaustive list below provides some examples of models that are not regarded as BIM:

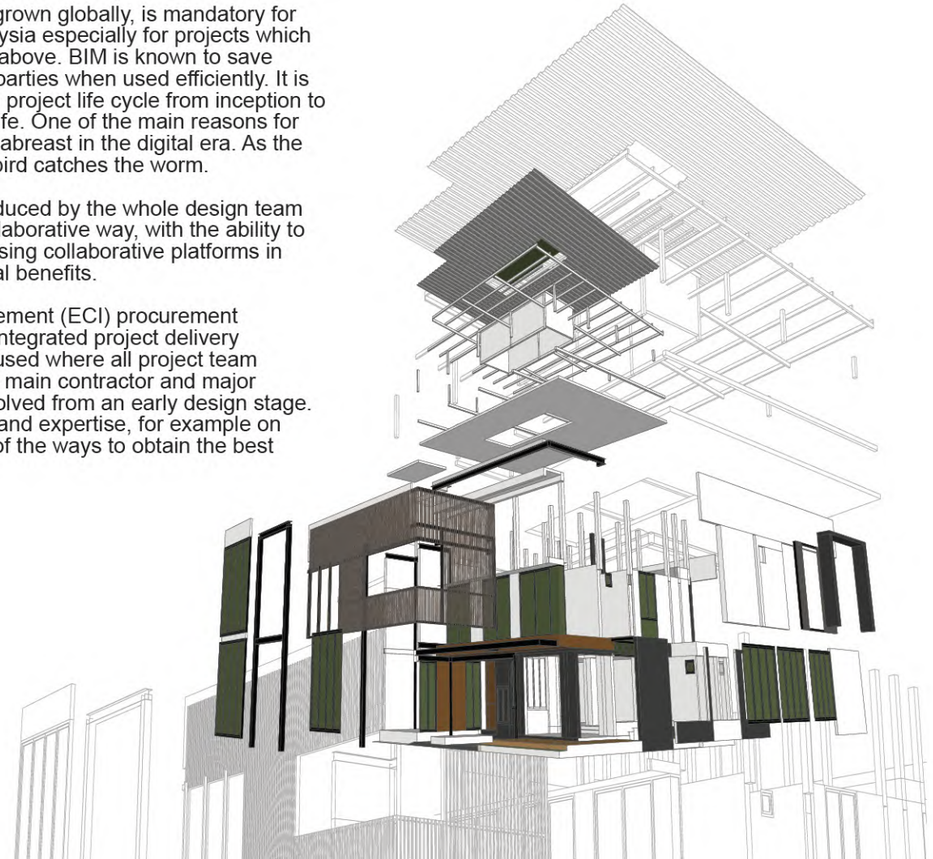
- Models that contain 3D data only and have no (or few) object attributes
- Models with no support of behaviour
- Models that are composed of 2D CAD reference files that must be combined to define a building
- Models that allow changes to dimensions in one view that are not automatically reflected in other views

1.3. Why is it Important to Adopt BIM?

BIM usage, which has grown globally, is mandatory for certain projects in Malaysia especially for projects which are RM100 million and above. BIM is known to save money and time for all parties when used efficiently. It is about adding value to a project life cycle from inception to the end of a building's life. One of the main reasons for adopting BIM is to stay abreast in the digital era. As the saying goes, the early bird catches the worm.

Project information produced by the whole design team should be used in a collaborative way, with the ability to exchange digital data using collaborative platforms in order to fulfil its potential benefits.

Early Contractor Involvement (ECI) procurement approach involving an integrated project delivery methodology could be used where all project team members, including the main contractor and major subcontractors, are involved from an early design stage. Obtaining design input and expertise, for example on constructability, is one of the ways to obtain the best outcomes from BIM.



1.4. The Adopted BIM Software

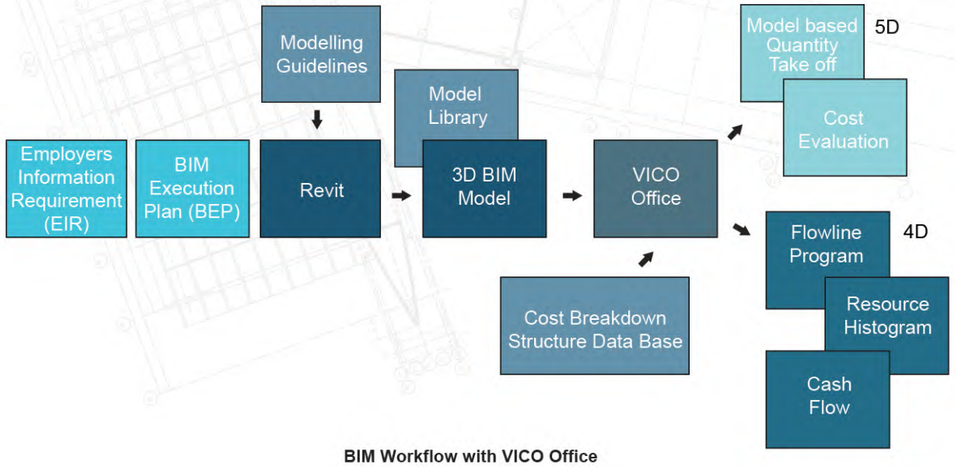
Various choices of BIM software are available in the market with different types of authoring tools, including Autodesk Revit, Archicad, Tekla, Bentley, and many others.

To conduct BIM for this DeLIGHT Homes case study, a software had to be selected for the use of all parties to collaborate and to perform the 3D design, 4D scheduling, and 5D Cost. In this case, Autodesk Revit 2018 was selected as the design authoring tool.

For the 4D and 5D BIM, many software options are available in the market such as Cost X, Cubicost (Glodon), Vico (Trimble), and others. For this case study, the Vico 5D BIM tool was used to extract quantities from the 3D BIM model followed by costing.



1.5. BIM Workflow



BIM Workflow with VICO Office

The BIM workflow was requested in the Employer's Information Requirements (EIR) and then defined in the BIM Execution Plan(BEP), which is developed at the commencement of the project by the project team including the client.

This workflow requires inputs from all parties and may be facilitated by the BIM Manager.

It is crucial that the 5D BIM/quantity surveyor specifies the required information from the beginning and collaborates with the design team to reach an agreement of what will and will not be included in the model.

Among its other common uses, BIM has the ability to extend a 3D design to add a planning dimension (4D) and a cost dimension (5D).

The fifth dimension (5D) in BIM refers to the quantity and cost extraction within specific elements according to the Standard Method of Measurement Malaysia.

In Malaysia, the Royal Institution of Surveyors Malaysia (RISM) are developing the new standard method of measurement in collaboration with CIDB with the title "MySMM – Malaysia Standard Method of Measurement" anticipated to be officially launched by middle/end of year 2020.

BIM is an effective digital tool for the 5D BIM/quantity surveyor to assess and affect the design and delivery process for better commercial outcomes.

The 5D BIM/quantity surveyor should be involved at the outset of the project, communicate with the design team effectively, and also contribute in guiding, understanding, and reviewing the model throughout the project's life cycle.

1.6. Misconceptions About 5D BIM/ Quantity Surveyors

Now that the BIM authoring software has become mainstream, some common misconceptions have emerged regarding the role of the 5D BIM/quantity surveyors, including:

- Quantity surveyors will be extinct once BIM is adopted
- All quantities reside within the 3D model
- Bill of quantities can be produced with the click of a button
- An architect or engineer can extract quantities from a model; hence, they can now perform the quantity surveyor's role
- The scope of work of 5D BIM is just extracting quantities from the 3D model

5D BIM is about cost rather than quantities. Extracting quantities is not the only intent of 5D BIM or quantity surveying. It exists in the workflow that the 5D BIM/quantity surveyors utilise their skill set and knowledge to perform the professional cost management role of a project.

Page 5 of Finland's COBIM 2012 Series 7 states that:

> *BIM does not resolve quantity take-off related issues "exhaustively" and not all quantities needed during a project can be taken off from BIM. The professional skill of a Quantity Surveyor is still needed in assessing the validity of the source data and source materials, ensuring the coverage of the take-off, proposing alternative solutions, and analysing the results.*

In conclusion, 5D BIM/quantity surveyors using BIM will still perform the same fundamental processes as in traditional quantity surveying.

However, the use of BIM tools allows 5D BIM/quantity surveyors to increase the time spent on value-adding processes such as benchmarking the cost rates and simulating the variations and cost effects of alternative material types or application of different methods of construction on the overall project budget. Thus, 5D BIM/quantity surveyors would be able to recommend alternatives for adoption, which would ultimately provide the client with the assurance that the most cost-effective options have been advised to the client.

The deliverables for the design phase, pre-contract, and post-contract quantity surveying are the same but enhanced due to the collaboration process enabled by BIM and the ability to use digital information for quantification.

The 5D BIM/quantity surveyor using BIM places greater emphasis on the verification and validation process.

1.7. Intellectual Property Rights and Reluctance to Share a Model

Often, design team members are reluctant to provide their models to quantity surveyors and contractors, citing liability or intellectual property rights and concerns.

Even though these concerns may be valid, discussing what and how the model will be used for, used at specific stages, and how it will affect the overall cost will often result in designers being more open to providing their models in their native format instead of converting to IFC format which would result in loss of data.

1.8. Verification of the 3D Model – Model Enhancement

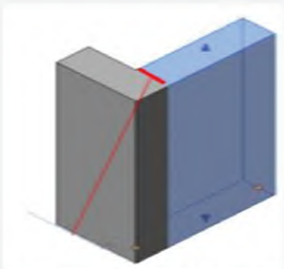
5D BIM/Quantity surveyors can achieve the following from the 3D information model:

- Fast and efficient quantity validation and verification
- Informed specifications/materials used in the 3D models
- Rapid processing of design revisions/updates
- More reliable and responsive cost advice/cost estimation
- Quick cost design options that allow early informed decisions

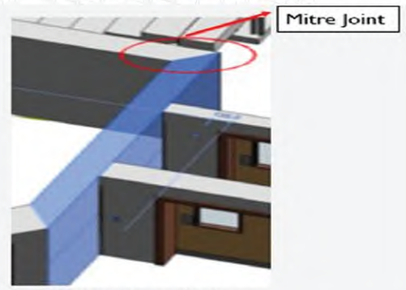
The 5D BIM/quantity surveyor could also help to critique the comprehensiveness of the digital information of the 3D BIM model for accuracy and reliability of use for cost advice or cost management.

The 5D BIM/quantity surveyor's required Level of Development from the digital data (whether graphical or non-graphical) depends on the expected quality output of the 5D BIM/quantity surveyor's cost information and the agreed Level of Development expected of the 3D information model at the specific stage of design development as specified in the BEP.

For example, when modelling the 3D model, it is advised to use the "Mitre joints" instead of "straight" conventional way for BIM compliance design, as shown in the diagram below. This is because the accuracy of the model will determine the accuracy of the quantifications extracted from the model and consequently, the accuracy of the pricing of items.



Conventional Way of Design

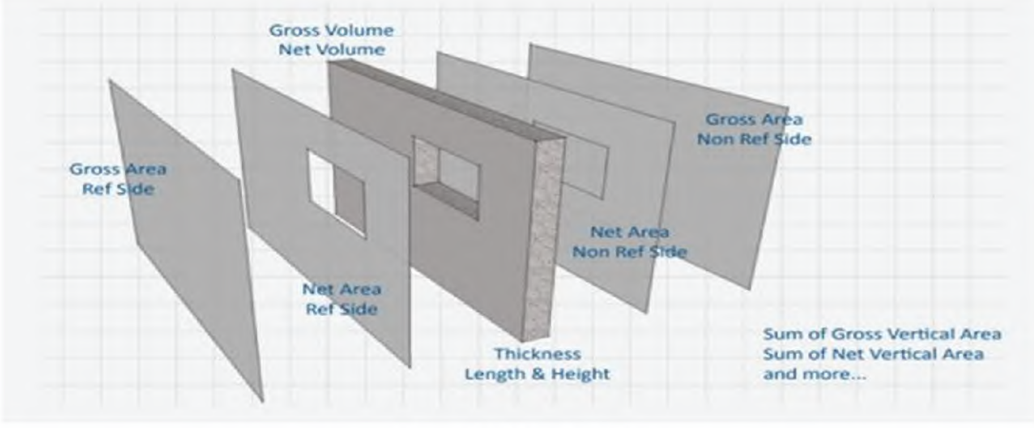


BIM Compliance Design

An advantage of the 5D BIM/quantity surveyor is that the Vico 5D BIM tool is able to extract different measurement units for each item, thus allowing flexible formulation of the quantification of the items taken off/extracted.

It is important to understand what the BIM tools have extracted and quantified, as the 5D BIM/quantity surveyor should be aware of the principle or concept of "rubbish in, rubbish out".

In identifying the quantity extraction for each of the elements, the Vico 5D BIM software is capable of extracting 19 different units of quantities, thus enabling the 5D BIM/quantity surveyor to choose the most suitable measurement of quantities that meets the required standard method of measurement.



Construction-calibre quantities

The types of quantities that could be extracted by the Vico 5D BIM tool are as follows:

	Name	Unit	Cost Me	Task Me	– Project
	Count	NR	No	No	6.00
	Edge Perimeter	M	No	No	235.00
	Hole Count	NR	No	No	0.00
	Hole Perimeter	M	No	No	0.00
	Bottom Surface Area	M2	Yes	No	530.88
	Top Surface Area	M2	Yes	No	530.88
	Edge Surface Area	M2	No	No	35.25
	Hole Surface Area	M2	No	No	0.00
	Net Volume	M3	No	No	79.63
	Gross Volume	M3	No	No	79.63
	Joint Horizontal Surface Area	M2	No	No	0.00
	Joint Vertical Surface Area	M2	No	No	0.00
	Piece Count	NR	No	No	6.00
	Edge Length	M	No	No	235.00
	Joint Length	M	No	No	0.00
	Hole Edge Length	M	No	No	0.00
	Hole Joint Length	M	No	No	0.00
CAD	CAD_Count	NR	No	No	6.00
CAD	CAD_Volume	M3	Yes	No	79.63

An example of the quantities (different types of units) extracted for the floor element

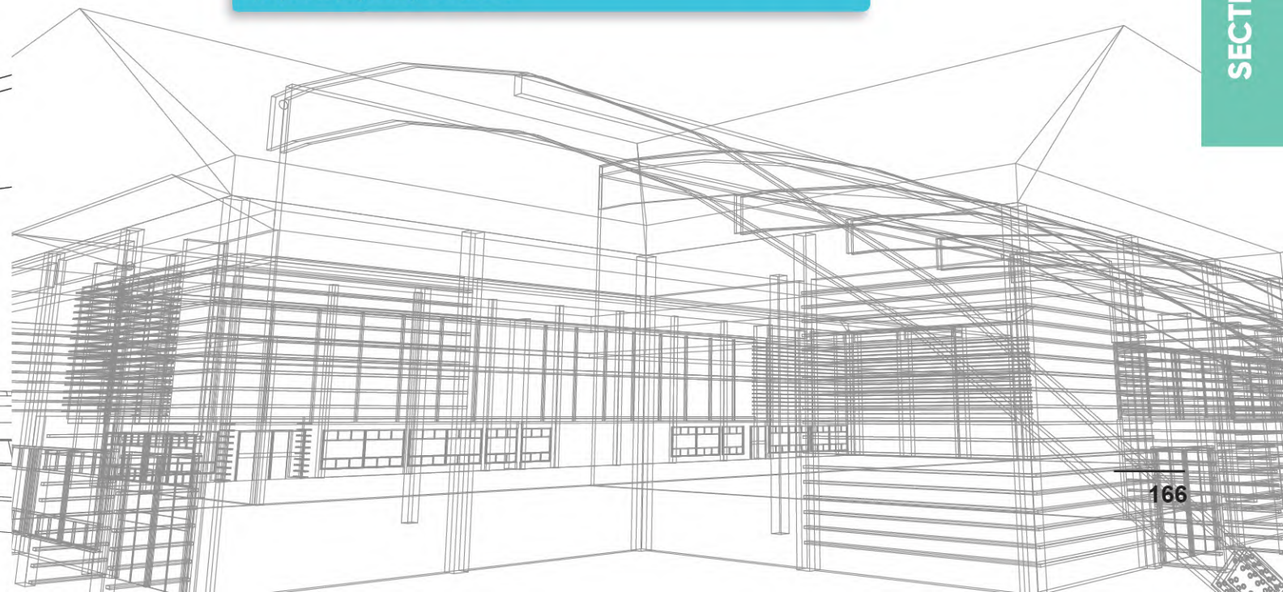
For example, the above illustration for the floor element shows that 19 different measurement units of quantity derivation and extraction could be obtained from Vico 5D BIM.



1.9. Understanding and Knowledge of 5D BIM for the Project

The understanding and knowledge of 5D BIM for the project would be beneficial and enhanced when the 5D BIM/quantity surveyor:

- Engages with the author of the BEP to achieve a common understanding and provide input where appropriate
- Shares the naming conventions that is standard for all respective parties/consultants so it would be easier to understand every component used when the model is imported
- Understands expectations and the timing of deliverables
- Understands the frequency and types of files that will be issued
- Understands the extent of model validation being performed before issuance
- Understands how information is being shared, updated, amended, etc.
- Understands the proposed classification coding system and how this could be leveraged by the 5D BIM/quantity surveyor
- Communicates/elaborates not only for the use of quantity surveyors but also for other downstream users that generic model objects should not be used for any elements that are required to be quantified
- Understands that digital models should be modelled the way the project is physically to be built





1.10. Collaboration – Building Execution Plan (BEP)

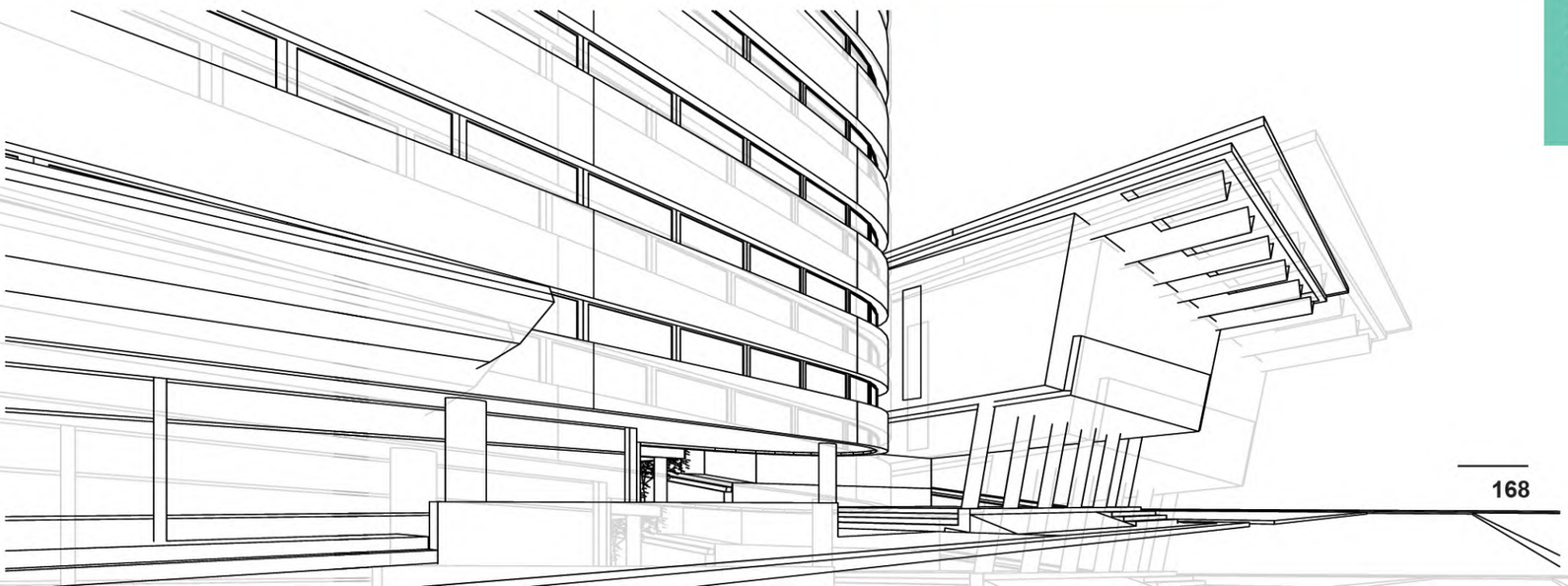
It is important for the 5D BIM/quantity surveyor to collaborate with the architects and engineers in the project team in which the keys to a collaborative BIM project are:

- Early communication of the client's BIM requirements to the design team
- An agreed set of requirements is established prior to commencing with the design with standardised naming conventions and set out in the BIM Execution Plan/BIM Management Plan, supported by the BIM Model Content Plan
- Respect and appreciation of others' disciplines and their objectives
- Appropriate collaborative software is in place

1.11. Benefits of 5D BIM

The benefits of 5D BIM include but not limited to:

- Enhanced visualisation
- Reduces inaccurate interpretation of project documentation (e.g. drawings, specifications)
- Reduces the assumptions which the 5D/quantity surveyor needs to make
- Visualises the different elements/components which are extracted directly from the 3D models (able to use different colours for different elements/components)
- Enables efficient and fast financial evaluation of alternative design options at the concept design stage
- Enhances collaboration between the quantity surveyor and other design team members at the cost planning stage
- Rapid identification of design changes during the design development stage
- Provides commercial advantage over competitors for the quantity surveyors who wholeheartedly embrace 5D BIM, utilising it on complex construction projects
- Sets the minimum level of compliance for ethical and legal implications



1.12. Legal Considerations in Using BIM

For projects that adopt BIM-based digital technologies, there are legal considerations that should be addressed early during the contract formation phase.

There should be an agreed protocol defining how BIM will be implemented in the project along with the limits of that implementation. The agreed protocol should be incorporated by reference into the contract documentation.

The BIM, at the agreed Levels of Development, should ideally form part of the construction contract documentation and be incorporated in the contract terms for each professional appointment, including the quantity surveyor.

Other amendments to the legal documentation may be needed depending on the BIM Levels of Development being used in the project. These include:

- Clarity as to the assumptions of risk and liability in relation to the BIM
- The duties, rights, and responsibilities of the BIM Manager
- Which parties are liable for mistakes in the BIM and to which other parties they owe liability
- The lines of communication between the BIM Manager and various construction and consultant parties
- Time limitation periods applied concerning each party's liability for the information included in the BIM
- The level of duty of care imposed on the consultants, including the quantity surveyor

D2 5D BIM EXTRACTION

2.1. DeLIGHT Homes: 5D BIM Extraction

The 3D BIM Model was built by the architect using the design authoring tool and provided to the 5D BIM for extraction, quantification, and pricing.

In this DeLIGHT Homes case study, the Vico 5D BIM tool was chosen to perform the 5D BIM extraction, quantification, and pricing.

The whole extraction, quantification, and pricing process is illustrated in detail in subsection 2.2 of this Handbook for Quantity Surveyors.

The extraction of quantities can be done by using the 5D BIM tools in the market. In choosing the software to perform the extraction in an idle environment, consideration should be given as to whether the tools are able to link the 3D model directly to the cost and the planning and scheduling, which would mitigate errors when changes/variations are made as these changes/variations are captured automatically.

This handbook for Quantity Surveyors aims as a hands-on walkthrough guide/reference for Quantity Surveyors and people who are interested in exploring further into 5D BIM. It gives a sneak preview and illustrates diagrammatically the extraction, quantification, model mapping linking and pricing of 5D BIM processes which would help Quantity Surveyors to perform fundamental Quantity Surveyors/5D BIM process.



2.2. Process and Methodology of 5D BIM

In walking through the process and methodology of 5D BIM of this DeLIGHT Homes case study, we will be exploring 2 types of standard modules which would be extracted, quantified and priced upon:-

- Individual standard modules
- 3 floors of standard modules – for high rise

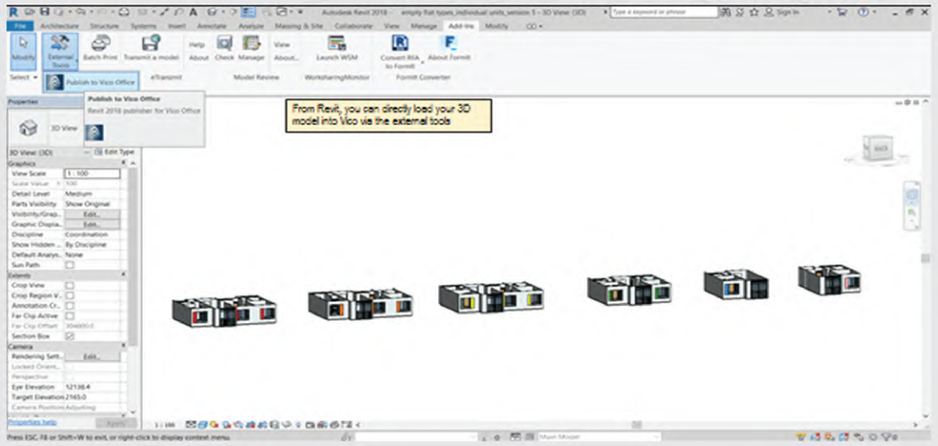
2.2.1. Individual standard modules

The 5D BIM process and methodology for individual standard modules are explained in detail in the attached visualisation slides.

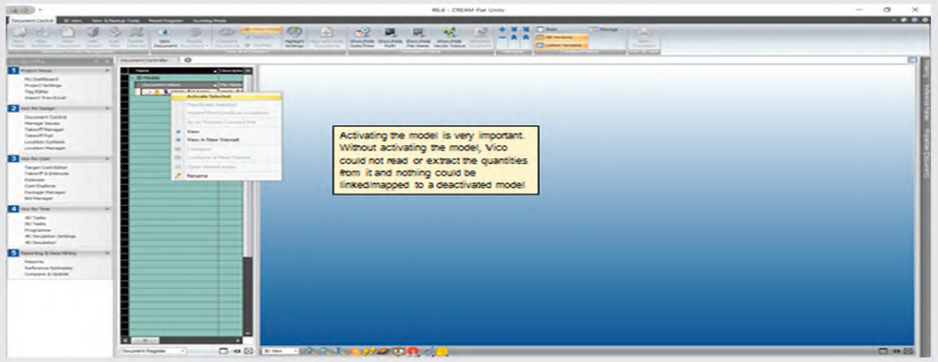
The model was built by the architect using the design authoring tool, Autodesk Revit 2018 software, and subsequently provided to 5D BIM/quantity surveyors for extraction, quantification, and pricing using the Vico 5D BIM software.

The extraction and quantification method would be explained and illustrated step by step accompanied by the visualisation slides for ease of understanding.

STEP 1: Export the 3D model from Autodesk Revit 2018 to Vico 5D BIM tool to start the 5D BIM extraction and quantifying process.



STEP 2: Activate the Autodesk Revit 2018 3D model in the Vico 5D BIM tool to start the 5D BIM linking and extraction process.



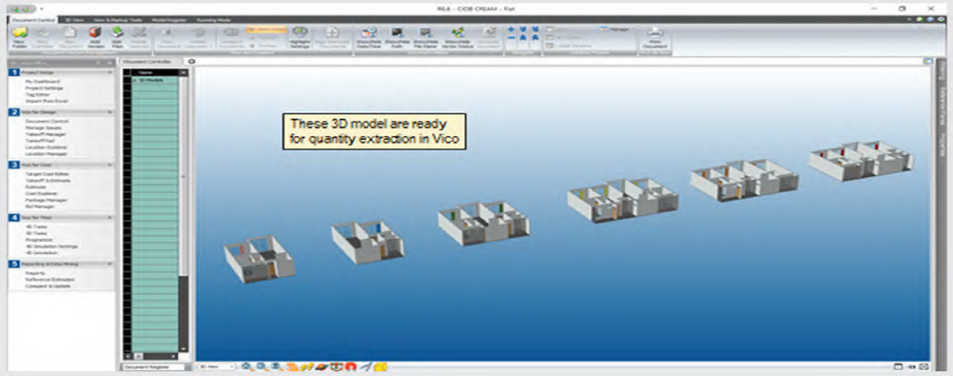
SECTION D

STEP 3: Once activated, the Autodesk Revit 2018 3D model could be imported into the Vico 5D BIM tool directly in (.rvt) native format.

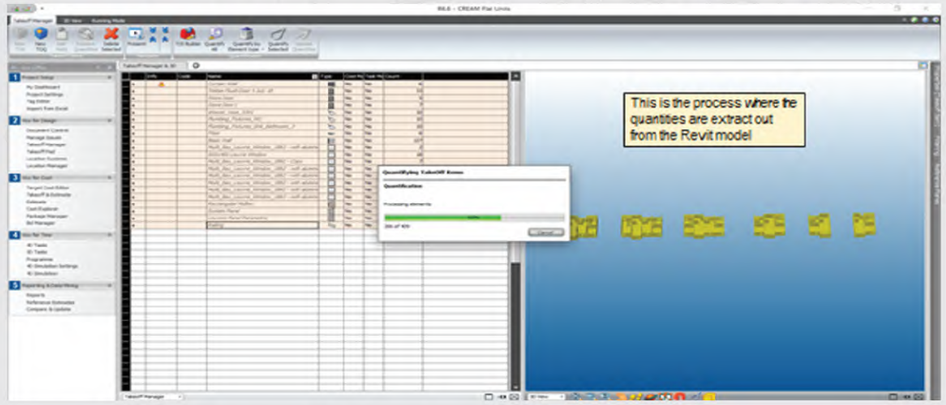


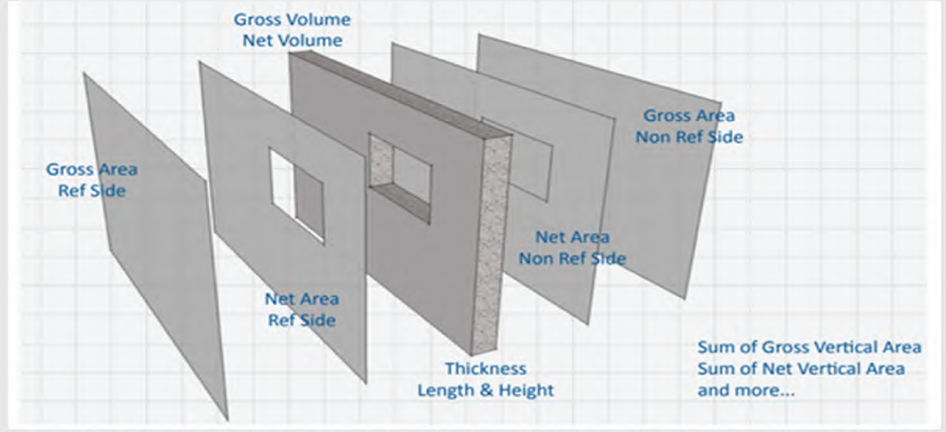
One of the special features of Vico 5D BIM is that the 3D model is directly exported from the Revit model to Vico 5D BIM using the native Revit file in the (.rvt) format instead of converting it into an IFC format file. This prevents lost or missing data during the conversion of the Revit file into an IFC format file.

STEP 4: The 3D Autodesk Revit 2018 model is ready for quantity extraction.



STEP 5: The 3D Autodesk Revit 2018 model's quantities are directly generated and extracted in the left window. For the highlighted materials, the corresponding elements in the 3D models which have been quantified would be highlighted in yellow.

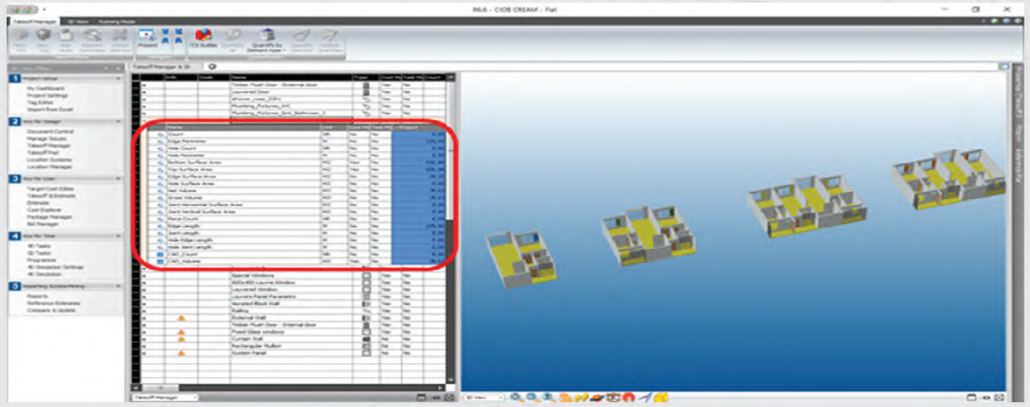




Types of quantities (units of derivatives) extracted by Vico 5D tool software

Additional information:

The types of quantities extracted using the Vico 5 D BIM tool are shown in a diagrammatic form.



An example of the quantities extracted for the Floor element

	Name	Unit	Cost Mz	Task Mz	– Project
	Count	NR	No	No	6.00
	Edge Perimeter	M	No	No	235.00
	Hole Count	NR	No	No	0.00
	Hole Perimeter	M	No	No	0.00
	Bottom Surface Area	M2	Yes	No	530.88
	Top Surface Area	M2	Yes	No	530.88
	Edge Surface Area	M2	No	No	35.25
	Hole Surface Area	M2	No	No	0.00
	Net Volume	M3	No	No	79.63
	Gross Volume	M3	No	No	79.63
	Joint Horizontal Surface Area	M2	No	No	0.00
	Joint Vertical Surface Area	M2	No	No	0.00
	Piece Count	NR	No	No	6.00
	Edge Length	M	No	No	235.00
	Joint Length	M	No	No	0.00
	Hole Edge Length	M	No	No	0.00
	Hole Joint Length	M	No	No	0.00
CAD	CAD_Count	NR	No	No	6.00
CAD	CAD_Volume	M3	Yes	No	79.63

An example of the quantities in 19 different measurement of quantity derivation and types of units extracted for the Floor element

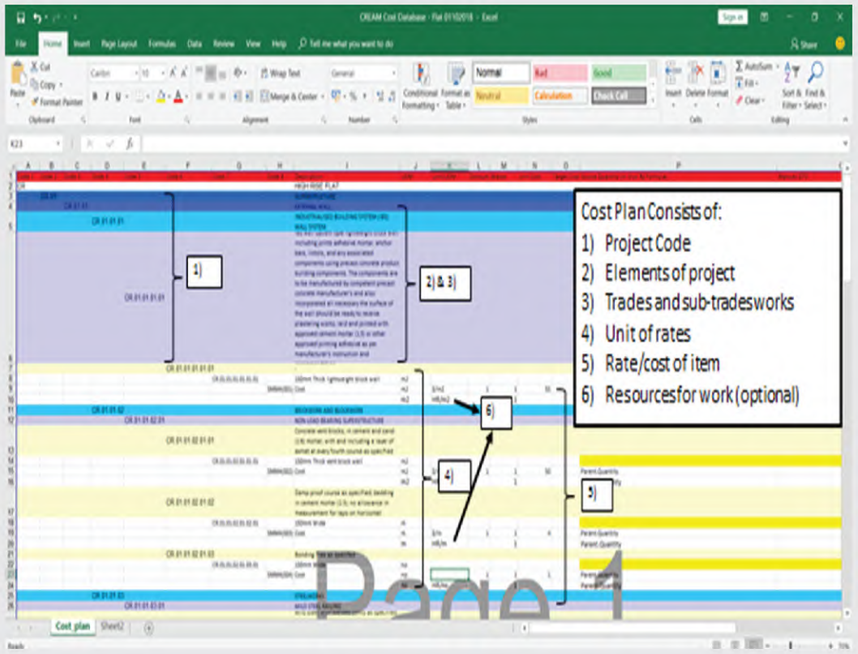
Additional information:

The types of quantities extracted using the Vico 5D BIM tool are displayed in a tabular form above, illustrating the 19 different measurement units of quantity derivation and extraction that could be obtained.

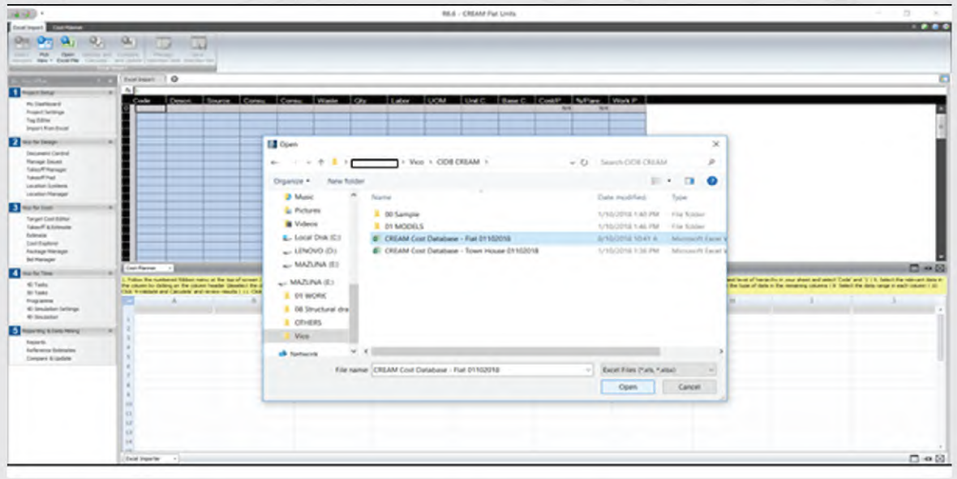
STEP 6: Preparation of the 5D Cost Plan could be done in the Vico 5D BIM tool or Excel for flexibility.

The Cost Plan consists of:

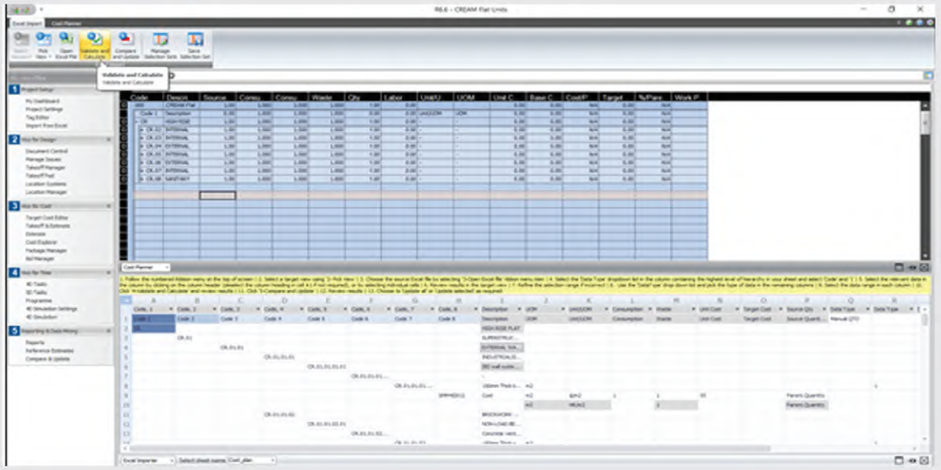




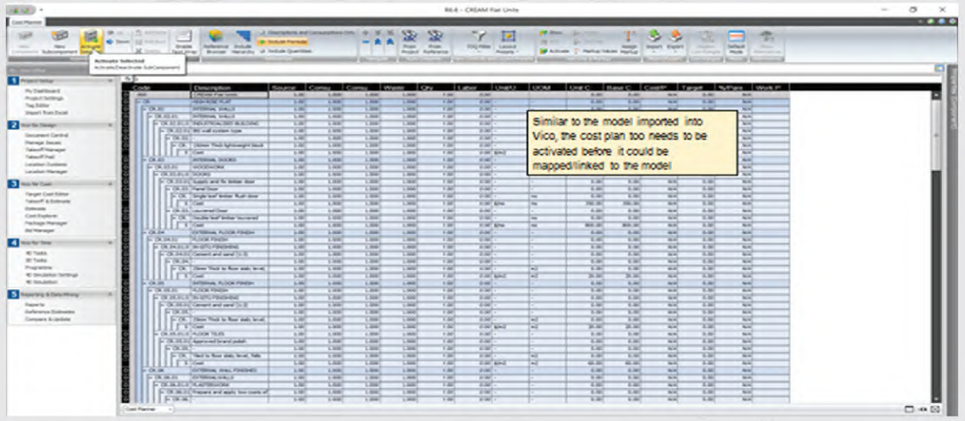
STEP 7: Once the 5D Cost Plan has been established (if it is done in Excel), the Cost Plan would be transferred into Vico 5D BIM.



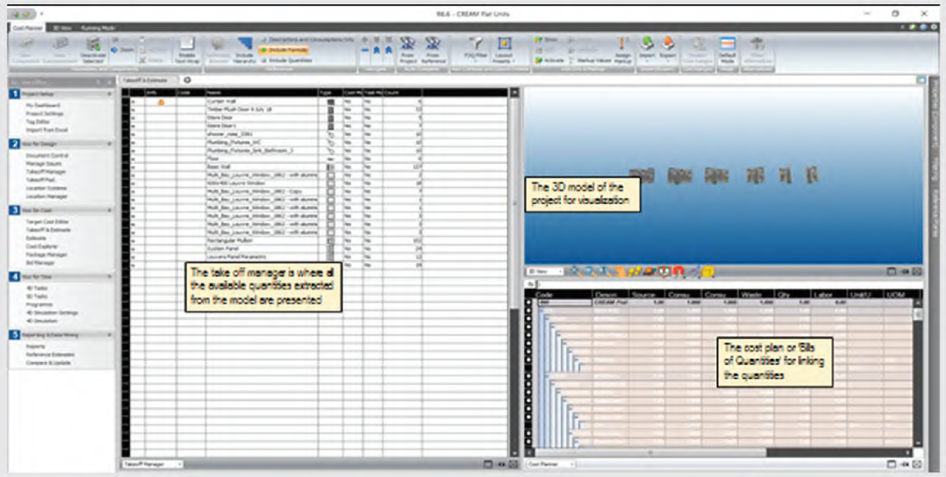
STEP 8: The 5D BIM Cost Plan needs to be validated.



STEP 9: The 5D BIM Cost Plan would be activated and ready to be mapped to the 3D model.

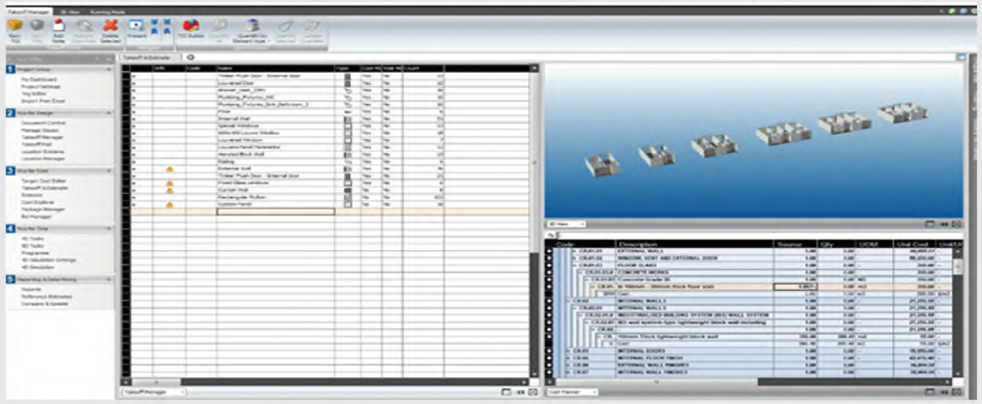


STEP 10: The 3D model is then linked to the Take Off Manager (Quantities) and linked to the 5D BIM Cost Plan. This could be seen in the 3-way view window.



SECTION D

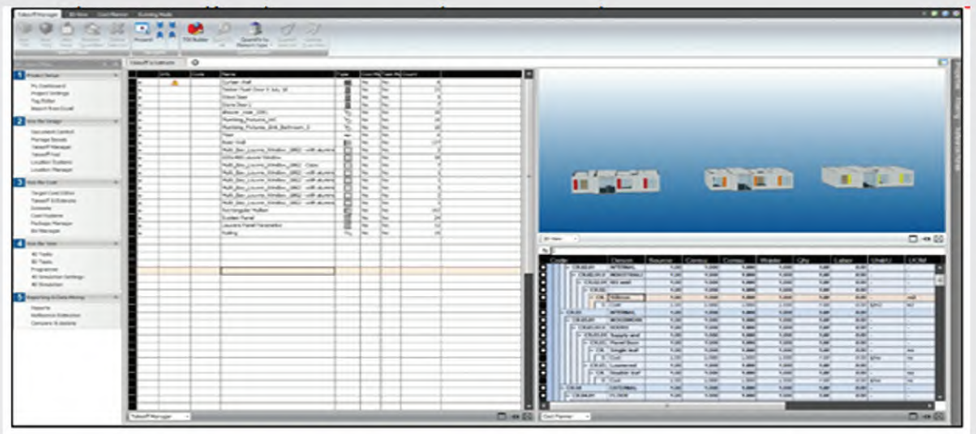
STEP 11: The 3D model for Concrete Floor Slab is linked to the Take Off Manager (Quantities of the Floor Slab) and linked to the 5D BIM Cost Plan for the Concrete Floor Slab.



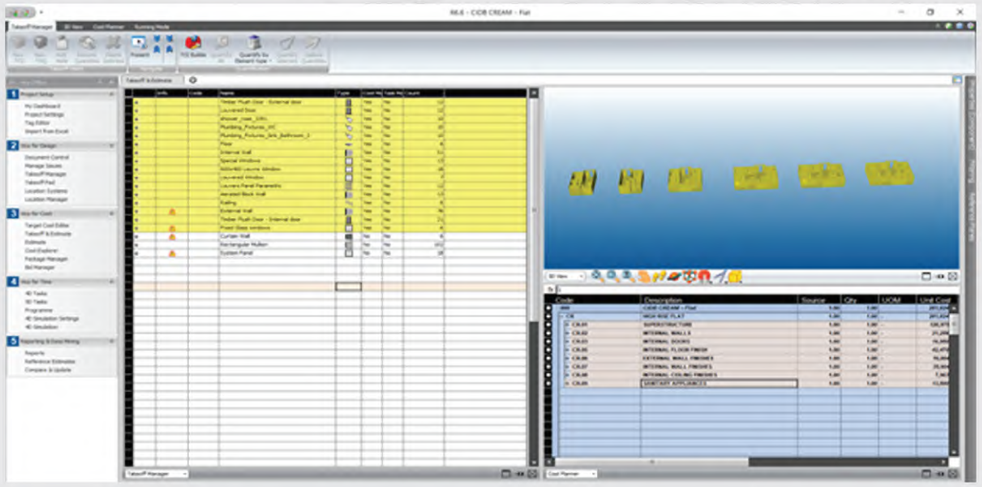
The most important feature is:

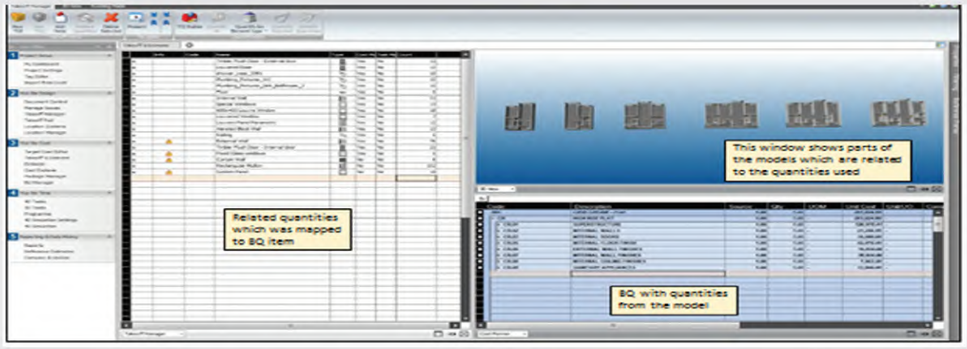
When the 3D Model changes, the associated quantities, cost, and time change accordingly. This is important to track changes in variations and capture these changes with cost.

STEP 12: The same process goes to extracting and mapping the 3D model of the External Wall linked to the Take Off Manager (Quantities of the External Wall) and linked to the 5D BIM Cost Plan of the External Wall.



STEP 13: Once all the quantities have been successfully mapped, the model would be highlighted in yellow and linked to the Take Off Manager would also be highlighted in colour (yellow).



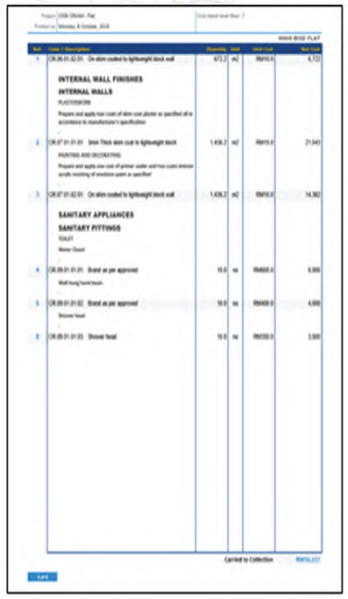


An example of completed model mapping (link quantities to 3D model and Cost Plan/BQ)

SECTION D

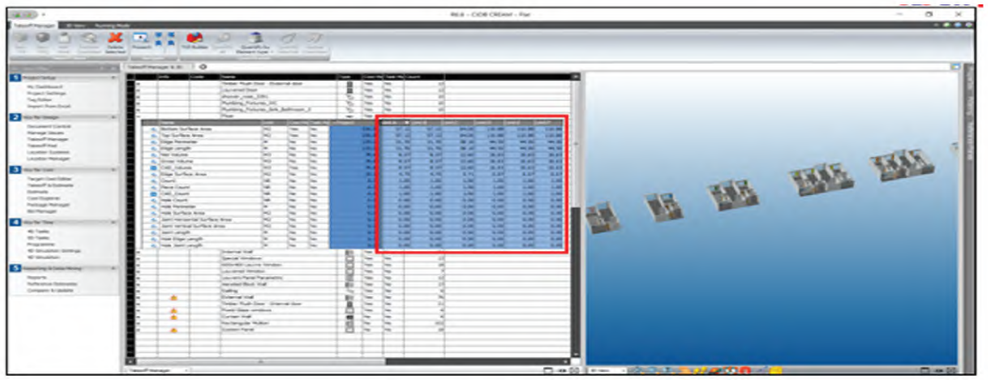
STEP 14 (FINAL): Once all elements in the 3D model have been mapped and linked with the cost and time, the 5D BIM tool could generate the costing report, as shown in the example below.





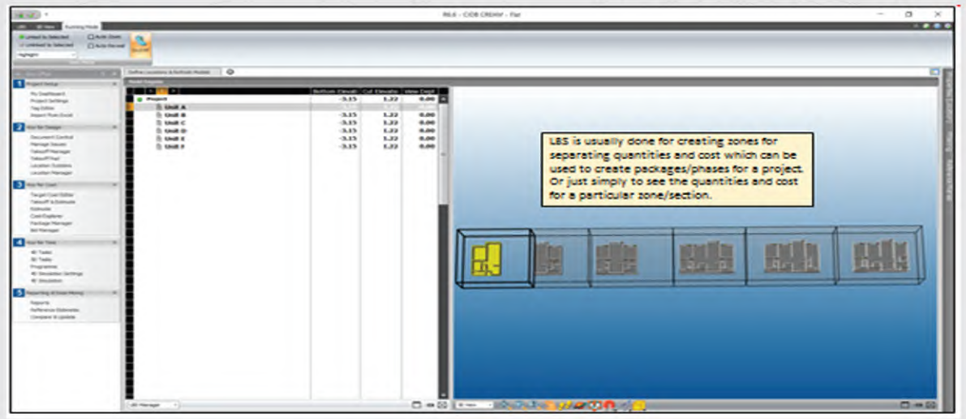
2.2.2. 5D BIM report and pricing for individual standard modules (location-based)

The 5D BIM report and pricing for individual standard modules using the location-based section is illustrated below:



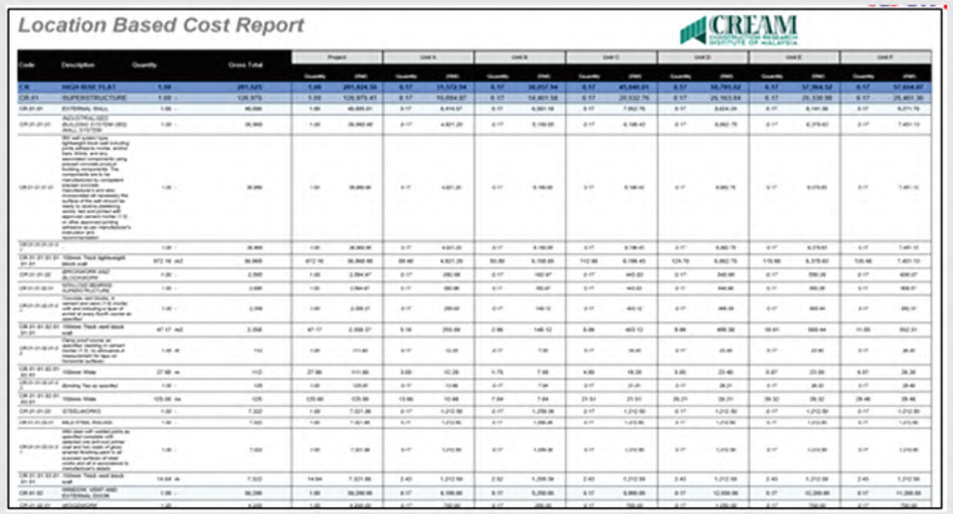
Location-based sectioning (LBS) – Quantities by section

The 3 D model is local-based sectioned according to the required zones for which the quantities and cost could be sub-divided and costed accordingly. This is important as the local based sectioning could be done vertically (split to zones) as well as horizontally(split to different floors) as per request by client.



Location-based sectioning (LBS)

The location-based sectioning would give the quantity and cost of each section, as required.



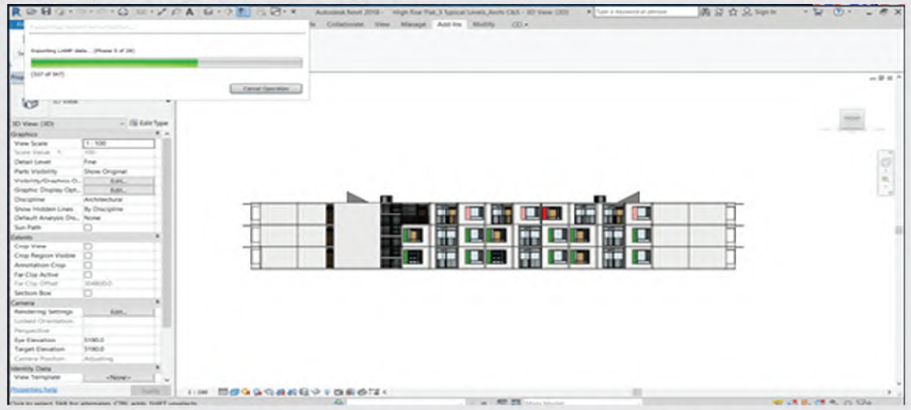
Location-based sectioning (LBS) – Cost report

2.2.3. 3 floors of standard modules – high rise

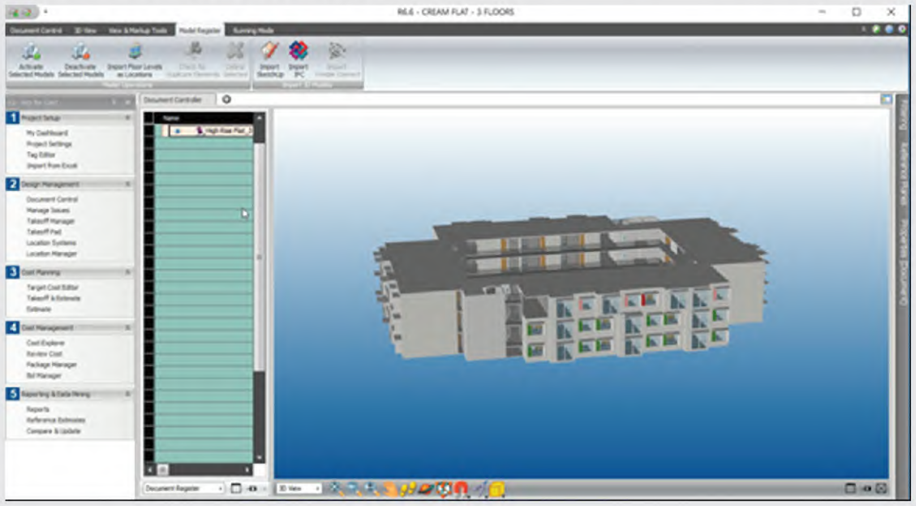
From the 5 basic modules of individual modules set as illustrated in the Architect Handbook above, the architect has built a 3D model using a different arrangement of the modules (mix and match concept). This is done to address constructability issues.

The same 5D BIM process and methodology for quantity extraction and costing are used for the 3 floors of individual standard modules.

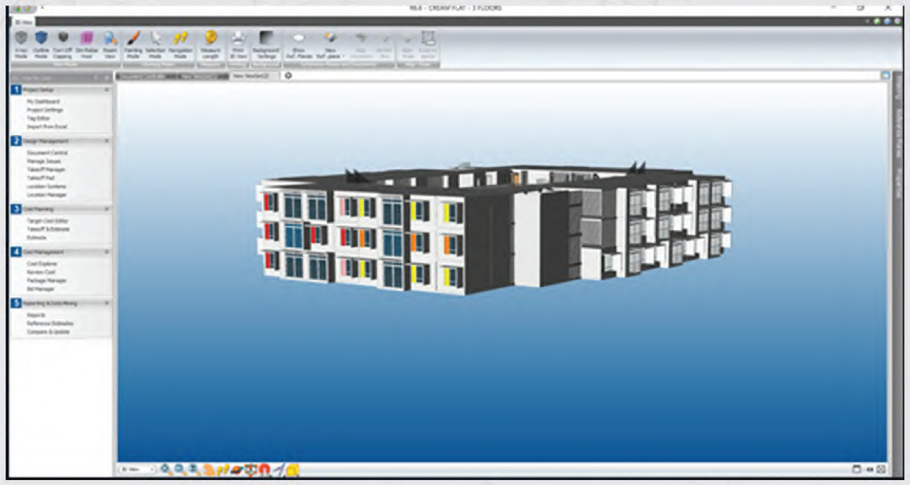
STEP 1: Export the 3D model from Autodesk Revit 2018 to Vico 5D BIM software to start the 5D BIM extraction and quantifying process for the 3 floors of standard modules



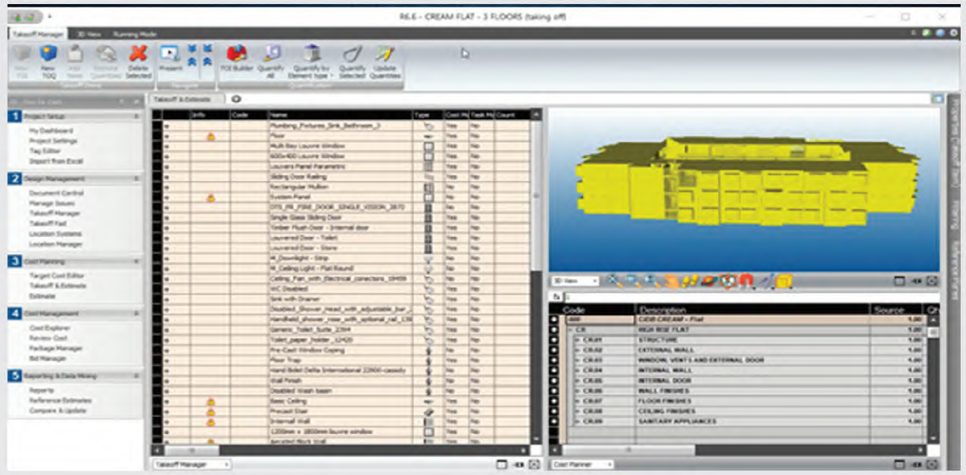
STEP 2: Activate the Autodesk Revit2018 3D model in the Vico 5D BIM tool to start the 5D BIM linking and extraction process.



STEP 3: The activated 3D model for the 3 floors of standard modules is illustrated below.

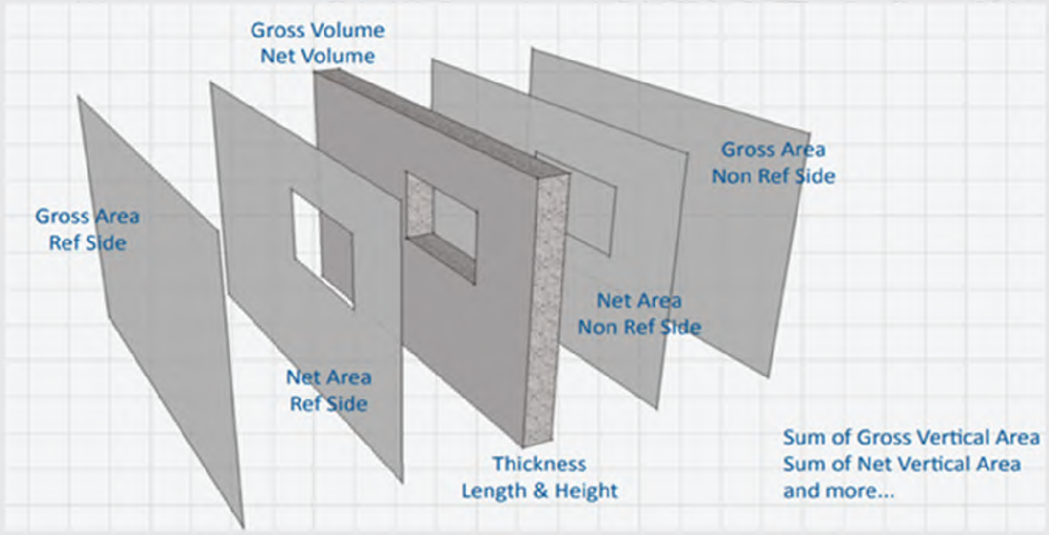


STEP 4: The 3D Autodesk Revit 2018 model quantities are generated and extracted directly in the left window. For the highlighted materials, the corresponding elements in the 3D models that have been quantified, would be highlighted in colour (yellow).



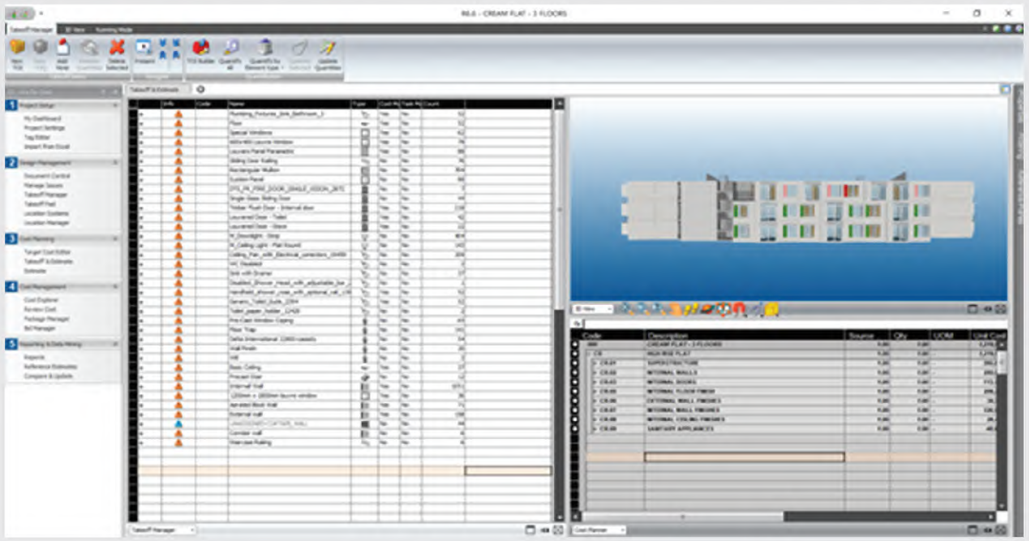
Additional Information:

The 19 different measurement of quantity derivation and types of units extracted by the Vico 5D BIM tool are shown in a diagrammatic form.

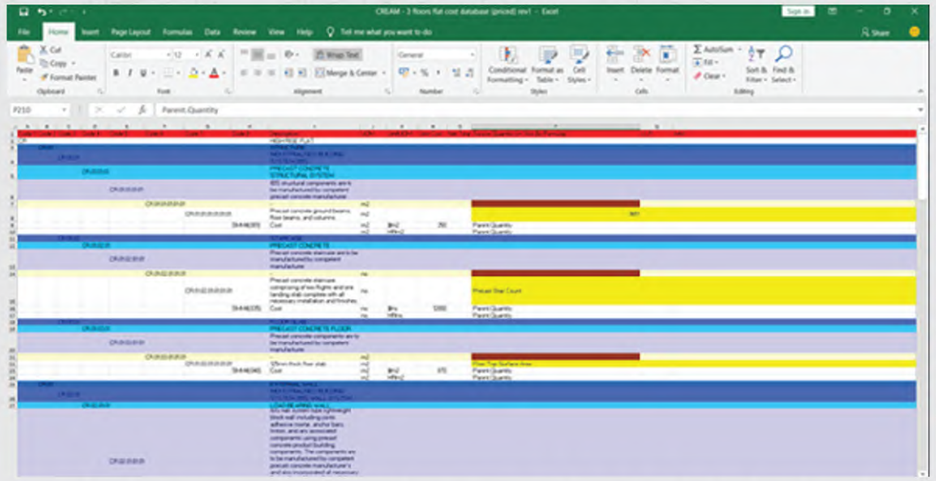


Types of quantities (units of derivatives) extracted by Vico 5D BIM tool software

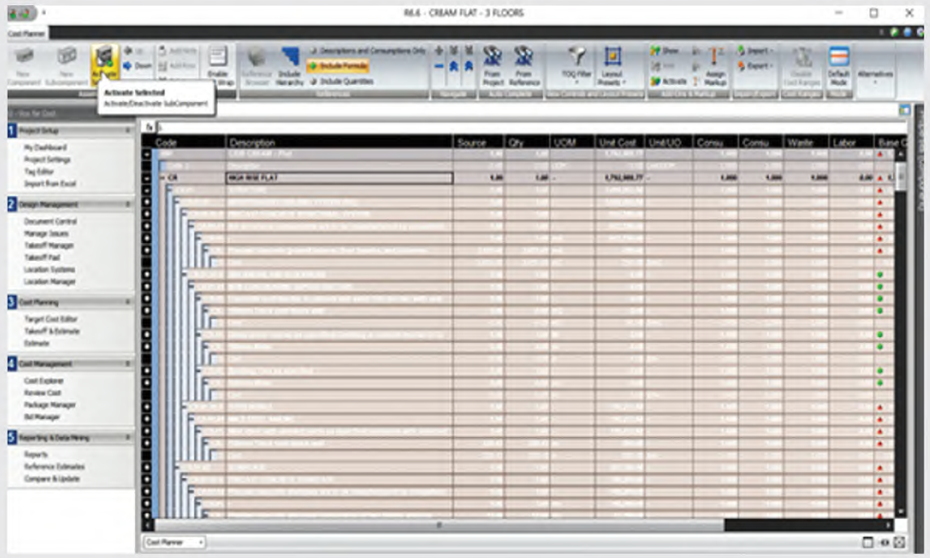
STEP 5: A 3D view showing the Quantity Take Off window on the left (with extracted quantities units measured), the 3D model on the top right, and the Cost Plan on the bottom right linked with one another. Once design changes, the quantities and cost would change directly



STEP 6: The Cost Plan could be prepared in an Excel format as well as Vico 5D BIM for flexibility.

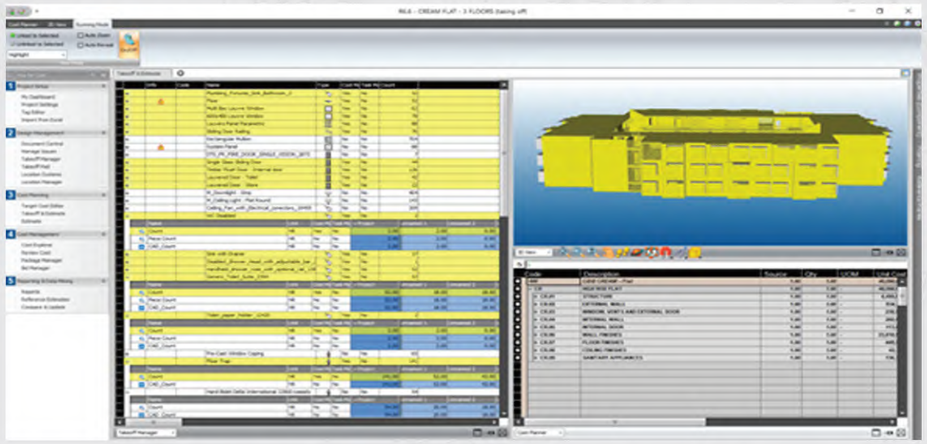


STEP 7: Once the Cost Plan has been successfully created, it can be transferred to the Vico 5D BIM tool, as shown below.



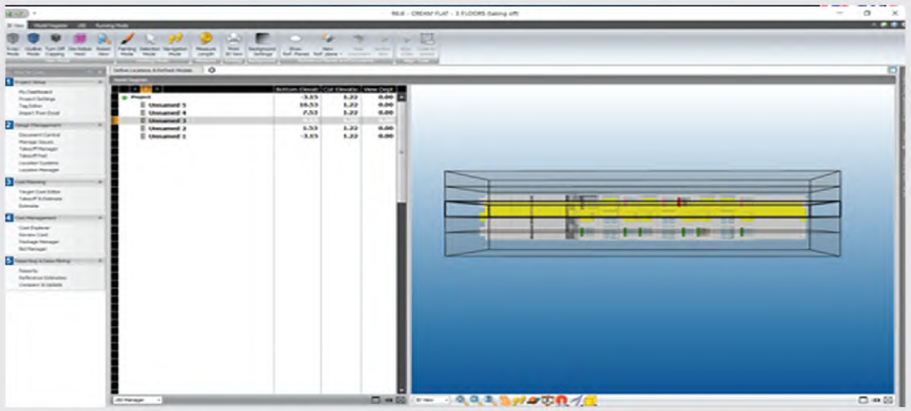
SECTION D

STEP 8: The 3D model, quantities, and cost could be mapped and linked.



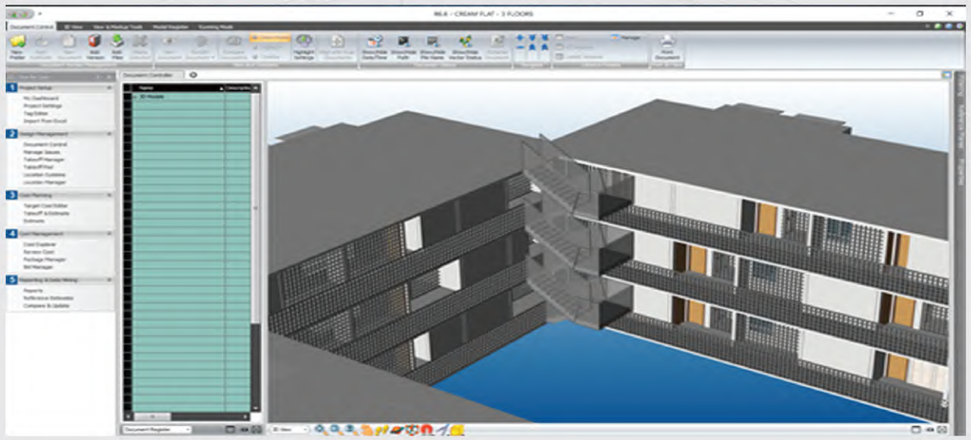
Upon the successful completion of the process, the completed items taken off could be visually checked by going through the items highlighted in colour (yellow) in the 3D model. The cost and time inputs are also linked to the 3D model.

STEP 9: Location-based sectioning is also available for quantities and costs to be carried horizontally (levels/floors) as well as vertically (zones)

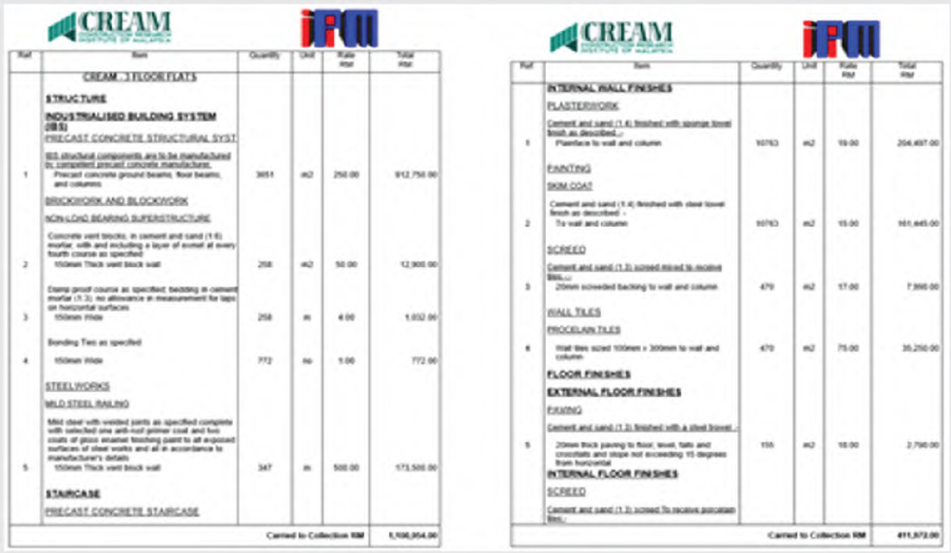


The 3D model could be sectionalised horizontally in order for the quantities and cost to be extracted according to levels/floors. This sectionalisation could also be done vertically in order for quantities and cost to be extracted into different zones. All the 3D model quantities and cost are mapped and linked.

STEP 10: The 3D model for the 3-floor units have additional stairs and corridors, which would affect the total cost.



FINAL STEP 11: The generation of the costing report is directly linked to the 3D model for quantities, cost, and planning.



CREAM 3 FLOOR FLATS

Ref	Item	Quantity	Unit	Rate RM	Total RM
	STRUCTURE				
	INDUSTRIALISED BUILDING SYSTEM (IBS)				
	PRECAST CONCRETE STRUCTURAL SYST				
	IBS structural components are to be manufactured by competent precast concrete manufacturer.				
1	Precast concrete ground beams, floor beams, and columns	3651	m2	250.00	912,750.00
	BRICKWORK AND BLOCKWORK				
	NON-LOAD BEARING SUPERSTRUCTURE				
2	Concrete vent blocks, in cement and sand (1:6) mortar, with and including a layer of eurset at every fourth course as specified 150mm Thick vent block wall	258	m2	50.00	12,900.00
3	Damp proof course as specified; bedding in cement mortar (1:3); no allowance in measurement for laps on horizontal surfaces 150mm Wide	258	m	4.00	1,032.00
4	Bonding Ties as specified 150mm Wide	772	no	1.00	772.00
	STEEL WORKS				
	MILD STEEL RAILING				
5	Mild steel with welded joints as specified complete with selected one anti-rust primer coat and two coats of gloss enamel finishing paint to all exposed surfaces of steel works and all in accordance to manufacturer's details 150mm Thick vent block wall	347	m	500.00	173,500.00
	STAIRCASE				
	PRECAST CONCRETE STAIRCASE				
				Carried to Collection RM	1,100,954.00

Ref	Item	Quantity	Unit	Rate RM	Total RM
	INTERNAL WALL FINISHES				
	PLASTERWORK				
	Cement and sand (1:4) finished with sponge towel finish as described ; -				
1	Plasterwork to wall and column	10763	m2	19.00	204,497.00
	PAINTING				
	SKIM COAT				
	Cement and sand (1:4) finished with steel towel finish as described ; -				
2	To wall and column	10763	m2	15.00	161,445.00
	SCREED				
	Cement and sand (1:3) screed mixed to receive tiles ; -				
3	20mm screeded backing to wall and column	470	m2	17.00	7,990.00
	WALL TILES				
	PROCELAIN TILES				
4	Wall tiles sized 100mm x 300mm to wall and column	470	m2	75.00	35,250.00
	FLOOR FINISHES				
	EXTERNAL FLOOR FINISHES				
	PAVING				
	Cement and sand (1:3) finished with a steel trowel ; -				
5	20mm thick paving to floor, level, falls and crossfalls and slope not exceeding 15 degrees from horizontal	155	m2	18.00	2,790.00
	INTERNAL FLOOR FINISHES				
	SCREED				
	Cement and sand (1:3) screed To receive porcelain tiles ; -				
				Carried to Collection RM	411,972.00

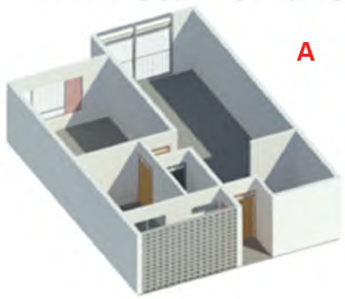
SECTION D

2.3. 5D BIM Cost Analysis Report

2.3.1. Individual standard modules

In the figure below, the unit labelled A is a two-bedroom unit, unit B is a one-bedroom unit, unit C is a standard three-bedroom unit, unit D is a four-bedroom unit, and units E and F are three-bedroom units.

The modular designs of the units are as follows:



A

2-Bedroom Flat



B

1-Bedroom Flat



C

3-Bedroom Flat



D

4-Bedroom Flat



E

3-Bedroom Flat Type A



F

3-Bedroom Flat Type B

a) Types of units in an IBS system

For this exercise, the IBS system used is assumed to be an “open system” that could be sourced from any supplier in the market.

No	Item	Unit	Quantity	Rate (RM)	Amount (RM)
	INDUSTRIALISED BUILDING SYSTEM (IBS)				
	STRUCTURE				
	PRECAST CONCRETE STRUCTURAL SYSTEM				
	IBS structural components are to be manufactured by competent precast concrete manufacturer				
A	Precast concrete ground beams, floor beams and columns	m2	531	180.00	95,580.00
	FLOOR SLAB				
	PRECAST CONCRETE FLOOR SLAB				
	Precast concrete components are to be manufactured by competent manufacturer				
B	150mm thick floor slab	m2	531	110.00	58,410.00

Example of IBS elements in BQ

b) MEP system

The estimated bills of quantities for the MEP fixtures are based on previous projects and allocations for the modular units, as summarised below:

1-bedroom flat (UNIT B)

a	Lighting	9
b	Power	8
c	Fan	3
d	Switch	8

3-bedrooms OKU (UNIT C)

a	Lighting	13
b	Power	10
c	Fan	5
d	Switch	11

3-bedrooms Type B (UNIT F)

a	Lighting	16
b	Power	14
c	Fan	5
d	Switch	13

2-bedrooms flat (UNIT A)

a	Lighting	9
b	Power	9
c	Fan	4
d	Switch	8

4-bedrooms flat (UNIT D)

a	Lighting	16
b	Power	14
c	Fan	5
d	Switch	13

Summary

a	Lighting	92
b	Power	79
c	Fan	32
d	Switch	77

3-bedrooms flat (UNIT C)

a	Lighting	13
b	Power	10
c	Fan	5
d	Switch	11

3-bedrooms flat Type A (UNIT E)

a	Lighting	16
b	Power	14
c	Fan	5
d	Switch	13

c) MEP system cost per unit

After carrying out the quantity extraction and model mapping in the Vico software, a bill of quantities was produced and priced accordingly. The Vico software could produce a "cost per location" report, which issues individualised costing for each modular unit. As such, the cost per square foot (ft²)/square metre (m²) for individual units are as follows:

(i) 2-bedroom flat (unit A)

Unit area (ft²) = 614 ft²/57.04 m²
Overall unit cost = RM47,856.71
Approximate percentage of the overall six units = 11.60%
Cost per square foot (ft²) = RM77.94/ft² (equivalent to RM839.00/m²)

(ii) 1-bedroom flat (unit B)

Unit area (ft²) = 614 ft²/57.04 m²
Overall unit cost = RM46,218.28
Approximate percentage of the overall six units = 11.20%
Cost per square foot (ft²) = RM75.27/ft² (equivalent to RM810.27/m²)

(iii) 3-bedroom flat/OKU (unit C)

Unit area (ft²) = 904 ft²/83.98 m²
Overall unit cost = RM66,717.97
Approximate percentage of the overall six units = 16.10%
Cost per square foot (ft²) = RM73.80/ft² (equivalent to RM794.45/m²)

(iv) 4-bedroom flat (unit D)

Unit area (ft²) = 1,195 ft²/111.02 m²
Overall unit cost = RM84,777.11
Approximate percentage of the overall six units = 20.50%
Cost per square foot (ft²) = RM70.94/ft² (equivalent to RM763.62/m²)

(v) 3-bedroom flat type A (unit E)

Unit area (ft²) = 1,195 ft²/111.02 m²
Overall unit cost = RM83,702.61
Approximate percentage of the overall six units = 20.20%
Cost per square foot (ft²) = RM70.04/ft² (equivalent to RM753.94/m²)

(vi) 3-bedroom flat type B (unit F)

Unit area (ft²) = 1,195 ft²/111.02 m²
Overall unit cost = RM84,441.55
Approximate percentage of the overall six units = 20.40%
Cost per square foot (ft²) = RM70.66/ft² (equivalent to RM760.60/m²)

Comparison of cost per square foot (sqft) of each different standard modular unit

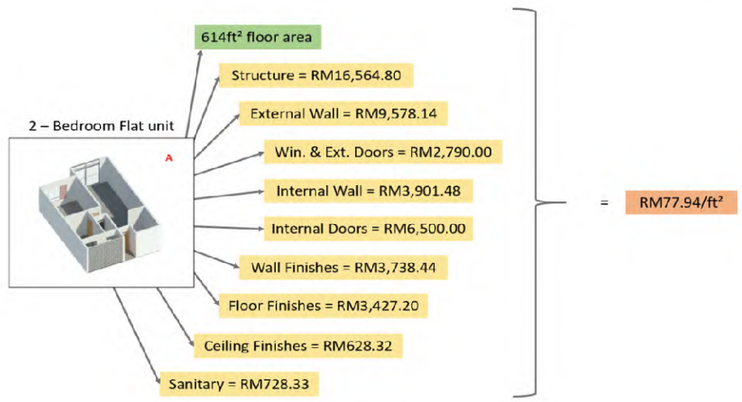
			614sqft				904sqft		1195sqft					
			A		B		C		D		E		F	
BIL	ITEM	PROJECT COST	2 BEDROOM	%	1 BEDROOM	%	3 BEDROOM	%	4 BEDROOM	%	3 BEDROOM TYPE A	%	3 BEDROOM TYPE B	%
A	**UNIT AREA (sqft)**	5717	614		614		904		1195		1195		1195	
B	**COST BREAKDOWN**													
1	STRUCTURE	153,955.20	16,564.80	11	16.564.80	11	24,360.00	16	32,155.20	21	32,155.20	21	32,155.20	21
2	EXTERNAL WALL	71,023.69	9,578.14	13	10,034.60	14	11,896.73	17	13,108.23	18	12,228.00	17	14,178.00	20
3	WINDOWS & EXT.DOORS	26,930.00	2,790.00	10	1,850.00	7	4,190.00	16	6,530.00	24	6,080.00	23	5,490.00	20
4	INTERNAL WALL	41,478.32	3,901.48	9	2,764.75	7	6,238.88	15	9,549.22	23	9,932.22	24	9,091.76	22
5	INTERNAL DOORS	46,550.00	6,500.00	14	6,600.00	14	8,000.00	17	8,500.00	18	8,500.00	18	8,450.00	18
6	WALL FINISHES	26,434.54	3,738.44	13	3,620.28	12	4,770.02	16	5,763.65	20	5,636.37	19	5,905.78	20
7	FLOOR FINISHES	31,852.80	3,427.20	11	3,427.20	11	5,040.00	16	6,652.80	21	6,652.80	21	6,652.80	21
8	CEILING FINISHES	5,839.68	628.32	11	628.32	11	924.00	16	1,219.68	21	1,219.68	21	1,219.68	21
9	SANITARY	6,650.00	728.33	11	728.33	11	1,298.33	20	1,298.33	20	1,298.33	20	1,298.33	20
C	**TOTAL**	413,714.23	47,856.71	11.60	46,218.28	11.20	66,717.96	16.10	84,777.11	20.50	83,702.60	20.20	84,441.55	20.40
	COST PER sqft (RM) (C+A)	n/a	77.94		75.27		73.80		70.94		70.04		70.66	

The above table shows the cost breakdown of each standard modular units according to the elements mapped from the 3D model and its percentage of the overall project cost for each element. Even though the cost table above uses ft², the unit of measurement is interchangeable to m².

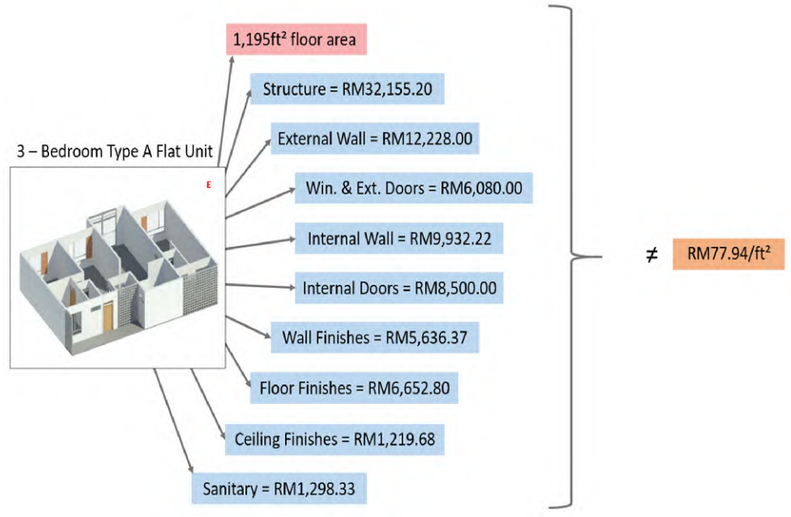
As shown in the table, the units are grouped into three categories based on their overall floor area. Units A and B have the same floor area of 614 ft²/57.04 m², unit C is the only unit to have an overall floor area of 904 ft²/83.98 m², and the remaining units are all 1195 ft²/111.02 m² modular units.

Based on the cost analysis, the units in the 614 ft²/57.04 m², group have a higher cost per square foot compared to the units in the 1195 ft²/111.02 m² group. This is mainly due to the division of the overall cost by a smaller area, resulting in a higher cost per square foot. Another reason is attributed to the composition of the elements contributing to the cost.

For example, if we were to double or triple the overall floor area and overall cost of unit A, and then divide the new overall cost by the new floor area, we will get back RM77.94/ft² /RM839.00/m². This is because all the elements were increased proportionately to the floor area. However, if we multiply RM77.94/ft²/ RM839.00/m² by the floor area of a different unit, for instance, unit E's area of 1195 ft²/111.02 m², we will not obtain unit E's total cost. The reason is that the cost per square foot consists of the elements and quantities of unit A, which are different from the elements and quantities of unit E.



Composition of cost per square foot for unit A



Composition of cost per square foot for unit E

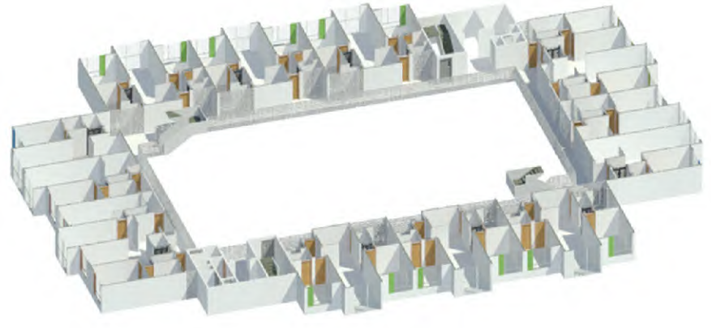
Composition of quantities which differs from Unit A and Unit E with same elements but different costs

2-Bedroom Unit A	ELEMENTS	3-Bedroom (A) Unit E
57 m²	FLOOR	111 m²
90 m²	EXTERNAL WALLS	116 m²
36 m²	INTERNAL WALLS	94 m²
4 nos	TIMBER FLUSH DOOR	6 nos
1 nos	MULTI BAY LOUVRE WINDOW	3 nos

As mentioned in the previous paragraph, the composition of each cost per square foot/cost per square metre is derived from each element's quantity and cost. From the cost composition of units A and E, we can see that the units have the same elements but with different costs because of the different quantities of each element. The table above illustrates the quantities of selected elements that relate to the cost composition of units A and E.

2.3.2. 3 floors of standard modules - Modular flats units for High Rise

For 3 floors of standard modules, 5 different modules are used with the mix and match concept, the cost analysis could be carried out and summarised accordingly. A typical layout view of one floor of the 3 floors of standard modules is visualised below.



A typical view of the layout of one floor

SECTION D

a) Unit distribution of each floor - Level 1, 2, and 3

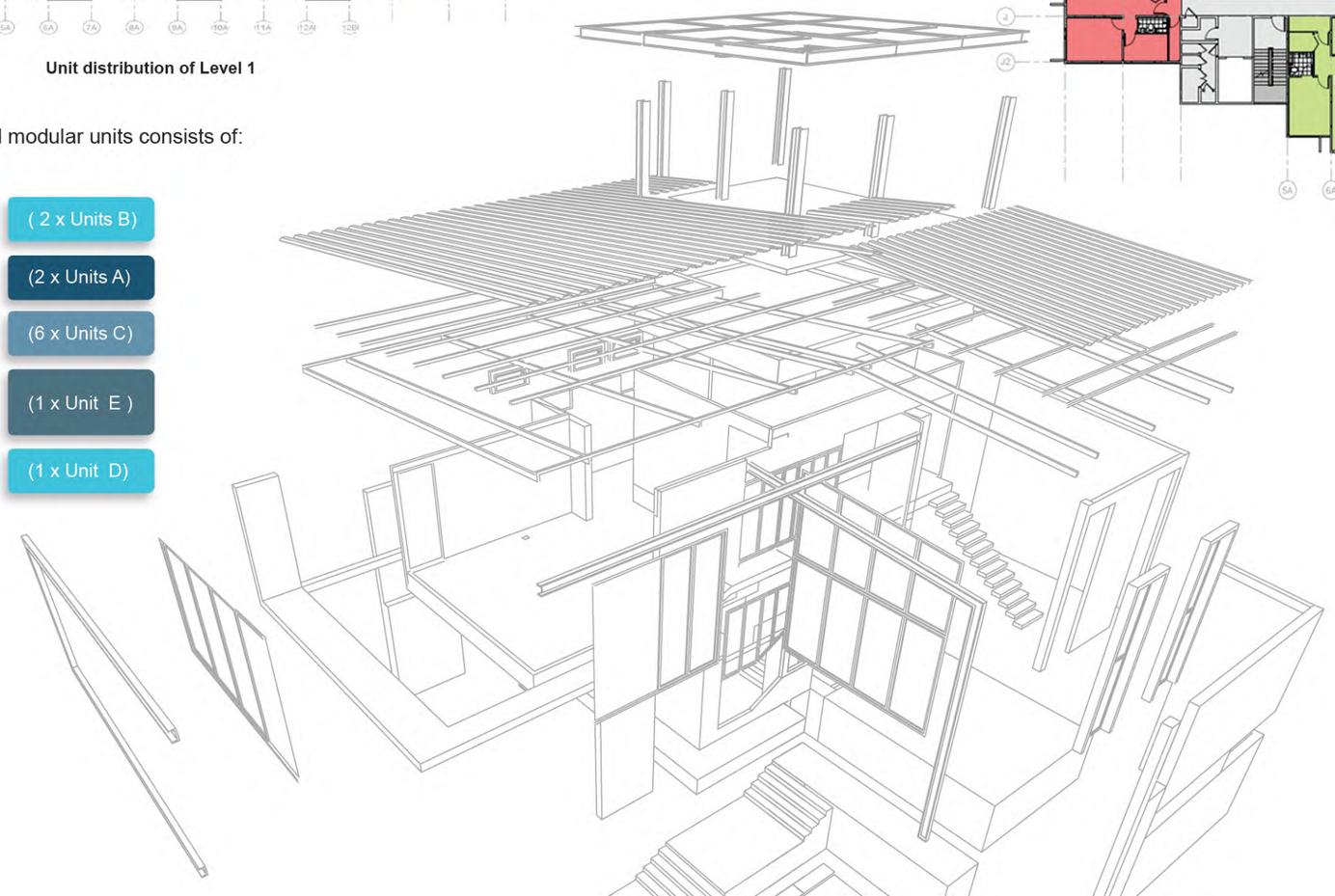
(i) Unit distribution of Level 1



Unit distribution of Level 1

Level 1 mix and match standard modular units consists of:

2 numbers of 1-bedroom flat	(2 x Units B)
2 numbers of 2-bedroom flat	(2 x Units A)
6 numbers of 3-bedroom flat	(6 x Units C)
1 number of a 3-bedroom flat type A	(1 x Unit E)
1 number of a 4-bedroom flat	(1 x Unit D)



(ii) Unit distribution of Level 2



Level 2 mix and match standard modular units consists of:

1 number of a 1-bedroom flat	(1 x Unit B)
3 numbers of 2-bedroom flat	(3 x Units A)
3 numbers of 3-bedroom flat	(3 x Units C)
1 number of a 3-bedroom flat type A	(1 x Unit E)
2 number of 3-bedroom flat type B	(2 x Unit F)
1 number of a 4-bedroom flat	(1 x Unit D)

SECTION D

(iii) Unit distribution of Level 3



Level 3 mix and match standard modular units consists of:

4 units of 1-bedroom flat	(4 x Unit B)
8 units of 2-bedroom flat	(8 x Units A)
1 unit of a 3-bedroom flat type A	(1 x Unit E)
2 units of 3-bedroom flat type B	(2 x Unit F)
1 unit of a 4-bedroom flat	(1 x Unit D)



b) IBS system (3 floors of standard modules)

As mentioned in subsection 2.3.1 part (a), the IBS system used for the cost estimation is an open system.

No	Item	Unit	Quantity	Rate (RM)	Amount (RM)
	INDUSTRIALISED BUILDING SYSTEM (IBS)				
	STRUCTURE				
	PRECAST CONCRETE STRUCTURAL SYSTEM				
	IBS structural components are to be manufactured by competent precast concrete manufacturer				
A	Precast concrete ground beams, floor beams and columns	m2	3651	180.00	657,180.00
	FLOOR SLAB				
	PRECAST CONCRETE FLOOR SLAB				
	Precast concrete components are to be manufactured by competent manufacturer				
B	150mm thick floor slab	m2	3651	110.00	401,610.00

An example of IBS elements in the bill of quantity

c) MEP system (3 floors of standard modules)

Based on the estimated MEP quantities for individual units, the quantities for the 3 floors of standard modules were calculated according to the types of units per floor.

No	Item	Unit	Quantity	Rate (RM)	Amount (RM)
	MECHANICAL & ELECTRICAL WORKS				
	MECHANICAL WORKS				
	Cold Water Plumbing:-				
A	Unit A	sum	1	1,500.00	1,500.00
B	Unit B	sum	1	1,500.00	1,500.00
C	Unit C	sum	2	1,500.00	3,000.00
D	Unit D	sum	2	1,500.00	3,000.00
E	Unit E	sum	2	1,500.00	3,000.00
F	Unit F	sum	2	1,500.00	3,000.00
	Soil, waste and sanitary plumbing				
G	Unit A	sum	1	1,200.00	1,200.00
H	Unit B	sum	1	1,200.00	1,200.00
J	Unit C	sum	2	1,200.00	2,400.00
K	Unit D	sum	2	1,500.00	2,400.00

Estimation of MEP items

d) Cost per floor (sqft/sqm) for 3 floors of standard modules

The same process as for the individual unit models was carried out for the 3 floors standard modules 3D building model, which involved using the Vico 5D BIM software to extract the quantities, perform model mapping, and link the quantities to the bill of quantities for pricing. The same rate was used to ensure price consistency.

The cost of each Level 1,2 and 3 are as follows:

(i) The cost for the level 1

Overall level area = 13,427.35 ft²/1247.44 m²

Overall level cost = RM1,379,257.39

Cost per square foot (ft²) = RM102.71/ft² (equivalent to RM1,105.67/m²)

(ii) The cost for the level 2

Overall level area = 13,391.19 ft²/1244.08 m²

Overall level cost = RM1,375,543.04

Cost per square foot (ft²) = RM102.72/ft² (equivalent to RM1,105.67/m²)

(iii) The cost for the level 3

Overall level area = 13,463.52 ft²/1250.82m²

Overall level cost = RM1,382,972.77

Cost per square foot (ft²) = RM102.71/ft² (equivalent to RM1,105.67/m²)



D3 FINDINGS



The cost analysis presented above is derived from the permutation of different numbers of different types of standard modules.

The cost per square foot represents the cost breakdown of a unit/project. It is greatly affected by the number of elements in a unit as well as the quantities of each element. The cost per square foot serves as a guide for clients, consultants and contractors by providing a rough cost estimate of a project, but it should not be regarded as the actual cost. Detailed quantity take-off and bills of quantity should be prepared to ensure the accuracy of the pricing of the bills of quantity.

The cost per square foot for the 3 levels of standard modules depends on the numbers of each type of modular units on each floor. In our example, Level 1 and Level 3 have 5 different types of standard modules, while Level 2 consists of 6 different types of standard modules.

It is also important to highlight that even though each Level has different “mix and match” permutations, the cost is almost the same i.e approximately RM102.71/ft²/1,105.67m².

The total cost of individual units for Level 1 as per the layout distribution in the figure below might not be the same as the total cost of RM1,379,257.39 mentioned in part (d)(i) above.

This difference is due to the circulation area and the cost of walls for each unit. In the cost calculation per unit, each unit has four walls surrounding it as the external wall. However, when the units are combined to form a floor of units, the walls between units are shared (circled in red below), resulting in a different cost for the walls compared to the individual unit cost.



Reduction in cost due to shared walls

The cost estimate in this Handbook is for the construction of a complete typical accommodation unit as shown in the 3D model starting from the ground floor slab.

The costs of piling works and other works below the ground floor slab and other items are not shown in the model and are not included in the cost estimate.

It is to be noted that the construction cost of an accommodation unit of a specific design depends on the IBS system used and the number of repetitive units. As a general rule, an open IBS system will allow greater design flexibility and cheaper costs provided the total number of repetitive units is large enough for economies of scale.

Besides, the cost estimates are affected by many other factors such as the mode of procurement and also locality and time factors.

The cost estimates provided here serve as a guide only.

It is imperative to stress that the cost of the units could very much be reduced if all the design units for all three levels are standardised to 3-bedroom units of 904 ft². Therefore, more units could be produced in one level, hence accommodating more people in the community. This approach would be suitable in pursuing affordable housing for the B40 group.

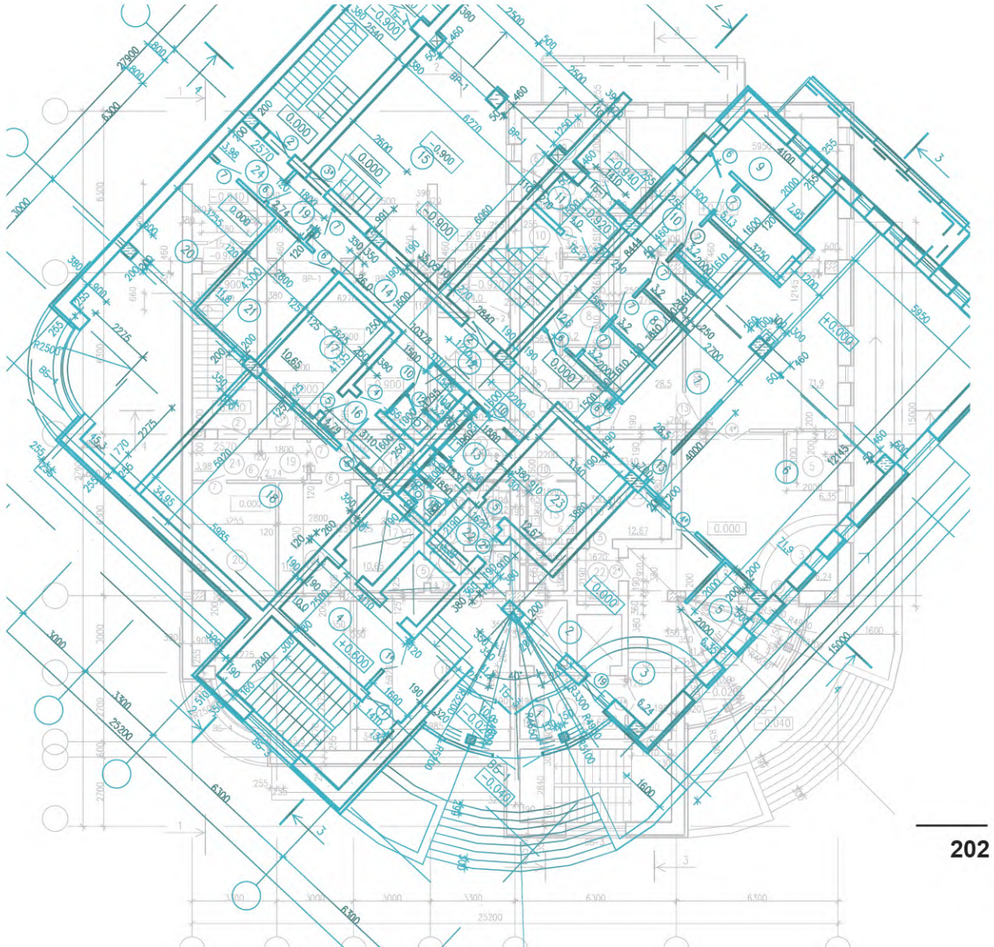
It is therefore proposed that further research is to be undertaken to optimise the design and area and investigate how much the cost could be reduced further. Apart from investigating different layout per floor, designers could consider to propose alternative designs, materials & finishes for better comparison of cost per unit.

It is important for Quantity Surveyors (QS) to embark on digitalisation (5D BIM) to stay abreast in the Technology Revolution of the Digital Construction Advancement .

Currently in Malaysia, 5D BIM is in their early stage of adoption, whereas 5D BIM are practised extensively in other countries like Hong Kong, Singapore, Australia etc. 5D BIM are the vehicle forward for Quantity Surveyors in the future.

Developers are advised to engage the services of professional quantity surveying consultants/5D BIM cost consultants for the preparation of realistic and reliable cost estimates of a proposed housing development.

"The "5D BIM tsunami" waves are coming, so hold on for the ride. The question is, will the Quantity surveyors be ready with the boat, capitalize and benefit from it. Or will be the bystander who will be gasping for help and drowned by it?"



SECTION D



SECTION E:

HANDBOOK FOR CFD SIMULATION AND ANALYSIS

E1 **Brief Introduction**
1.1 Air Movement

E2 **Methodology**
2.1 Geometry and Boundary Condition Set-up

E3 **Results and Findings**
3.1 Case 1: Wind Acting at 90 Degrees (Perpendicular) from the Building wall
3.2 Case 2: Wind Acting at 45 Degrees (Edge) from the Building Wall

E4 **Conclusion**

Written by:

SIRIM



DeLIGHT Homes
A Sustainable and Innovative Affordable Housing Design Handbook

E1 BRIEF INTRODUCTION

Computational fluid dynamics (CFD) was used to simulate the natural air flow or prevailing wind scenario for DeLIGHT Homes. The simulation and analysis were done using STAR-CCM+ CFD software. The building model consists of 16 storeys, 5 modules, and 167 house units.

The objective of this simulation is to obtain the natural air flow (prevailing wind) velocity profile:

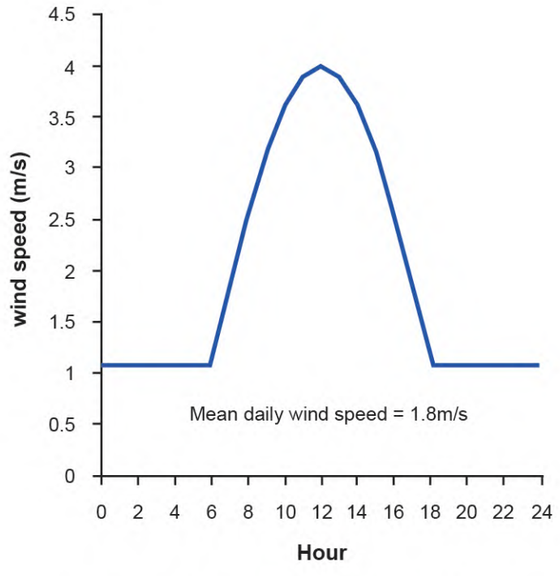
- i. vertically across the entire building
- ii. horizontally across the floors of the building

1.1. Air Movement

Air movement affects thermal comfort. According to MS 2690, the presence of air movement enhances evaporative and convective cooling from the skin and can further increase thermal comfort. The table below provides a guide on the impact of air speed on occupants' sensation.

Impact of air speed on occupants		
Air Speed (m/s)	**Mechanical effect**	**Occupants' Sensation**
≤ 0.25	Smoke (from cigarette) indicates movement	Unnoticed, except low air temperatures
0.25 – 0.5	Flame from a candle flickers	Feels fresh at comfortable temperatures, but draughty at cool temperatures
0.5 – 1.0	Loose papers may be moved. Equivalent to the walking speed	Generally pleasant when comfortable or warm, but causing constant awareness of air movement
1.0 – 1.5	Too fast for deskwork with loose papers	Acceptable in warm conditions but can be from slightly to uncomfortably draughty
> 1.5	Equivalent to a fast walking speed	Acceptable only in very hot and humid conditions when no other relief is available. Requires corrective measures if comfort and productivity are to be maintained

In a naturally ventilated space, the thermal condition varies according to the changes in ambient conditions. The graph below shows the idealised daily wind speed distribution. On the whole, Malaysia's mean annual wind speed is 1.8 m/s.

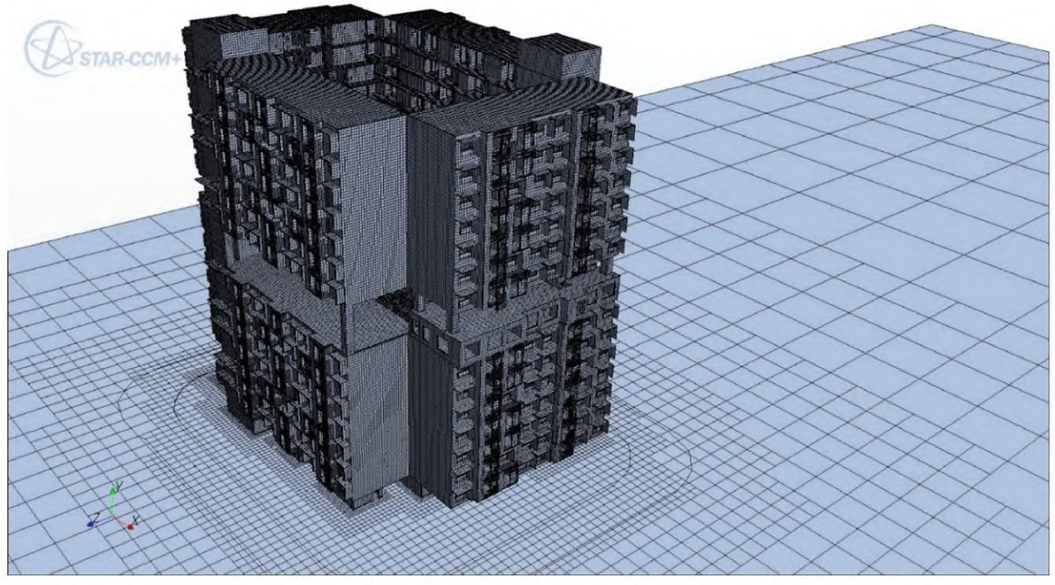


Idealised daily wind speed distribution in Malaysia

E2 METHODOLOGY

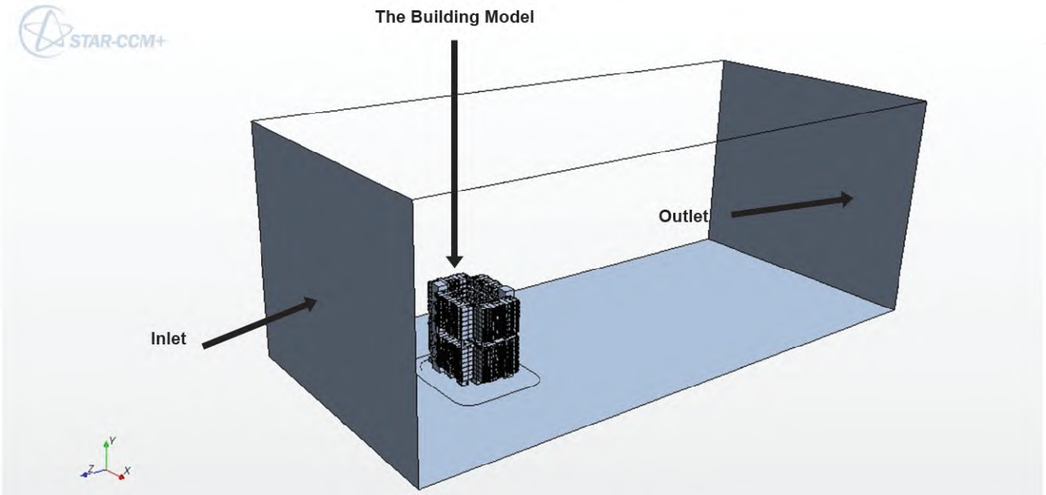
2.1. Geometry and Boundary Condition Set-up

The geometry of the building is based on the 3D Revit CAD file, which was simplified and redrawn in Solidworks. The model was exported to STAR-CCM+ for pre-processing.



DeLIGHT Homes building model in an isometric view

The simulation of DeLIGHT Homes building was carried out under a steady-state condition, based on the assumption that the top and two (2) sides of the domain faces are symmetrical.



The boundary condition of the objects

The inlet's object properties are:

i. Wind velocity = 1.8 m/s

ii. Constant density of air, ρ = 1.18415 kg/m^3

iii. Dynamic viscosity, τ = 1.85508 x 10^{-5} Pa-s

The domain size, building model size, and mesh number are specified in the table below.

Domain size, building model size, and mesh number

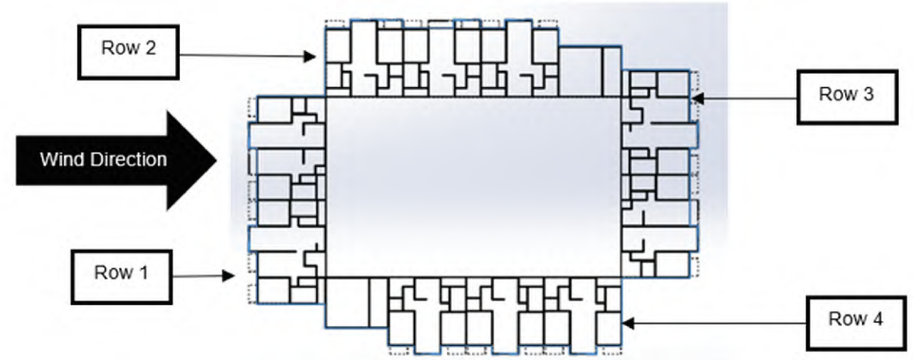
Domain size (rectangular)	Building model size	Mesh no. (refinement)
Length = 391.484 m Width = 179.830 m Height = 150.000 m	Length = 55.650 m Width = 41.000 m Height = 55.650 m	Case 1 = 4,187,011 cells Case 2 = 4,738,259 cells

The energy equation was excluded from the analysis due to limited input for temperature parameters and no assumption fits such boundary conditions. During processing, the solver was set at 1000 iterations.

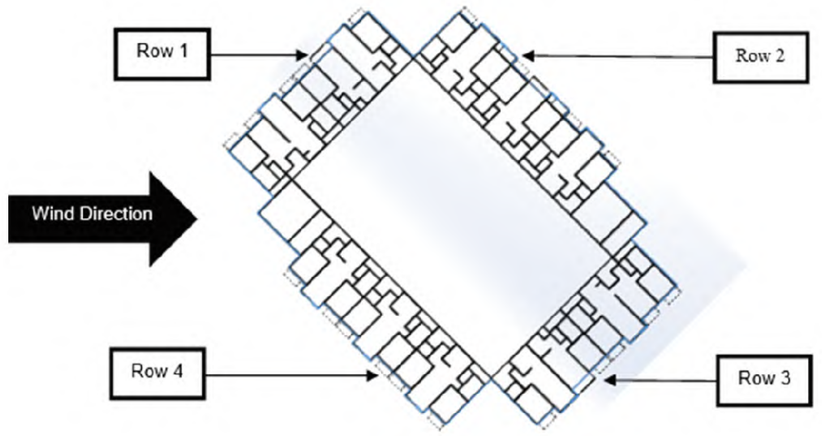
Two cases are presented in this simulation and analysis report, namely:

i. Case 1 – Wind acting at 90 degrees (perpendicular) from the building wall

ii. Case 2 – Wind acting at 45 degrees (edge) from the building wall



Top view of Case 1 in the simulation

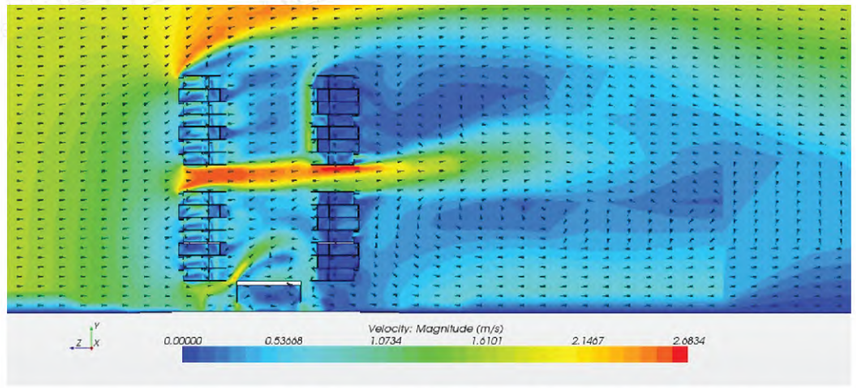


Top view of Case 2 in the simulation

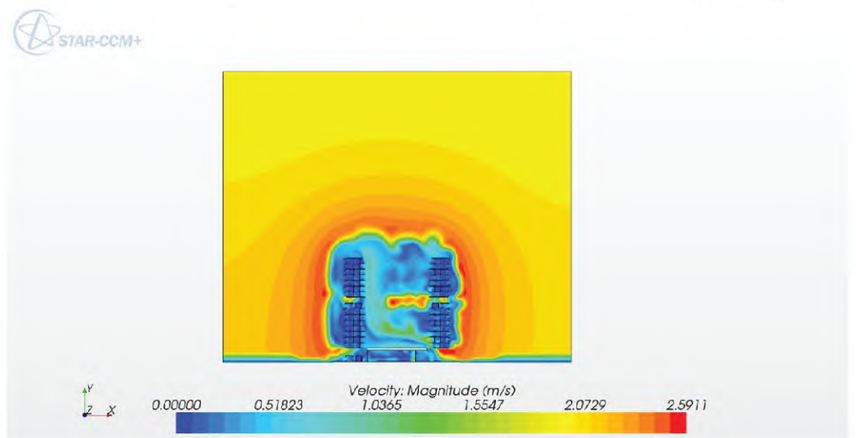
SECTION E

E3 RESULTS AND FINDINGS

3.1. Case 1: Wind Acting at 90 Degrees (Perpendicular) from the Building Wall

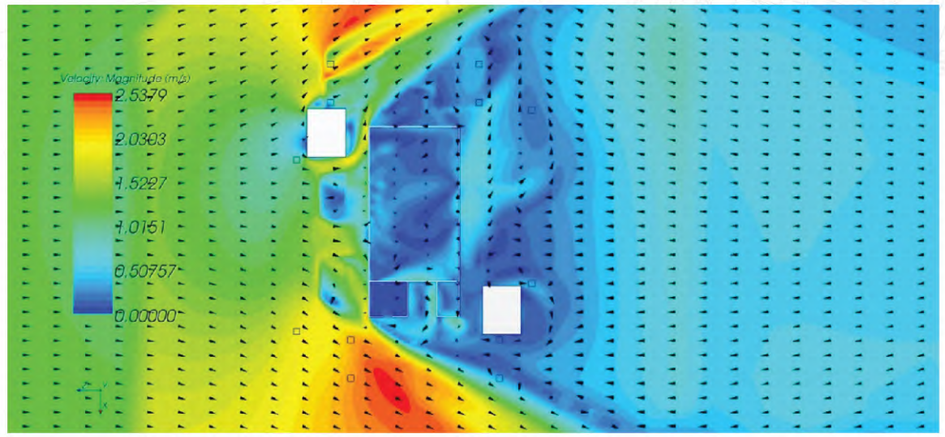


Wind velocity vector and contour vertically across the entire building (Z-Y plane)



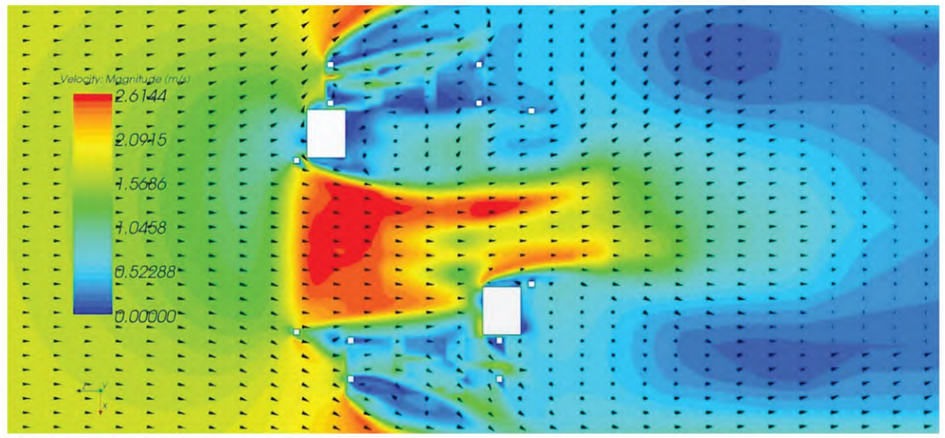
Wind velocity contour vertically across the entire building (X-Y plane)

The wind profile from the above figure shows the initial wind direction passing through open space at the Ground Floor level (from left to right). In the next stage of flow, the wind travelled upwards through the void located at the centre of the building.



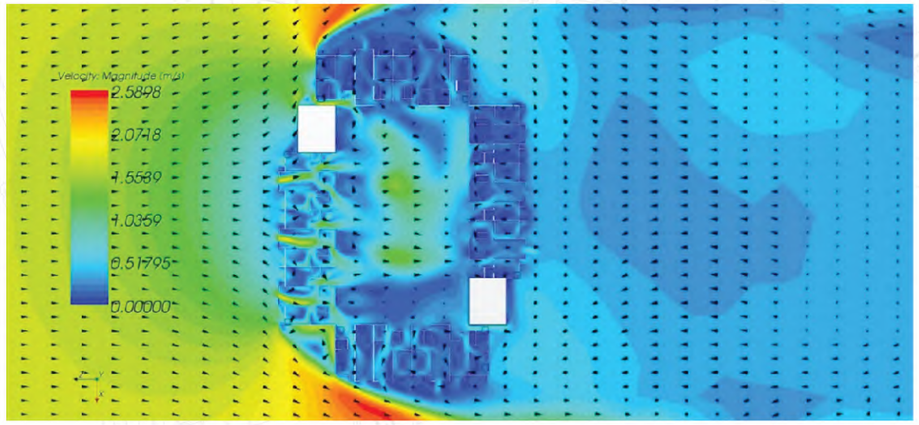
Wind velocity vector and contour horizontally across the Ground Floor of the building (Z-X plane)

The wind profile across the Ground Floor of the building shows the rows' definition of location.

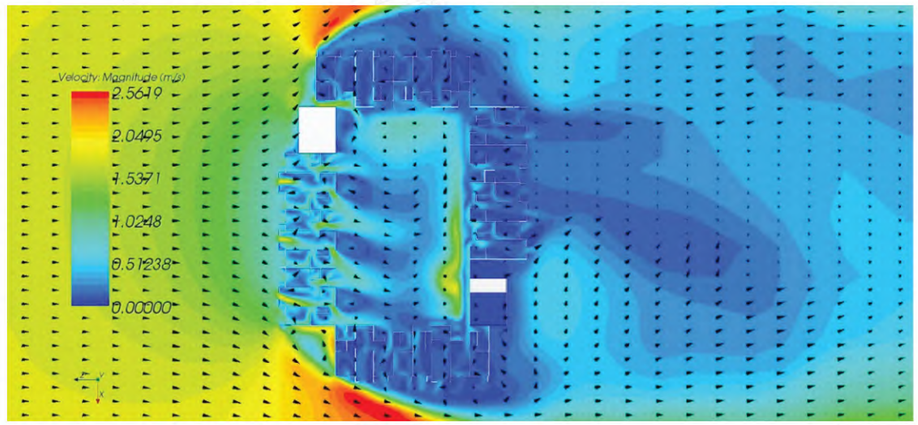


Wind velocity vector and contour horizontally across Level 8 of the building (Z-X plane)

From the wind profile at Level 8 of the building, it can be observed clearly that relatively high velocity of air flows occurred.



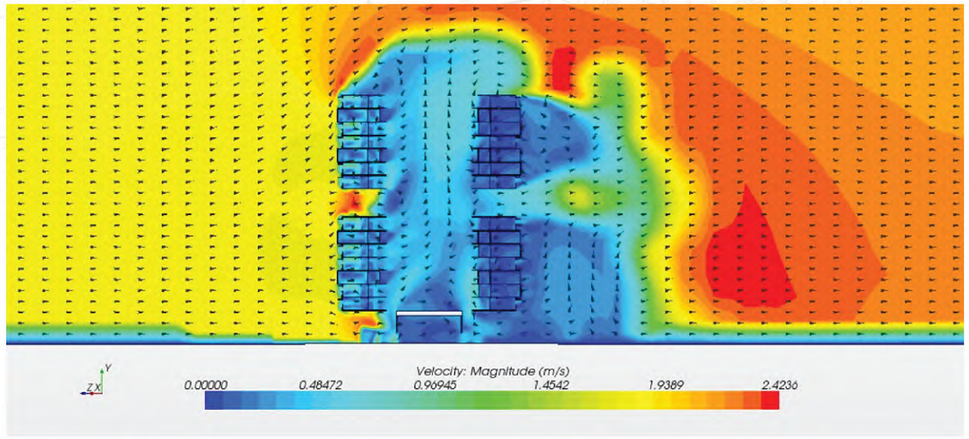
Wind velocity vector and contour horizontally across Level 4 of the building (Z-X plane)



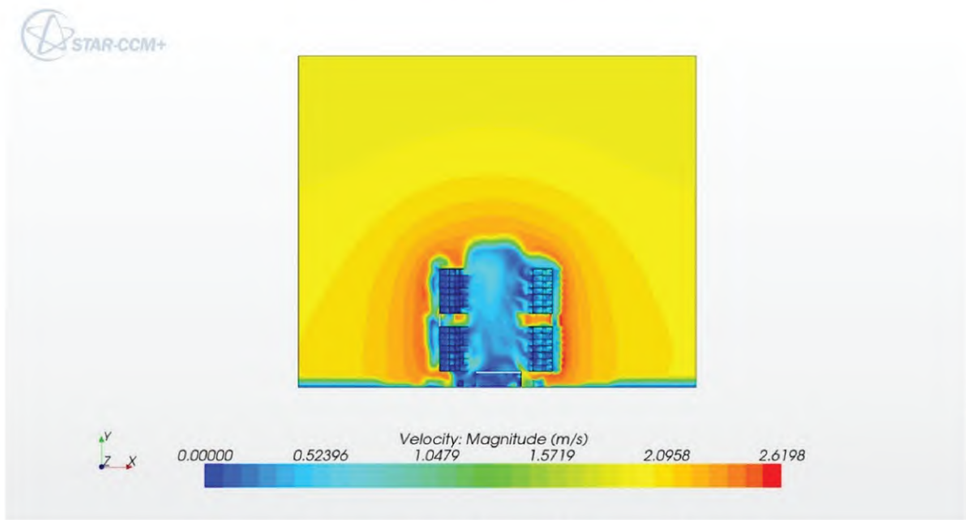
Wind velocity vector and contour horizontally across Level 12 of the building (Z-X plane)

The wind profile at Levels 4 and 12 of the building exhibited a similar scenario. The initial wind direction passed through row 1 of the building floor and travelled outwards to the void. Relatively low velocity of air flows passed through row 2, row 3, and row 4 of the floor.

3.1. Case 2: Wind Acting at 45 Degrees (Edge) from the Building Wall



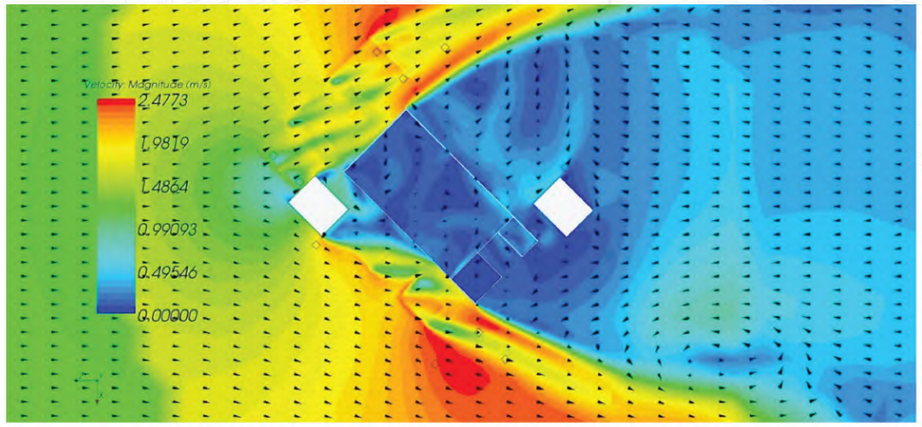
Wind velocity vector and contour vertically across the entire building (Z-Y plane)



Wind velocity contour vertically across the entire building (X-Y plane)

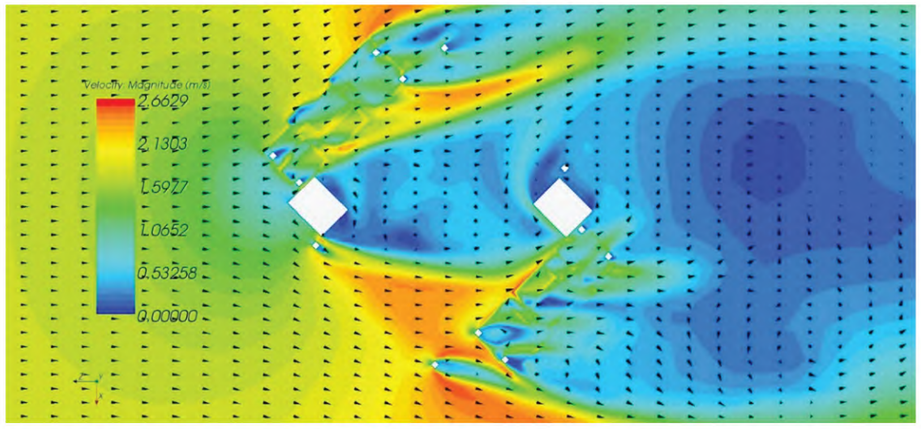
SECTION E

For case 2, the wind travelled vertically across the entire building and acted in a similar manner to Case 1, i.e., through open space at the Ground Floor (from left to right) and upwards through the void.



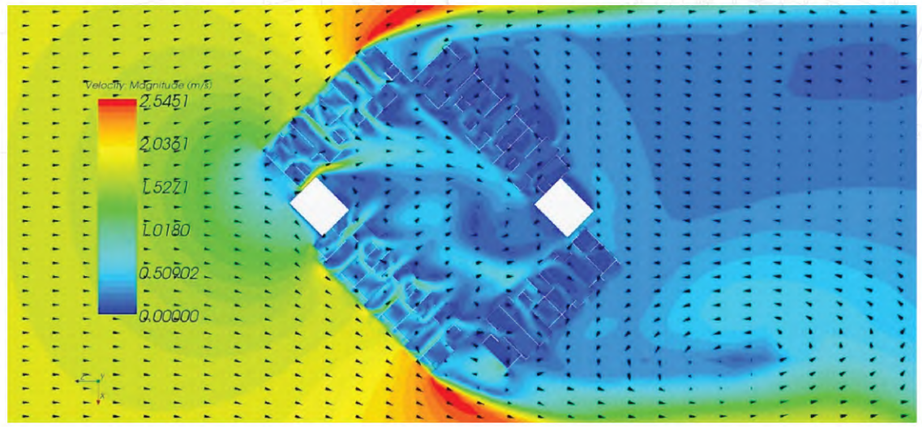
Wind velocity vector and contour horizontally across the Ground Floor of the building (Z-X plane)

The wind profile across the Ground Floor level of the building shows the rows' definition of location.

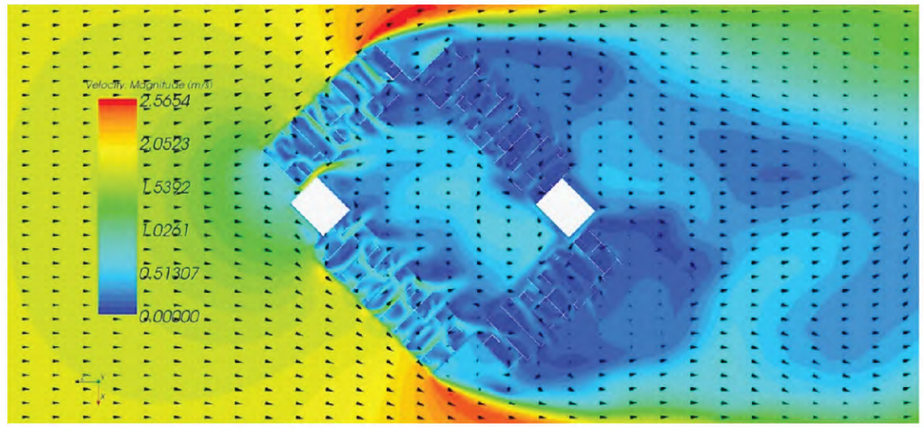


Wind velocity vector and contour horizontally across Level 8 of the building Z-X plane)

The wind profile at Level 8 of the building was observed as having a relatively high velocity of air flow divided by stairway columns.



Wind velocity vector and contour horizontally across Level 4 of the building (Z-X plane)



Wind velocity vector and contour horizontally across Level 12 of the building (Z-X plane)

The wind profile at Levels 4 and 12 for Case 2 exhibited similar scenarios to Case 1. However, when the angle of wind attack was modelled at 45 degrees to the building, the initial wind direction passed through to row 1 and row 4 at the left section of the building floor and later travelled outward to the void. Comparatively low velocity of air flow passed through row 2 and row 3 at the right section of the floor.

E4 CONCLUSION

From the observation of the two cases, it can be concluded that:

i. In Case 1, row 1 of the building floor which faces the wind offers better ventilation compared to row 2, row 3, and row 4.

ii. Crosswind flow occurred at both row 1 and row 4 of the building floor and speed reduced when flowing through row 2 and row 3.

iii. Wind acting at 90 degrees (perpendicular) to the building wall as per Case 1 will produce good ventilation, which means that each housing unit facing the wind will gain adequate natural ventilation of air flow. However, as per Case 2, wind acting at 45 degrees measured from the edge of the building wall is the best orientation for the headwind.

iv. An accurate orientation strategy prior to the construction site determination is needed to maximise the surface exposure to the prevailing wind.

v. Sufficient opening with a 6 m height at the Ground Level enables the wind to pass through the ground space.

vi. Sufficient opening with a 6 m height at the middle of the building floor (Level 8) also enables the wind to pass through the DeLIGHT Homes garden. It will gain a refreshment space due to the increased prevailing wind.

vii. The DeLIGHT Homes building's void space (33.367 m long × 19.202 m wide × 53.540 m high) inside the building will produce stack ventilation driven by buoyancy. Buoyancy ventilation results from density differences between interior and exterior air, causing warm air to rise above cold air thus creating an upward airstream.

In general, the DeLIGHT Homes building has good design features of a natural ventilation system. The building has an adequate opening which produces enough natural air flow. The air flow is well distributed in every housing unit, especially in the living, dining, and master bedrooms. The average air flow speed of around 0.5 m/s at every level will have an impact on occupants' sensation: feeling fresh at comfortable temperatures.



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Acknowledgement

The Construction Industry Development Board (CIDB) Malaysia would like to acknowledge the following individuals and organisations for their valuable contributions and insights in designing the journey of this research.

Jayaselan A/L K. Navaratnam	JABATAN PERUMAHAN NEGARA (JPN)
Mohd. Noor Nasriq Mohd Hudal	JABATAN PERUMAHAN NEGARA (JPN)
Farah Sasha Rajahdin	JABATAN PERUMAHAN NEGARA (JPN)
Muhammad Firdaus Ab. Aziz	JABATAN PERUMAHAN NEGARA (JPN)
Rozaiman Hj. Hassan	CIDB IBS SDN BHD
Zaharuddin Mohamed	CIDB IBS SDN BHD
Che Mohd Zahir Che Ahmad	CIDB IBS SDN BHD
Izyan Hafizah Samin	CIDB IBS SDN BHD
Ir Tan Ek Khai	GAMUDA IBS
Adil Putra Ahmad	GAMUDA IBS
Mohd Hafiz Mohd Ameran	GAMUDA IBS
Yeoh Ee Leng	GAMUDA IBS
Davendran Krishnamoorthy	GAMUDA LAND



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978-967-0997-90-2