VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

TOWARDS THE ADOPTION OF MODULAR CONSTRUCTION AND PREFABRICATION IN THE CONSTRUCTION ENVIRONMENT: A CASE STUDY IN MALAYSIA

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ABSTRACT

Modular construction is classified as off-site prefabrication and modern method of construction and used in developed countries such as US, UK, Japan, European countries and Australia due to its benefits. Modular construction is also known as volumetric construction, modular building system or modular system. Modular construction was developed since the 1940's, during the World War 2 as a solution for the soldier's accommodation and after World War 2 due to the increase in housing demand in the US. Modular construction is a construction method to construct a building using three-dimensional or modular units, which are assembled and produced in a factory. The three-dimensional units used for modular construction includes the logistic and assembly aspect of it, done in proper coordination through planning and integration. The research aims to investigate the definition, history, benefits, application and characteristics of modular construction and the adoption of modular construction in the Malaysian construction industry through a case study.

Keywords: modular construction, volumetric construction, off-site prefabrication, modern method, shipping container construction, industrialised building system (IBS).

INTRODUCTION

While prefabrication and modular construction are commonly considered in line with technological and material innovations, the beginning of prefabricated building involves neither factory nor mass-produced materials. The process of sending integrated, ready-cut building components to be assembled has been part of the construction process in the US since the 17th century. In the 1850s, the balloon frame system of construction revolutionised the speed with which new housing could be built. In the early 20th century, families could order a Sears, Roebuck and Company house from a catalog and wait for a house assembly kit to arrive. In World War 2, prefabrication allowed soldiers to be housed in portable shelters and then spawned as a comfortable house in US's suburbs inhabited by returning soldiers from the war [1]. Prefabrication and modular construction have made recent strides to architects, contractors and developers find new applications for the technology beyond the single family house: now towers can be constructed from modular units and prefabricated components. Although the technology has grown with the building practice itself, the widespread adoption of prefabricated components has faced barriers. Modularity's association with trailer house has led to its public perception as unattractive, unstable and the difficulties of coordinating delivery systems. Furthermore, personnel has to face new construction process in dense urban areas, and lack of integration into the design process when using prefabrication and modular construction has ensured its exclusion from many projects. Furthermore, the use of shipping containers in modular construction has led to the misconception of modular construction. Given the arrival of new technology like Building Information Modeling (BIM) software, it is now easier to integrate modular units, delivery systems, and personnel. Despite the challenges, modular construction is a less costly, faster, and simpler means of construction with wide applications across many building needs [1]. Industrialised Building System (IBS) is the term to represent the prefabrication concept in the Malaysian construction industry. IBS is a construction process that uses standardised building components mass produced in a factory or on the site. Then the IBS is transported and assembled into a structure or building using suitable machinery and equipment with minimal workers on site with proper preparation and integration [2, 3]. The IBS agenda in Malaysia began in the early 1960's, whereby the Malaysian government introduced IBS pilot project aiming to speed up the delivery time of the project [4]. In an attempt to address the IBS agenda in Malaysia, the Malaysian government through Construction Industry Development Board (CIDB), inspires a paradigm shift in the construction industry from the conventional construction approach to IBS.To promote IBS in Malaysian construction industry, the Malaysian government and CIDB introduced plans and policies to encourage the implementation of IBS. The introduction of Construction Industry Master Plan (CIMP 2006-2015) is a guide for the future direction of Malaysian construction industry by the Malaysian government. CIMP has highlighted the importance of IBS and sustainability for Malaysian construction industry [5]. IBS Roadmap was

introduced to guide the direction of IBS implementation and addressing issues related to IBS. IBS Roadmap 2003-2010 was the first IBS Roadmap and replaced by IBS Roadmap 2011-2015. The objectives of the new IBS Roadmap 2011-2015 are to impose high level intended outcome of implementing IBS. The objectives are sustainability, quality, efficiency and competency [6]. Modular construction has all the features point out in the Thrust 3 and 5 of CIMP 2006- 2015 and objectives of IBS Roadmap 2011- 2015. Modular construction provides quality building, efficiency, sustainability, capability and speeds up in the schedule.The move towards the adoption of modular construction in the Malaysian construction industry is to be anticipated because of modular construction's features to eliminate the existing IBS limitation. The implementation of modular construction is proven to improve productivity, economically and promotes sustainability of the construction industry [3, 7]. Since IBS is already established in Malaysia, thus it is essential for modular construction to adapt IBS approach to ensure the effectiveness of modular construction implementation in the Malaysian construction industry [8].

DEFINITION OF MODULAR CONSTRUCTION

Modular construction is a construction method to construct a building using three-dimensional or modular units, which are assembled and produced in a factory. Modular construction also includes the logistic and assembly aspect of it, done in proper coordination through planning and integration[3, 7]. Modular construction is also referred to as volumetric construction, modular building system or modular system. The three-dimensional or room unit is built using the same materials and designed to the same standards. The three-dimensional units are fully fitted out before being transported to the site and stacked onto prepared foundations to form buildings. Modular construction speeds up the project construction schedule, reduces wastages, enhances the quality of building products and promotes sustainability. These three-dimensional units can be made from most materials including light gauge steel frame, timber frame, concrete, and composites. These units are sometimes used alongside panels (readily made walls, floor, and roofs) in hybrid or composite construction. Modular construction is most efficient when used for a large number of identical units, as may be found in flats. The three-dimensional or room units may form complete rooms, parts of rooms, or separate highly serviced units such as toilets or lifts. The collection of separate three-dimensional units usually forms a self-supporting structure on its own or, for tall buildings, may require an independent structural framework[9].The modular building has the same features as conventional building as shown in Figure-1 [10].

Figure-1. The modular building has the same features as a conventional building [10].

Structurally, modular buildings are stronger than conventional construction because each three-dimensional or modular unit is engineered independently to withstand the rigors of transportation and to be lifted onto foundations. Once together and sealed, the units become one integrated wall, floor, and roof assembly and a completed modular building [10].Modular building is a building constructed using three-dimensional or modular units. The three-dimensional units or modular units are manufactured using the same materials and design as conventional construction. Once the three-dimensional units are assembled, they are virtually indistinguishable from their conventional built counterparts. These three-dimensional units are factory-fabricated structures that are transported to be tied together as a building.

HISTORY OF MODULAR CONSTRUCTION

Modular construction often considered the prospect of the house and building construction industry that has roots near a century old. Two important events in the first thirteen years of the 20th century have led directly to the evolution of today's modern modular building and home. Sears, Roebuck and Company began selling house kits through its popular catalog. While these house kit were not constructed in any way before reaching the house or designated site, they were among the first houses to have their complete system of materials transported to the required site. A Sears house buyer could expect their house kits, complete with 30,000 pieces and a 75-page instruction manual, to arrive by train. In the year 1913, automotive pioneer Henry Ford introduced the assembly line concept at his automotive factory. Ford's revolutionary idea reduced the construction and production time of a new automobile significantly while maintaining control and quality at each phase of the process. Nearly a half-century later, the concepts introduced by Ford and Sears, Roebuck and Company would be combined at the beginning of modular building industry [1].In the 1950s, to meet up with the high demand for new houses following World War 2, companies began to produce houses in factories. The prefabricated houses were equivalent to today's HUD-code or mobile houses and were not prefabricated modular houses. However, when a housing manufacturer first produced a two-section house conforming to an applicable building code in 1958,

the modular building industry was formally born. In the decades that followed, the modular building industry worked hard to differentiate itself from the HUD-code house industry. HUD-code manufactured houses or often called mobile houses are built to a Federally-mandated (HUD) building code. Modular prefabricated houses and buildings are built to meet all state building codes. Erected on a permanent foundation, appreciate in value and are virtually indistinguishable from conventionally constructed houses and buildings. Through the 1970s, most modular houses and buildings remained simple rectangular, two or four modular units structure. Today, with the advent of computers and Computer Assisted Design (CAD) programs, the modular building industry began to move and improve [1]. Today's modular houses and buildings rival any conventionally constructed structure in design and functionality. Advancements in computer design and factory technology allow almost any custom house or building plan to be constructed as a modular house or building.

CHARACTERISTIC OF MODULAR CONSTRUCTION

High-quality, identical three-dimensional or room size volumetric units

The main feature of the modular construction is the identical or standardised three-dimensional or room size volumetric units. The three-dimensional or room size volumetric units are mass produced in a controlled factory or manufacturing facility that generates less waste, and high-quality modules. Manufacturing facilities or factories have stringent quality assessment/ quality control (QA/QC) programs with the independent inspection and testing protocols that promote a superior quality of construction. Furthermore, the production of modular units in factory produces less waste at every step of the way [3, 7]. The three-dimensional or modular units are produced in a factory presented in Figure-2 [9].

Figure-2. Three-dimensional or modular units are produced in a factory.

Faster project schedule

Modular construction takes most of the construction phase away from the building site. Quicker and efficient factory processes are replacing the slow, less productive site activities. Construction of modular buildings occurs simultaneously with building site work, allowing projects to be completed in half the time of traditional construction method [3, 7]. Comparison between modular construction and conventional construction schedule as shown in Figure-3 [10].

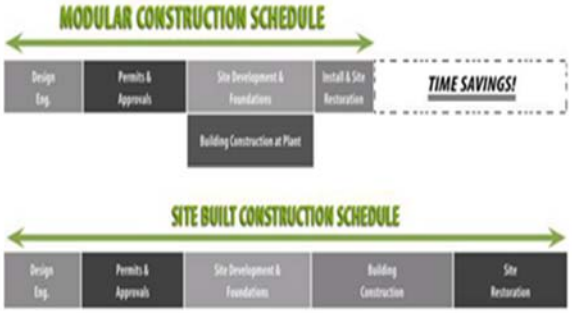

Figure-3. Comparison between modular construction and conventional construction schedule [10].

Promotes sustainability in the construction environment

Sustainability in modular construction can be achieved through the factory production of the modular units. Production of the modular units and building construction in a controlled environment such as a factory reduces waste through escaping upstream rather than diversion downstream. Modular construction can minimize the impact on the environment, reduces waste, significantly less on site activity and disturbance, and inherently promotes sustainability [3, 7].

Flexibility and reuse of three-dimensional or room size volumetric units

Modular buildings are movable and flexible. It can be dismantled, refurbish and move to another location for a new use. Modular construction reduces the demand for raw materials and minimises the amount of energy to create a building to meet the new need [3, 7].

Logistic and storage

Modular construction can reduce the labour and material cost. However, these cost saving is partially offset by the transportation cost. The transportation of modular units is also subject to the country's road department. Due to the size and weight of a three-dimensional or modular unit, early consideration of logistics transportation and erection is necessary. Furthermore, storage of the units on the site before erection is not recommended or practical. Once the three-dimensional or modular units arrived on site, the units must be installed immediately to the designated location [3, 7].

Coordination, planning, and communication

For a modular construction project to complete with a good result, proper planning, coordination and communication must exist between various relevant parties involved from the early stage of the project. Participation of the client, consultants, manufacturer, contractor and supplier at the beginning stage of a modular construction project is crucial. If any amendments made during the middle phase of the project, it would cause

problems to the modular construction project. The design of services, mechanical and electrical (M&E) is essential before manufacturing begins because any late design changes will be costly. Furthermore, proper foundations (less or more than 5mm on flatness) are necessary due to tight tolerances of the-the modular units. Connections between the modular units must also be carefully considered by the parties that involve in the project. Also, the modular units must be inspected both in the factory and on-site.

Ease renovation

Modular construction eases renovation work. Just select and add suitable three-dimensional or modular units for the renovation project, and then install the selected units at the existing building.

BENEFITS OF MODULAR CONSTRUCTION

General benefits

Speed up project schedule, whereby modular buildings can occur simultaneously with the site and foundation work; modular construction projects can be completed 30% to 50% sooner than traditional construction. 60 - 90% of the construction is completed inside a factory, which mitigates the risk of weather delays [10].

Three-dimensional or modular units are built with quality materials and using factory QA/QC management and control. Modular buildings are constructed to meet the same building standards as site conventional constructed structures. Modular buildings are also built with the same architect-specified materials used in conventionally constructed buildings such as wood, concrete, and steel [10].

Ability to service remote locations: It is hard to build a house in Hill area using conventional construction method due to problems with transporting materials, difficulty due to the terrain if surrounding the area and other factors. A house built using modular construction in a hillside is easily built since the house building or structure complete with finishes is already completed in the factory. The only assembly of the house's modular units is required and the construction of the foundation.

Modular buildings are movable and flexible. Since the modular building is made up of assembled three-dimensional units, the modular building can be easily moved by removing the joints and connections [9].

Eases renovation and refurbishment work. The required and selected three-dimensional or modular units can be easily added to the existing modular building or conventionally constructed building for renovation work. The same goes for the refurbishment work, whereby the required refurbished modular unit can be moved to another location for refurbishment work or replace by a new modular unit.

Safer Construction. The indoor construction environment (factory or manufacturing facility) reduces the risks of accidents and related liabilities for workers.

Economical

- For modular construction to be cost efficient and economical, the three-dimensional units need to be mass produced identically with the same design and materials in a factory [10].
- Modular construction saves on commissioning, defect, and low repair costs. It can be achieved through high-quality materials and using factory QA/QC management and control. Defects usually occur for traditional construction method due to lack of workmanship and low-quality materials.
- Saving through wastage reduction because modular units are produced in a factory with controlled condition and environment.

Promotes sustainability

Modular construction stands up well to the characterisation of sustainability. Modular construction improves the sustainability of the construction process and the performance of the completed modular buildings.

- Less site disturbance from workers, suppliers, and equipment since the three-dimensional or modular unit are produced at the plant. Also, the bulk of transport mostly materials is moved to the factory [3, 7, 10].
- Modular buildings can be dismantled and relocate to a new location or refurbish for new use. Thus, modular buildings reduce the demand for raw materials and minimizing the energy to create new building [3, 7].
- Modular construction produces less wastage by recycling materials, controlling inventory and protecting construction materials since three-dimensional, or modular units are produced in the factory [3, 7].
- Improved air quality: the three-dimensional or modular unit is completed in a plant or factory using dry resources. Therefore, the potential of high levels dampness trapped in the new construction is eliminated [3, 7, 10].
- Modular construction improved safety on the site and factory, and fewer accidents on the site and factory. The three-dimensional or modular units can be installed with pre-attached barriers or protective cages as part of the lifting system [3, 7, 10].

APPLICATION OF MODULAR CONSTRUCTION

The applications of modular construction are multipurpose. Modular construction has the same application as conventional construction but with additional values such as quality, movability, and flexibility. Modular construction can cover multi-storey and high-rise construction including single-storey and low-rise construction. The applications of modular construction are presented in Figure-4 and 5 [9].

Figure-4. The applications of modular construction for high-rise and multi-story construction.

Figure-5. The application of modular construction for single-storey and low-rise construction.

Furthermore, modular construction can be used for the following applications presented in Figures 6 until 11 [10].

Figure-6. Residential [10].

Figure-7. Office and Administration [10].

Figure-8. Education [10].

Figure-9. Healthcare and Hospital [10].

Figure-10. Retail and Commercial [10].

Figure-11. Construction/ Oil and Gas [10].

CASE STUDY OF MODULAR CONSTRUCTION IN THE MALAYSIAN CONSTRUCTION INDUSTRY

The case study is the construction of 72 lecturer office units using an innovative and revolutionary construction technique known as the Modularcraft system. The system is jointly developed by Portland Group of Companies and University Malaysia Pahang (UMP). The case study is also part of University Malaysia Pahang's new Green Policy of using recycled industrial commodities and adapting to sustainable building construction technologies, in line with global efforts toward protection of the environment. The Modularcraft system comprises the use of shipping containers as the basic building module combined with Primer'X'- a thermal insulation coating or G-Bricks that used in masonry works. The essential products in the Modularcraft system package are made of recycled material and are the results of extensive research carried out by University Malaysia Pahang (UMP). The case study that involves the important use of Primer-X on shipping containers demonstrates the habitability of shipping containers despite our equatorial climate. The creations of custom-built buildings are mobile, sustainable, environmentally friendly and greater efficiency by the drastic reduction of construction time when compared to conventional construction method. The Modularcraft system also significantly reduces the use of reinforced concrete or other labour-intensive construction methods and minimise on-site disruption.

Design development

There are five design approaches for the case study. There are:

- Passive energy design (Orientation) - The orientation of the building is designed to adopt passive lighting hence reduce the energy consumption of the building.
- Passive energy design (Cross Natural Ventilation) - The design also has considered natural air ventilation to lessen the use of the active cooling system.
- Utilize site profile - The design of the pilot project also considers the surrounding site profile. The building has three levels consist of ground level, first level, and second level. The entrance to the building is the bridge connecting the first level and elevated counter near the existing road.
- Circulation -The entrance to the building is through the bridge to the lobby. There are two staircases located the east and west of the building.
- Using shipping containers.

The following figures, Figure-12 and 13 are the design approaches for the case study.

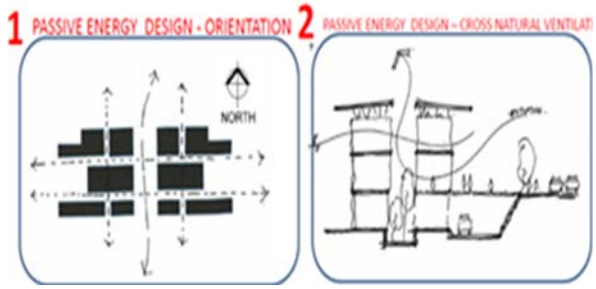

Figure-12. Passive energy design.

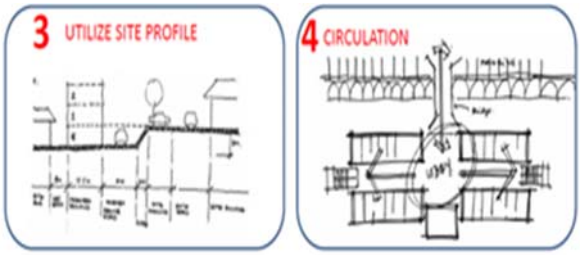

Figure-13. Utilisation of site profile and circulation consideration.

Manufacturing process

The manufacturing process of the shipping container in a factory offers a controlled and better production environment. It reduces wastage, fast construction and reduces defect. Figures 14 to 17 are the shipping containers refurbishment and production process of the case study.

Figure-14. Cleaning, cutting and primer coating works.

Figure-15. Insulation, electrical and piping installation.

Figure-16. Finishing and fittings installation.

Figure- 17. Transportation of the containers to site.

Construction method

The following figures**,** Figures 18 to 23 are the construction method for the case study.

- Earthwork and foundation preparation.

Figure-18. Earthwork and foundation preparation.

- Site installation of the shipping containers.

Figure-19. Site installation of the shipping containers at the site.

- Site installation of staircases, floor joists, and other structures.

Figure-20. Site installation of staircases, floor joists and other structures between stack shipping containers.

- Site installation of floorboards and railings.

Figure-21. Site installation of floorboards and railings.

- Site installation of roof structure and coverings.

Figure-22. Site installation of roof structure and coverings.

- Mechanical and Electrical (M&E) and fittings installation.

Figure-23. Mechanical and Electrical (M&E) and fittings installation.

Summary of the case study

The summary of the case study is presented in Table-1.

Table-1. Summary of the case study.

	Descriptions
Application	Office
Year constructed	2014
Project period	5 months
Cost of project	RM3.5 million (including internal M&E works, air-conditioning and furniture)
No. of modular units	72 units
Additional structural framework	-Steel framing for supporting structural (staircases, floor joists and walkways) -Only used pad footings and ground beams for substructure
Contractor/ Manufacturer	-A total solution provider (contractor & manufacturer)
Benefits of adopting modular construction/ building	-Fast speed of construction-Environment friendly -High quality

Figure-24 is the image of the case study.

Figure-24. The image of the case study.

DISCUSSION AND FINDINGS

Based on the results of the case study, the easiest way to adopt modular construction is to use shipping container. Shipping container suits the main feature of modular construction which is the three-dimensional and room unit feature. The shipping container is found to be the most suitable solution or material to be used for modular construction. There is a misconception amongst the Malaysians that the shipping container is modular construction. The shipping container is mainly a material or solution to modular construction because it fulfills the main criteria of modular construction that is a three-dimensional unit with value added factors on strength and durability. The three-dimensional units or room units used for modular construction can be produced using timbers, galvanised lightweight steel, composite materials or any materials that can withstand the rigor of transportation and structurally strong. The setback of using a shipping container for modular building or construction is the container is ready made or prefabricated with a fixed standard size, for example, 20'x8'x8$^{1/2}$'. Thus, the design and construction using a shipping container for a building must consider the fixed size of the container. The second problem is the heat. Shipping containers are made from steel that absorbs heat. Living in a shipping container without any active or passive cooling system will cause discomfort towards the occupiers in the tropical or hot climate areas. The third problem, most of the refurbished shipping containers for construction are used or second-hand. Nobody knows what the shipping containers carried previously. The goods transported in the containers might be something hazardous and dangerous to any human and living creature. Malaysia is lack of expertise or the technology and knowledge to produce a three-dimensional or modular unit. However, Malaysia can produce cabin that suits the modular construction main feature that is the three-dimensional unit. The cabin may not have the strength and durability of the used containers that have been used in modular construction.

CONCLUSIONS

The study has highlighted the features and benefits of modular construction and building. The Malaysian construction industry is still at the initial stage of adopting modular construction. Most of the modular building in Malaysia uses refurbished shipping containers as material for the modular buildings. Finally, the current study is a part of an ongoing study that will enhance the IBS developments through modular construction in Malaysia. The results of the study will hopefully provide the guideline to support and improve the Malaysian construction industry in modular construction.

ACKNOWLEDGEMENT

The Authors wish to thank the Universiti Teknologi MARA, Seri Iskandar Campus and the Construction Industry Development Board (CIDB) Malaysia. A remark of indebtedness to the Acculturation Grant Scheme (RAGS), No: 600-RMI/RAGS 5/3 (134/2014) by the Ministry of Education, Malaysia for its grant award.

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