A COMPREHENSIVE STUDY ON THE PRE-FABRICATED MODULAR HOUSE

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

In the construction industry, the anticipation of effectiveness and sustainability exists within every construction project. A proper construction method has to be adopted to obtain the desired outcomes. However, due to the uncommonness of modular buildings in Malaysia and only being at the early implementation stage of modular construction, the numerous advantages that can be provided have been squandered. This study aims to establish an innovative conceptual design for a modular house and analyse its feasibility. A thorough literature review was carried out to conduct the research, and the modular house conceptual design was proposed using SketchUp software. The feasibility study of the modular house was performed by evaluating it from different aspects and by performing a SWOT analysis. The modular house proposed is an 1800 square feet single-storey residential house with a timber frame, and it consists of three bedrooms, two bathrooms, an open plan kitchen, and a living room. It exudes an aesthetic and modern ambience and is best suited for a family to reside. After performing the SWOT analysis and evaluating the modular house that has been proposed, it can be said that the conceptual design is feasible. Nonetheless, proper planning must be ensured for the project to successfully undergo. On the whole, modular construction is a promising method that should be widely adopted by the key players in the construction industry to make the best out of it and to become more innovative in the future.

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LIST OF SYMBOLS / ABBREVIATIONS

IBS	Industrialised Building System
PMC	Permanent Modular Construction
RB	Relocatable Buildings
MEP	Mechanical, Electrical, and Plumbing
SWOT	Strengths, Weaknesses, Opportunities, and Threats
CAGR	Compound annual growth rate
PPVC	Prefabricated, pre-finished, and volumetric construction
MMC	Modern methods of construction
BOQ	Bill of Quantities
HVAC	Heating, ventilation, and air conditioning
CII	Construction Industry Institute
CIDB	Construction Industry Development Board
CIMP	Construction Industry Master Plan
CITP	Construction Industry Transformation Programme
MCS	Modular construction system
IT	Information technology
SHS	Square hollow section
PFC	Parallel flange channel
OSB	Oriented strand board
CLT	Cross-laminated timber
NLT	Nail-laminated timber
DLT	Dowel-laminated timber
LSL	Laminated strand lumber
LVL	Laminated veneer lumber
PSL	Parallel strand lumber
CMU	Concrete masonry units
CAD	Computer aided design
BIM	Building information management
BIM	Building information modelling
M&E	Mechanical and electrical systems

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Modular construction is a process that involves the manufacture of buildings off-site under strict quality control measures. These buildings are modular buildings, and they are made up of modules prefabricated in factories, then assembled after being shifted to the construction site. The whole process starting from manufacturing modular units to assembling them requires perfect coordination through the means of thorough planning and integration (Musa, et al., 2014). Despite using the same building codes and standards for designing, modular construction is much more efficient, time-saving, and cost-effective compared to traditional construction (Muresan, 2019).

Ganiron and Almarwae (2014) have stated that the first modular building occurred in 1837. The design and manufacture of the building were all in charge by carpenter Henry Manning. The building components were built in London and then shipped to Australia. Hundreds of Manning’s buildings were sent to Australia from that time onward. Up till now, Quaker (Society of Friends) Meeting House, one of Manning’s buildings, is still standing strong in North Adelaide, Australia. Ganiron and Almarwae (2014) have also mentioned that modular buildings started to gain massive popularity after World War 2. Due to the lack of money, the veterans were forced to work in different places, and this was where modular houses came into play because of their mobility and low cost.

In general, Permanent Modular Construction (PMC) and Relocatable Buildings (RB) are the two types of modular construction (Muresan, 2019). Permanent Modular Construction prefabricates single- or multi-storey buildings in modular units by utilising lean manufacturing techniques. PMC modular units can be assembled alone or integrated into existing buildings and also can be delivered with Mechanical, Electrical, and Plumbing (MEP) appliances and interior finishes in a shorter duration than projects using site-built construction. On the other hand, Relocatable Buildings are partially or entirely assembled buildings manufactured using a modular construction process that complies with building codes and standards as well as state regulations. The purposes of RB are to be reused and delivered to different locations. Relocatable buildings are installed according to the manufacturer's installation guidelines and local code requirements. Being able to offer swift delivery, low-cost configuration, flexibility, and ease of relocation, they are very crucial when temporary space and speed are needed. Some of the common examples of relocatable buildings are site offices, medical clinics, etc.

Currently, Malaysia is still in the initial phase of implementing the modular building system. As stated by Aziz and Abdullah (2015), in Malaysia, the modular construction system (MCS) acts as an innovative method in the Industrialised Building System (IBS). MCS has been implemented as a solution to improve the productivity and quality objectives of the Malaysian construction industry, and it is believed that it can resolve the sustainable challenges of the Malaysian construction industry.

1.2 Importance of the Study

This research is conducted to study modular construction, especially the advancement in other countries and analyse them, which will help with the future development of modular construction in Malaysia. The problems contributing to the implementation of modular construction in Malaysia which have been analysed will also assist Malaysia in realising the issues and therefore make improvements on these concerns. Other than that, the design of a modular house will be studied thoroughly, and this will provide the reader with a basic idea for the design of a modular building. In short, this study allows the reader to have a more in-depth knowledge regarding modular construction from different aspects.

1.3 Problem Statement

In this era of urbanisation, effectiveness and sustainability are anticipated within every construction project. Based on the limitations of each construction project, it should be adequately analysed which method to use, modular construction or traditional construction, for that particular project in order to obtain the desired outcomes.

Nonetheless, modular construction systems being unpopular and yet to be adopted by many companies in the construction industry has made it difficult to achieve the goal. With the modular construction system not being generalised, the benefits that it can provide have gone to waste.

Introducing modular construction would surely help the construction industry keep up with the pace of urbanisation. According to Reds10 (2015), modular construction provides consistency, ensures quality control, and saves plenty of construction time. On top of that, it will help achieve more outcomes in future construction.

This study aspires to discover the possibilities of the modular construction system in the future construction industry and analyse the feasibility of modular construction systems. The obstacles causing modular construction systems to be uncommon will also be explored.

1.4 Aim and Objectives

This research aims to establish an innovative conceptual design for a prefabricated modular house. To achieve this, a few objectives for this study have been defined:

(i) To identify types of modular buildings and materials used in the current construction industry.

(ii) To propose a conceptual design for a modular house.

(iii) To propose suitable compartment materials for the developed design of modular house.

(iv) To analyse the feasibility of the proposed modular house design.

1.5 Scope and Limitation of the Study

Throughout this study, the main focus will be the prefabricated modular house in the construction industry. Various articles and journals regarding prefabricated modular houses will be reviewed and analysed. Other than that, the study will evaluate the feasibility of the modular construction system and its application in Malaysia according to the research done by other researchers. This study also requires a conceptual design of the modular house to be proposed and SWOT analysis as well as a feasibility study to be performed.

However, with modular construction systems being scarce in Malaysia, it will be challenging to conduct intensive research due to a lack of resources. Thus, the analysis performed will only be fundamental.

1.6 Contribution of the Study

In the end, this study will allow the reader to have a more thorough understanding of prefabricated modular houses, hence discovering the possibilities that modular construction would provide to the construction industry. Besides, in this era of urbanization, introducing more modular houses will bring many benefits to Malaysia. The eco-friendly characteristics of modular houses might also help improve and save the environment.

1.7 Outline of the Report

In total there will be 5 chapters included in this report. These chapters are explained in detail as follows:

(i) Chapter 1: Introduction

This chapter gives a brief idea about modular houses and the background of modular construction. The focus and intended goal of this study are also declared clearly. Moreover, this chapter will explain the contributions that this study is able to provide to the construction industry.

(ii) Chapter 2: Literature Review

Various sources such as articles and journals by other researchers are analysed and reviewed to provide comprehensive knowledge and information on modular construction in general and also particularly in Malaysia.

(iii) Chapter 3: Methodology & Work Plan

In this chapter, the research methodology involved throughout the study and the sources as well as software used are mentioned. The procedure required to propose the conceptual design of modular house will also be discussed.

(iv) Chapter 4: Results & Discussion

The modular house conceptual design will be demonstrated and analysed accordingly from different aspects and a SWOT analysis will also be performed to evaluate the feasibility of the proposed design in terms of the construction industry in this chapter.

(v) Chapter 5: Conclusions & Recommendations

The research study will be concluded with a summary and recommendations for the development of modular construction in the future construction industry will also be included.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Back then, modular construction was deemed a cheap solution for properties in low-priced areas, and this has changed over these years. As stated by Woollard (2020), modular construction is currently prevalent in the construction industry. It is used in different high-end commercial real estate projects with its market projected to be $157 billion by 2023. In the report of Schoenborn (2012), prefabricated components and preassembly have been identified by the National Institute of Standards and Technology (NIST) as one of the top five chances for advancement in the construction industry. Many developed countries, such as the United States, United Kingdom, Japan, European countries, Australia, and so on, have already adopted modular construction (Musa, et al., 2016). It can be seen that many interests in modular construction are starting to develop around the world. Considering its benefits, especially the delivery speed of the final products, increasing demand for modular construction has taken place (Gunawardena, et al., 2014).

As noticed from the current trend, the worldwide modular construction industry is anticipated to register a CAGR of 8 % from 2020 to 2025 (Business Wire, 2020). The main reason for this growth is the rising demand from the Asia-Pacific countries' construction industries. With China alone having more than 7,000 devoted players, Asia-Pacific currently holds the largest share of the modular construction market worldwide. One of the forces driving the rise in modular construction activities in China and India is their rapid population growth. Government housing, social infrastructure, schools, hospitals, and so on are among the prime areas with promising growth. Apart from that, Business Wire (2020) mentioned that the projects on the government land of Singapore would have the privilege of having essential components of prefabricated, pre-finished, and volumetric construction (PPVC). Subsidy from the government was even allocated to the companies involved, aiming to enhance and systematise modern methods of construction (MMC) in Singapore. These are why the market for modular construction is on the rise in the Asia-Pacific region.

Figure 2.1 illustrates the demand for new housing versus the construction labour supply for different countries. In Australia, although modular construction takes up only 5 % of the new housing, the right conditions appear to be in place because it turns out that there is a high unfulfilled demand for housing and also high construction wages in the country. Today, much off-site manufacturing uses only primary manual production lines, but the leading players are gaining interest and slowly investing in it. According to Bertram, et al. (2019), Singapore's Housing Development Board utilises modular construction to build up to 30,000 units a year, mainly due to the speedy construction. Whereas for the United Kingdom, the number of homes built using modular construction was about 15,000 in 2018. Even though the production costs are still high, the labour costs which are also rising are causing the modular products to be more competitive. For the western United States, the system is considered small scale with approximately 200 low-capacity manufacturers. Nonetheless, a recent shift towards modular construction has been driven by the rising construction wages in skilled trades such as electricians. More and more investors (SoftBank, Amazon, etc.) have started to invest in prefab modular home developments and builders, e.g., Factory OS, Katerra (Bertram, et al., 2019).

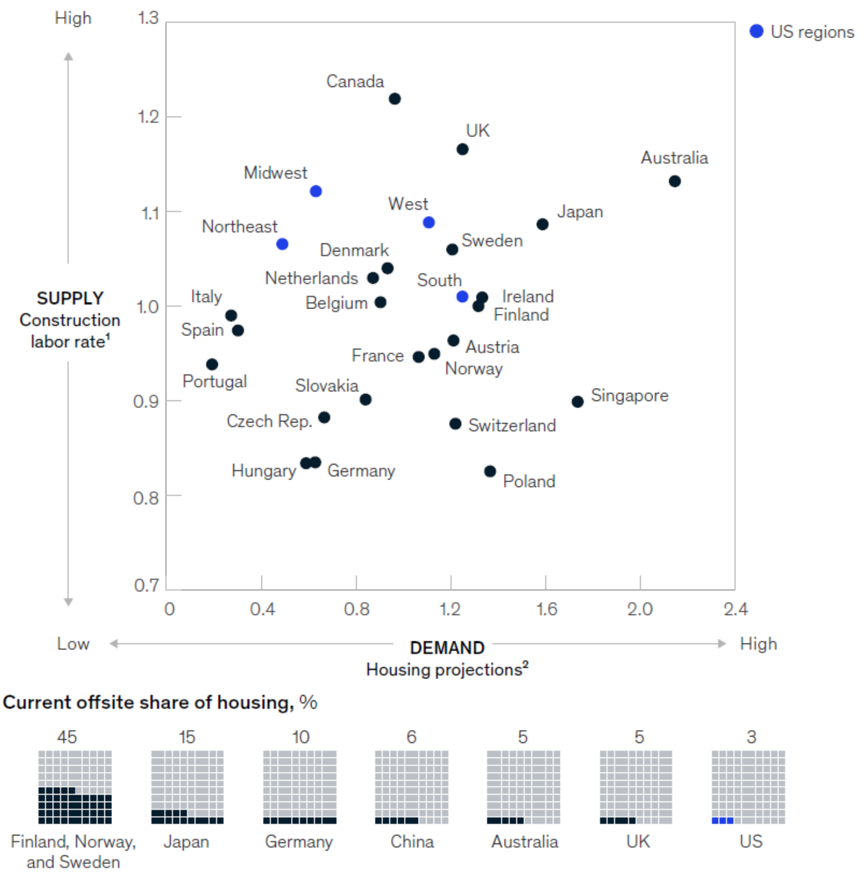

Figure 2.1: Near-Term New Housing Demand vs Construction Labour Supply (Bertram, et al., 2019).

2.2 Types of Modular Buildings in Current Construction Industry

As modular construction starts gaining more recognition in the construction industry, a wide variety of modular buildings with different configurations and sizes have come forth. There are different building types and styles as well as various options for customized configurations available, which is not much different from traditional construction. Designing Buildings (2021) has put together a list of modular buildings which are currently available in the construction industry:

(i) Temporary buildings.

(ii) Educational buildings and nurseries.

(iii) Healthcare buildings.

(iv) Emergency buildings for urgent accommodation requirements.

(v) Showrooms and marketing suites.

(vi) Offices.

(vii) Dwellings.

(viii) Hotels.

(ix) Schools.

(x) Clean rooms, etc.

Figures 2.2 to 2.5 are some of the examples of different types of modular buildings in the current construction industry. Figure 2.2 shows Ten Degrees, the current world's tallest residential modular building located at Croydon, south London. Besides the 546 rentable homes, an art gallery, a café, there are other shared spaces such as a gym, rooftop lounge, co-working spaces, and so on provided (Parkes, 2021). Ten Degrees incorporates almost 1,500 modules and the two towers are spanning 38 and 44 storeys.

Figure 2.2: Ten Degrees in Croydon, South London (Bolton, 2021).

In response to the people working from home due to the pandemic, Boano Prišmontas, a studio in London, has designed a prefabricated timber home office named My Room in the Garden, as shown in Figure 2.3. According to Ravenscroft (2020), this modular pod can be built within a day, and it serves as external exclusive office space for the people who are currently working from home.

Figure 2.3: My Room in the Garden, South London (Drake, 2020).

Figure 2.4 shows Hotel Bauhofstrasse designed by German architecture studio Von M which is made of wooden modules clad in white shingles (Carlson, 2020). Aside from the building's base and staircase made from concrete, the other parts of the structure, including the load-bearing elements, are all constructed using wood to create a more sustainable building.

Figure 2.4: Hotel Bauhofstrasse in Ludwigsburg, Germany (González, 2020).

Melopee School located in Belgium (Figure 2.5) is a five-storey building made of steel modules containing classrooms, playgrounds, nursery, and sports facilities. The school was built in this configuration due to limited space and it turns out to have a high degree of flexibility. Not only visually exciting, Melopee School is also very technically efficient (Frearson, 2021).

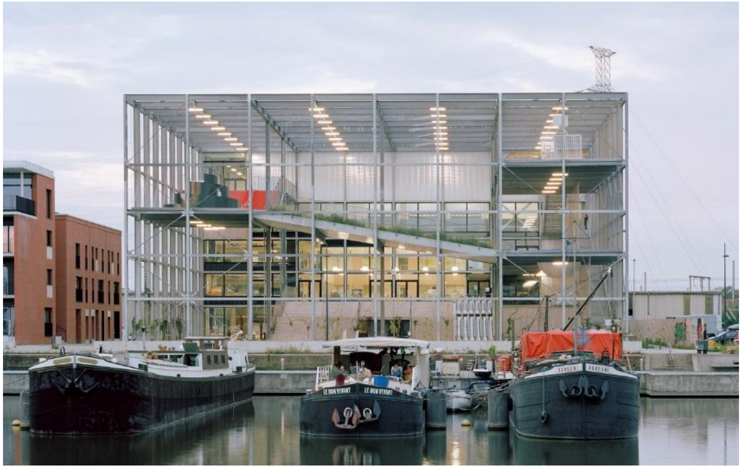

Figure 2.5: Melopee School in Belgium (Delvaux, 2020).

From the few examples shown above, it can be noticed that the application of modular construction in buildings is becoming more and more innovative nowadays and it has reached this far from just being utilized as small-scale office blocks or apartments, emergency homes, or extensions (Brown, 2018).

2.3 Types of Materials Used in Modular Construction

Generally, there are three common materials used in modular construction: wood, steel, and concrete. Each of these materials has its use in modular construction, and the design of the modular building for a project will determine which material is the most suitable to be used. Sub-sections 2.3.1 to 2.3.3 will explain each material’s uses in modular construction.

2.3.1 Wood

Wood framing has been widely used since the 1960s and is mainly used in the manufacturing of temporary or relocatable buildings in modular construction (Lawson, Ogden and Goodier, 2014). Modular Building Institute (n.d.) states that wood is used to construct exterior wall panels that comprise additional layers for the purposes of waterproofing, insulation, vapour barrier, siding, and drywall. Lawson, Ogden and Goodier (2014) also mentioned that modules made of wood must be tied together at strong points like corner posts, which will be used to lift the modules during the installation process.

As a construction material, wood is very beneficial in terms of its cost-efficiency, lightweight, versatility, and low toxicity. It is much lighter than steel and concrete, so it tends to be easier to work with, either by hand or machinery. Proper forestry practices and harvesting enable wood to be a sustainable construction material (VESTA, n.d.). In addition, wood can always be reused when a building is disassembled or demolished, and untreated wood will even naturally decompose, making wood very eco-friendly, where it doesn’t harm the environment like some other construction materials. Furthermore, wood has better insulation properties compared to steel and concrete. It is a good insulator against electricity and can help minimize energy loss and electrical shocks during an emergency.

Figure 2.6 below shows an eight-storey apartment block named Puukuokka, designed by Finnish studio OOPEAA in Finland (Frearson, 2015). It was built using prefabricated cross-laminated timber (CLT) construction. Prefabricated modules of CLT were assembled like Lego pieces to construct this apartment block. In Frearson’s (2015) article, she mentioned that the architect and studio founder, Anssi Lassila, has declared wood as a promising material that can be applied to different types of buildings, and its full potential has yet to be discovered.

Figure 2.6: Puukuokka in Finland (Auerniitty, 2015).

2.3.2 Steel

Having a higher strength-to-weight ratio, light-gauge steel components can act as an alternative to 2 inches thickness dimensional board size lumber or alongside wood framing (Modular Building Institute, n.d.). Channel steel sections are used for the top and bottom wall plates as well as joist headers. Lawson, Ogden and Goodier (2014) have also listed the difference between steel application in traditional and modular construction, where steel-based modules use galvanised steel strips which are cold-rolled into C sections, where these sections are prefabricated into ceiling panels, floor, walls, etc. Steel is often associated with buildings that require a longer lifespan.

One of the benefits of a steel-frame building is that it is non-combustible. With the fire resistance properties, the steel modular buildings have an advantage against fire and can provide a safer space for the occupants (VESTA, n.d.). If protected from corrosion, the strength and durability of steel will allow it to withstand extreme weather conditions and have a long life span. As a solid and rigid material, steel can be shaped into different forms and used in unique geometric designs in customisable modular construction. Steel modules are bolted and fitted together, so this will ease the shifting of the modules just by dismounting them.

In Changsha, China's Broad Group has erected a ten-storey steel apartment building, Living Building, which is shown in Figure 2.7, using only 28 hours and 45 minutes. The Living Building was constructed using modular units made of pure stainless steel manufactured off-site in a factory. After the modular components are transported to the site, they are bolted together and connected to the factory-fitted electric and water systems (Bahadursingh, 2021). Broad Group claimed that the stainless-steel slabs used are ten times lighter and a hundred times more potent than conventional alternatives, and the apartment building is supposed to resist extreme earthquakes and typhoons.

Figure 2.7: Living Building in Changsha, China (*BUILDING TEN STOREYS IN ONE DAY*, 2021).

2.3.3 Concrete

Concrete is often used after being reinforced with appropriate fibre and steel to generate its tensile strength (Modular Building Institute, n.d.). To ensure the stability and integrity of modular concrete buildings constructed on permanent, cast-in-situ reinforced concrete foundations, they are permanently attached to a deep footing foundation that caters for heavy seismic loads. Using concrete to build a modular building requires intensive labour because it requires more work compared to other materials, where formwork has to be erected, concrete has to be placed, and finishing works have to be carried out by an experienced team.

Modules made of concrete are frequently used in applications that require high security because they have very high damage resistance (Lawson, Ogden and Goodier, 2014). According to VESTA (n.d.), the concrete modular buildings are robust from concrete tiles to reinforced walls. Even though it takes time, these buildings will become very solid and heavy buildings once in place. They are highly durable and can even withstand almost everything, from earthquakes to hurricanes (Cupa Pizarras, 2018).

Figure 2.8 shows Clement Canopy, a housing project in Singapore, which is made up of 1,899 concrete modules and consists of 505 luxury residential apartments. Each of the towers is 140 metres high. Walsh (2019) reported that the module structures were prefabricated in Senai, Malaysia, while the technical and architectural works were carried out in Tuas, West Singapore. After that, the modules were then transported to the construction site and stacked to form the structure.

Figure 2.8: Clement Canopy in Singapore (Finbarr Fallon, 2019).

2.4 Breakdown of Modular Construction Process

In this section, the steps involved in a modular construction process from the beginning to the end will be explained in detail.

2.4.1 Design and Planning

The modular construction process begins with the design phase, the essential step requiring a systematic approach. The client's needs, building's function, space requirements, and so on are the main things that have to be considered. Every little detail has to be appropriately planned beforehand. Hyun, et al. (2020) mentioned that if there are any errors in the design, i.e., missing out information, conflicts of data from participants, etc., rework will be involved, and it will be very time-consuming and costly. Gray (2001) has claimed that it has to be ensured that the organization of the design process is formed correctly for the task at hand and that there are adequate coordinating mechanisms for the work to progress meaningfully (cited in Gassel and Roders, 2006). The information required includes the concerns for unit production, transportation, on-site work, or the whole construction project, which can be applied to the design (Hyun, et al., 2020).

Similar to traditional construction, there are building codes and standards as well as zoning regulations that have to be complied with (Modular Building Institute, n.d.). There are many regulations that every builder should follow, from electrical regulations and fire to mechanical codes, energy efficiency measures, and so on.

2.4.2 Planning Approval

Once the planning is done and the client is satisfied with it, the required construction documents such as license, architectural drawings, construction schedule, specifications, cost estimation, bill of quantities (BOQ), etc. should be submitted to the local authority to be approved (Rodriguez, 2019). Sometimes this step will take up a lot of time due to the modification of designs and the unmet requirements where many amendments are needed. Once the design is finalized, the next step, site preparation, can proceed.

2.4.3 Site Preparation

Subsequently, the construction site has to be prepared once permission has been granted. As mentioned by Designing Buildings (2020), the site preparation begins with the groundwork such as site clearance, substructure and ground stabilisation work, etc. Site preparation is an important step and has to be carried out appropriately to ensure the smooth installation of modules when they arrive on site. First, the boundaries of the construction site have to be established by using the architect's blueprint and hoardings also have to be erected around the site accordingly. Next will be soil tests where the soil is evaluated to detect contaminated areas and ground scans to identify any potential hazards located under the construction site. Besides, a levelled and well-drained area has to be designated and prepared for the construction materials and building modules to be stored until the final assembly. Many other essential tasks are to be done during site preparation, such as utility access, construction office, traffic management, waste management, and site security (Vanguard Modular, 2019).

2.4.4 Construction of Modules

While the site preparation is in progress, the construction of the modular components will be ongoing in a controlled off-site factory environment simultaneously. Based on Modular Building Institute (n.d.), the works performed in the factory include assembly of basic structural components like exterior and interior walls, floorings, and windows, installation of MEP appliances, and installation of interior finishes (partitions, ceilings, cabinets, etc.). As almost everything is manufactured off-site, the labour force involved in the factory will consist of various specialists including carpenters, plumbers, electricians, HVAC workers, and many more. Inspections will take place at different stages in the factory. The modules will then be prepared to be transported to the construction site upon completion.

2.4.5 Transportation

The completed modules are usually transported by either chassis that is integrated into the structure or carriers towed by trucks. Since the modules have to go through a distance to reach the construction site, they have to be built in a manner where they can withstand the conditions like strong winds and crane manipulation. Some of the critical factors in the transportation of modules are travel distance, method of transport, and weight of modules. Shipping modules through a far distance is not practicable due to the limitation of road size and load restrictions. As mentioned by Modular

Building Institute (n.d.), the maximum desirable distance for transportation of modules is in the range of 400 to 640 kilometres. Further than that will cause the costs and transportation to be unfavourable.

2.4.6 Installation

As soon as the modules are ready to be installed, they will be stacked by crane or rolled onto the foundation prepared. After that, they are bolted together and sealed for weather-proofing purposes. Following up will be the connection of modules, installation of utilities, completion of the exterior siding as well as roofing components, and finishing of site work. To complete the whole modular construction process, the tasks that did not occur at the factory will also occur during this stage. For instance, completion of interior elements (painting, trim, countertops, etc.), completion of external systems, the addition of stairs and elevators, and installation of appliances (Modular Building Institute, n.d.).

2.5 Comparison between Modular Construction and Traditional Construction

As mentioned in Chapter 1, modular construction is a process where the prefabricated elements are manufactured in a factory under strict control measures and transported to the site to be assembled. The off-site and on-site construction works are carried out at the same time. Whereas for traditional construction, the structural elements are mainly constructed on the construction site, and every single task has to be completed prior to the commencement of the upcoming tasks.

From design and engineering, obtaining permits and approvals, site development, site preparation, to the construction of the foundation, this progress will be similar for both modular construction and traditional construction (Reds10, 2015). However, for traditional construction, the construction of the building structure can only begin after the foundation has been completed. This will cause a lot of time to be taken up, and it would take a much longer duration for a project to be completed. The estimated timeline for traditional and modular construction can be summarized in Figure 2.9 below based on the statements provided by Reds10 (2015). Figure

2.9 only provides a rough idea of the project schedule and the procedures involved during the construction.

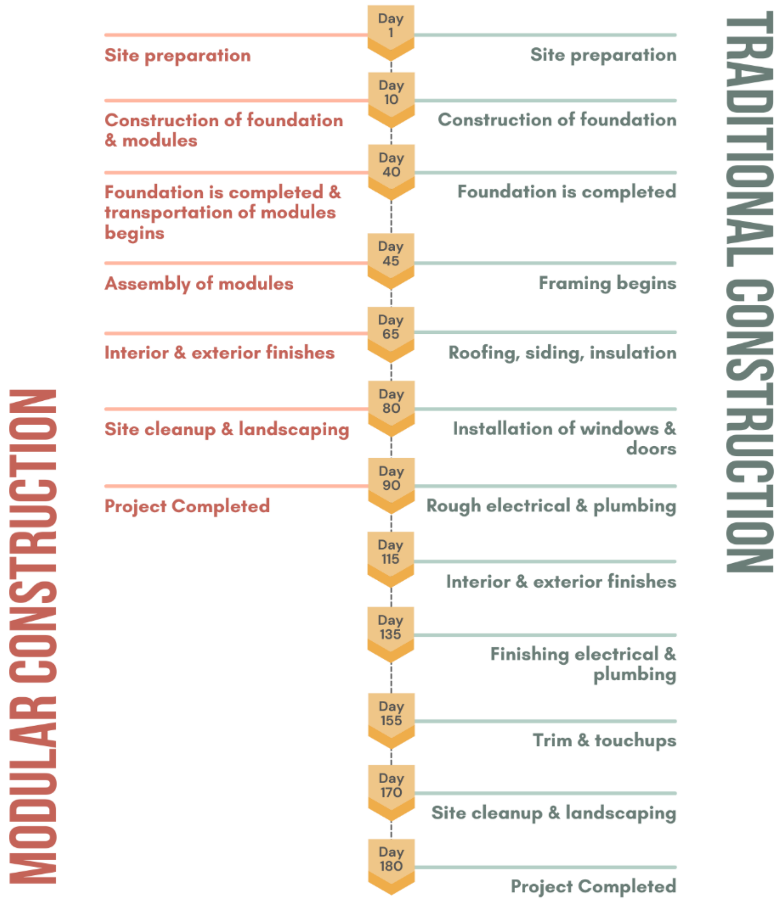

Figure 2.9: Estimated Timeline for Traditional and Modular Constructions.

2.5.1 Advantages of Modular Construction

The adoption of modular construction is expanding in many countries nowadays because of its advantages. Modular construction provides lots of benefits in terms of costs, productivity, quality, safety, environmental performance, and so on.

2.5.1.1 Cost-Effectiveness

Construction Industry Institute (CII) declared that implementing modular construction will help decrease the construction cost of projects by about 10 to 25 % (cited in Subramanya, Kermanshachi and Rouhanizadeh, 2020). There are a few reasons that contribute to this reduction in cost. First, since most of the construction takes place in the factory, the material transportation for on-site labour will be reduced. The high efficiency of installing modules off-site and the invulnerability to extreme weather conditions are also reasons why the construction progress will not be delayed, thus saving the construction cost.

2.5.1.2 Speedy Construction

Providing speedy construction is one of the essential benefits of modular construction. Being able to undergo the off-site and on-site activities simultaneously and not affected by the weather conditions, the project's schedule can run smoothly without any hindrance. In optimal conditions, modular construction can even speed up the construction by as much as 50 % compared to that of traditional construction (Fabris, 2019). This situation is very favourable during the need for rapid construction, such as the reconstruction of infrastructures (hospitals, shelters, etc.) after disasters, as stated by Subramanya, Kermanshachi and Rouhanizadeh (2020).

2.5.1.3 High Productivity

Prefabricated components for modular construction are manufactured under stringent guidelines and by skilled professionals. Subramanya, Kermanshachi and Rouhanizadeh (2020) emphasised that these professionals specialise in their fields and often perform the same procedure during the manufacturing of prefabricated components. In addition, since the modules are built under a controlled condition and not exposed to any situation which might affect the quality of the materials, such as extreme weather conditions, the modular components produced are ensured to have better quality and also able to provide much higher productivity compared to off-site construction.

2.5.1.4 Safety

Lingard (2013) reported that the International Labour Organization (ILO) estimates that at least 60,000 fatal construction accidents occur every year, meaning that one fatal accident will appear every 10 minutes. This situation is still happening these days. A few studies have looked into how modular construction influences safety in construction, and it shows that the rate of construction accidents has been reduced by 80 % when this method is used. Nevertheless, Peñaloza, Formoso and Saurin (2017) stated that a framework has to be established for modular construction during the process of assembling prefabricated components as there are still many possibilities of hazards faced by workers while handling the large components or having to deal with height.

2.5.1.5 Environmentally Friendly

Construction in the factory allows a more precise estimation and use of materials. Any extra materials from one project can be stored and used for another upcoming project (Cartwright, 2011). Cartwright (2011) said that the pre-cut and panel systems in modular construction have significantly reduced the amount of waste that ends up in the landfill after construction. The products can be reused and recycled, and the wastes are easier to be disposed of. Amiri, Caddock and Whitehead (2015) further added that modular construction would not produce on-site dust, greenhouse gases, or noises that will threaten the environment. In short, modular construction is an ideal solution to reduce the volume of waste and create less impact on the environment.

2.5.2 Limitations of Modular Construction

Despite having many advantages, there are quite some challenges that modular construction is facing too. The limitations of modular construction will be discussed in the aspects of project planning, transportation, initiation costs, etc.

2.5.2.1 Accurate Planning Required

O'Connor, O'Brien and Choi (2016) pointed out that the difference between project planning procedure for traditional construction and modular construction is approximately 37 %. The difference includes the overall planning, scoping, design, cost estimation, and so on. Knowing that modular construction requires a systematic approach, the planning process will be pretty challenging due to the production and assembly of the complex prefabricated components in the factory (Li, Shen and Xue, 2014). On this account, detailed planning with a precise scope and design details is necessary before commencing the construction project (Aarseth, et al., 2016). Establishing coordination throughout the construction process is an excellent challenge in modular construction.

2.5.2.2 Challenges in Transportation

The transportation of modules is also a very challenging task in modular construction. According to National Modular Housing Council (2017), a number of vehicles will be needed to deliver the modules to the construction site. Suppose there are oversized components for a particular project. In that case, extra considerations have to be made, and this will cause delays in the transportation and incur additional delivery costs, thus resulting in the complexity of the construction process (Wei, et al., 2014). These restraints in transportation are some of the obstacles to the cost-effectiveness and timeliness of modular construction projects.

2.5.2.3 Negative Perception

Smith (2019) revealed that people are afraid of living in factory-built housing, which they consider tiny, "identikit" homes. Besides, Home Group has surveyed to find out the public perception of modular homes, and more than 2000 opinions from across the United Kingdom have been collected. Nearly half of people thought modular homes are less durable than traditional ones (Shah, et al., 2020). Overall, modular construction can be said to be viewed negatively by quite many people, and this mindset has to be changed from now onwards for people to acknowledge its positive aspects.

2.5.2.4 High Initiation Costs

Modular construction is known for its lower construction cost compared to traditional construction. Nevertheless, it requires the establishment of a manufacturing plant which will cost even more than the labour and other expenses (Ferdous, et al., 2019). This is why most project stakeholders prefer to go for traditional construction. Implementing modular construction requires a team of engineers, designers, contractors, and suppliers who are experienced in prefabricated construction. Modular construction is a relatively complex construction method, so extensive research will be needed to identify the costs required (Kamali and Hewage, 2017). Furthermore, the modularisation process will need appropriate monitoring in order to balance the timesaving factors and cost-effectiveness.

2.6 Modular Construction in Malaysia

This section focuses on modular construction in Malaysia, where the current situation of modular construction, types of modular buildings, application of modular construction, and the factors that hinder the implementation of modular construction in Malaysia will all be studied.

2.6.1 Introduction

According to Musa, et al. (2018), the Malaysian construction sector uses the Industrialised Building System (IBS) strategy to implement modular construction. IBS is a construction method that employs pre-engineered building elements, which are mass-produced either in a factory or on the construction site and then transported and assembled to form a structure with minimal workforce and proper integration (Musa, et al., 2015).

The Malaysian government and the Construction Industry Development Board (CIDB) have introduced various plans to promote IBS in the Malaysian construction industry, including the Construction Industry Master Plan (CIMP) 2006-2015, Construction Industry Transformation Programme (CITP) 2016-2020, IBS Roadmap 2003-2010, and IBS Roadmap 2011-2015 (Musa, et al., 2016). The execution of modular building in the Malaysian construction sector is eagerly awaited due to the characteristics and benefits it offers and to eliminate the constraints of the Industrialised Building System. IBS has already been launched and established in Malaysia; therefore, modular construction must adapt to the IBS strategy to effectively execute modular construction in the Malaysian construction industry (Musa, et al., 2016).

2.6.2 Types of Modular Buildings in Malaysia

Although modular construction is not well-known in Malaysia, there are still a lot of existing modular building manufacturers which can be found in Malaysia, especially in Selangor.

Modular construction can be used to build different types of buildings mentioned in Section 2.2 earlier. Yet, the variety of modular buildings available in Malaysia is not as much, and the most common ones are containers and cabins. Some of the completed projects for different purposes (residential, commercial, educational, etc.) by the manufacturers are shown in Figures 2.10 to 2.16.

Figure 2.10: Designer Guardhouse (Solid Horizon Sdn. Bhd., n.d.).

Figure 2.11: Shipping Containers (Solid Horizon Sdn. Bhd., n.d.).

Figure 2.12: Portable Toilet Cabins (Solid Horizon Sdn. Bhd., n.d.).

Figure 2.13: Prefabricated Construction Site Office (Solid Horizon Sdn. Bhd., n.d.).

Figure 2.14: Working Studio Unit (ModularCraft., n.d.).

Figure 2.15: Private Retreat House (ModularCraft., n.d.).

Figure 2.16: Lecturer Office (ModularCraft., n.d.).

2.6.3 Application of Modular Construction in Malaysia

According to the Department of Statistics Malaysia (2021), Malaysia's population is projected to be 32.7 million in 2021 and is projected to rise to 41.5 million by 2040. Furthermore, PR1MA (2015) has reported that approximately 37 million or 87 % of Malaysians will stay in urban areas by 2050. This population expansion and urbanisation will inevitably result in a significant demand for affordable housing (Shuid, 2016). This will be a substantial issue for the Malaysian construction industry, as current construction practices will not meet the rising housing demand, given the current construction capability trend (Chai, et al., 2019). A rapid construction method will be needed to overcome these emerging issues. However, another issue has arisen, which is the increasing housing price.

As stated by Delmendo (2020), the average price for Malaysia's property stood at about MYR 423,179, and the average prices for each type of property are shown in Table 2.1 below. With that being said, the average salary in Malaysia is only MYR 3,224 per month, as stated in the 2019 Salaries and Wages Survey Report that the Department of Statistics Malaysia had published (Dzulkefli, 2020).

Table 2.1: Average Prices Based on Types of Property (Delmendo, 2020).

Property Type	**Price (MYR)**
Terraced house	387,532
High-rise residential property	341,660
Detached house	660,760
Semi-detached house	658,241

Having a basic salary is somehow difficult for Malaysians to afford a house in Malaysia nowadays. Having to pay for all the necessities, bills, taxes, and so forth are already burdensome, not to mention the unaffordable housing price, which will cause them to be overwhelmed with burdens.

With all these arising issues, modular construction has served as the solution. The prefabrication method of modular construction, which enables modularity and standardisation in the manufacturing processes, is superior in creating safe and quality-assured dwellings in a short period, as mentioned by Chai, et al. (2019). On top of that, modular construction has proved to be more cost-effective than traditional construction where the cost of the houses will be much lower; hence people are able to afford them. The president of the Malaysian Institute of Architects (PAM), Datuk Ezumi Harzani, further mentioned that adopting modular construction will bring Malaysia plenty of benefits in all aspects rather than just money-wise, such as a cleaner environment, better time efficiency, etc. (Chew, 2020). By this, Malaysia will also be able to shift to the next level in the construction industry very soon.

2.6.4 Issues of Implementing Modular Construction in Malaysia

Many reasons have brought about the lack of modular construction applications in Malaysia. These barriers can be summarised into five main areas: skills and knowledge, cost and finance, project delivery and supply chain, perception of construction industry players, and the lack of government support (Mydin, et al., 2015).

2.6.4.1 Lack of Skilled Modular Experts

Aziz and Abdullah (2015) pointed out that the Malaysian construction players seem to lack expertise in the modular construction system (MCS). In addition, the construction stakeholders are unskilled and unaware of modular construction. To implement MCS in Malaysia, the newest construction technology must be acquired, as well as appropriate strategy, procedures, and policy (Azman, Ahamad and Wan Hussin, 2012). Aside from that, architects appear to lack understanding and information on IBS, which leads to design failure during detailed construction documentation, creating delays in construction projects' schedules and improper fabrication of building components. Aziz and Abdullah (2015) also said that the low quality of IBS projects in Malaysia is attributable to inexperienced manufacturers and contractors, as well as unskilled workers. Low-quality end products have arisen from a lack of knowledge in building materials and fitting methods and a lack of optimal design or specifications on the MCS.

2.6.4.2 Lack of Technology in Automation and Robotic Industry

Implementing modular construction requires a large amount of money to utilise high technology equipment and machinery, and the works involved are very complicated. On the other hand, the automation and robotic industry still has not gained much popularity among the construction building players in Malaysia. This is because the investment will impose a very high cost compared to the much lower labour cost these players prefer (Aziz and Abdullah, 2015). Also, the usage of special transportation machinery such as self-propelled modular transporter or trailer (SPMT) to transport the modular components from the factory to the site is very low in the country.

2.6.4.3 Preference for Cost-saving Conventional System

As mentioned earlier, new building methods like MCS require skilled workers, whereby the construction players have to spend more to attract talents (Chew, 2020). In contrast, the conventional system provides a variety of material choices, flexible designs, cheap labour costs, and lower forefront investment. One of the reasons for more affordable labour costs is the illegal immigration of foreign workers. These are probably why the construction players still decide to go for the conventional construction system. However, the construction players are unaware that adopting new construction technology is a long-term cost-saving strategy that will benefit even more in the future.

2.6.4.4 Risks Faced in Current IBS Projects

The construction industry players encountered numerous challenges when managing IBS projects, which caused them to be unprepared for MCS (Musa, et al., 2015). To begin with, many IBS-based projects in Malaysia still use traditional building methods. There is no coordination between the architect and the manufacturer; there is a manufacturer-to-manufacturer interaction dispute, and so on. In short, there is a lack of cooperation within the IBS construction project team. Besides that, one of the difficulties is the occurrence of technical failures in previous IBS projects. Due to the construction defects that were difficult to repair, structural failure and water leakage occurred (Aziz and Abdullah, 2015). Inadequate technical knowledge of IBS has sometimes resulted in poor craftsmanship for the final quality of construction projects. Building faults such as moisture penetration blemishes and cracks have also been caused by poor thermal insulation and inappropriate connections. To achieve sustainable construction in Malaysia, proper knowledge of new construction technologies must be explored.

2.6.4.5 Lack of Innovation in Modular Construction

According to Aziz and Abdullah (2015), the lack of innovation in the modular construction system in terms of design, system, and materials has become a barrier to its use in the Malaysian construction industry. Automation and robotics and information technology (IT) are fields of innovation that have the potential to increase building quality in terms of construction methods and industrialisation processes. Through material engineering, production, manufacturing, and improvements in building practices and activities, innovation and industrialisation must be introduced for the future development of MCS in Malaysia (Musa, et al., 2015).

2.6.4.6 Lack of Government Support on Sustainability Agenda

Musa, et al. (2015) stated that the Malaysian government's effort to promote IBS incentives and public awareness is insufficient, and grant allocation for sustainability building should be enhanced. To increase and create new knowledge and technology in the country, groundwork and innovation are required (Aziz and Abdullah, 2015). Kamar and Hamid (2011) have also mentioned that the government's absence of a policy-making framework for green technology and green growth has failed to control and implement the country's sustainability strategy. Grading guidelines and certification mechanisms in green technology should be used to advance the Malaysian construction industry. Kamar and Hamid (2011) also added that green construction should be added to the education syllabus from primary to university level. To implement green construction in Malaysia, investment from the private sector and the government's support are needed. Abdullah (2010) also suggested that the government provides rules and regulations, planning standards, and building specifications in order to improve the adoption of IBS and MCS in Malaysia.

2.6.4.7 Unpreparedness of Malaysian towards Modular Construction

The unpreparedness and unacceptance of construction stakeholders, players, and end-users are one of the main obstacles to implementing modular construction in Malaysia (Musa, et al., 2015). The growth of the modular construction system in Malaysia has been hampered, as mentioned by Mydin, et al. (2015), due to a lack of enthusiasm, delayed action, and opposition from construction players and local authorities to changes in the construction sector and building regulations. MCS and IBS stakeholders and customers are hesitant to use these new building methods because they think it will be difficult to manage issues such as form inflexibility and the production of monotonous building components, which they believe will limit the creativity of the architectural design of the buildings. These unfavourable perceptions are hindering the future development of modular construction in Malaysia.

2.7 Designs and Requirements of Modular Buildings

As the design procedure of a modular building is known to be different from that of traditional construction, it is imperative to recognise that this approach will require the design team to take on new challenges and responsibilities. The design of a modular building should consider many different aspects, including the manufacturing process, transportation issues, and so on (The American Institute of Architects, n.d.). Different design of modules and general design issues which should be considered during the design of modular buildings will be discussed in this section.

2.7.1 Different Designs of Modules

There are several different types of modules available in the construction industry, and each of them will be introduced.

2.7.1.1 4-Sided Module

The four sides of a 4-sided module are enclosed to create cellular-like spaces that carry the modules' combined vertical load from above and in-plane loadings (primarily due to lateral forces) along their longitudinal walls. Buildings constructed entirely of modular components range in height from 6 to 10 storeys, depending on wind exposure and building location.

The production of modules begins with the floor cassette, which is then screwed to the four wall panels and ceiling panel. The longitudinal walls of the module above rest on the walls of the module below to transfer the vertical loads. Extra steel angles can be added to their recessed corners for lifting purposes and improving the modules' stability. The plates are customarily bolted together on the construction site and then used to join the modules as a connection. Sometimes, special lifting frames are necessary to ensure that the modules are safely unhooked.

The cladding materials are either pre-attached in the factory or installed on the construction site, and 4-sided modules can be built with inbuilt balconies. The walls are insulated and usually are boarded to protect them from extreme weather conditions. In-plane bracing or diaphragm action of the board materials offers shear resistance for low-rise buildings, aided by the connections between modules where the wind force is transferred to the group of modules. Vertical bracing is positioned around the access core in six to ten-storey buildings, and horizontal bracing is provided in the corridor floor between modules. The characteristics of a 4-sided module with recessed corners and additional angle sections are illustrated in Figure 2.17.

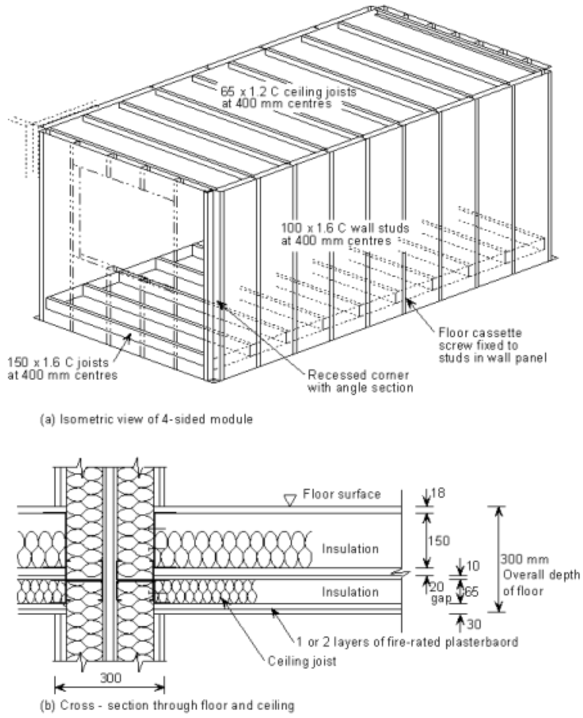

Figure 2.17: 4-Sided Module (SteelConstruction.info, 2012).

2.7.1.2 Partially Open-Sided Module

By incorporating corner and intermediate posts and a stiff continuous edge beam in the floor cassette, a 4-sided module can be made partially open-sided. The limit for the width of the opening will be influenced by the edge member in the floor cassette in terms of stiffness and bending resistance. Square hollow sections (SHS) are usually used as the additional intermediate posts to fit within the width of the wall. By combining two modules, a larger space can be created. The corner or internal post-compression resistance restricts a modular building's maximum height, but fully modular-constructed buildings can reach 6 to 10 storeys. Modules with incorporated corridors can speed up construction by preventing weather tightness issues during installation and finishing.

Partially open-sided modules are identical to 4-sided modules, except for the additional posts, typically 70 × 70 to 100 × 100 SHS members. Other components like balconies, for example, can be linked to the corner or internal posts. The modules' overall stability can be improved by adding bracing to the walls. If necessary, temporary bracing may be installed throughout the lifting and installation process. Furthermore, since this kind of module mostly does not have sufficient shear resistance in some applications, an extra bracing system can be provided. Figure 2.18 displays an apartment layout plan employing partially open-sided modules where the shaded ones are alternate modules, while Figure 2.19 demonstrates a long partially open-sided module with an integral corridor.

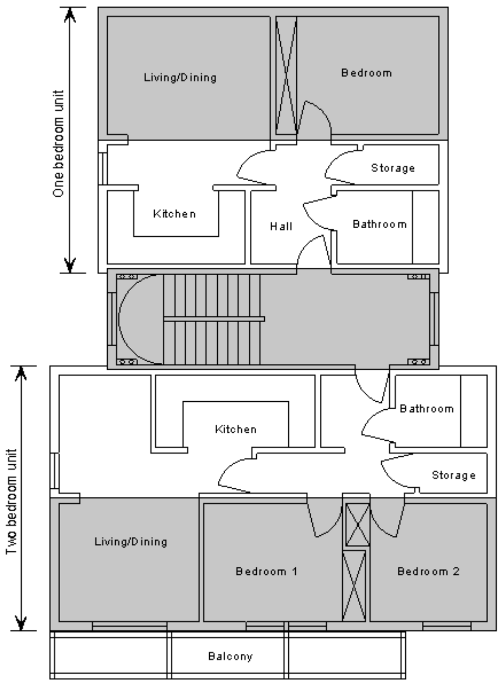

Figure 2.18: Apartment Layout of Partially Open-Sided Modules (PCKO Architects, 2012).

Figure 2.19: Partially Open-Sided Module with an Integral Corridor (Kingspan Off Site and Modular UK, 2012).

2.7.1.3 Open-Sided (Corner-Supported) Module

Load transfer from the longitudinal edge beams to the corner posts provides fully opened sides in open-sided modules. The module's framework comprises hot-rolled steel members bolted together (e.g., parallel flange channel (PFC) edge beams and SHS columns). A shallower PFC section can support the ceiling, but the overall depth of the edge beams is always more outstanding than that of 4-sided modules. Open-sided modules can be placed alongside to form more extensive open areas, which are frequently needed in buildings such as hospitals, schools, etc. Because the building's stability depends on a separate bracing system formed as an X in the separating walls, structures using this type of module are usually not more than three-storey high. The corner posts, which are typically 100 × 100 SHS members, offer compression resistance, while nominal bending resistance is provided by the edge beams which are joined to these corner posts by fin plates.

An open-sided module can be recognised as a different version of the 4-sided module, where a rigid end frame made up of welded or rigidly attached rectangular hollow sections (RHS) is usually provided. These rigid end frames are either built into the module or constructed as separate components. In addition, to offer stability, an external steel framework with walkways or balconies can be created. Modules made of hot-rolled steel framework can be used to support concrete floors in medical applications and other settings where vibration control is critical. Figure 2.20 depicts the end view of an open-sided module's structural frame, whereas Figure 2.21 demonstrates the longitudinal edge beams of an open-sided module.

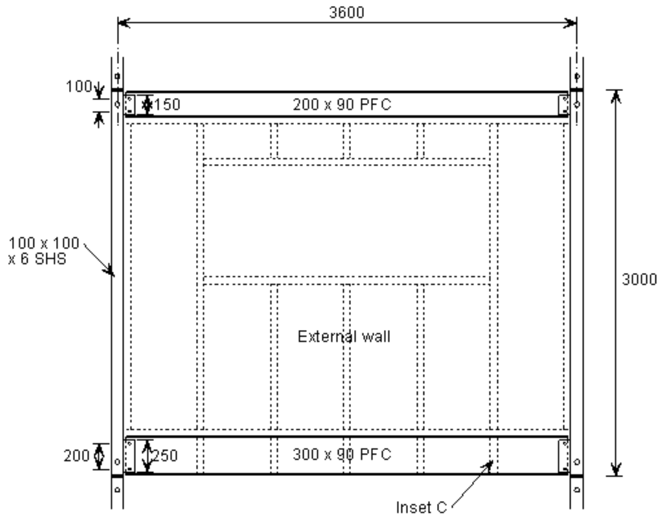

Figure 2.20: Structural Frame of an Open-Sided Module (SteelConstruction.info, 2012).

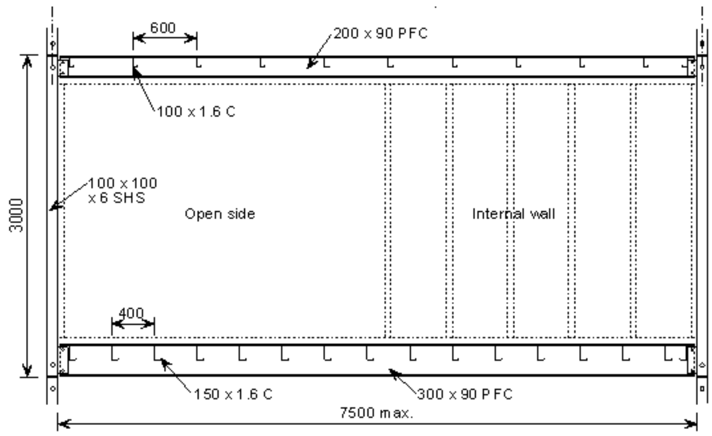

Figure 2.21: Longitudinal Edge Beams of an Open-Sided Module (SteelConstruction.info, 2012).

2.7.1.4 Module Supported by a Primary Structure

Another module type will be modules with a primary platform level structure as support. The supporting columns are usually spaced at 2 or 3 times the modules width, while the beams sustain the combined load from the modules above. The supporting structure is a traditional steel framework containing beams and columns aligned with multiples of the module width. There will also be open spaces provided at ground and below ground levels. This type of structure is suited for mixed-use developments, including retail, commercial, and residential components, mainly residential units above commercial areas or even parking lots, and so on. The long-span cellular beams supporting the modules have generated open-plan space on the lower floors, as seen in Figure 2.22.

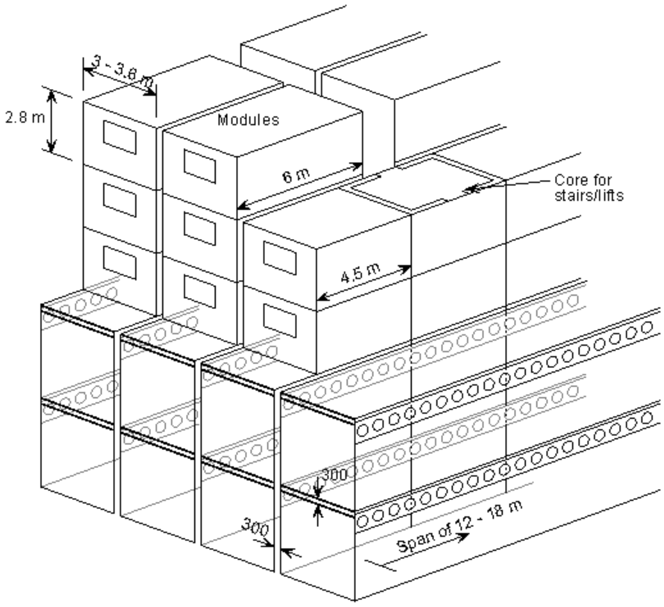

Figure 2.22: Modules Supported by Long-Span Cellular Beams (SteelConstruction.info, 2012).

Other than these four types of modules, there is also a variety of configurations of modules such as mixed modules and prefab panels, non-load bearing modules, stair modules, etc., which have been used in different modular construction building projects.

2.7.2 General Design Issues

According to SteelConstruction.info (n.d.), there are several requirements to be reviewed during the design of modular buildings: dimensional planning, structural stability and integrity, service systems, acoustic performance, and also fire safety.

2.7.2.1 Dimensional Planning

The factors that will influence the modular buildings’ dimensional planning are:

(i) Requirements for cladding (including alignment with the cladding’s external dimensions).

(ii) Internal fit-out planning grid.

(iii) Requirements for transportation.

(iv) The form of the building, as impacted by its utility.

(v) Modular manufacturing repeatability.

The brickwork is established on a standard unit with a width of 225 mm and a depth of 75 mm. As a result, the floor depth must be a multiple of 75 mm to prevent non-standard brick coursing. Various forms of cladding (e.g., clay tiles, metallic finishes, and so on) have different dimensional requirements, and their designs can be modified to meet the window's measurements and so on. The fitting between the lightweight cladding and the modules can be carried out beforehand. However, to account for misalignments and geometrical tolerances, a cover piece must be installed over the connections between the modules on site.

Since other building components and fitments will govern the planning grid, standardising it during the scheme design stage is critical. A dimensional unit of 300 mm can be used as the standard for both vertical and horizontal measurements, and vertical dimensions can be reduced to 150 mm as a second level. External walls vary depending on the type of cladding used, but for most cladding materials, a total wall width of 300 mm can be used as a baseline. The actual width varies from 200 mm to 320 mm for insulated render as well as board materials and brickwork respectively. The dimension planning for modular construction is listed in Table 2.2, and the typical wall and floor dimensions are shown in Figure 2.23.

The norms and regulations of the local government must be considered and followed when it comes to transportation.

Table 2.2: Dimensions for Modular Construction Planning (SteelConstruction.info, n.d.).

Uses	Internal wall height (mm)	Internal module width (mm)	Internal module length (m)	Ceiling-floor zone (typical) (mm)
Bedroom	2400	2500 - 2700	5.4 - 6	300
Apartment	2400	3300 - 3600	6 - 9	450
Hotel	2400 - 2700	3300 - 3600	5.4 - 7.5	450
School	2700 - 3000	3000 - 3600 open-sided	9 - 12	600
Office	2700 - 3000	3000 - 3600	6 - 12	600 - 750
Health sector	2700 - 3000	3000 - 3600 open-sided	9 - 12	600 - 750

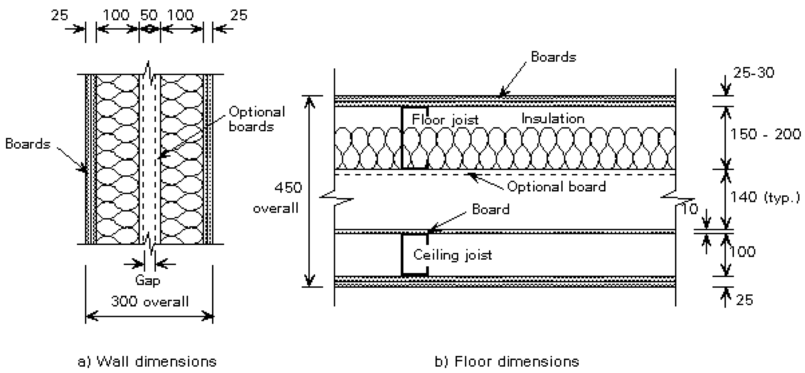

Figure 2.23: Typical Wall and Floor Dimensions (SteelConstruction.info, 2012).

Internal walls made up of adjacent module walls, comprising internal plasterboards, sheathing boards, and insulation between the C sections, can be constructed for a typical 300 mm overall width. The gap between the walls is determined by the number and thickness of the boards and the size of the wall studs.

For planning purposes, different types of modules imply varying overall ceiling floor dimensions. The floor-to-ceiling dimension for 4-sided modules is 300 or 450 mm. The dimensions of open-sided modules range from 450 to 600 mm, while frame-supported modules range from 750 to 900 mm. Even though many systems have smaller depths, the average floor-to-ceiling dimension can be taken as 450 mm in most circumstances. The number of boards and the joist size determine the distance between the floor and the ceiling.

2.7.2.2 Structural Stability and Integrity

The modules or an exterior structure provide the overall stability of a structure. Because the load path is via the walls of the 3D units, removing the load path infers that the walls have to be built to either be sustained by adjacent units' forces or span horizontally over a destructed area by functioning as a deep beam. The units must be linked horizontally and vertically to be sustained by the forces of the nearby units. The connections between modules provide robustness, with a generally anticipated minimum tying power equivalent to half the module's loaded weight. The tying forces in modular construction when one module is lost due to a fire or explosion are depicted in Figure 2.24.

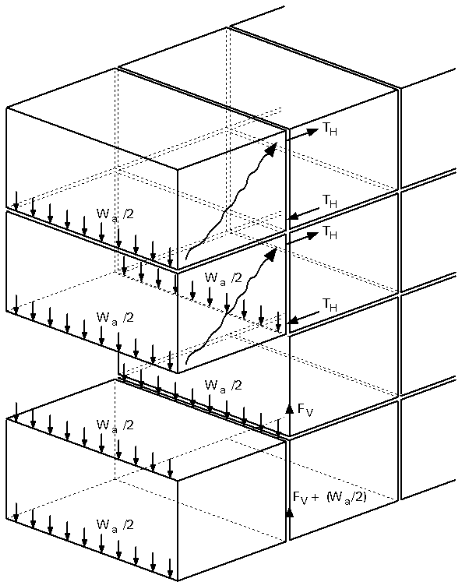

Figure 2.24: Tying Forces of Modular Components (SteelConstruction.info, 2012).

2.7.2.3 Service Systems

The electrical, plumbing and heating systems for modular structures can be installed in the factory while the final connections are carried out on site.

Modular construction, unlike traditional construction, has presented a few different service strategies:

(i) Services are distributed through communal places.

(ii) Service distribution is performed at each module's floor or ceiling zone.

(iii) In the factory, services are installed within each module, leaving only module connections for site work.

(iv) Drainage connections are connected to vertical risers (placed in the corners of the modules).

(v) The concentrate service zones are linked to the wet areas.

To accommodate vertical drainage and pipes, a vertical service duct is built into the corner of each module unit. The horizontal distribution of services varies according to the type of modular building. The corridor ceiling and floor spaces serve as service areas in most residential buildings and hotels. The drainage stacks are manufactured in the factory, and the final connection to the drains will be installed in the ground on the construction site with the detachable floor panel provided. Figure 2.25 illustrates a service duct usually built in a modular hotel building.

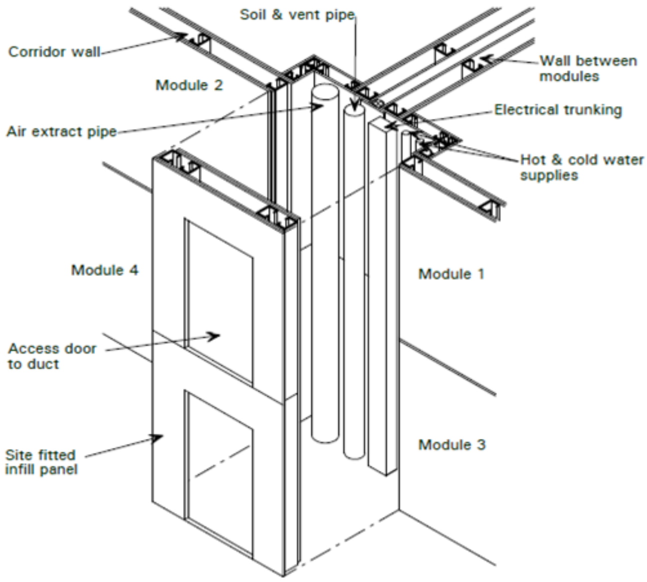

Figure 2.25: Service Duct in a Modular Hotel (SteelConstruction.info, 2012).

2.7.2.4 Acoustic Performance

Each module offers a high degree of acoustic isolation since it includes separate floor, ceiling, and wall components, thus limiting direct sound transmission through these elements. Manufacturers use several techniques to improve sound attenuation between modules, including two overlapping layers of plasterboard within each module, plasterboard or oriented strand board (OSB) attached as exterior sheeting, and quilt insulation between steel sections. Because air routes between compartments may influence sound reduction, extra care must be given around apertures for service pipes and other penetrations. Since the electrical sockets pierce through the plasterboard layer, adequate insulation with a back quilt is needed.

2.7.2.5 Fire Safety

Fire safety can be defined as the fire spread control over the compartment boundaries, the maintenance of structural integrity of the building, and providing appropriate escape routes. Each dwelling in a residential building has its fire compartment typically. Each wall and flooring that serve as dividers between compartments must be fire-resistant for 60 minutes, as stated in ISO 834 (Promat, 2019). Each bedroom in buildings like hotels, residential structures, and so on consists of its own compartment.

The spacing between modules acts as an efficient fire barrier. Escape routes must be investigated in the early stage of the scheme design process to ensure that these criteria are per the module design and layout. Cavity barriers are required in some areas to help prevent the spread of smoke and flames. These areas include the space in the exterior walls between the modules and the cladding at intersections with compartment walls. Any penetration through fire-resistant walls must have fire stops installed. Figure 2.26 illustrates the compartment floor at the intersection with external and compartment walls.

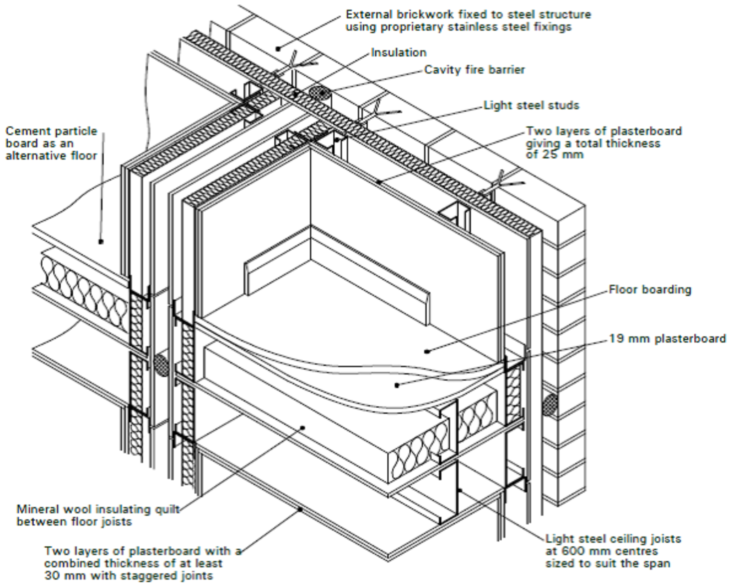

Figure 2.26: Compartment Floor at Junction (SteelConstruction.info, 2012).

2.8 Summary

In this chapter, the current trends of modular construction in general and in Malaysia have been discussed, and modular construction has also been introduced thoroughly in terms of building types, materials used, construction process, design and requirements, and differences compared to traditional construction. Modular construction has much potential in the construction industry; however, many barriers have caused the Malaysian construction industry to face difficulties in adopting modular construction. Solutions are needed to tackle these issues so that modular construction can be implemented and benefits can be gained from the adoption.

For modular construction systems, other countries like the United States, United Kingdom, and Australia have already achieved the standard of modular building. However, Malaysia has yet to reach the same stage and is still in the early implementation stage (Musa, et al., 2014). The classification of modular construction systems for the countries mentioned is shown in Table 2.3.

Table 2.3: Classification of Modular Construction System (Musa, et al., 2014).

Countries	**Classification of Modular Construction System**
United States	- Off-site preassembly - Hybridization system - Panellised system - Modular building
United Kingdom	- Manufacture of component & sub-assembly - Volumetric preassembly - Non-volumetric preassembly - Modular building
Australia	- Volumetric preassembly - Non-volumetric preassembly - Modular building
Malaysia	- Prefabricated timber framing systems - Precast concrete systems - Block work systems - Formwork systems - Steel framing systems - Innovative product system

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

In this chapter, the methodology and work plan used to fulfil the aim and objectives of the research study will be discussed. The software that will be utilised throughout the research will also be mentioned.

First and foremost, an in-depth literature review regarding the topic, which is the prefabricated modular house, was conducted from various aspects. Journals, articles, conference proceedings, and other information sources were reviewed to obtain a detailed analysis. An analysis of case studies from different countries was also performed, and a comparison between modular construction and traditional construction was also carried out. Various articles from Malaysian researchers were studied and evaluated to learn about the feasibility of modular construction applications in Malaysia. After that, the basic designs and requirements of modular buildings were analysed.

After conducting the literature review, the underlying problems of modular construction were identified. The aim and objectives of the study were then established on the basis of the problem statements.

Based on the literature review outcomes, a conceptual design of the modular house was proposed, and suitable compartment materials for the proposed modular house design have been determined. The completed design was then illustrated using SketchUp, a 3D modelling software. The feasibility of the proposed design of the modular house was then analysed, followed by a SWOT analysis.

Once the results and analysis had been completed, the research study was concluded, and the future development of modular construction in the construction industry was discussed. Figure 3.1 summarises the steps taken to carry out this research study.

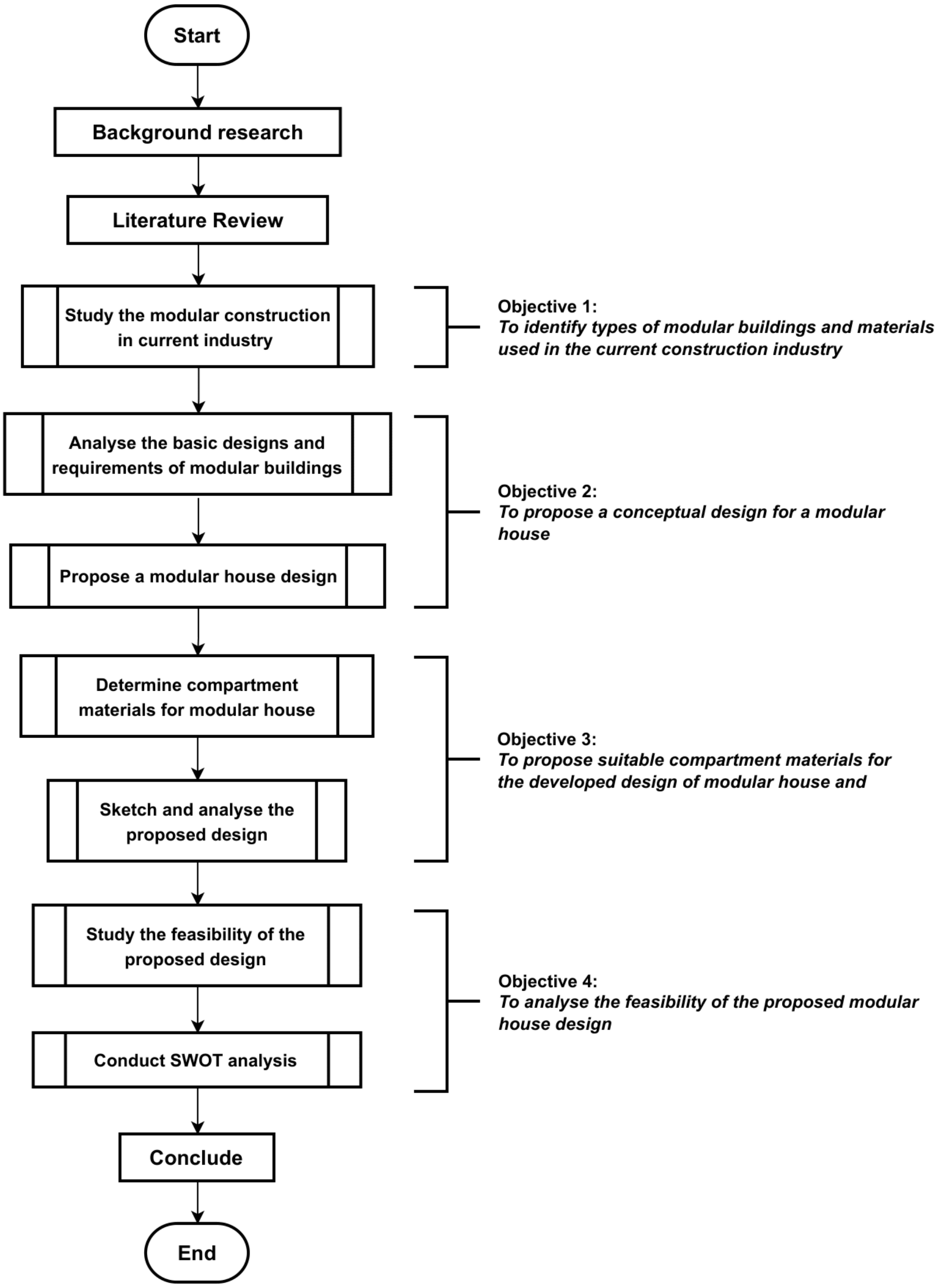

Figure 3.1: Research Methodology Flowchart.

3.2 Analysis of Different Designs of Modular Buildings

Prior to the development of conceptual design, numerous examples of modular buildings from all around the world were analysed. The sources utilised were published articles, online magazines about architecture and design (e.g., Dezeen), and so on. From the types of modular buildings to their uses, various existing modular buildings were being studied in detail.

While analysing these modular buildings, the points taken note of are locations, types of building, the number of storeys, the material used, time taken to build, shapes, designs, functions and uses, etc. The modular buildings of Malaysia were also being analysed in comparison to the modular buildings of other countries to investigate their strengths and weaknesses.

3.3 Development of Conceptual Design for Modular House

After the analysis of different modular buildings had been completed, a conceptual design for a modular house was then developed. The theory and idea of the modular buildings studied were arranged accordingly and adopted into the design. In proposing the conceptual design, several essential elements have been taken into consideration. For instance, the climate of Malaysia, the land condition, the suitability of the materials used, the practicality and sustainability of the modular house, and so on. Most importantly, the proposed modular house design must comply with the local building codes and standards.

Suitable compartment materials for the modular house were then proposed in line with the design of the modular house. Wood, steel, concrete, or other appropriate materials were assigned to the compartment parts like roof, wall, floor, etc. A thorough study of the materials was carried out to analyse their uses, advantages and disadvantages, suitability and compatibility with the modular house, and so on. Each of the materials chosen is very important because they will be integrated into the modular house and contribute to the function and aesthetic of the house overall.

Subsequently, the finalised proposed conceptual design was then illustrated using SketchUp software, enabling design ideas to be transformed into 2D and 3D models with adherence to the standards and guidelines. Figure 3.2 is the logo of SketchUp software.

Figure 3.2: SketchUp Logo.

3.4 Feasibility Study

Several aspects that have to be taken into consideration while analysing the feasibility of the proposed modular house are:

(i) Material availability.

(ii) Site location and analysis.

(iii) Construction time.

(iv) Cost.

(v) Expertise.

(vi) Design codes and standards.

(vii) Application.

The accessibility of the materials used has to be affirmed before proposing the modular house's design. It has to be ensured that the materials chosen are being supplied in Malaysia. Besides, the modular house design proposed also has to be suitable for the site selected, and the analysis of the site, which includes climatic, geographical, social, infrastructural context, etc., has to be carried out to study their compatibility. The construction time required for the modular house is then evaluated. Next, the modular house will be analysed in terms of cost to ensure that the proposed design is financially feasible, within the estimated cost and not over budget. Expertise-wise, since modular construction is unpopular in Malaysia, the availability of expertise has to be confirmed beforehand. Furthermore, it has to be made certain that the design of the modular house complies with the design codes and standards required by Malaysia. Lastly, it will be analysed whether the application of the modular house is feasible or in line with its proposed use.

3.5 SWOT Analysis

A SWOT analysis was carried out for this design approach to examine its feasibility. SWOT (strengths, weaknesses, opportunities, and threats) analysis is an evaluation of the internal possibilities and external environment, where internal possibilities consist of the strengths and weaknesses of a project, and the external environment is made up of the opportunities as well as threats which might be faced in the project (Milosevic, 2010). It is a practical strategy that helps the user understand the project's advantages, make the most out of it, and recognise the disadvantages of the project, hence reducing the chances of failure and eliminating the possible risks. Figure 3.3 illustrates the summary of the SWOT analysis.

Figure 3.3: SWOT Analysis.

The strengths, weaknesses, opportunities, and threats were all analysed for the proposed conceptual design of the modular house. In terms of internal factors, 'strengths' indicates the parts which can be done well and the unique resources possessed. For example, the short duration of project completion time, which other conventional construction projects cannot achieve. Whereas for 'weaknesses', the critical points are the parts where improvements could be made or the parts where resources are lacking. This can be explained by the proposed design is not innovative or the occurrence of budget overrun due to improper planning.

On the other hand, the two external factors in SWOT analysis are 'opportunities' and 'threats'. 'Opportunities' is an element in the external environment where strategies can be implemented to obtain more profit or the trends which can be taken advantage of. Since modular construction is gradually gaining recognition, many people might start being interested once more modular houses are constructed, resulting in the innovation of modular construction in Malaysia. In contrast, 'threats' is the element that endangers the profitability or the risks that could cause harm to the project. The possible 'threats' to the design approach will be the difficulties faced in the transportation process if the design is not compatible with the transportation guidelines.

By understanding these four main elements: 'strengths', 'weaknesses', 'opportunities', and 'threats' in a project, all the potential advantages and disadvantages can be improved or resolved, which can lead to the success of that particular project.

3.6 Summary

This chapter has outlined the methodological approaches used to undergo the research study, and the information sources accessed have also been stated. Furthermore, the process of conducting the literature review was mentioned. The course of action involved in proposing the conceptual design of the modular house and the analysis of its feasibility with the aid of SketchUp software was explained in detail.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Different types of modular buildings and materials of modular buildings available in the construction industry utilised which have been reviewed in Sections 2.2 and 2.3 will be analysed in this chapter based on various aspects, and a comparison will be made accordingly.

Based on the outcomes, a conceptual design for a modular house in Malaysia and suitable compartment materials for the house will then be proposed.

Lastly, the feasibility of the results will be evaluated in terms of material availability, site location and analysis, construction time, cost, expertise, design codes and standards, and application of the modular house. SWOT analysis is also performed to study the feasibility of the design.

4.2 Comparison of the Materials Used in Modular Construction

Generally, modular buildings can be either made up of one or a mix of three of the primary construction materials: wood, steel, and concrete. The choice of materials depends on the client's requirements or the specifications of the buildings desired.

Modular buildings made of wood are constructed from either conventional light-frame wood construction or mass timber systems. Based on Naturally Wood (n.d.), light-frame wood construction is often composed of repetitive wood framing to produce trusses or rafters out of standard size lumber. Oriented strand board (OSB) and plywood are used to construct roof decking, walls, and floors. On the other hand, mass timber products are thick, compressed layers of wood that serve as a building's load-bearing structure. Due to its versatility, cross-laminated timber (CLT) is one of the most common mass timber products, and it is used to build walls, floors, roofs, and elevator shafts. Glued laminated timber (glulam) is often used in load-bearing arches, headers, beams, columns, and trusses. Nail-laminated timber (NLT), dowel-laminated timber (DLT), laminated strand lumber (LSL), laminated veneer lumber (LVL), and parallel strand lumber (PSL) are some of the other engineered wood products utilised in modular construction.

Light steel framing is a prevalent method used in steel modular buildings nowadays. It comprises galvanised cold-formed C sections (70 to 100 mm) in the wall panels and deep C sections (150 to 300 mm) or lattice joists in the floors (PBC Today, 2019). Light gauge steel is used as a cladding system and a whole building, with thin steel studs linked together to produce non-load bearing or load-bearing walls. The studs are formed by folding strips of galvanised light gauge steel into the desired shape, and C sections are commonly used in walls (Mangan, 2018).

The walls of concrete modular buildings can be made of high-strength precast concrete masonry units (CMU), and the floors can be built with structural steel and precast concrete. The roofing materials include concrete tiles, lightweight precast concrete panels, metal panels, or traditional shingles. Also, concrete modular buildings can be fabricated using poured-in-place reinforced concrete foundations. There are various types of concrete for different uses in modular buildings, where poured concrete is ideal for setting a solid and non-combustible floor, fibre cement sidings are used for sidings such as vertical, lap, or stucco, cement boards can be treated as backers to ceramic tiles or flooring underlayment, while poured gypcrete is utilised in floor underlayment for floor levelling, radiant heating, sound reduction, as well as fire resistance (Northgate Industries Ltd., 2021). The concrete used in modular construction is more to lightweight concrete due to its properties such as lower thermal conductivity, better fire resistance, and so on (SpecifyConcrete.org, 2019).

The areas of comparison of the materials for modular buildings include sustainability, durability, lightweight, insulation properties, and fireproofing.

4.2.1 Sustainability

Owing to its ability to absorb carbon dioxide while growing, versatility as a product, and recyclability or usage as a biofuel, wood is acknowledged as one of the most sustainable and environmentally beneficial construction materials (Wooduchoose, n.d.). According to Northgate Industries Ltd.

(2019), wood tends to enhance its strength properties due to moisture-induced shrinkage and expansion, making it a long-term weatherproofing material. Whereas steel, one of the most sustainable materials, is environmentally sensitive and economically strategic in terms of its immanent lifespan and durability. Steel is the world's most recycled material, and it is only used and never consumed. According to Wiley (2020), steel is one of the few materials that can be reused indefinitely once manufactured, making it an actual cradle-to-cradle material.

In all stages of its lifespan, from raw material production to destruction, concrete is very friendly to the environment, making it a sustainable building material. This can be explained by its resource efficiency, where its predominant raw material, limestone, being the most abundant material on earth. It can also be made with waste by-products such as fly ash, silica fume, slag cement, etc. (Balogh, 2020). After the original purpose of a concrete structure has been served, it can be crushed and recycled into aggregate for use in other construction purposes, hence minimising the waste.

With that being said, steel and concrete, for example, require a tremendous amount of energy to manufacture, transport, and install. The energy consumed by these processes is known as Embodied Energy (EE), as Evan (2016) mentioned. The EE of wood, steel, and concrete are 2.0 MJ/kg, 10.5 MJ/kg, and 12.5 MJ/kg, respectively, making concrete the material with the highest EE. Having much higher Embodied Energy, the environmental impacts brought by steel and concrete are dramatically heavy. In contrast, wood-frame buildings have a lower carbon footprint because they consume less energy throughout resource extraction, production, distribution, usage, and end-of-life disposal. They also contribute to fewer greenhouse gas emissions, air pollution, and water pollution. Therefore, it can be concluded that wood is the most sustainable construction material, where steel comes in second and subsequently concrete.

4.2.2 Durability

As per VESTA (n.d.), wood is a highly durable construction material. Many modular construction companies have proven that wood increasingly hardens as it dries, and the hardening process will help increase the overall strength and durability of the wood-frame building.

Steel is also a very strong construction material having a high strength-to-weight ratio. Once proper protection from corrosion is provided, steel-frame modular buildings will last a very long time and have the ability to sustain the worst weather conditions.

From concrete tiles to reinforced walls, concrete modular buildings are extremely solid and heavy once in place. These buildings are highly durable where they can even survive the disasters, such as earthquakes, hurricanes, and so on.

Nevertheless, Coastal Steel Structures (n.d.) suggested that steel is dimensionally more durable than concrete. It does not warp, split, crack, or creep as concrete does, while concrete works better in durability than wood as it is more durable and resistant to degradation. This is why steel is mainly used to construct tall modular buildings, either residential or commercial, which require high durability and a longer lifespan. Concrete is also a common material used to build multi-storey modular buildings, but it is less preferable than steel as maintenance is required in the long run. Instead, for wood, it is more suitable for small modular buildings such as dwellings as its durability is much lower than that of steel and concrete. Figure 4.1 shows a multi-storey city centre hotel built using light steel frame construction.

Figure 4.1: Multi-Storey Light Steel-Framed Hotel (PBC Today, n.d.).

4.2.3 Lightweight

Table 4.1 indicates the density of different types of wood, steel, and concrete used in modular construction. The density of wood ranges from 400 to 750 kg/m^3 and that of steel ranges typically from 7750 to 8050 kg/m^3 (AmesWeb, n.d.). Concrete used in modular construction usually has a density of approximately 1650 to 2000 kg/m^3.

Table 4.1: Density for Different Materials Used in Modular Construction (Wood Panel Industries Federation, 2014; GreenSpec, n.d.; Dale Glass Industries, n.d.; Vigneshkannan, Abdul Bari and Easwaran, 2017; Basalite Concrete Products, n.d.; LATONIT, n.d.).

Materials	Types	Density (kg/m^3)
Wood	Oriented strand board	600 – 680
	Plywood	400 – 700
	Cross-laminated timber	480 – 500
	Glued laminated timber	550 – 750
Steel	Light gauge steel	7850
Concrete	Concrete masonry unit	1680 – 2000
	Fibre cement siding	1650

By comparison, wood is the lightest material to work with, followed by concrete and steel. This will ease the professionals or the carpenters while assembling a wood-frame modular building either by hand or machinery (VESTA, n.d.). Furthermore, wood-frame modular buildings have an advantage in the transportation process, which is one of the essential components in modular construction, as they are lighter in weight. The transportation cost incurred to deliver the modules from the factory to the site will definitely be lesser than that of steel-frame or concrete-frame modular components.

4.2.4 Insulation Properties

The approximate thermal conductivity values of wood, steel, and concrete are as follows: 0.13 W/mK, 45 W/mK, and 0.16 W/mK (Designing Buildings, 2020; Thermtest, 2021). Having the lowest thermal conductivity value where concrete comes close, wood works best in providing insulation and reduced energy waste due to its cellular structure that allows heat energy to be maintained. With additional insulation materials, the energy bill can even be cut down. VESTA (n.d.) also mentioned that wood-framed buildings provide better insulation from electrical shock, which will come in handy during construction and maintenance whenever an electrical problem arises.

4.2.5 Fireproofing

Steel modular structures offer an advantage against fire due to their fire-resistant capabilities. Also, steel does not combust in the event of a fire so the potential fire damage will be limited, thus providing the residents with a safer environment (VESTA, n.d.).

Besides steel, concrete is also classified as one of the most fire-resistant materials. Based on CLM Fireproofing (n.d.), concrete does not transfer thermal energy or react easily with other substances, making concrete a safe and effective material for structural fire protection.

In spite of that, once exposed to extremely high temperatures, steel and concrete will begin to lose their compressive strength. Concrete will lose its strength at temperatures between 427 ℃ and 649 ℃, while steel is less resistant to fire than concrete where it starts losing strength once the temperature reaches 288 ℃.

On the contrary, wood does not possess fire-resistant properties. Combustion risk and fire protection are its most significant drawbacks. Wood is made up of organic carbon molecules, which makes it highly flammable (Emily, 2021). However, the fireproofing properties of wood can be improved, and its susceptibility to combustion can also be reduced by using different techniques.

Figure 4.2 summarises and compares the materials used in modular construction in various aspects such as sustainability, durability, lightweight, insulation properties, and fireproofing, where 1 (best), 2 (intermediate), and 3 (worst) represent the performance of the materials for that particular aspect. Wood performs best in sustainability, lightweight, and insulation properties; steel performs best in durability; concrete performs best in fireproofing.

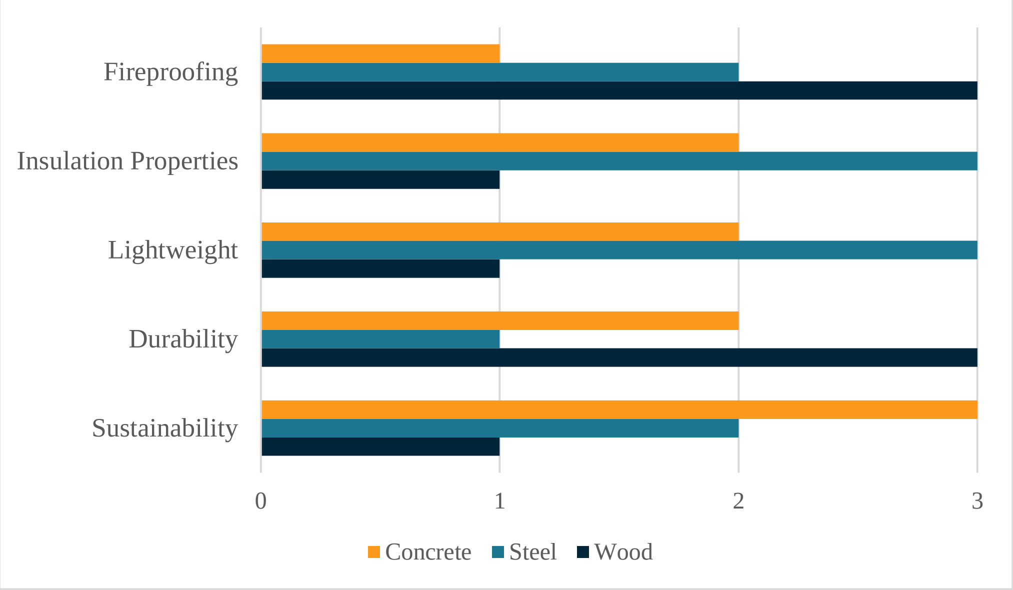

Figure 4.2: Comparison of the Materials Used in Modular Construction.

4.3 Comparison of the Types of Modular Buildings

In general, wood is suitable for small-sized buildings like modular homes, hostels, cabins, temporary shelters, etc., whereas larger-scale modular buildings (up to 30 – 40 storeys) usually are built using steel. Figures 4.3 to 4.6 show some modular buildings made of wood (cross-laminated timber, plywood) in England, Netherlands, and Paris. Examples of steel-framed modular buildings are Melopee School in Belgium (Figure 2.5) and Living Building in Changsha (Figure 2.7). The use of concrete for short or tall modular buildings is very commonly seen. Some examples of concrete modular buildings include Clement Canopy in Singapore (Figure 2.8), Habitat 67, Montreal (Figure 4.7) and VDC in Portugal's Vale de Cambria (Figure 4.8).

Figure 4.3: Modular Student Housing for Dyson Institute (Crook, 2019).

Figure 4.4: Interior of Student Housing for Dyson Institute (Crook, 2019).

Figure 4.5: Indigo Prefabricated House in Netherlands (Belkom, 2021).

Figure 4.6: Aire de Repos, Paris (Tanto, 2022).

Figure 4.7: Habitat 67, Montreal (Gaetan, n.d.).

Figure 4.8: VDC, a Modular Housing Scheme in Portugal (Guerra, 2020).

Three of the materials (wood, steel, and concrete) introduced can be integrated into a single modular building, as shown in Figures 4.9 and 4.10. This building is named Weggishof, a mixed-used residential block comprised of a concrete base topped with a timber structure using a system of prefabricated and standardised elements (Astbury, 2022). Weggishof consists of a modular grid of exposed steel that forms several balconies, staircases, and terraces. Its apartment interiors acknowledge the building's hybrid materiality, with concrete floors, wooden walls, and curved steel sections on the balconies.

Figure 4.9: Weggishof, a Mixed-Use Residential Block Designed by HHF Architects (Baan, 2022).

Figure 4.10: Concrete Flooring and Wood Ceilings Used for Weggishof (Baan, 2022).

By implementing hybrid materiality, the benefits of each of the construction materials can be fully utilised, thus being able to construct a better modular building. For instance, using wood for walls and ceilings will give the building better insulation, whereas using concrete flooring provides the building with higher durability and improved fire resistance compared to wood.

4.4 Conceptual Design of Modular House

After evaluating the materials used in modular construction from different aspects and comparing various modular buildings built with different materials, a modular house design has been duly proposed using SketchUp software.

The modular house proposed has a total area of 1800 square feet (167.23 m^2) and it is comprised of two modular units of 60 feet (18.29 m) long and 15 feet (4.57 m) wide alongside, and the height of the floor to the ceiling is 10 feet (3.05 m). There are three bedrooms and two bathrooms, where one of the bathrooms is located in the master bedroom. Besides that, there is an open plan kitchen that allows the modular house to have a brighter and bigger space, which is perfect for a family. Figures 4.11 to 4.14 illustrate the perspective view, front view, plan view, and interior view of the modular house that has been proposed.

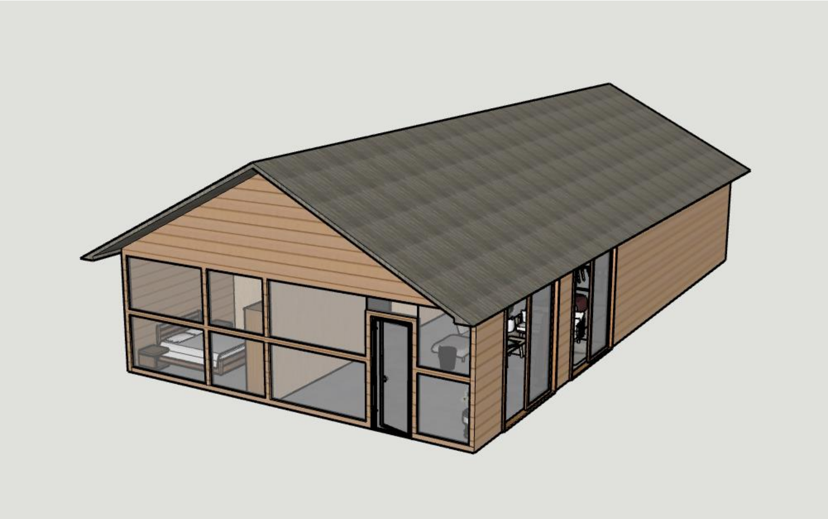

Figure 4.11: Perspective View of Modular House.

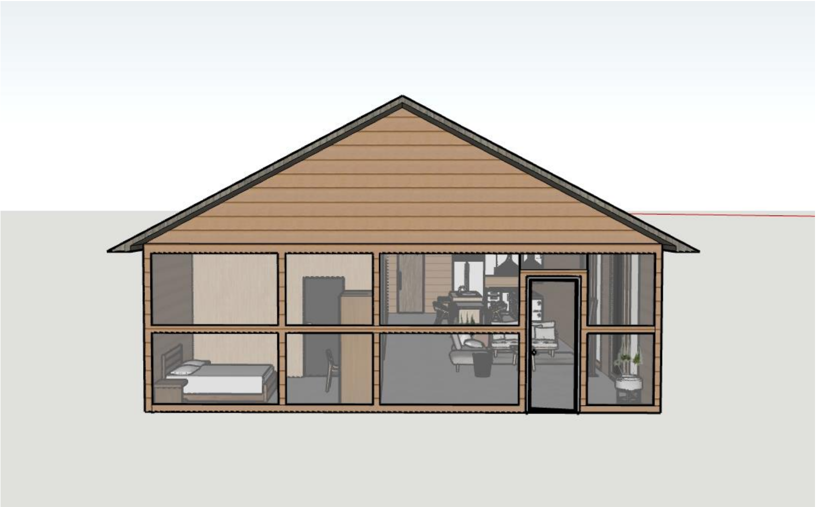

Figure 4.12: Front View of Modular House.

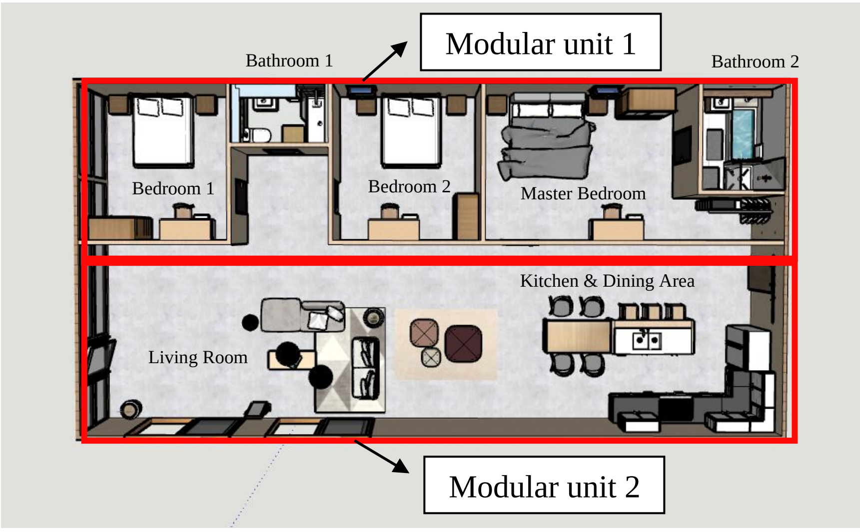

Figure 4.13: Plan View of Modular House.

Figure 4.14: Interior View of Modular House.

From the plan view (Figure 4.13), the structure of the house can be observed. The upper half comprises a modular unit and the lower half another. The upper modular unit consists of three bedrooms and two bathrooms, while the lower modular unit consists of an open plan kitchen and living room. And as mentioned earlier, both of the modular units have the same size where the length is 60 feet and the width is 15 feet.

Going in from the main entrance, the occupant will first see a living room and further back will be the kitchen and dining area. On the left will be the bedrooms as well as bathrooms where the master bedroom is opposite the kitchen area and the other two bedrooms are opposite the living room.

Open plan kitchen design has been adopted for this modular house as it allows interaction between the host and guests and also enables the flow of beams and rays of sunlight or lighting from the living room directly into the kitchen. Besides, the open plan design eliminates the walls and adjoining spaces between the kitchen and living room; hence there will be a larger space available and a better flow of air (Kitchen and Stone, 2019).

Figures 4.15 to 4.21 demonstrate each of the rooms and components of the modular house, including the bedrooms, bathrooms, kitchen and dining area, and the living room. Bedrooms 1 and 2 have the exact dimensions: 12 feet 7 inches × 13 feet 3 inches (3.84 m × 4.04 m). At the same time, the measurement of the master bedroom is 25 feet 4 inches × 13 feet 3 inches (7.72 m × 4.04 m), inclusive of bathroom 2. Bathrooms 1 and 2 are 8 feet × 5 feet (2.44 m × 1.52 m) and 9 feet × 7 feet (2.74 m × 2.13 m), respectively.

Figure 4.15: Master Bedroom.

Figure 4.16: Bedroom 1.

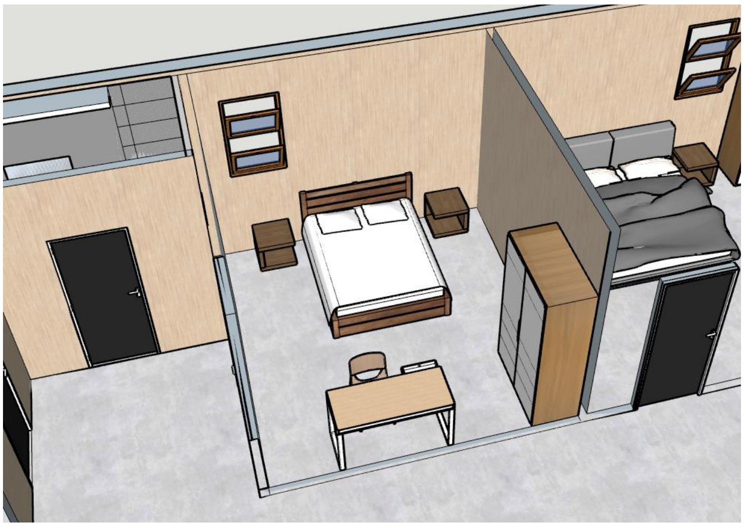

Figure 4.17: Bedroom 2.

Figure 4.18: Bathroom 1.

Figure 4.19: Bathroom 2.

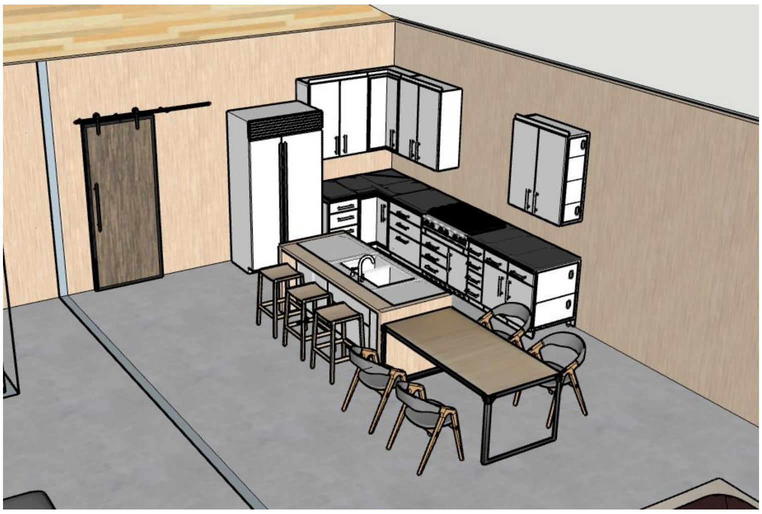

Figure 4.20: Kitchen and Dining Area.

Figure 4.21: Living Room.

4.5 Compartment Materials of Modular House

Like other buildings, the modular house is built up of different compartment materials, including framing, wall, flooring, and roofing. The materials selected for each of these components are according to their suitability for the house. The chosen compartment materials will be discussed and explained in the following subsections.

4.5.1 Framing System

As one of the most important elements, a structural frame is a rigid structure that provides support to a building or other infrastructures such as tunnel, bridge, etc. Its purpose is to assure that the structure can withstand the load placed on its walls, roof, and other components. There are many types of framing systems available in the construction industry, and the framing system chosen for the modular house is timber frame.

A timber frame refers to a system of panelised structural walls and floors made of small section timber studs and cladded with board products that transfer vertical and horizontal loads to the foundations (Designing Buildings, 2022). Figure 4.22 depicts a timber frame comprised of stud walls, collar beams, ceiling joists, header joists, corner posts, and so on. Since the modular house proposed is a wooden modular house and large structural spans do not exist in the design, a timber frame will be the most suitable choice for the house.

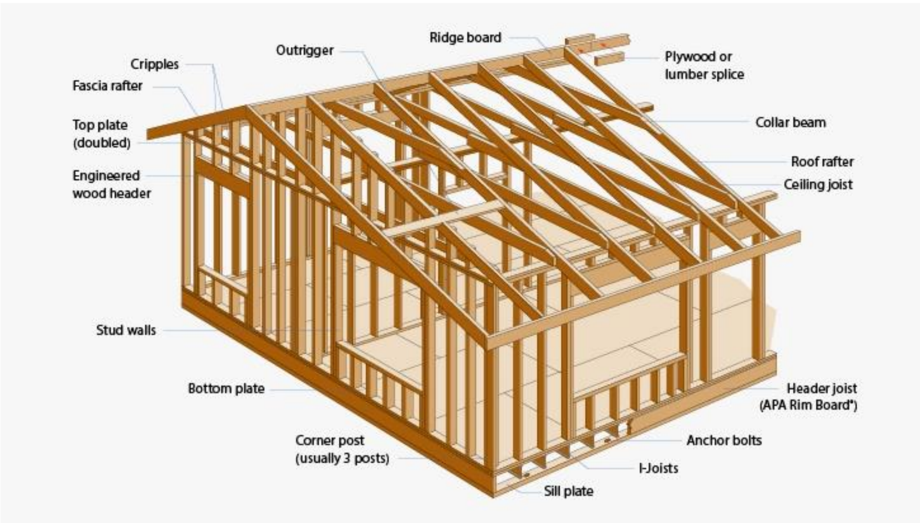

Figure 4.22: Timber Frame of a House (WaFdBank, n.d.).

A prefabricated timber frame can be installed faster than brick and block construction on the construction site. Because the interior will be exposed to the weather for a shorter time, interior trades (plastering, electrical wiring, etc.) can start work earlier in the construction programme. If the structure is to be cladded in dry plasterboard, the moisture content of the timber frame must be allowed to stabilise after it is weathertight. Anyhow, the time needed is still lesser than that required for mortar drying. Off-site prefabrication of the timber frame under controlled conditions will also provide a higher quality product.

In terms of thermal performance, timber frame structures with a thinner construction can achieve a better performance in comparison to masonry structures, steel frame structures, and so on. The low thermal mass of the buildings allows the spaces enclosed by timber frames to warm up significantly faster.

Timber frame structures may not attain the same level of sound insulation as masonry or concrete due to their lower density. Constructing two independent wall leaves with a structural gap in between and filling part of the break with sound-absorbing materials like mineral wool, rock wool, and fibreglass will help improve the soundproofing performance.

Timber frame structures, known for their fire risk, might fail if exposed to high temperatures. To prevent a fire from spreading through the cavity, cladding boards or fire stops can be used to provide additional fire protection to the timber structure. It is also worth noting that if the timber frames are not correctly erected and construction is not completed before the fire protection is installed, the fire risk will be enhanced.

4.5.2 Wall

The purpose of walls in a building is to divide it into distinct rooms or spaces for diverse uses and protect it from damage. Many functional requirements of walls must be met to fulfil their tasks properly. Strength, stability, weather and ground moisture resistance, fire safety, and sound resistance are some of the few examples (Hamakareem, n.d.). The wall is divided into interior wall and exterior wall, and the compartment materials selected will be explained accordingly.

4.5.2.1 Interior Wall

The materials suitable for building the interior walls for the wooden modular house are oriented strand board (OSB), plywood, and cross-laminated timber (CLT).

4.5.2.1.1 Oriented Strand Board (OSB)

Oriented strand board (OSB) is a popular and versatile engineered wood panel made from rectangular-shaped wood strands and waterproof heat-cured adhesives. Figure 4.23 shows wood strands 8 to 15 cm long and arranged in cross-oriented layers. In terms of strength and performance, OSB is quite similar to plywood, resisting deflection, warping, and distortion (Naturally Wood, n.d.). OSB can be treated with chemicals to improve its resistance to fire or decay, and once treated correctly with resins, OSB will be water-resistant.

Figure 4.23: Oriented Strand Board (Naturally Wood, n.d.).

Just like plywood, OSB is often preferred for its variety of uses. It can be fabricated into panels that are larger than plywood. But compared to plywood, OSB is heavier and swells more under wet conditions, especially at the edges of the panel, retaining water longer. OSB can provide exceptional lightweight strength and durability. Figure 4.24 shows a prefabricated house installed with OSB wall panels.

Figure 4.24: Prefabricated House with OSB Wall Panels (Jantscher, n.d.).

4.5.2.1.2 Plywood

Plywood is a very well-recognised multi-purpose engineered wood-based panel product where it combines resin with wood fibre sheets to create a composite material that is marketed in panels. As per Naturally Wood (n.d.), the face veneers of a typical plywood panel have a higher quality than the core veneers. The core layers are designed to improve bending resistance by increasing the spacing between the outer layers, which are subjected to the most bending pressures. The components of plywood are illustrated in Figure 4.25. If chemically treated, plywood's resistance to decay or fire can be improved. Plywood can withstand a certain amount of water contact, unlike other comparable products. As the wood dries, it will return to its nominal thickness.

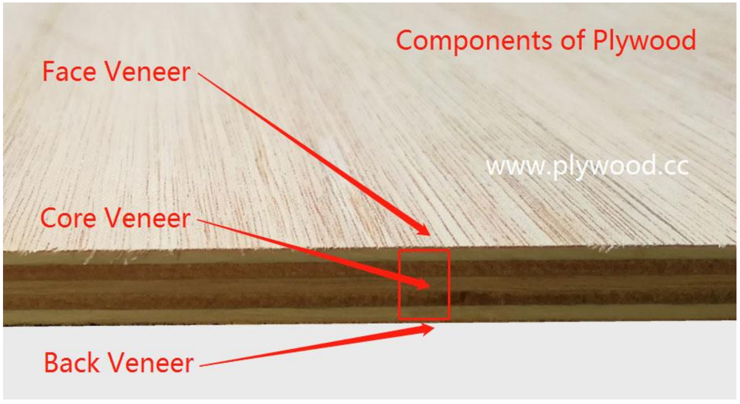

Figure 4.25: Components of Plywood (China Emburg Co. Ltd, n.d.).

Similar to OSB, plywood is a popular choice for a wide range of applications and its excellent lightweight strength and durability. On the other hand, plywood is lighter, stiffer, and retains less water than OSB. Figure 4.26 shows Karri Loop House which utilises plywood wall panels.

Figure 4.26: Karri Loop House with Plywood Wall Panels (Bennetts, n.d.).

4.5.2.1.3 Cross-laminated Timber (CLT)

Cross-laminated timber (CLT) is an engineered wood product that stands out for its strength, sustainability, appearance, and versatility (Souza, 2018). Multiple layers of kiln-dried dimension lumber are glued together to form structural panels and are positioned perpendicular to one another. The configuration of CLT is shown in Figure 4.27. The panel achieves excellent structural stability in both directions by attaching the layers of wood at right angles. CLT is a sustainable material since it is made of wood, which is a renewable resource, and it does not require the burning of fossil fuels in its manufacture.

In accordance with Naturally Wood (n.d.), as it chars, CLT, like other mass timber products, naturally resists fire. When a fire occurs, the char on the outside provides a protective layer while maintaining its strength. This gives the residents more time to evacuate the building safely. Typical CLT construction, which uses panels for flooring and load-bearing walls, helps prevent a fire from spreading to other parts of the building for extra safety. Additional fire protection can be provided by enclosing the CLT in a protective layer or treating it with fire retardants to improve its fire performance, such as slowing the spread of flames, lowering the rate at which heat is generated, and so on.

Figure 4.27: Cross-Laminated Timber Configuration (ZTC, n.d.).

Similar to other woods, CLT will not rot or form mould if correctly installed and maintained. Naturally Wood (n.d.) mentioned that proper detailing or the application of coatings, sealants, and flashing, especially on the edges, is required to protect CLT elements from direct contact with moisture for an extended period of time. Deflection devices such as cladding and window flashings can be added to the building's exterior to protect CLT from moisture and deterioration. It is also recommended that CLT be treated with a preservative to further protect against decay.

With its crosswise design, CLT is strong and has exceptional structural stability. Being on par with concrete in terms of strength, CLT can be used as a concrete alternative despite being a much lighter material. Also, using CLT will allow a faster construction as lesser joints are required between elements. Figure 4.28 demonstrates an apartment with CLT wall panels.

Figure 4.28: Rye Apartment Installed with CLT Wall Panels (Hobhouse, 2020).

In summary, the most suitable material for the modular house's interior wall is cross-laminated timber. It provides strength, speed, flexibility, thermal benefits, and is also environmentally friendly. In addition, CLT is selected due to its attractive appearance and aesthetic compared to oriented strand board and plywood.

4.5.2.2 Exterior Wall

On the other hand, there are various options available for exterior wall cladding. Brick wall cladding, lightweight brick finish cladding, hardwood weatherboard cladding, vinyl wall cladding, prefinished fibre cement panels, fibre cement wall cladding, natural stone cladding, and so on are some of the options available. Among all the options, fibre cement siding is chosen as the exterior wall cladding.

Fibre cement siding is a type of siding installed outside a house or other structures. It is a masquerade of masonry or wood that wears down like concrete and can assist the building to withstand some of the harshest elements of the surrounding environment. Fibre cement siding is produced by mixing Portland cement with wood pulp to improve the property's durability, affordability, and aesthetics (Miller, 2019).

One of the best benefits of fibre cement in the siding industry is its longevity. Fibre cement is a composite of cement, wood fibre, and other additives that are sustainable and can withstand the weather, rot, wear, and insects compared to other siding materials (Allura, n.d.). Despite having higher upfront costs than vinyl or aluminium, fibre cement siding, which can last up to 50 years, makes it a more affordable deal.

As stated by Miller (2019), 90 % of the composition of fibre cement comes from inflammable materials, wherein in instances of extreme heat, the siding can still hold firm. Having a Class 1 or Class A fire rating, fibre cement will not ignite under direct flame or heat and will not contribute fuel to the fire.

Compared to other materials available in the market, fibre cement offers many durability advantages. For instance, it does not warp as other natural sidings do in extreme heat or high moisture. Also, there is no need to worry that it will melt as vinyl siding does. Exposure to Ultraviolet A or Ultraviolet B rays from the sun will not degrade the siding. Figure 4.29 shows Blackburn Center in Portland that utilises fibre cement wall cladding.

Figure 4.29: Blackburn Center in Portland, Oregon (Nichiha, n.d.).

4.5.3 Flooring

Typically, a floor of a building offers structural support for the components of the rooms, the occupants, the floor's self-weight, and a surface finish that contributes to the look and acoustics of the building (Designing Buildings, 2021). A wide range of flooring materials are available in the industry, e.g., cement or lime concrete, timber, vinyl, laminate, porcelain or ceramic tile, marble, etc., and the selection depends on the applications and aesthetics of the building.

The type of flooring suggested for the proposed modular house is concrete flooring. Concrete is the most often utilised flooring material since it can be used in any form of construction and is economical and long-lasting. It can be polished, stained, or etched to serve as the finished flooring surface for the building (Lewitin, 2022).

The polishing method has been chosen among all the finishing materials available for the concrete floor. The advantages of polished concrete have made it a popular flooring choice for a variety of applications, including processing plants, commercial and manufacturing facilities, and other applications.

To begin with, polished concrete flooring is highly durable and resilient and is capable of withstanding the strain of heavy loads. It is quite rare that a chip or scratch, as well as damage, will occur. Based on Blackbearconcrete (2015), a properly laid, sealed, and maintained polished concrete floor can last up to a hundred years, much beyond the lifespan of other floorings (wood laminates, vinyl tiles, and so forth). Compared to other types of flooring, polished concrete is relatively easy to clean and maintain, as dirt may be avoided by dust mopping and sweeping. To remove smudging or watermarks and restore the gloss of the floor, damp mopping can be performed.

According to Blackbearconcrete (2015), polished concrete floor installations are cost-effective, particularly if an existing concrete slab is available for staining, polishing, or applying decorative coatings or overlays. This perfectly describes the condition of the proposed modular house, where there will be an existing concrete slab ready to be worked on. In addition to the polished concrete floor's aesthetic appeal, the use of raw materials can help save resources by bypassing additional coatings and processes.

Some of the examples of residential buildings installed with polished concrete flooring as shown in Figures 4.30, 4.31, and 4.32 are Hass House, Cariló House, and New Concrete House, respectively. These residential homes are all using polished concrete floors.

Figure 4.30: Hass House (Ritsch, 2019).

Figure 4.31: Cariló House (Adden, 2018).

Figure 4.32: New Concrete House (Henz, 2012).

According to Souza (2020), while choosing a concrete floor for the building, the factors that have to be taken into account are the conditions of the terrain, the loads distribution, the function of the space, and the possibility of exposure to components which can corrode the concrete. It is very crucial that the relationship between the materials in the concrete (water, sand, gravel, and cement) allows it to be finished with special machines after curing, giving it the desired strength and shade.

Once the concrete pouring has been completed, slab levelling and proper density must be ensured to eliminate trapped air bubbles, excess water, and empty spaces inside the concrete. Cuts for expansion in predefined areas in the project are also necessary to prevent cracks during the expansion and contraction of the structure. After the concrete dries, polishing works with special machines will only commence. Pigments can also be added to the mixture to obtain desirable shades of the concrete floor.

To conclude, a polished concrete floor is a good flooring choice for the modular house due to its durability, aesthetics, cost-effectiveness, and ease of execution.

4.5.4 Roofing

A roof is a structure that covers the upper part of a building that serves for safety, protection, security, privacy, insulation, and other purposes. Roofs can be built from a wide variety of materials into different configurations depending on the requirements that have to be satisfied, such as the climate, the span to be covered, the availability of the materials, the expertise available and so on.

Figure 4.33 shows the roof that has been proposed for the modular house, and the type of roof is a pitched roof with a slope of approximately 27.6° (Figure 4.34). A pitched roof often slopes downwards, with a central ridge dividing it into two portions at an angle.

When coping with extreme weather conditions such as heavy rain, a pitched roof is particularly solid and practical as it is shaped like a triangle. This is attributable to the design of the roof that deflects water away from the building and prevents waterlogging (Mallik, n.d.). The sloped roof's design which promotes natural airflow between the outer layer and the building helps conserve energy and reduce utility bills. Aside from that, natural ventilation beneath the top roof layer improves the building's thermal efficiency and provides comfort to the indoor during any climate change.

Despite being more expensive, a pitched roof does not need constant repairing, which contrasts with a flat roof where its drainage system requires constant maintenance to avoid leakage. According to Mallik (n.d.), if the pitched roof uses high-quality natural slate, the roof will have a long lifespan of even over 100 years without any maintenance.

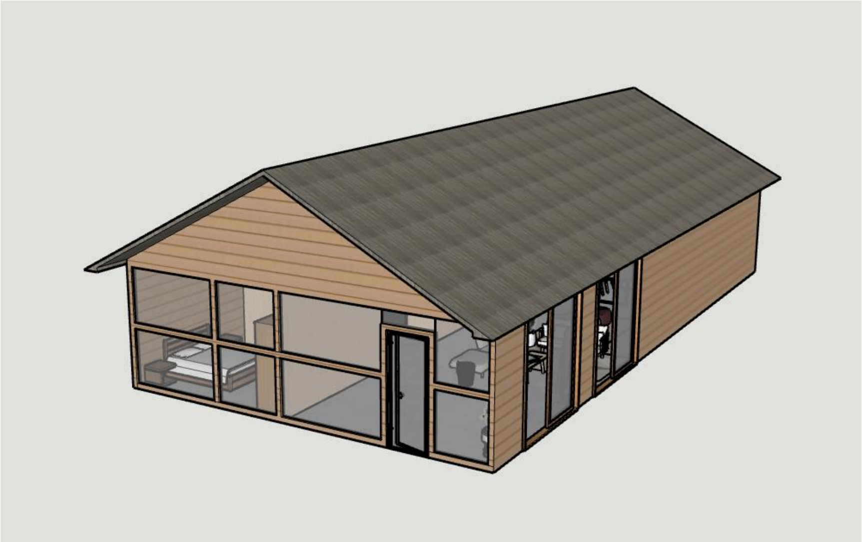

Figure 4.33: Proposed Pitched Roof for the Modular House.

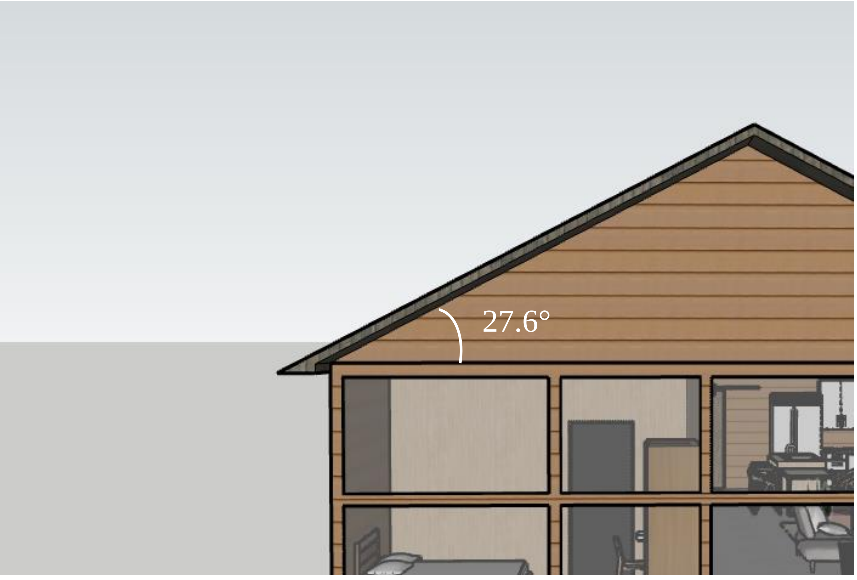

Figure 4.34: Slope of the Pitched Roof.

With that being said, natural roofing slate is selected as the roofing material. Based on Chris Ball Roofing (2018), natural roofing slate is formed underground by intense heat and pressure, and it is regarded as one of the highest-quality roofing materials. It is formed by splitting the fine-grain and metamorphic rocks into several smooth, flat-faced pieces.

As an extremely durable material, natural slate can last up to half a century when correctly installed, protecting the building from water and external elements while requiring relatively minimal care. The density of natural slate tiles helps maintain the temperature of the building, preventing energy loss and reducing the cost of bills. Natural slate also provides adequate fire resistance and resistance to pest damage and rot. Natural slate comes in various textures and natural colours and is commonly seen in multiple shades of grey (Chris Ball Roofing, 2018). Figures 4.35 and 4.36 show the appearance and texture of natural slate tiles and a residential home "Bioclimatic 'Longère' House" that applies natural slate tiles as the roofing material.

Figure 4.35: Natural Slate Tiles (Roof Giant, n.d.).

Figure 4.36: Bioclimatic 'Longère' House (Indy Architectes, 2017).

4.5.5 Summary

From the discussion above, different compartment materials are chosen for each of the components of the modular house. The selected materials and the respective compartment will be summarised in Table 4.2.

Table 4.2: Chosen materials for each compartment of the modular house.

Compartment of Modular House	Materials
Framing	Timber frame
Wall	Cross-laminated timber wall panel (Interior) Fibre cement wall cladding (Exterior)
Flooring	Polished concrete floor
Roofing	Natural slate tiles

For the framing of the modular house, a timber frame has been chosen due to its suitability for the modular house proposed. Timber frame requires a shorter duration to construct than other types of framing; at the same time, it also provides better thermal performance.

Whereas for wall, cross-laminated timber (CLT) wall panels are used to construct the interior wall, and the exterior wall is built using fibre cement wall cladding. CLT wall panels are chosen because of their strength, sustainability, appearance, and versatility. It resists fire, provides protection against rot or mould, and even possesses strength similar to concrete. While having a very realistic appearance like natural wood, stone, or brick, fibre cement wall cladding provides various benefits that these materials might not be able to. It has a long life span, is heat and fire-resistant, and resistant to rotting and warping.

Polished concrete floor is selected as the flooring for the modular house as this type of flooring is very strong and is able to resist heavy loads, and it can even last up to a hundred years. Easy maintenance and cost-effectiveness are also the benefits of a polished concrete floor.

Lastly, for the roofing of the modular house, the material chosen is natural slate tiles. Low maintenance is required for natural slate tile roofing, and high durability is provided. Natural slate tiles help maintain the house's temperature, thus reducing the bill costs by preventing energy loss. It also has decent fire resistance and is resistant to pests and decay.

4.6 Feasibility Study on the Proposed Modular House

In this section, the feasibility of the modular house proposed will be evaluated in terms of different aspects individually. These aspects include material availability, site location and analysis, construction time, cost, expertise, design codes and standards, and application.

4.6.1 Material Availability

The materials proposed for the compartments of the modular house are timber frame, cross-laminated timber wall panel, fibre cement wall cladding, polished concrete floor, and natural slate tiles.

First of all, there are many timber suppliers available in West Malaysia. These companies supply diverse types of timber and can provide customised specification, cutting, and fabrication supplies for construction projects in Malaysia. Also, they specialise in various levels of wood manufacturing where framing is also included.

In Peninsular Malaysia, cross-laminated timber is readily available, and design assistance, 3D modelling, structural engineering, fabrication, and installation services can be provided as requested.

For fibre cement wall cladding, the source will be obtained from the fibre cement manufacturers in Malaysia. Different types of fibre cement products available in various surface textures and colours can be easily obtained from these manufacturers.

Many companies in Malaysia are providing the service of concrete floor polishing, and most of them are based in Klang Valley. Therefore, it will be very convenient for the service to be carried out.

The companies that are able to supply natural slate tiles are located in Penang, Selangor, Johor, and so on. There are many variations of slate tiles that can be chosen from, e.g., colours, patterns, textures, etc.

Last but not least, all the other materials required for the construction of the modular house are readily available in the market and can be easily acquired.

4.6.2 Site Location and Analysis

The modular components will be prefabricated in the factory beforehand and transported to the project site to be assembled. Since the assembly of modules will be carried out on-site, sufficient space has to be provided in order to ease the assembling process.

For the modular house, the site proposed is any firm and solid ground in or near a residential area in Malaysia's town or city with a lower population density, e.g., Seremban. A firm and solid ground has a higher soil bearing capacity, which helps reduce the house's foundation cost. A comparatively lower population density allows the occupants to have a more comfortable and pleasant lifestyle without having to live in a highly crowded place.

Furthermore, a site location equipped with facilities and infrastructures such as a supermarket, post office, bank, railway station, school, police station, etc. nearby (about 5 to 10 kilometres) will be very convenient to the occupants.

Climatic-wise, the tropical weather of Malaysia remains constant all year round, and the humidity level is also consistent throughout the year. Hence, there will not be much difference no matter where the construction site is located.

4.6.3 Construction Time

In general, a traditional home usually takes about 9 to 12 months to complete, whereby constructing the foundation uses up to one month. However, a modular house only needs 3 to 4 months, or even shorter depending on the configuration of the house (Next Modular, n.d.).

Modular construction enables the construction of the foundation and the prefabrication of modules to commence simultaneously; therefore, the duration of construction needed will be much shorter. The foundation would be done even before the construction of modular components is completed. Once the construction of modules finishes, the modules can be transported to the project site immediately without any time delay.

Malaysia experiences rainfall frequently all year round, so this might be an obstacle for traditional construction. The construction works have to be suspended for some time, thus causing a delay in the project's progress. Instead, for the construction of the modular house, the climate will not be a problem as the construction will be performed in the factory.

4.6.4 Cost

A modular house saves money by lowering building costs, personnel costs, material costs, water usage, and labour costs. At a rough estimate, a modular house is 10-15 % cheaper than a traditional house (Ramamirtham, 2021).

The construction materials needed for the modular house are all available and supplied by different companies in Malaysia, so there will be no extra charges of import duty or importing fees which might cost a fortune. As the weather is not a problem for modular construction and will not delay the progress, the construction and labour cost incurred will also be much lower.

According to the info from Property Guru, the price for a single-storey semi-detached house in Seremban with an area of approximately 1800 square feet ranges from RM 430,000 to RM 650,000 or even more (Property Guru, n.d.). In contrast, a similar modular house may only cost about RM 380,000 to RM 550,000, following the statement of Ramamirtham (2021).

4.6.5 Expertise

There are different existing modular building manufacturers which can be found in Malaysia whereby these companies consist of teams of professionals and builders specialised in design, manufacturing, and construction of modular buildings. With the assistance of these professionals and builders, the construction of the modular house will be executed with ease and success.

4.6.6 Design Codes and Standards

There are many design codes and standards involved in the construction of the modular house. The guidelines and standards include:

(i) Guide to Modular Coordination in Buildings, Malaysian Standard MS 1064: Part 1 to Part 10, Department of Standards Malaysia, 2003.

(ii) Sizing Guide for Precast Concrete Building Components for Residential Buildings, CIDB Malaysia 2004.

(iii) Guideline for Volumetric Module House: Manufacturing Design and Construction for Malaysia, CIDB Malaysia 2019, etc.

The design codes and standards mentioned have to be strictly followed to ensure that the modular house proposed is able to provide the requirements in terms of safety and quality.

4.6.7 Application

In this study, the modular house has been assigned as the main focus, and it is a straightforward approach to influence the community as people nowadays are quite into property investments, predominantly residential properties. Therefore, the modular house can be treated as an investment.

Apart from that, the modular house proposed is very suitable for a family of three or four or even five to reside as it will be very comfortable and cosy. The modular house is designed to encourage social interactions among family members, thus improving their relationships.

4.7 SWOT Analysis of Modular House

SWOT analysis in this study will help identify the proposed modular house's strengths, weaknesses, opportunities, and threats. First, the internal factors, strengths and weaknesses, will be discussed, followed by the discussion of external factors: opportunities and threats.

4.7.1 Strengths

For 'strengths', it indicates the areas that the modular house does exceptionally well, in a way that distinguishes it from the other types of dwellings or its advantages over other houses. The modular house's strengths over other types of houses are high productivity, safety, cost-effectiveness, and sustainability.

Firstly, one of the most significant strengths is the speed of construction. While other types of houses of similar configuration require 9 to 12 months to complete, the modular house proposed only needs one-third of the time span, where 3 to 4 months is already sufficient.

As the modular house will be fabricated in the factory, the safety of the workers can be ensured during the construction process, and potential construction accidents will also be reduced since the working environment is more controlled.

Situations such as delay of construction due to unpredictable weather conditions and extra materials due to improper planning will not occur during the construction of the modular house. Therefore, the construction cost, labour cost, and materials cost can all be cut down, thus contributing to a lesser cost overall.

The use of building information management (BIM) and computer-aided design (CAD) tools in constructing the modular house and the efficiency of the production line allow for more precise access and use of materials. Unused materials can often be recycled or used for other purposes and projects. In addition, the materials used to build the modular house are sustainable, so the environment will not be harmed.

4.7.2 Weaknesses

'Weaknesses' are the parts where the modular house can improve and the areas that it is lacking compared to other types of houses. Some of the modular house's weaknesses are the need for precise planning and the difficulties faced during the transportation process.

The planning of the modular house has to be carried out correctly before the commencement of the project, and the scopes that have to be considered are cost, time, labour, design, development of the project, detailing, orders, fabrication, delivery process, assembly, etc. Without proper and precise planning, the construction process wouldn't be as smooth, and the unforeseen issues will cause many problems to the project.

Transporting the modular house to the project site is another difficult task. The modules have to be safely placed on the trucks using cranes, and if necessary, weatherproof materials will be used to wrap the modules. After the modules have reached the site, they will be lifted off the trucks using a crane. If the modular house is heavy, the transportation fee will definitely be much higher. Also, taking the distance into consideration, heavy traffic or bad weather conditions will lead to a challenging transportation process.

4.7.3 Opportunities

The openings or chances that can be exploited and taken advantage of define 'opportunities'. The ability to observe and exploit opportunities can make a massive difference to modular construction in future.

A modular house is known to be cheaper than a traditional house; therefore, if more modular houses are introduced into Malaysia, a lot of Malaysians who could not get a house for themselves will slowly be able to purchase and build an affordable modular house of their own.

Moreover, by having and introducing more modular houses in Malaysia, modular construction will start gaining more recognition, which in turn leads to the innovation of modular construction as well as development in the construction industry in Malaysia. By this, more investors will be attracted and willing to invest in the construction companies of Malaysia.

4.7.4 Threats

'Threats' are the possible obstacles that this project of modular house might encounter and that may negatively affect the project gradually. It is crucial to anticipate threats and take action against them before anything happens.

One of the underlying threats of the modular house is the cost. In view of the fact that modular construction is not common in Malaysia, the collaborating modular company might demand an exorbitant price for the modular house. Proper communication between the parties involved is necessary with legal documentation to prevent this from happening.

4.8 Summary

In this chapter, the comparison of the materials used in modular construction has been made, and the areas of comparison are sustainability, durability, lightweight, insulation properties, and fireproofing. The materials with the best performance in these areas are wood, steel, wood, wood, and concrete. The following section is the comparison of the types of modular buildings constructed using different types of materials: wood, steel, and concrete. The types of modular buildings built with each material are explained and discussed, and examples are also given.

After analysing the materials used in modular construction and types of modular buildings built with different materials, a conceptual design of a modular house is then proposed using SketchUp software accordingly. The modular house is made up of two modules of 60 feet × 15 feet, and it has a total area of 1800 square feet.

Then, the compartment materials for the components of the modular house are proposed. The components of the house include framing, interior and exterior wall, flooring, and roofing. A timber frame is proposed for the framing of the house, and the respective materials for the interior wall and exterior wall are cross-laminated timber wall panel and fibre cement wall cladding. The flooring type that has been suggested is polished concrete floor, and the type of tiles proposed for the roof is natural slate tiles.

Subsequently, the modular house is evaluated for material availability, site location and analysis, construction time, cost, expertise, design codes and standards, and application. On top of that, a SWOT analysis is also carried out to analyse the feasibility of the modular house.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Throughout the research study of prefabricated modular house, several conclusions are made.

This research aims to establish an innovative conceptual design of a prefabricated modular house. To achieve this, a literature review of various articles and journals has been carried out to obtain an in-depth understanding of modular house. The scopes studied are types of modular buildings in the current construction industry, types of materials used in modular construction, breakdown of the modular construction process, comparison between modular construction and traditional construction, modular construction in Malaysia, and the designs and requirements of modular buildings. The methodology used to conduct the research study in order to meet the study's goals and objectives is also determined.

In Chapter 4, a single-storey timber modular house has been proposed, and respective compartment materials are also suggested accordingly by adopting each of the material's benefits after the analysis of materials used in modular construction and types of modular buildings reviewed in Chapter 2 is performed. The modular house proposed is a residential house with an area of 1800 square feet that fulfils the building codes and standards and is perfect for a family to dwell in.

The evaluation of the modular house performed has proven that the conceptual design of the modular house proposed is feasible. This project is practicable and can be put into practice in the future. Last but not least, the SWOT analysis conducted has analysed all the strengths, weaknesses, opportunities, and threats of the modular house. Actions should be taken to improve or resolve the advantages and disadvantages by using the information and bringing about the success of the project.

5.2 Limitations and Recommendations

In this research, the available sources and information utilised are articles, journals, conference papers, e-books, websites, and so forth. Nonetheless, due to the scarcity of reliable sources such as journals and books, most of the information retrieved for the study are from websites. Additional research on modular construction is highly recommended in the future so that there will be more established information available for future researchers.

Modular construction is an up-and-coming solution for expensive housing and greener buildings in the construction industry, and the advantages of modular construction outnumber its limitations; however, further development and research in terms of technology would surely lessen or mitigate the challenges faced in the future.

To utilise and raise the potential of modular construction in Malaysia, the perception of the people has to be changed by the cooperation of each authority and party including the government. By eliminating the obstacles faced in the adoption of modular construction, Malaysia will only be able to implement modular construction regularly and thus become more innovative in the construction industry.

For future research, qualitative and quantitative approaches can be employed by studying the perspective or acceptance of the citizens, developers, constructors, and other parties involved in the implementation of modular housing. In addition, further design analysis in compliance with the code of practice can also be carried out on the proposed modular house with the aid of other software such as SCIA Engineer, midas Gen, etc. Lastly, Building Information Modelling (BIM) may be adopted where all the M&E features can be embedded into the proposed modular house design.

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