Building the Future with **Prefabrication Volumetric Module**

Implementation & Business Model Framework

CIDB Technical Publication No.:2110

CIDB MALAYSIA

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PREFACE

Throughout the history of the construction industry, great strides and advancements have been reached by its undergoing a significant paradigm shift. Now, the industry is observing a growing trend towards multi-trade prefabrication. It is believed that this practice will continue to grow in coming years to focus on approaches that support and propel the industry forward.

Another growing trend is off-site construction applying three-dimensional (3D) volumetric modules, also known as Prefabricated Prefinished Volumetric Construction/ Volumetric Modular Construction, using Prefabricated Volumetric Module (PVM). PVM construction involves the prefabrication of whole building units under controlled conditions in factories. These units are then transported to the construction site, where they are installed and assembled on-site to create functional buildings. According to latest definition of prefabricated IBS by Mohd Zairul, (2021) as an innovative process of building components utilising mass production Industrialised systems, produced within a controlled environment (on or off- site) which includes organised logistics and installation process on-site with systematic planning and management.

This present document titled "Building the Future with Prefabrication Volumetric Module - Implementation & Business Model Framework" produced by the Construction Industry Development Board (CIDB) Malaysia via the Construction Research Institute of Malaysia (CREAM) will be used as a primary reference to provide information about PVM implementation in Malaysia and Business Model Framework for those who desire to get involved in PVM manufacturing. This business model framework also lends ideas to first-timers in the PVM business as well as to those who intend to expand existing production building components to PVM.

The CIDB wishes to express their gratitude and appreciation to the IBS manufacturers, contractors, consultants, developers, and all industry players involved in sharing data, experiences, and knowledge towards the success of this report's development. This document will be a useful reference for policy-makers to encourage the construction industry players to be game-changers for the betterment of the industry in moving towards Construction 4.0. Furthermore, it will help to cultivate increased productivity performance, high-quality building construction, improve on-site safety, minimise

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EDITORIAL

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

ABBREVIATIONS

BM	Business Model
CAT	Customer and Top
CIDB	Construction Industry Development Board
CLQ	Centralised Labour Quarter
CREAM	Construction Research Institute of Malaysia
CS	Customer Satisfaction
HBS	Hickory Building Systems
IBS	Industrialised building system
IT	Information Technology
MMC	Modern Method Construction
MSB	Modular Steel Building
OHS	Occupational safety and health
OSM	Off-site Manufacturing
PPVC	Prefabricated Prefinished Volumetric Construction
PVM	Prefabricated Volumetric Module
R&D	Research and Development
SWOT	Strengths, Weaknesses, Opportunities, and Threats

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Building the Future with
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1.0 INTRODUCTION

1.0 INTRODUCTION

1.1 Overview

Prefabrication Volumetric Module (PVM) is a typical construction method in developed countries such as the United Kingdom, the United States of America, Australia, Japan, and many others. This construction method has currently become a growing trend in the Malaysian construction industry. PVM is also known as Volumetric Modular Construction/ Modular Construction, Off-site Manufacturing (OSM)/ Off-site Construction, Modern Method Construction (MMC), Prefabricated Prefinished Volumetric Construction (PPVC), Modular Integrated Construction and Prefabricated Modular. Table 1.1 shows the world's tallest PVM buildings and their respective number of storeys.

Table 1.1: World's Tallest PVM Building (Thai, Ngo, & Uy, 2020)

Project	Storeys	Year	Country	Modular type	Material	Highlight
Collins House	60	2019	Australia	2D Panel and 3D Module	Concrete	The tallest building combining both penalised and PVM method
J57 Mini Sky City Tower	57	2015	China	2D Panel	Steel	The fastest-built building upon completion (in 19 days)
Croydon Tower	44	2020	United Kingdom	3D Module	Steel	The tallest PVM building upon completion
Atira Student Accommodation	44	2018	Australia	2D Panel and 3D Module	Concrete	Combined of both penalised and PVM methods
La Trobe Tower	44	2016	Australia	2D Panel and 3D Module	Concrete	Combined of both penalised and PVM methods
Clement Canopy	40	2019	Singapore	3D Module	Concrete	The tallest PVM building
B2 Tower	32	2016	United State	3D Module	Steel	The tallest PVM building upon completion
T30 Tower	30	2011	China	2D Panel	Steel	The fastest-built building upon completion (in 15 days)
Apex Tower	29	2017	United Kingdom	3D Module	Steel	The tallest PVM building in Europe
SOHO Tower	29	2014	Australia	3D Module	Steel	The tallest PVM building upon completion

According to Abd Hamid, Mat Kilau, Mohd Zain, & Musa, (2019); CIDB Malaysia, (2019 & 2020a), PVM offers advantages such as improved build time, environmental benefits, and reduced on-site labour cost as shown in Figure 1.1. It also incorporates a broad range of technologies and innovations to improve project delivery.

Figure 1.1: Benefits of using the PVM Construction Method

Despite the many benefits of using the PVM construction method, Figure 1.2 highlights five expected challenges that are commonly faced by the construction industry, which were derived from numerous surveys and literature from previous researchers (Kamali & Hewage, 2016; Lacey, Chen, Hao, & Bi, 2018; Razkenari, Fenner, Shojaei, Hakim, & Kibert, 2020).

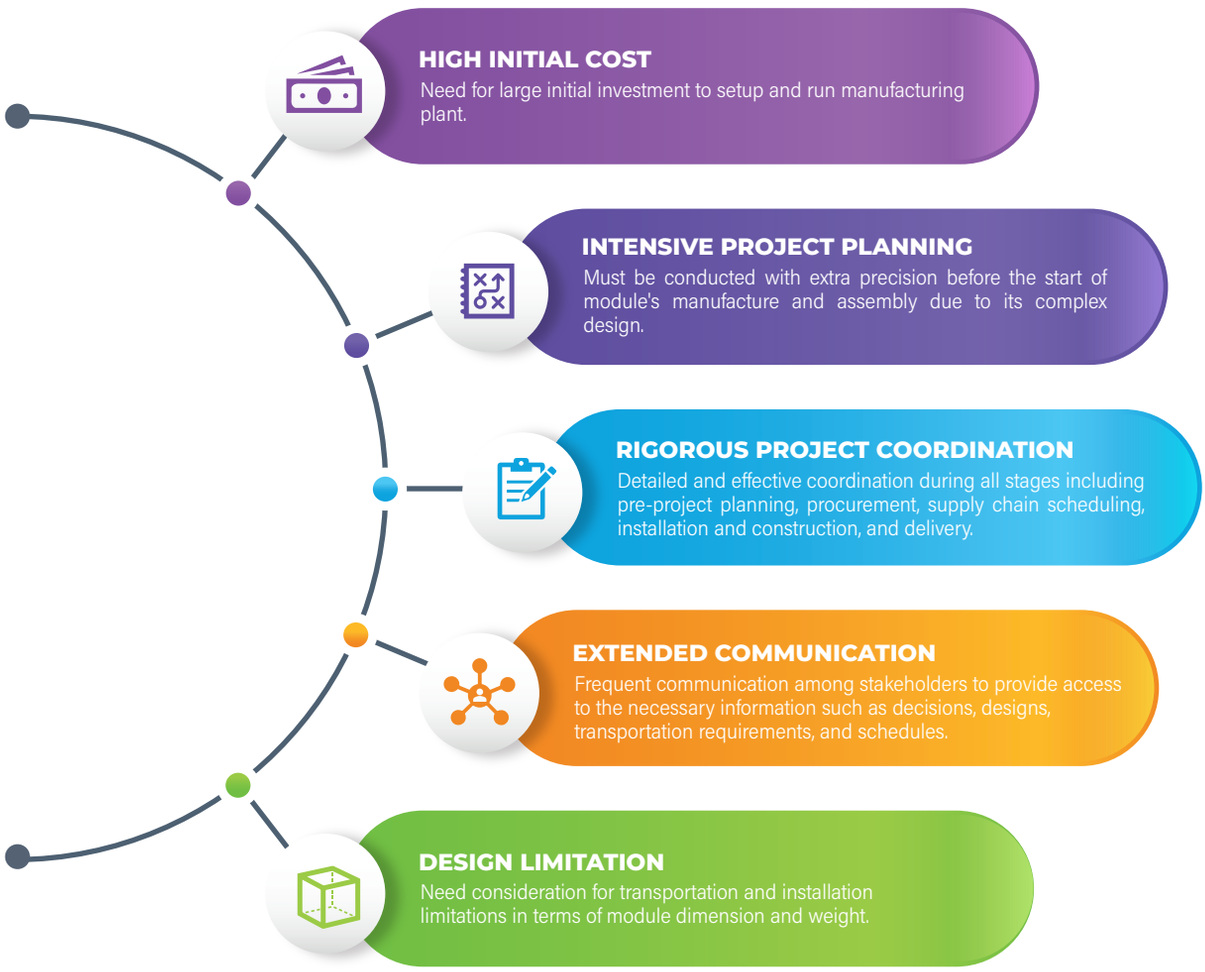


Figure 1.2: Challenges in using the PVM Construction Method

1.2 PVM Classification

PVM can be classified according to: 1) primary construction material; 2) load transfer mechanisms; and 3) structural systems.

1.2.1 PVM Classification Using Primary Construction Material

According to Lacey et al. (2018), PVM can be classified according to the primary construction material such as concrete, metal, or timber as shown in Figure 1.3 to Figure 1.5. For metal PVM, it can be further classified as Modular Steel Building (MSB), light steel-framed modules, and shipping container modules. Table 1.2 shows the applications, advantages, and disadvantages of each PVM classification.

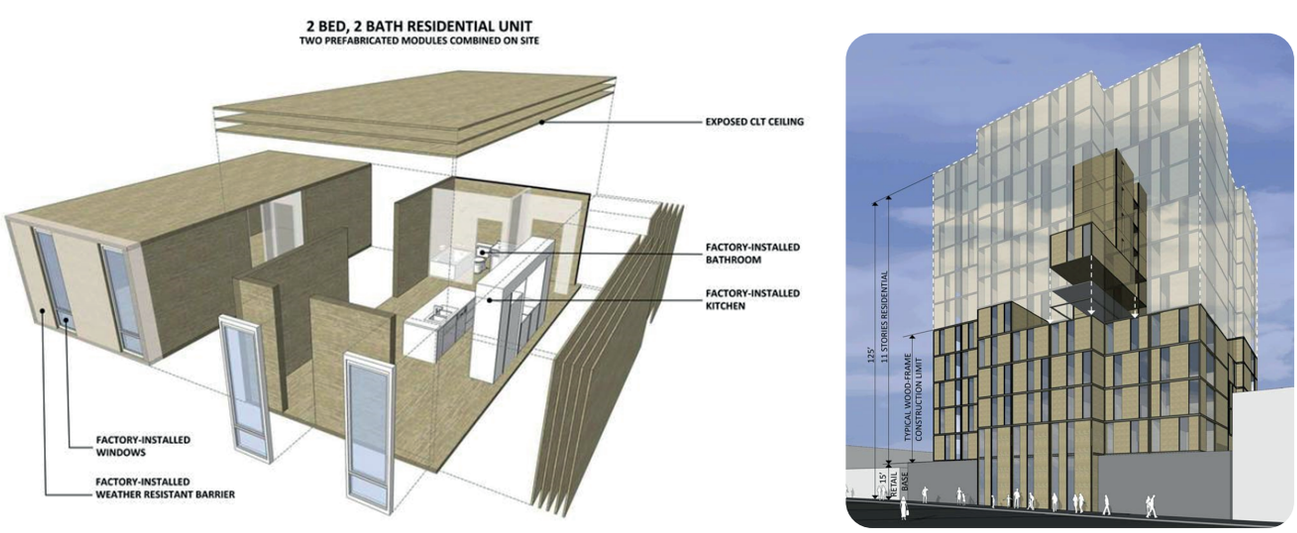
Sources: Aurélie Cléraux (2018)

Figure 1.3: Example of Precast Concrete PVM

a) MSB Module *b) Light Steel Framed Module* *c) Shipping Container Module*

Sources: Lacey et al. (2018)

Figure 1.4. Example of Metal PVM



Sources: Alter (2014)

Figure 1.5. Example of Timber PVM

Table 1.2: PVM Primary Material Classification

PVM Type	Application	Advantages	Disadvantages
a) Metal PVM			
• MSB Module	Hotels, residential apartments	Suitable for high-rise buildings, high strength	Corrosion, lack of design guidance
• Light Steel Framed Module	Maximum 10-storey, 25-storey with additional core	Lightweight, easy to transport and install	Suitable mainly for low-rise buildings
• Shipping Container Module	Post-disaster housing, military operations, workers' quarters, and residential development	Recyclable shipping containers, easy to transport	Additional reinforcing required to strengthen the container when openings are cut in the walls
b) Precast Concrete PVM	Hotels, prisons, residential apartments, educational buildings, etc.	Fire resistant, acoustic insulation, thermal performance, high capacity	Heavy to transport and install, potential cracking at corners
c) Timber Frame Module	1 to 2-storey high buildings, educational buildings, housing	Sustainable material, easy to assemble, easy to transport and install	Poor fire resistance, need extra treatment to improve durability

Adapted from Lacey et al. (2018)

1.2.2 PVM Classification Using Load Path

According to R. M. Lawson, Ogden, & Bergin, (2012) and Liew, Chua, & Dai (2019a), there are two common types of PVM systems with different types of load paths:

1. load-bearing wall modules, and
2. corner-supported modules.

Load-bearing wall modules are commonly used in concrete buildings, in which the concrete walls are used to transfer gravity loads to the foundation, as well as resisting the lateral loads as illustrated in **Figure 1.6.** Meanwhile, corner-supported modules are generally made of steel, in which the gravity loads are transferred to the slab, then to the edge beams and corner columns, and finally to the foundations as shown in **Figure 1.7.** In this system, separately braced frames or reinforced concrete core walls resist the lateral load.

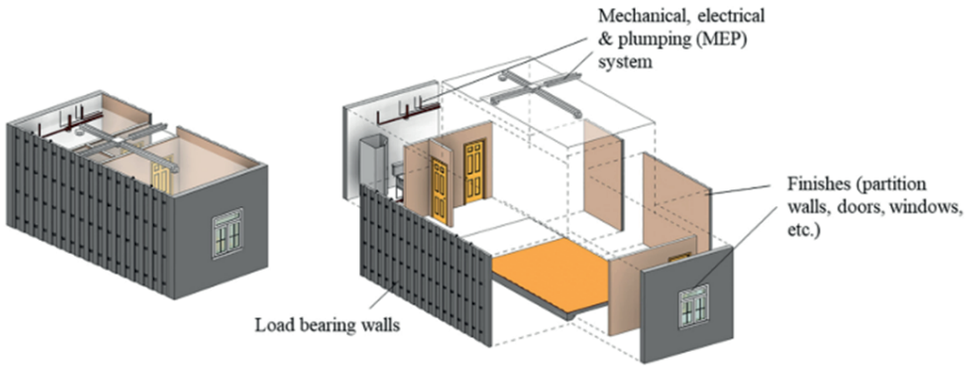


Figure 1.6: Load-bearing PVM System (Liew et al., 2019)

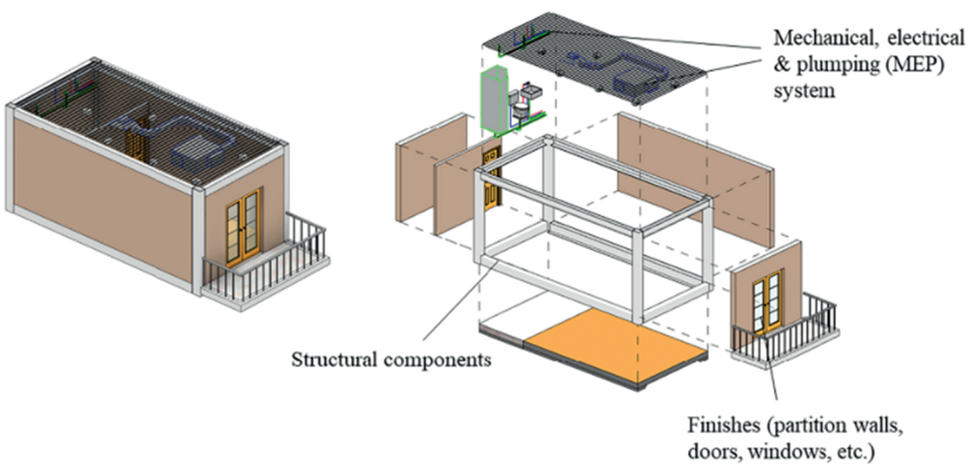


Figure 1.7: Corner-Supported PVM System (Liew et al., 2019)

1.2.3 PVM Classification Using Structural System

According to Gunawardena (2016), existing PVM buildings can also be categorised according to the structural system that has been used as follows:

1. **Load-Bearing System**

   The gravity loads of each stack of modules are run down through the side walls down to the foundation. The neighbouring modules do not share loads or transfer any lateral loads from one to the other. This load-bearing system is the same as the load-bearing wall module under load path classification.

2. **System with Central RC Core and modules that are directly connected to the core**

   Here, the system consists mainly of corner-supported modules as previously introduced previously PVM load path classification. The gravity loads are directly transferred down to the

foundation through the perimeter or corner columns of each module. One vertical stack of modules acts as one block of vertical loads. This system can go up to any height, and typically result in structures of 8 to 10 storeys high. The lateral load-resisting system is essentially managed by the central core that is made out of reinforced concrete. The modules are connected laterally to the central core either directly or through neighbouring modules. The lateral loads are expected to be transferred to the foundation mainly through the central core.

3. **System with Central RC core where modules are stacked up in rows and the floor levels are eventually poured with concrete**

   The poured concrete fills up the vertical gap between the roofs of a certain level of modules and the floors of the level of modules directly above it. Once hardened, this concrete membrane acts as a rigid diaphragm that is continuous and connected to the core, and can transfer all of the lateral loads to the core. However, this results in excessive use of the material in the form of concrete, where the floors and roofs of each module are already in place. It also hinders the ability of the modules to be removed and reused in a different location. In practice, this system has been used in buildings that go up to 25 to 30 storeys high.

4. **Advanced Corner-Supported Modular System with stiff modules**

   This is a system where the dependency of the central core is no longer a constraint to the structural system. This system is self-sustained as far as the lateral load resistance is concerned. The modules themselves are allowed to incorporate stiff wall elements, and are placed strategically on a building plan to ensure effective lateral load resistance. The system presents designers with many attractive benefits, including flexibility with arranging spaces without being restricted by an in-situ unmovable core. This prompts the need for this structural system to be investigated further on its structural behaviour against lateral loads to be used for medium to high rise structures.

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2.0 IMPLEMENTATION OF PVM

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2.1 Constraints and Barriers in PVM Implementation

The key factors hindering the implementation of PVM should be identified to encourage local industry players to embark on PVM technology in the Malaysian construction industry. Extensive research and study have been done to identify the constraints and barriers in PVM technology implementation.

2.1.1 Constraints to PVM Implementation Worldwide

The constraints to PVM implementation are highly varied, with a consequent variation in emphasis between researchers and authors. Blismas (2007); CRC Construction Innovation (2007); and Tan (2021) summarized the viewpoints of numerous literature from various researchers and authors in Table 2.1 below.

Table 2.1: Key factors hindering PVM implementation worldwide

Constraints	Descriptions
Process and programme	• Longer lead times/ early commitment. • Prefabrication must be designed in, not backward. • Inflexibility to repair design without further design changes. • Design restrictions because of traffic limitations (e.g. module size). • Requirement for extra project planning and design efforts. • More communication is requested before and during construction. • Complicated process for inspection.
Cost/ value/ productivity	• Clients have difficulties understanding. • High initial set-up costs. • High construction cost compares to the traditional construction method. • Obliged to accept element-specification costing. • Reluctance to accept the best value than a lower cost. • More costly compared to traditional construction methods, i.e. commercial sales of prefab components are high.
People and OHS	• Raised organisational demand (e.g. changes in the roles of project participants). • May increase and cause accidents and incidents.
Regulatory	• Limited codes and standards available. • Restrictive, inconsistent, unnecessary, burdensome, costly regulations, especially between jurisdictions.
Industry & market culture	• Deep pessimism is rooted in past mistakes rather than a determination to learn from history. Resistance from customers, mostly due to negative image. • Resistance to change (i.e. designers, builders, and workers). • Lack of awareness of benefits among developers/ owners. • Seen as restrictive and unable to meet the needs of the client. • Difficulty in obtaining financial support.
Leadership	• The shortage of visionaries dedicated to progress in the industry.
Supply chain & procurement	• Loss of on-site and supply chain control. • Limited distributor capacity. • Inter-manufacturer competition and protection. • Low imported quality.

Constraints	Descriptions
Skills & knowledge	• Lack of skills by professionals (design), subsequently impacting the entire process. • Lack of skills among manufacturers/suppliers to improve technology efficiency. • Lack of installation skills and knowledge among builders and workers. • Lack of knowledge repository. • Lack of industry investment in R&D.
Logistics & site operations	• Legal restriction on safety and site conditions. • Difficulties in the control of stock/ inventory due to large heavy products. • Requirements for extra materials for module protection. • Limited site distribution (e.g. limited space for unloading, moving, and storing the modules). • Need escort for oversized modules. • Difficult and costly for long-distance transport, especially for heavy and large modules. • High tolerance issues in terms of on-site interface.
Technological	• Reticulation of service through modules is problematic. • Lack of digitalisation adoption in the industry.

Adapted from Blismas (2007); CRC Construction Innovation (2007); and Tan (2021)

2.1.2 Constraints on PVM Implementation in Malaysia

A study on identifying the key factors of major constraints that hinder the construction industry to implement PVM in Malaysia was conducted by Tan (2021). The study focused on evaluating the main factors that obstruct the implementation of PVM in Malaysia, with a specific focus on Johor Bahru as a case study.

The study referred to the Australian study report (CRC Construction Innovation, 2007) as the benchmark. From the study, 6 out of 10 main factors were identified as important factors to the construction industry in Malaysia, with focus on Johor Bahru as shown in Table 2.2.

Table 2.2: Key factors hindering PVM implementation in Malaysia based on a study in Johor Bahru, Malaysia

Constraints	Descriptions
Process, programme, and productivity	• Prefabrication must be designed in, not backward. • Shortage of visionaries dedicated to progress in the industry. • Inability to repair design without further changes. • High tolerance issues in terms of on-site interface. • Service linkage is problematic.
Cost/ value	• High initial set-up costs. • Reluctance to accept the best value than a lower cost. • Costly compared to the current IBS construction method and conventional construction method. • Obligated to accept element-specification costing. • Difficulty in obtaining financial support.
OHS and regulatory	• Large capacity/ massive machinery needed at site i.e. potential blind spot for handling the modules. • Lack of codes and standards available in the market. • Legal restriction on safety and site conditions. • Restrictive, inconsistent, unnecessary, burdensome, costly regulation, particularly between jurisdictions.

Constraints	Descriptions
	• High risk for accidents and incidents during transportation and installation
People, industry & market culture	• Clients having difficulties understanding the benefits. • Resistance to change (i.e. developers, designers, and contractors). • To be seen as restrictive and unable to meet the needs of the client. • Negative image due to past mistakes. • High destruction in industry.
Logistics, supply chain & procurement	• Limited distributor capacity. • Difficult and costly for long-distance transport, especially for heavy and large modules. • Inter-manufacturer competition and protection. • Longer lead times. • Difficulty handling massive modules in storage. • Loss of on-site supply chain control. • Low imported quality.
Skills, knowledge & technological	• Absence of appropriate training available. • Unavailability of industry investment in R&D. • Shortage of skilled and knowledgeable professional designers and contractors in the market. • Lack of knowledge repository. • Lack of knowledge among manufacturers/supplier to improve technical efficiency. • Lack of digitalisation technology adoption in the industry due to limited resources (outdated hardware to support current software).

Adapted from Tan (2021)

2.2 Moving Forward to PVM Implementation

Apart from factors that constrain PVM implementation, there are broad benefits that drive the industry to embark on PVM technology. Numerous studies have been conducted to discover the benefits of PVM implementation to industry stakeholders.

2.2.1 Drivers and Benefits of PVM Implementation

Blismas (2007) and CRC Construction Innovation (2007) believe that PVM implementation has broader advantages that can benefit the construction industry stakeholders. The drivers and benefits are summarised in Table 2.3.

Table 2.3: Drivers of PVM implementation based on Australian Industry Report

Constraints	Descriptions
Process & programme	• Less time on-site—speedy construction. • Speedy product delivery. • Less time spent on commissioning. • Guaranteed delivery, more certainty over the programme, reduced management time. • Programme is driven centrally. • Simplified construction process – pragmatism
Quality	• Higher quality—on-site and from the factory. • Product tried and tested in factories. • Greater consistency—more reproducible.

Constraints	Descriptions
	• More control of quality, consistent standards, reduced snagging, and defects. • Products work the first time.
Cost/ value/ productivity	• Lower cost. • Lower preliminary costs. • Increased certainty, less risk. • Increases added value. • Lower overheads, less on-site damage, less wastage. • Reduced whole-life cost. • Allows systems to be measured.
People & OHS	• Fewer people on-site – possibly reducing OHS risks.
Skills & knowledge	• Site skills/knowledge – People know how to use products. – Limited or very expensive available skilled on-site labour.
Logistics & site operations	• More success at interfaces. • Less site disruption. • Reduced use of wet trades. • Removal of difficult operations off-site. • Work continues on-site independent of off-site production and vice-versa. • Restricted site layout or space. • Multi-trade interfaces in restricted work areas eliminated. • Live working environment limits site operations. • Site restriction by external parties alleviated. • Security on-site or high levels of theft mitigated.
Environmental sustainability	• Reduced environmental impact during construction. • Maximised environmental performance throughout the lifecycle

Adapted from Blismas (2007) and CRC Construction Innovation (2007)

2.2.2 Proposed Action plan for PVM Implementation

Given the constraints and drivers of PVM Implementation in the previous section, an action plan is needed to furnish the industry stakeholders. The plan must have a key focus on skills training, education, and knowledge provision to enable a broader understanding and acceptance of the benefits of PVM and overcome the constraints limiting its implementation. Table 2.4 shows a proposed action plan, for PVM implementation in the Malaysian construction industry.

Table 2.4: Action plan for PVM implementation based on Australian Industry Report

Factor	Actions
Skills & knowledge	• Skills training in trades are required to ensure the industry is well furnished. • Regular conferences/ meetings should be arranged to demonstrate current PVM projects and their benefits. • Encourage government to provide improved research incentives to stimulate local innovation and business start-ups. • Increase appeal for manufacturers to employ apprentices. • Encourage the location of manufacturing plants in areas with suitable labour sources. • Conduct career days at schools to get people interested in the PVM market. • Create an online portal to disseminate international trends, products, and processes associated with PVM. • Conduct market research study to ascertain market opportunities.

Factor	Actions
Process & programme	• Disciplines and processes need to be streamlined using integrated IT systems. Include the development of IT-based project management system to coordinate subcontractors and integrate the process. Need to learn from other industry's systems – from design to order and production. • Advice on information and document distribution and management protocols required in a high IT environment. • Advice on storage and ownership of digital information should be addressed. • Encourage the design of PVM into a project from the concept stage through education and showcasing.
Industry & market culture	• Establish annual PVM products and careers expo to showcase and promote PVM. Include trade shows and seminars. • Commence initiatives to ensure that tertiary education focuses on future trends and ideas, including PVM and manufacturing. • Improve government standards for civic architecture intended to improve building quality and longevity, thus, showcasing PVM products in operation and dispelling negative perceptions. Showcasing will demonstrate all benefits of PVM. • Establish government-funded display centres showcasing PVM products in use.
Cost/ value	• Whole-life cost needs to be emphasised with an understanding of value rather than purely direct costs. A system or method is required to show and convince clients that PVM is beneficial.
Regulatory	• Energy rating systems to be used to demonstrate that PVM can exceed current standards. • Appropriate authorities need to examine the introduction of a separate section to code for PVM.
Logistics & site operations	• Inventory management research and advice necessary for manufacturers. • Advice on the location of manufacturing plants close to the project to reduce transport costs and logistics.
Environmental sustainability	• Demonstration of better efficiency ratings due to better dimensional tolerances being possible. • Demonstration of sustainability benefits.

Adapted from Blismas (2007) and CRC Construction Innovation (2007)

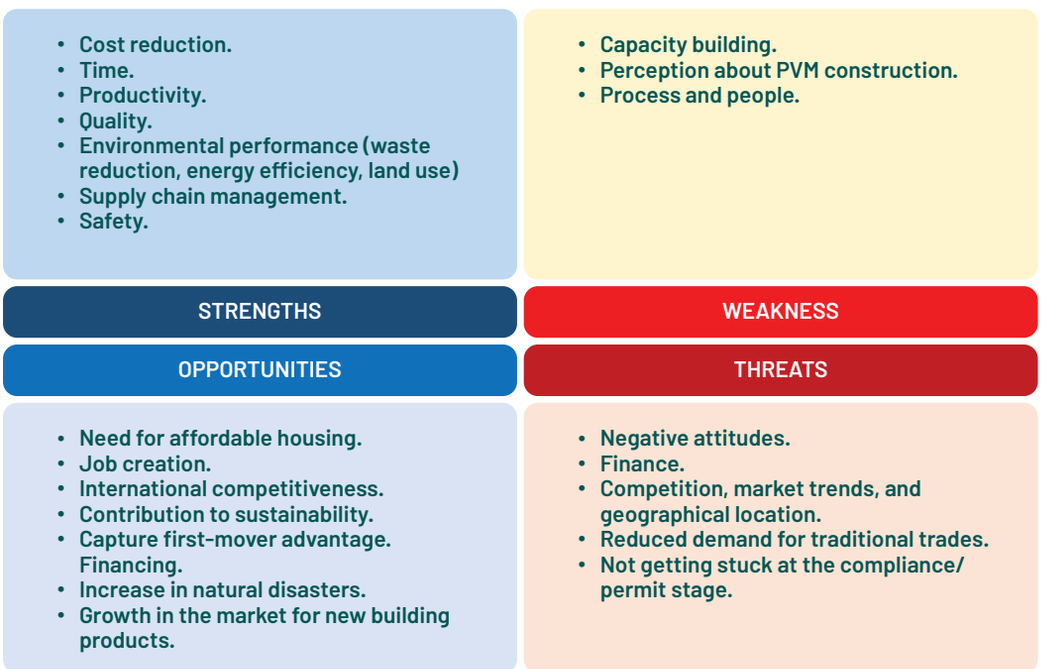
2.2.3 Proposed SWOT Matrix for PVM Implementation

The following section will present a strengths, weaknesses, opportunities, and threats (SWOT) analysis from the Australian research report which can be associated with PVM implementation in the Malaysian construction industry. The SWOT analysis considers the following factors, which are summarised in **Figure 2.1.**

The SWOT analysis considers the following factors:

1. Analysis of the strengths and weaknesses by looking at real-life examples of successes and failures.
2. Provision of a gap analysis of metrics, which is required to fully understand the performance of the manufactured housing industry.

3. Evaluation of the perceptions of people in the construction industry about manufactured buildings, those both, directly and indirectly, involved in the construction industry.
4. Performance statistics for manufactured housing related to value-adding factors such as time, cost, quality, and long-term sustainability benefits of manufactured building systems.
5. Identification of practical solutions for stakeholders so that the industry can innovate and grow to its fullest potential.



Adapted from Built & National (2014) and SBEnrc (2015)

Figure 2.1: SWOT analysis matrix for PVM implementation

2.2.4 Potential Opportunities and Risk for PVM Implementation

PVM is a prefabricated building component that is transported from the factory to the construction site for assembly. By utilizing this construction method, new opportunities and additional risks will be introduced. According to Ottinger, Minglani, Gibson, & Alexander (2020), the opportunities and risks of the industrialized construction method is related to the four core dimensions of project management such as (a) scope; (b) time; (c) cost; and (d) quality. The findings from their assessment is summarised in Table 2.5. below.

Table 2.5: Potential opportunities and risks of PVM Implementation

OPPORTUNITIES	RISKS
Scope	
• Standardised designs. • Repeatability. • Housing demand. • Commercial construction application.	• Limited design options. • Lack of customisation. • Predefined conditions with subjected limitations. • Tenant improvements must work within the confined interior build-out. • Inherited projects that are predesigned or partially built. • Scaling increases customisation and complexity.
Time	
• Reduced planning phase. • Efficient production lines. • Optimised productivity. • Regular inspections. • Site and factory work occur in parallel. • On-site coordination. • Schedule compression. • Less weather risk. • Controlled factory environment.	• Difficulty in estimating. • Productivity factor sensitivity. • Delay impacts.
Cost	
• Design costs allocated to multiple projects. • Quicker payback period. • Less general conditions. • Less wastage. • Site labour reduction. • Lower-skilled labour. • Fewer accidents. • Integrating the supply chain. • Realising quantities of scale.	• Financing. • Significant upfront costs. • Greater operational costs. Transportation. • Partaking in multiple stages of the supply-chain requires increased coordination. • Resourcing and training.
Quantity	
• Testing and inspections. • Building operations. • Technology implementation. • Sustainability.	• Poor industry perception.

Adapted from Ottinger, Minglani, Gibson, & Alexander (2020)

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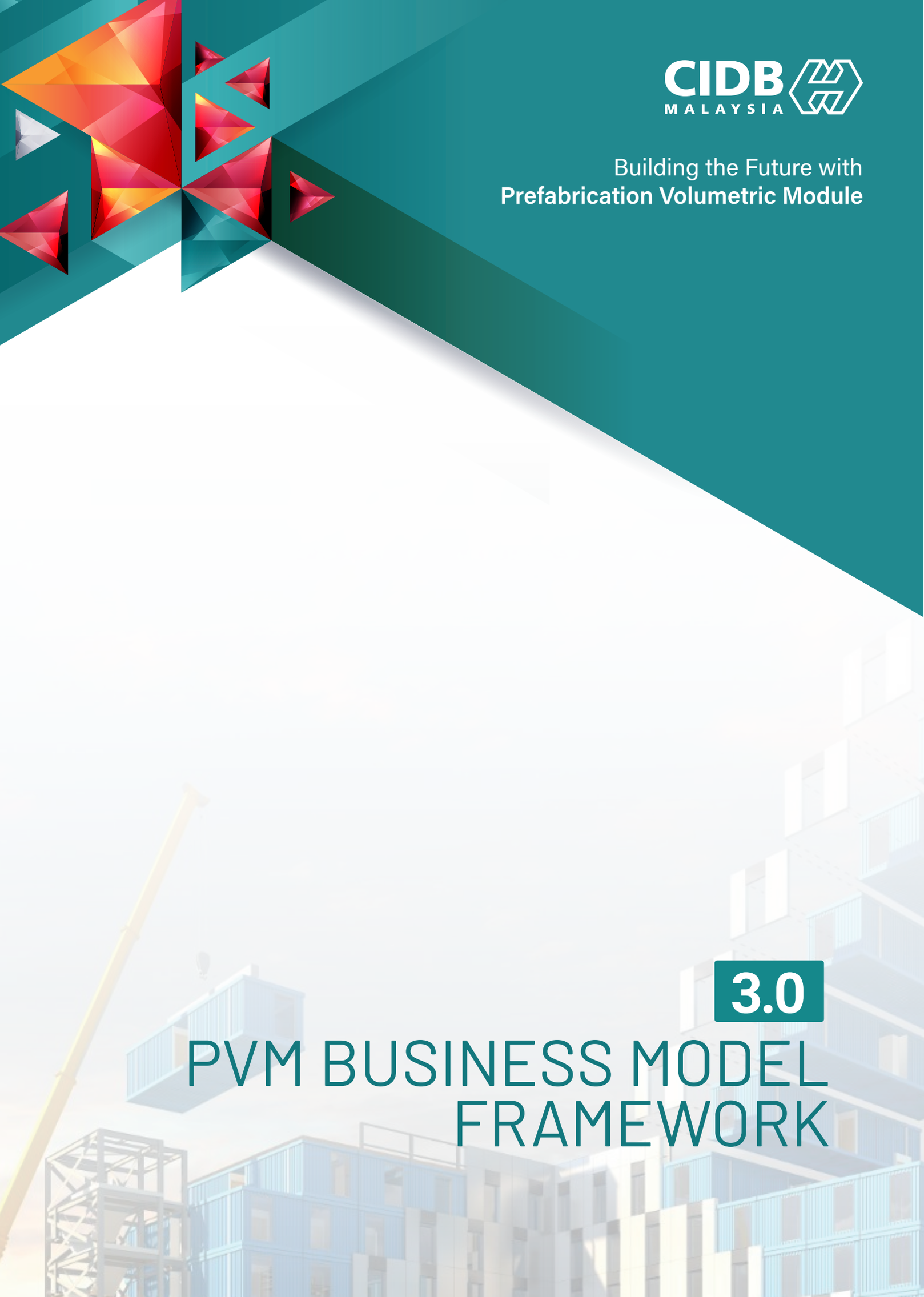

3.0

PVM BUSINESS MODEL FRAMEWORK

3.0 PVM BUSINESS MODEL FRAMEWORK

3.1 Definition of Business Model

The business models for the companies of the future are in the making today. A company that cannot reinvent itself and develop a workable business model has no future at all: it will fade and become obsolete. We are in the midst of change, and when there is a change, there is opportunity. According to Mohd Zairul, (2017), there is no single definition that can define the term 'business model'. Some describe it as a company innovation, a recipe to generate more money, or a framework that explains how a company does business with clients, partners, and vendors.

A business model is composed of various components. These components describe various processes of delivering the product, and the deployment of internal and external resources (Hedman & Kalling, 2003). Several authors have produced structures for BMs based on different components. Mahadevan (2000) listed three main elements that help to shape the components as shown in **Figure 3.1.**

Figure 3.1: Main Elements to Shape Business Model Component Mahadevan (2000)

There are numerous examples of components used for defining a BM. For example, Stewart & Zhao (2000) combined revenue stream and cost structure in what they called profit stream. Afuah & Tucci (2000) explained the connection between components and dynamics. They emphasized customer value, namely, how a company's product differs from existing products or can be provided at a lower price (Afuah & Tucci, 2000). In terms of revenue, Afuah & Tucci (2000) asked where the money comes from. Who pays what value, and what drives the customer segment to buy? New components that involve legal issues and technology were also discussed (Alt & Zimmermann, 2001). More recently, new components such as sustainability and sustainable income generation were deliberated as part of BM components (Bocken, Short, Rana, & Evans, 2014; Richter, 2013; Schaltegger, Lüdeke-Freund, & Hansen, 2012).

To select appropriate BM components for PVM businesses, it is important to highlight the relevant business model components. In this case, it is important to select components that can describe the methods and resources a company might use to start a business in PVM. The process of business model construction and modification is also called business model innovation, and forms a part of business strategy (Geissdoerfer, Savaget, & Evans, 2017). Table 3.1 below shows some business model definitions from various resources, summarised by Fábio & Zilber (2014).

Table 3.1. Business Model Definitions (Fábio & Zilber, 2014)

Business Model Definition	Authors
Architecture for product and service flows including a description of the business activities and its sources of income.	Timmers (1998)
How the company aims to make profits and sustain them over time.	Stewart & Zhao (2000)
Structure prepared to create value.	Amit & Zott (2001)
Choices made by a company to make a profit. These include resources and expertise to create value through products operated by the firm, internally or externally.	Plé, Lecocq, & Angot (2010)
How the organization creates and delivers value to its stakeholders.	Casadesus-Masanell & Ricart (2010)
The logic of creation, delivery, and capture of value by an organization.	Osterwalder & Pigneur (2010)
How a company does business and creates value.	Zott, Amit, & Massa (2011)
Coherence of the strategic choices of the company, which enable relationships to create value at its operational, tactical, and strategic levels.	Nielsen & Lund (2012)

3.2 Business Model Framework for PVM

3.2.1 Business Model Components

According to Mohd Zairul (2017), several elements in a business model can drive the innovative business model in the future, as shown in Table 3.2.

Table 3.2: Business Model Components (Mohd Zairul, 2017)

Components	Description
Value propositions	Value propositions as products that help the customers in their routine and daily life. Further definition by Bonaccorsi, Giannangeli, & Rossi-Lamastra (2006) describes the value as products and services offered by a company to be delivered to target customers. Identify products and services that the company can offer to potential customers
Target customers	Offering different products for different customer segments; accommodate different needs at various stages of life. Identify the business target customer.

Components	Description
Customer relationship	Nowadays, customers are more aware of their rights. In today's business, consumers appreciate better pre-sales, during sales, and after-sales service from the service providers. In the PVM industry, this challenges businesses to improve their customer relationship from time to time.
Revenue streams	Determining methods of payment from the customers, how much the customers want to pay for the goods and services, and how they prefer to pay for the goods and services offered by the manufacturer. In this case, to identify how the company gets revenue from the customer.
Cost structure	Determining the cost of the product based on investment in key resources; value-driven companies to aid the customer rather than cost-driven. In this strategy, to identify the price based on the cost involved in the resources.
Key resources	Determining the types of resources required to operate this business; determine the physical, financial, intellectual, or main resources needed to run the company.
Partnership	Determining the partnerships required to operate the business, sharing and reduce risk, and acquiring resources for the company.
Channels	Determining through which channels the customers want to be reached. Determining the way to raise awareness of the products, help customers evaluate the goods and services, help the customers to know about their products much better.
Key activities	Determining the main activities run by the company in its daily operation.

3.2.2 The Conceptual Business Model Framework for PVM in Malaysia

Developing a novel, innovative PVM business model that can rise to future challenges in the revolution IR4.0 era is important. Thanks to technology, the skills of design, strategy, and enterprise will lead to new business models, which will change the future of IBS in the country. We need vision and leadership to transform entire industries from end to end, but we must see that this is done in a way that brings us a meaningful portion of the value thus created. Hence, there lies ahead a tough game for the leaders of the company in the future.

The logic of the business model explains how the business will meet its profit and growth targets. In the framework, the PVM companies shall highlight how their business can be successful, how it will attract customers, be competitive, and be profitable. This often takes the form of a "virtuous cycle," which shows how the basic elements of the business model reinforce one another (Figure 3.2).

VALUE CREATION	FINANCIAL	SUPPLY CHAIN
Propositions	Cost Structure	Activities
What are the company's products and services?	How does the company put value to their propositions?	What are the activities run by the company?
Target Customer	Revenue Streams	Channels
Who are the company's target customers?	How does the company generate revenue?	How do the propositions reach the customer?
Customer Relationship	Key Resources	Partnership
How does the company keep its relationship with the customer?	What are the resources involved in the company?	Who are the partners to help the business?

Figure 3.2: Conceptual Business Model Framework for PVM Companies

3.3 Business Model Case Studies from Overseas PVM Companies

3.3.1 Sekisui Chemical Group, Japan – Sekisui Heim

In 1971, Sekisui Chemical Group launched Sekisui Heim M1, which was the world's first prefabricated modular house. Sekisui Heim utilises modular construction methods that use factory production to build steel-framed and wooden modular housing (Figure 3.3) that take into consideration comfort, safety and security, and environmental friendliness precisely per design specifications.

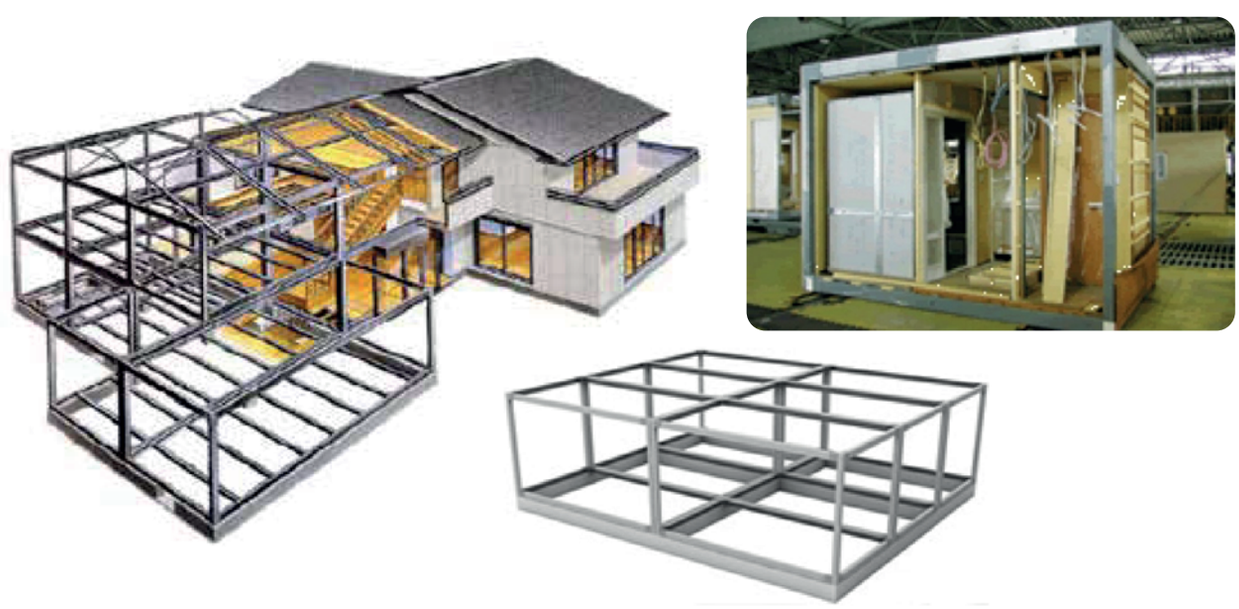

Figure 3.3: Example of Sekisui Heim Modular House

Table 3.3: Business Model Components for Sekisui Heim

Components	Description
Value propositions	Modular housing, factory production system, barrier-free design. Part customisation and part standardisation.
Target customers	High-income, professionals
Customer relationship	1) Customer information & consulting services and Hayamimi network 2) Customer satisfaction level survey 3) Customer and Top' (CAT) meetings 4) After-sales support 5) 20-years warranty, 60-years scheduled diagnosis system 6) Proposal for maintenance 7) Proposal for functional renovation 8) Proposal for addition and improvement
Revenue streams	Selling house and mortgage through financial institutions
Cost structure	Manufacturing plant, crane for logistics, engineers, designers, trucks, trailers
Key resources	Maintenance, resources location, manufacturing technology, resources, crane facilities, people, designer, technical personnel
Channels & network	Showhouse, roadshow, websites
Partnership	Co-creation of next-generation, alliances with outside parties, industry-academic partnerships, mergers with competitors
Key activities	1) Manufacturing container-size housing 2) Sales and lease 3) Demolition work 4) Design consultation 5) Design customisation/ engineering/ piping works

- *Value Propositions*

In terms of value propositions, Sekisui Heim housing production is focused on environmentally responsive housing. The house projects undertaken by the company can be divided into seven categories:

1. steel frame housing
2. wooden frame housing
3. complex housing
4. housing environment business
5. refurbishing
6. real estate
7. overseas housing projects.

The company value propositions encompass the fabrication and sale of Heim series and Two-U home modular houses, and interior and exterior housing products and services for the renovation of existing houses. The Heim boxes are made of factory-fabricated units which can be combined to make a complete house. The box type or 'units' are produced in the plant and sometimes require 30,000 components to complete one house on a production line.

- *Target Customers*

Sekisui Chemical Group (or better known as Sekisui Heim) provides services mainly to baby boomers, professionals, and the higher segment of the housing market. As part of its mission, the company strives to attend to the customer's needs as much as necessary, and to ensure the customer will return to their business again.

- *Customer Relationship*

As regards the customer relationship, the company strives to satisfy its customers. This includes CS management focusing on customer satisfaction. In 2004, the company launched a CS programme and quality management focused on their value propositions. The programme aims to progress and create a long-lasting relationship with the customers so that they will return to the company for the right services. The company values continuous feedback from customers and utilizes that feedback and other information received from customers. The company strives to maximize the client relationship by prolonging the warranty on the product and providing a proposal for the maintenance, renovation, and improvement of the product.

- *Revenue Streams*

The company generates its revenue by selling its goods and services. The contribution from the housing segment is mainly in the form of the buyers' mortgages from financial institutions. We noted that the company provides a service to return the demolished steel frame structure for trade-in purposes. The units that are returned go through a cleaning and anti-corrosion process before being used again as Heim units. This process could be regarded as a sustainable approach and creating a loop of production.

- *Key Resources*

The process of Heim production normally involves 10,000 structure elements and parts to build a single Heim, involving various kinds of high technology. In particular, connecting elements are produced by specialized machines to ensure the accuracy and quality of the production. The prefabrication activities

are mainly conducted off-site in a big manufacturing plant. All the processes involved in the manufacturing unit are carried out using computerized automated machine tools.

The Heim factory assembly process relies on skilled workers to operate the business. Human resources are crucial, especially where human senses and skilled techniques are needed. The accuracy of 16 welded and finished box units of various sizes are measured to ensure the quality of the product.

- *Cost Structure*

In the case of Sekisui Heim, the business involves a big investment in key physical and human resources. As far as the data are concerned, we have no structured information to support this. However, the huge investment the company has made in technology indicates why the product is mainly targeted at the high-income group.

- *Channel & Network*

The company is working hard to reach its customers through several kinds of programmes, and to create awareness of its product and the quality of its goods and services. This is evidenced by its continuous customer social responsibility (CSR) programmes. In this case, we assume the company is reaching its customers by providing useful services, and establishing show houses to promote its products and services.

- *Partnership*

The company emphasizes its relationship with the stakeholders and alliances with external parties, industry–academia partnerships, and mergers with competitors to deliver the products.

- *Key Activities*

The parent company, Sekisui Chemical Group, develops and provides a wide variety of goods and services that are used in various applications in both industry and daily life. Its activities range from housing products, through urban infrastructure, to high-performance plastics. In the housing sector, the company's activities involve steel frame and wood frame modular housing. Other activities include refurbishing and real estate. However, our focus was on the steel frame modular housing produced by the company.

3.3.2 Hickory Group, Australia - Hickory Building Systems

Hickory was founded in 1991 and has steadily evolved from a family-owned company to one of Australia's preeminent construction groups. Hickory has forged a reputation as an innovative and dynamic company that has grown into a nationwide group of construction, structures, facades, manufacturing, fit-out, and crane logistics specialists. As an integrated construction company with over 1000 employees, Hickory provides its clients with turnkey "best for project" solutions, partnering with clients, subcontractors and suppliers to ensure the most effective and efficient solutions.

Hickory Building Systems (HBS) is a patented building technology that delivers an innovative, technological alternative to the construction of high-rise projects. HBS accelerates on-site and off-site construction programs by 30 to 50%, minimising material and energy waste, whilst maximising quality and safety. HBS blends the best of manufacturing and construction technology, processes, and personnel to deliver a turn-key building solution to their clients **(Figure 3.4)**.

HBS is suitable for a range of high-rise projects including:

- Apartments
- Hotels
- Student accommodation
- Hospitals & healthcare centres

Figure 3.4: Example of Hickory Building Systems Production and Construction

Table 3.4: Business Model Components for Hickory Group, Australia

Components	Description
Value propositions	Standardised modular apartment blocks, facades, bathrooms design
Target customers	Middle to high-income
Customer relationship	No data
Revenue streams	Selling houses and mortgages through financial institutions
Cost structure	Maintenance, resources location, manufacturing technology, resources, crane facilities, people, designers, technical personnel
Key resources	Manufacturing plant, assembly plant, crane for logistics, engineers, trucks, trailers
Channels & network	No data
Partnership	No data
Key activities	1) Producing building structures (in-house formwork structures) 2) Prefabrication building systems 3) Producing modular bathrooms 4) Design and built facades 5) Carpentry services 6) Plant hiring 7) Design & engineering services 8) Crane logistic services

- *Value Propositions*

The Hickory Group produces standardized modular apartment blocks, including medium- and high-rise residential, hotel, and healthcare projects. The company uses a unified system that is built off-site but parallel with on-site works. The building components are engineered concrete flooring, load-bearing columns, designated wet areas, and building façade and service penetration chute. The designs mainly use a series of predesigned but interchangeable components. The flexibility of the system comes from the interchangeable components that can be scaled from medium to high-rise and from a large to small aspect ratio, as required.

- *Target customers*

Part of the company's slogan is to provide affordable housing for Australians. It appears on the website's information that the company builds for urban dwellers.

- *Revenue streams*

Based on the information obtained, the revenue for the company is mainly obtained from selling the products, leasing and renting the plants, and mortgages from financial institutions.

- *Key activities*

The company specializes in:

1) producing concrete structures and formwork
2) designing facade and installation
3) plant hiring
4) crane logistics leasing
5) carpentry and fit-out
6) design and engineering
7) prefab housing
8) design & build modular bathrooms.

The company mainly deals with different phases of construction services. The company strives to reduce the cost of the building by providing its in-house operation. In terms of structure design, the company's principal activity is providing a high-quality structure design with precise quality control. The company is involved in façade design and consultation on façade design, backed by a skilled installation team.

- *Key Resources*

To avoid the cost of producing plant equipment at short notice, the company has invested a huge amount of money in physical resources such as manufacturing plants, alimaks, scissor lifts, booms, semis, scaffolding, elevator work platforms, hoists, and generators. Another of the company's resources is the crane equipment to install the units on site. The company's second-biggest resources are human resources, namely designers, engineers, surveyors, scaffolders, concreters, steel fixers, riggers, labourers, craftsmen, metal fabricators, and skilled and semi-skilled workers running the daily operation of the company. The company invests heavily in people from automotive backgrounds to ensure accountability in design and engineering. Time management, design, and engineering skills are the most valuable skills to operate this type of housing industry. High precision in manufacturing and design engineering and R&D capability is something the company is proud of.

- *Cost structure*

The cost structure of the business is mainly derived from the key resources that the company acquires. The company invests an enormous amount of capital in both physical and human resources to operate its business operations.

- *Channel & Network*

The business relies on its prestigious and landmark projects to promote its business. The reputation the company has earned in recent years has led to broader awareness of its products and services, as promoted on the company's website and by other advertising means.

3.4 Business Model Case Studies from Malaysian PVM Companies

3.4.1 Castwell Industries (M) Sdn Bhd - Castwell Modular Systems

Castwell Industries (M) Sdn Bhd is one of the pioneers company Industrialised Building System (IBS) doing modular construction in Malaysia since 2006. With continuous product innovation efforts, the company now have a variety of construction methods to suit different site conditions and customer needs. They are the first company in Malaysia awarded with Modular Construction Solution Certification issued by Construction Industry Development Board (CIDB) in 2015. The company adapt with modular construction with incorporating other elements such as walls, roof trusses, door and window systems and more. Through the in-house manufacturing and design capability, the company can complete projects swiftly and efficiently.

The company has good track records in multiple turnkey projects in the public and private sector. Specifically for workers accommodation projects, the company had completed projects in Petronas RAPID Pengerang, KVMRT Line 2 and others. In the past, the company had achieved delivering 16 blocks of 4 storey accommodation block with ancillary buildings for 4500 workers in 7 months including design, engineering, fabricate, install, commissioning and obtaining Certificate of Completion and Compliance (CCC). The performance in delivering projects is well recognized by both local and overseas organizations too.

On certain occasion, Castwell modular building can be designed to enable for relocation after the intended purpose, whereby it can be disassembled, transport and re-assemble on another location swiftly, giving a rejuvenation to the building. This progression could be regarded as a sustainable approach and revitalizing of an obsolete building. Castwell Industries (M) Sdn Bhd is a one-stop centre that is well experienced and capable to design & build building / development (either temporary or permanent), that are compliance to the latest Malaysia Standards and fulfilling the customer needs.

Figure 3.5: Example of Castwell Modular Building Systems Production and Construction

Table 3.5: Business Model Components for Castwell Industries (M) Sdn Bhd, Malaysia

Components	Description
Value propositions	Proprietary products that compose the customizable modular housing, accommodation blocks, bathrooms, facades and other building design. Partly customisation and partly standardisation
Target customers	Public sector and private company
Customer relationship	1) Customer Retention – providing solution proposal and technical assistance 1) After-sales support 2) Proposal for functional renovation 3) Proposal for addition and improvement
Revenue streams	Experienced professional team that are capable :- • To provide design & build solution fit for the environment and customer specification with complying the local authority requirements. (Professional Consultation) • To manufacture and supply of various proprietary IBS and modular system. (Manufacturing) • To construct and complete projects that are adopting Castwell system and products for both public and private sectors. (Specialist Construction) • Other fabrication of customized products.
Cost structure	The company had invested huge amount of capital in both physical (manufacturing plant, assembly facilities, trucks, trailers) and human resources (engineers, designers, installation specialist) to run its business operations. The cost involved for each project is varies depending on the size (economies of scale), location (mobility), complexity and the specific scope of works.
Key resources	Manufacturing technology & plant, assembly facilities, engineers, designers, installation specialist.
Channels & network	Show unit, exhibition, websites
Partnership	No data
Key activities	1. Design and engineering services 2. In-house modular structure fabrication 3. In-house proprietary IBS system production 4. In-house roof truss system production 5. In-house door frame and window production 6. In-house multipurpose panel production 7. Floating concrete pontoon production 8. Installation services for IBS building system 9. General construction services 10. Logistic services 11. Research and Development of new / improved IBS system

- *Value Propositions*

In terms of value propositions, Castwell Industries (M) Sdn Bhd. carrying variety of proprietary product that compose the customizable modular housing, accommodation blocks, bathrooms, facades and other building design. The building system can be designed as partly customisation and partly standardisation. The company is capable to provide a one-stop centre services which includes Design, Engineering, Fabrication, Assembly, Construction Installation all the way up to the Testing and Commissioning of a building. With a group of experienced professional team, the company is capable to design & build

building / development (either temporary or permanent), that are compliance to the latest Malaysia Standards and fulfilling the customer needs. The Castwell modular made of factory fabricated units which can be combined to make a complete house / building.

The core value that the company focuses are:-

a. Simple and effective construction method

b. To ensure time and cost effectiveness while ensuring the project site safety.

c. To accelerates overall construction duration emphasizing on the maximum off -site works and minimum on-site works that can be conducted in parallel.

d. To minimising material and energy waste, whilst maximising quality and safety.

e. Modular system will be completed off-site in unit and to be delivered to the construction site for installation.

f. Rapid modular construction allows the building to be commissioned and start generating income sooner compared to the conventional method. Meanwhile reducing the finances interest by a shorter compounding period for the customer.

g. The modular design concept of "relocation after the intended purpose" could be regarded as a sustainable approach and revitalizing of an obsolete building.

- *Target Customers*

The slogan of the company is "Simple & Better", where providing the customer (public sector and private company) a superior choice to build and applied an efficient and innovative construction technology along with maximum value for money. The company aspire to focus to the customer's desires as much as necessary and to ensure maximum customer satisfaction.

- *Customer Relationship*

The company aspire to generate new customer base and retention existing customer relationship by providing relevant design proposal and build to the customer specification with complying the local authority requirements. This includes multiple technical experience sharing session with the institution and public about the fundamental of the IBS / modular technologies and the benefits of the systems. The company also provide supportive after sales services to the customer by having follow up project site visits to understand about feedback from the end-user. The company also attempts to exploit the customer relationship by providing additional services such as proposal for functional renovation and improvements of the product.

- *Revenue Streams*

The company generates its revenue by selling its goods and services. The main income source is from the manufacturing and construction segment of the modular and IBS system. Design and Engineering serve as the ancillary services to the customer. On certain occasion upon customer request, the relocation works (disassemble, transport and re-assemble) of an existing Castwell modular building can be another income source to the company. This progression could be regarded as a sustainable approach and revitalizing of an obsolete building.

- *Key Resources*

To maintain the business agility and react to the market quickly, the company had opted to keep most of the key component manufacturing in-house. The company has invested massively in its physical resources, such as manufacturing plants, tools, and machineries. It allows the company to make changes in response to innovative ideas, or even resolve problems with the product. Research found that extensive outsourcing of manufacturing activities has a strong negative impact on a company's profit and productivity. In-house manufacturing is often a more cost-effective avenue, especially for businesses that manufacture highly customized products or low product volumes. Besides, keeping manufacturing in-house makes communication faster and easier. According to research, miscommunication is fairly common when utilizing the services of external suppliers in any capacity, with 30% of companies outsourcing their work citing communication breakdowns as a key problem. Ultimately, real-time conversations provide less opportunities for misunderstandings and result in a clearer brief regarding specifics task.

Human resources are another crucial component especially where human senses and skilled techniques are needed. The technical know-how skills developed by a team of experienced professional from the R&D stage to the implementation stage are another key success aspect of the company. Detailed design engineering, manufacturing and R&D capability is something the company are proud of.

Maintaining a good relationship with the raw material supplier to safeguard the best bargain rate in the market is also one of the vital aspects.

- *Cost Structure*

The cost structure of the business is mainly derived from the key resources that the company acquired. The company is investing an enormous amount of capital in both physical and human resources to operate its business operations.

- *Channel & Network*

The company built it reputation through its remarkable track record in both public sector and private company. The reputation has led to broad awareness of its products and services, as promoted on the company's website. The company is also reaching its customers by providing supportive information and establishing show unit to promote its products and services.

- *Key Activities*

The company mainly focus on design and manufacturing of modular & IBS system. At the same time, the company also involved in different phases of construction services. The company strives to provide a total solution to the customer on modular construction with by safeguarding time and cost effectiveness while ensuring the project site safety. The company specialized in:

a. Design and engineering services
b. In-house modular structure fabrication
c. In-house proprietary IBS system production
d. In-house roof truss system production
e. In-house door frame and window production
f. In-house multipurpose panel production
g. Floating concrete pontoon production
h. Installation services for IBS building system
i. General construction services
j. Logistic services
k. Research and Development of new / improved IBS system

3.4.2 AME Construction Sdn. Bhd.

AME Construction Sdn. Bhd. is the local dominant player in the construction and structural steel industry. State-of-the-art computerized equipment and Tekla steel structure 3D software have been introduced to enhance productivity and efficiency. Backed by a string of successfully delivered projects under its credentials, AME Construction has repositioned itself as a leading industrial building system (IBS)

company for structural steel & precast concrete works, which renders decent services, incorporated with internationally recognized safety practices.

AME Construction is located strategically at Taman Teknologi, Senai, Johor. The fabrication yard occupies an area of 18,750 sq. meters with a lifting height of 12 meters. This spacious yard allows multiple jobs to be carried out simultaneously, and renders a working place free of weather hazards. An open yard area of 16,880 sq. meters adjacent to the extension of its precast concrete fabrication yard is designed for multipurpose use.

To optimize efficiency, AME Construction has adopted the industrialized building system (IBS) & precast concrete works in recent years. It has better control over quality as all elements are finished in the factory and hence directly reduces reliance on manpower and construction timelines. With continuous improvement, professionalism, and commitment to stay focused on customer needs, AME Construction has taken the necessary innovative steps to achieve the desired success.

a) Concrete PVM *b) Metal Frame PVM*

Figure 3.6: PVM Manufacturing Plant, AME Construction

Figure 3.7: Example of 2-storey PVM for Worker's Dormitory, AME Construction

Table 3.6: Business Model Components for AME Construction

Components	Description
Value propositions	PVM fabrication and installation (steel modules, concrete modules, and hybrid type) based on client design
Target customers	Middle to high-income
Customer relationship	Contracting
Revenue streams	Supply and install PVM works
Cost structure	Manufacturing plant, labour, raw material, steel mould, transportation and site installation
Key resources	Skill labour, batching plant, steel manufacturing, resources, crane facilities, people, technical personnel
Channels & network	No data
Partnership	No data
Key activities	1) Producing PVM structures 2) Concrete batching (meet SS EN 206) 3) Prefabrication building systems 4) Concrete mould fabrication 5) Steel fabrication

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DEVELOPMENT OF PVM BUSINESS MODEL FRAMEWORK

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