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Characteristics of Modular Construction: Meeting the Needs of Sustainability and Innovation

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Abstract—Industrialised Building Systems (IBS) is a construction process that uses building components manufactured in a factory or on site, transported and assembled into a structure using appropriate machinery and equipment with minimal workers on site. Modular construction is a novel innovation in Malaysia, contributes to sustainability and improves site safety in the built environment. Modular construction is a construction method that produces a building consist of modular units or modules, mass produce off site in a manufacturing facility. It includes the logistic and assembly aspect of it, done in proper coordination through detailed planning and integration.

This paper is part of an on-going research on the adoption of modular construction through Industrialised Building System (IBS) approach in the Malaysian construction industry. The data and information presented is the review of the available relevant literature on this research topic. This paper incorporates an analysis of the definitions and characteristics of modular construction from all over the world. The identification and establishment of a clear definition and characteristics of modular construction from the analysis is essential so that people and industry players will understand what is the fundamentals of modular construction.

Keywords - *Industrialised Building System (IBS); Modular construction; Definition; Characteristics;*

I. INTRODUCTION

In view of meeting the government's ambition to transform the Malaysian construction industry into adopting the modern method of construction and being able to expedite the implementation of the IBS Roadmap and Construction Industry Master Plan (CIMP) 2006-2015, there is a call by the industry players for a proper and structured planning and implementation strategy for IBS to be established. In 2008, a circular from the Malaysian Treasury Department of the Ministry of Finance denotes that the policy on full utilization of IBS to be imposed for all government projects in Malaysia [1].

CIDB launched IBS Roadmap 2011-2015 to replace the current roadmap launched in the late 2010 [2]. The policy is aimed to introduce high level intended outcomes in implementing the IBS. The new roadmap will be focusing on the adoption of IBS by the private sector. The four policy objectives were competency, quality, efficiency and sustainability. A sustainable IBS industry will contribute to the competitiveness of the construction industry and the adoption of sustainable agenda lead by the government. It is crucial towards the growth of the construction industry which will eventually affect the whole spectrum of the Malaysian economy. The goals for the IBS Roadmap 2011-2015 are to maintain the existing momentum of 70% in IBS content for public sector building projects. In addition, IBS Roadmap goals are to increase the IBS content to 50% for private sector building projects by 2015.

The Malaysian construction industry is evolving towards greater use of innovative and modern method of construction techniques. The importance of the IBS has been highlight under the Strategic Thrust No 5: Innovation through R&D to adopt a new construction method in the CIMP 2006 – 2015 [3]. The IBS are categorised into prefabricated timber framing systems, precast concrete systems, formwork systems, steel framing systems, block work systems and innovative systems [4] [5, 6].

Modular construction can be categorised as a Modern Method of Construction (MMC) or offsite construction industry system. It is also known as volumetric construction. From the information gathered, modular construction has all the features mention in the CIMP 2006- 2015 and IBS Roadmap 2011- 2015 [7-9]. Modular construction provides quality building, efficiency, sustainability, competency and speed up in the time schedule. According to Lawson [10], the primary advantage of modular construction are:

- Speed of installation on site,
- Economy of scale in manufacturing of multiple repeated units, and

- Manufacturing process improves the quality and accuracy of its building.

Modular buildings can be dismantled and reused, thereby maintaining their asset value [9, 10]. The current range of applications of modular is in cellular type buildings (hotels, military accommodation, social housing and student residents), where the module size is compatible with manufacturing and transportation requirements.

II. DEFINITION OF MODULAR CONSTRUCTION

Modular construction is a construction process to produce a building components or modules with the same design and standard in a manufacturing facility, then to be transported and installed to become a building. There are many definitions of modular construction that came from all around the world. The following Table (1) highlights the definitions to describe the modular construction:

TABLE 1: The Definitions of Modular Construction

Countries	Authors	Definition of Modular Construction
USA	Modular Building Institute, Lu [11-13]	Modular construction is a process that constructs a building off site, under controlled plant conditions using the same materials and designed to the same codes and standards as conventionally built facilities but in about half the time. Buildings produce in “modules” and when put together on site, reflect the identical design intent and specifications of the most sophisticated traditionally built facility without compromise.
UK and Europe	Lawson [10], Goodier and Gib [14]	Modular construction is a fully fitted out in a manufacturing facility comprises of prefabricated room size volumetric units. This room sized units as load bearing “building block” will be install on site.
Australia	Blismas and Wakefield [15]	Modular construction is an inspirational unconstrained building design combined with highly efficient industrialised production in a control manufacturing facility. Once modular units are complete, it will be transport to the site and combine together to a completed building.
Japan	Japan Modular Construction [16]	Modular construction is produced out off the site and refers to as an offsite construction method. It is produce in the factory into modular units. Then, the modular units are transport to the building site.
Korea	Won-hak Lee [17]	Modular construction is from USA and Europe, an architectural system whose fundamentals technologies that are already been developed where this method is a production and construction method of buildings in a way that combines each box- type module produced from the factory and laminates them.

There are many different terms and definitions to describe modular construction. Literatures highlighted several key fundamentals to define modular construction. The fundamentals are modular units, control plant condition, offsite construction, logistics, on site construction and coordination. From the reviewed information from relevant literature, a comprehensive definition of modular construction can be derived as the following:

“Modular construction is a construction method that produces a building consist of modular units or modules, mass produce off site in a manufacturing facility. It includes the logistic and assembly aspect of it, done in proper coordination with through planning and integration”.

III. CHARACTERISTICS OF MODULAR CONSTRUCTION

Just as the definitions, modular construction has various characteristics depending on the client, owner, manufacturers, consultants, contractors, surrounding environment, building usage, projects, local authority requirements and end users. The following examples as illustrated in Table (2) shows the characteristics of modular construction.

TABLE 2: The Characteristics of Modular Construction

Countries	Authors	Characteristics of Modular Construction
USA	Modular Building Institute, Lu [11-	-Identical modules

	13]	-Greener -Smarter -Faster
UK and Europe	Lawson [10], Goodier and Gib [14]	-Room size volumetric units -Economic -Faster -High quality -Sustainable
Australia	Blismas and Wakefield [15]	-Modular units -High efficiency and productivity -Faster -Flexibility
Japan	Japan Modular Construction [16]	-Modular units -Quality control -Green -Movable -Faster -Solid construction
Korea	Won-hak Lee [17]	-Box type units -Faster -High quality -Sustainable

The literature highlighted several influential and essential characteristics of modular construction. They are:

A. High quality identical modular / room size volumetric units

The main feature of modular construction is the identical or standardised modular or room size volumetric units. They are mass produced in a controlled factory or manufacturing facility that generates less waste, and high quality modules [9, 10, 16, 17]. Building offsite ensures better construction quality management. Materials delivered to the plant location are safely and securely stored in the manufacturer's warehouse. This is to prevent damages or deterioration from moisture and the elements. Manufacturing facilities or factories have stringent quality assessment/quality control (QA/QC) programs with independent inspection and testing protocols that promote superior quality of construction every step of the way.

B. Sustainable

As clients and designers look for more sustainable design and construction solutions for improved environmental impact, modular construction is inherently a natural fit. Building in a controlled environment reduces waste through avoidance upstream rather than diversion downstream. This, along with improved quality management throughout the construction process and significantly less on site activity and disturbance, inherently promotes sustainability. In

addition, modular construction produces less noise and improves air quality because the modular structure is substantially complete in a factory-controlled environment using dry materials [10-12, 16].

C. Speed up project schedule

Modular construction takes most of the production away from the construction site. Faster and efficient factory processes are replacing the slow unproductive site activities. Construction of modular buildings occurs simultaneously with site work, allowing projects to be completed in half the time of traditional construction method [10, 12, 16-18].

D. Smarter

Modular buildings are produced with the same materials, same building standards and architectural specifications as traditional construction. Once assembled, they are virtually indistinguishable from their site-built counterparts [11].

E. Flexibility and reuse

Modular buildings are movable and flexible where it can be dismantle, refurbish and move to another location for new use, reducing the demand for raw materials and minimising the amount of energy to create a building to meet the new need [10, 16, 18].

IV. MODULAR CONSTRUCTION IN MALAYSIA

Table (3) shows the pattern and the degree of technology changes. The USA, UK and Australia have achieved the modular building standard, but Malaysia is still in the initial stage to implement it. The three countries have the similarity in offsite preassembly, but UK and Australia have divided the offsite preassembly into non-volumetric and volumetric order. Thus, UK and Australia share the similarity in the categorisation of offsite system where most of the Australian researchers referred to the UK. Malaysia is still in the stage of hybridization system, and the evolution pattern of the categorisation of offsite system in Malaysia is shown in Figure (1).

TABLE 3: Categorisation of Offsite Construction System [19]

Countries	Categorisation of Offsite Construction System
USA	-Offsite preassembly -Hybrid system -Panellized system -Modular building
UK	-Component manufacture & sub-assembly -Non-volumetric preassembly -Volumetric pre-assembly -Modular building

Australia	-Non-volumetric preassembly -Volumetric pre-assembly -Modular building
Malaysia	-Precast concrete systems -Formworks systems -Steel framing systems -Prefabricated timber framing systems -Block work systems -Innovative product system

FIGURE 1: Evolution Pattern of Offsite Construction Industry [19]

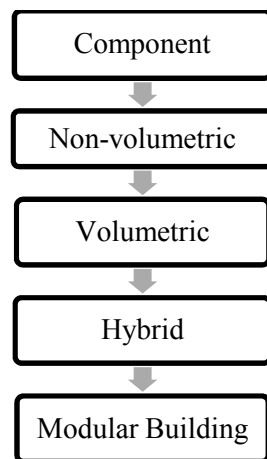


Table (4) shows the levels of industrialised production and definition [20]. It presents various degrees of prefabrication including pre-cutting, fabrication of panels, construction volume closing sections and manufacturing of a complete mobile dwelling unit. Malaysia has not yet reach level 4, modular building level.

TABLE 4: Levels of Industrialised Production and Definition [20]

Level 0	Basic Materials	With no pre-installation assembly aspect
Level 1	Component sub-assembly	Small sub-assemblies that are habitually assembled prior to installation
Level 2	Non-volumetric pre-assembly	Planar, skeletal or complex units made up from several individual components, and that are sometimes still assembled on-site in traditional construction
Level 3	Volumetric pre-assembly	Pre-assembled units that enclose usable space can be walked

		into, installed within or onto other structures, usually fully finished internally
Level 4	Modular building	Pre-manufactured buildings – volumetric units that encloses usable space but also form the structure of the building itself, usually fully finished

V. SUSTAINABILITY THROUGH MODULAR CONSTRUCTION

Sustainability involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Sustainable construction needs to perform along this triple bottom line. Modular construction stands up well to the definition of sustainability. Modular construction improves the sustainability of the construction process and the performance of the completed modular buildings [10, 11, 21].

- Less site disturbance from workers, suppliers and equipments since the modular units are produced at the factory. In addition, the bulk of transport mainly materials is moved to the factory.
- Modular buildings can be dismantle and relocate to a new location or refurbish for new use. Thus, reducing the demand of raw materials and minimizing energy to create a new building.
- Less wastage by recycling materials, controlling inventory and protecting building materials since modular units or modules are produced in the factory.
- Improved air quality: the modular structure is completed in a factory using dry resources. Therefore, the potential of high levels moisture trapped in the new construction is eliminated.
- Safety on the site and factory is improved, and fewer accidents on the site and factory. The modules can be install with pre-attached barriers or protective cages as part of the lifting system.

VI. RESEARCH METHODOLOGY

The methodology for data collection in this paper is done through the literature review. The literature search and review involve an extensive review of the current development of modular construction through definitions, issues and characteristics across the sectors. In addition, the current development of modular construction in Malaysia is included and the contributions of modular construction towards meeting sustainability and innovations. The information is

gathered from the secondary data comprising relevant books, journals, reports, webpage and conference proceedings. It attempts to review the definitions and characteristics of modular construction.

VII. RESULT AND DISCUSSION

Construction research that focuses on modular construction is at an initial stage and relatively a new field, especially in developing countries as the Malaysian construction industry exemplifies. Modular construction is widely used, practiced and implemented in developed countries such as the USA and UK for many years due to its advantages and benefits toward the end users in the respective countries. Findings from the literature illustrate that, despite modular construction's various definitions, the same essential fundamentals emerge. The fundamentals are:

- *Modular units*
- *Control plant condition*
- *Offsite construction*
- *Logistics*
- *On site construction*
- *Coordination*

These are the vital fundamentals and elements which defines modular construction. From the literature, the generic definition of modular construction can be derived as the following:

"Modular construction is a construction method that produces a building consists of modular units or modules, mass produce off site in a manufacturing facility. It includes the logistic and assembly aspect of it, done in proper coordination with through planning and integration".

Important and essential characteristics of modular construction have been identified from the findings. The characteristics are:

- *High quality identical modular / room size volumetric units*
- *Sustainable*
- *Speed up project schedule*
- *Smarter*
- *Flexibility and reuse*

More research on modular construction needs to be conducted in the context of the Malaysian construction industry scenario. This is necessary to enable Malaysia to move forward from the conventional prefabrication of the IBS towards modular building, which will revolutionize the pattern and mode of the offsite construction industry.

The classification of IBS in the Malaysian context should be expanded to cater the scope of modular construction. IBS is not to be seen as a threat to traditional methods. Both methods should be able to work in tandem and improve their processes collectively. The sharing of best practice between the two approaches is essential for the

continued successful development of both construction sectors.

VIII. CONCLUSION

The current study has established the definition and explored the characteristics of the modular construction. The presented literature has shown that the definition and characteristics of modular construction constitute to the main challenge on the implementation of modular construction in Malaysia. In addition, the current development of modular construction in Malaysia in meeting sustainability and innovation is also included. Future studies should examine this topic, the overall process, the requirements and the implementation. Finally, the current study is a part of ongoing main research that will further enhance the process and the implementation of modular construction in Malaysia. The results of the main research will hopefully provide the basis of a guideline to support and enhance the Malaysian construction industry.

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