Modular Construction System (MCS) in Malaysia: Mass Customization Through Combinatorial

S Aziz1, S N Che Mohd Nasir2, R Hatrom3, L Ahmad Bazuli4 and M R Abdullah1
1Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, 32610 Seri Iskan, Perak, Malaysia
2Faculty of Architecture & Ekistics, Universiti Malaysia Kelantan, 16100 Pengkalan Chepa, Kelantan, Malaysia
3Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia
4Jabatan Kejuruteraan Awam, Politeknik Ungku Omar, Jalan Raja Musa Mahadi, 31400 Ipoh, Perak, Malaysia

Email: myyaarc@gmail.com

Abstract. Combinatorial is another sub-topic and sub ordinate of Golden Mean theory. This paper is part of on-going research of modular construction system (MCS) in Malaysia. Objectives of the research were to propose an appropriate scheme and concept for sustainable design for modular home based on research findings. The researcher conducted case study (Personnel Expert Interviews) to collect data of MCS in Malaysia. Proposed combinatorial design for spatial planning of home design has been carried out by the researcher at the end of analysis as design experimental yet need validation from computer science experts. Combinatorial in modular architecture is the theory of conceptual design for future building design process of MCS. The researcher discuss in details and to clarify the proportion combinatorial for MCS in aspect of building forms and arrangements through proposed combinatorial formula. In Malaysia, design technique should relate to local culture, weather, and available materials sources as mentioned by the experts. Combinatorial design of modular architecture is an alternative design for compact affordable home. This combinatorial geometry (3D module) repeated, duplicate and can be oriented in a few ways to forming combinatorial models of building design. Pattern A and B are considered to be the best in economic aspects and practicality in term of shape of green. Proposed concept possibly can improve user decision making (digital design process) e.g. building players to plan their building lifecycle projects in term of economical design, green shape, reduced construction time and cost. Thus, it may be able to promote user friendly design, fast track construction, and quality based product, less wastage and varied of design selection can be chosen of the user.

1. Introduction
The basic aspects of architectural design were the buildings must conveniently and functional to use, durable and delight [1]. Alexander stated pattern was important part of architectural design. Pattern defined as ordered and logical structure [2]. Pattern can be found in natural environment, human, art, space, time, and music. Successful buildings obey the same system law as a complex organism and an efficient computer program. The user used the building to suite their own needs of common and daily life while the contractor tried to minimize cost and to standardize the building parts. In Malaysia, the construction industry is highly aware of the need to improve the integration, planning and control of
its design and production process [3]. Consequently, the reality of construction is that most of the problems encountered in the field such as reworks, delay, low in quality or productivity and even legal entanglement and claims often compounded by inherent design flaws that generated in the design phase [3]. Architecture is designed to satisfy the different representational, functional, aesthetic, and emotional needs of organisations and people who live or work in structures [4]. Affordable home price normally in between RM 250, 000 to RM400, 000 [5]. The type of affordable home can come in different range of types and sizes such as for singles, couples, families and flat shares as well as for seniors.

2. Modular Architecture in Malaysia

In Malaysia, MCS or Offsite Manufacturing included in Industrialised Building System (IBS). The definition of offsite is the manufacture and pre-assembly of components, elements or modules, before installation into their final location [6]. As mentioned by Zaikhan (2015) from the author case studies, the problems of modular construction in Malaysia were about limited durable materials and higher cost. The improvement of constructability rarely been mention as the benefit of offsite but in theory offsite can improve constructability by providing designers with the fresh perspective and outlook on the concept of repetition, preassembly and standardization [3].

2.1 Analysis of MCS in Malaysia

The trends of MCS in Malaysia are creating big waves among building players but to risk and use this option of construction system is a bit scarier to them. Majority of the experts agreed that MCS is getting well known in the Malaysian construction industry as an option over conventional system as it is more cost and time saving. The experts are positive and optimistic of the MCS industry in Malaysia because there is high demand among Malaysians.

Based on case studies, it has been established that MCS is defined as a 3D module which is produced, manufactured and assembled in a factory (control environment). As for the construction of MCS module, it uses various tools and machinery and the MCS has a good quality of construction. There are many advantages of MCS compared to the conventional system. The experts agreed that MCS product are of high quality. MCS has a high quality product because approximately 80% of the process is conducted in a factory. 14% of the expert suggest that MCS is more suitable for future construction in Malaysia. In terms of green shape, rectangularity is a practical shape to use in design. The experts claimed that square or rectangularity is a commonly use shape in construction. They suggested that one of the factors in which rectangular is considered as a green shape is because this shape is economical and has less wastage of materials compared to other shape. Beside that, another factor that rectangular is considered as a green shape in architectural design is because it has been proven that this design has been in architectural history for a long time. Moreover, the flexibility of square and rectangular shapes makes it the best shapes to use in architectural design and can make the space functional. These factors were agreed by all the experts. In addition, to promote MCS in Malaysia, the building players should not follow exactly what other countries such as in the UK, Australia, and USA, the cost of labour is expensive. Therefore, these countries result in using prefab and MCS as a solution to overcoe the high cost of labour. Malaysians are looking for versatility in home design. They want something new but cost saving and can be constructed in a shorter period of time. MCS is one of the solutions for this home design. The experts agreed that the future of MCS in Malaysia is bright. There is a demand among Malaysians in using MCS for construction. However, there are still is a few issues that need to be tackled, such as home price of MCS within home of Conventional System type should be fair. As a result of design sustainability in terms of green shape, the researcher discovered that pattern B was the most practical shape of affordable home design (high-rise type). The second most practical shape to be used in house design was Pattern A. All these pattern have been proposed using block arrangements and Combinatorial Concept (Mathematical Way of Design). These two pattern are considered as the most economical and practical shape in MCS. Other patterns were not favorable because of certain issues such as ess economical, uses a lot of footprint and poor ventilation
in terms of arrangements and orientation. Therefore, the experts agreed that MCS in Malaysian construction industry but the government should play a big role in supporting building players in the IBS field itself. The suitability of MCS to be a new construction system for affordable homes could still be achieved if the MCS house is priced at a fair rate within conventional house design.

3. Combinatorial for Modular Architecture
Modularity in general is part or series module of something whether it became appliances, furniture, machinery, automotive, aerospace, or buildings. Constructed a modules or unit packaging schemes. Standard parts of modular approaches offer gains in time, cost and quality [7]. For building design, modular refer to parts of a building define by 3D compartments such as LEGO. As combinatorial is arrangements and combination of geometric objects and with discrete properties of these objects. Mentioned by Christopher Alexander houses were generated by patterns. Spatial configuration is concerned with finding feasible locations and dimensions for a set of interrelated objects that meet all design requirements and maximize design quality in term of design preference [8]. Spatial configuration is relevant to all physical design problems, so it is an important area inquiry [8]. Reported attempts to automate the process of layout design started over 35 years ago [9]. Geometry decomposition is one of the ideas to relate modular construction and combinatorial things. Combinatorial geometry is the study of combinations and arrangements of geometric objects and with discrete properties of these objects. Historically, modularity has play an important role in the study of combinatorial geometries [10]. Theory development of combinatorial design has brought incredible success in the application is not expected, in connection with basic math, and the desire to produce order out of chaos [11]. Moreover, he questioned about the future of application of combinatorial geometry. He explained that new mathematical truths will be found and that unanticipated application will arise. Christopher Alexander in his book, Pattern Language defines that pattern in a solution of space. In an aspects of design, combinatoric as mathematical approach can be found in that research. The building blocks can be combined in an infinite number of ways. The question is for a given fixed area which shape will create the greatest feeling of spaciousness [12].

4. Research Methodology
The aim of this study is to investigate current practises and issues of IBS and modular construction. In addition, it opens a prospect to test the new method of modular construction using ‘Combinatorial Concept’ during design phase. Therefore, a collection of data is obtained through literature review in the aspects of IBS and MCS development to achieve innovation in green construction and the implementation of combinatorial geometry. The data is supported using case studies and questionnaires. Both method are described as follows.

A) Case studies
Case studies performed in data collection are x Intrinsic and x Instrumental [13]. The reason is x intrinsic offer better understanding in cases carried out while x Instrumental help to examined and refine the theory proposed. Thus, case studies is carried out to acquire in-depth knowledge about registered MCS companies under the Malaysia Construction Industry Development Board (CIDB) to define controlled environment. The area selected is located in three cities highly involved in MCS, i) Kuala Lumpur; ii) Johor Bahru and iii) Sarawak involving four registered companies in 2015. It is limited because the implementation of modular construction in Malaysia are low [14]. It is essential to select registered companies as it has reliable track record and gradually monitored by professional bodies. Data observation is validated through content analysis with the outcome of all variables in theoretical model tested showed significant relationship. The data collection are categorized in two. First is validated documentations related to MCS and the other is on site data. Data collection is limited to photos, size and dimensions, specifications, cost estimation, materials and location.
B) Questionnaires

The supporting data is run through structured questionnaires among target group experts in design, engineering, costing and manufacturing in MCS. Specifically the MCS project is focusing on affordable housing scheme in Malaysia. Professionals selected are architects and contractors directly involved in MCS. In specific, nine issues were discussed and evaluated. The outcome is described in Table 1.

Table 1. Data collection by Different Company on MCS in Malaysia

| Name/Company | Definitions of MCS | Trend of MCS in Malaysia | Advantages of MCS Vs. Site Built | Factors of Rectangularity | Agreement of Rectangular Shape is green shape of design (Yes/No) | Future MCS in Malaysia | Best option of shape design for MCS | Generalization of MCS and Affordable (Suitability) |
|--------------|--------------------|--------------------------|----------------------------------|--------------------------|---------------------------------------------------------------|------------------------|------------------------------------|-----------------------------------------------|
| Company A    | -Standard size & form (10 years experienced in MCS) | -Increased, getting popular. | -Fast | -Most of furniture, transportation, house floor plan and machinery were square (design logic of daily life) | Yes. Same with No. 4 reasons. | -House price need to be fair within using conventional system or MCS | -There is hope for MCS in Malaysia | -Don't compare MCS in Malaysia with other countries because different issues such as labor in Australia and USA were too expensive. |
|              | -expandable | -Easy installation | -Smarter | -Hexagonal was too difficult to organized things in the house (only customized the furniture) | -Yes. To avoid wastage of materials. | -Structure replacement | -ID Modularize | -Govern have to create the plan to educate Malaysian on green & sustainabilit y of MCS. |
|              | -Pre-assembly in factory | -Greener | | | | | | |
|              | -Fabricated on site | -Controlled environment (quality and clean logistic) | | | | | | |
|              | -Flexible / variety of shapes (complex shape lead to difficult joinery system) | -Easy for transportation | | | | | | |
|              | -Conventional form (square) most practical & economical | | | | | | | |
| Company B    | -LEGO (15 years experienced in MCS) | -Existed demand among Malaysian | -Container (ISBU); Durability 2.5 to 108 times strength than site built. | -Trend timeline; history, square to organic to square (contemporary) | -Golden Section by Le Corbusier | -ID Modularize | -Optimist of future of MCS | -Inevitable option |
|              | -IBS-Prefab | -Inquiries; 10 questions/day | | | | | | |
|              | -Produced in factory | -Necessary option | | | | | | |
|              | -Repeated | | | | | | | |
|              | -Duplicate | | | | | | | |
|              | -Volumetric | | | | | | | |
|              | -Extensible/ Expandable | | | | | | | |
|              | -ISBU | | | | | | | |
### Company C

- Everything should be done at factory (controlled env.)
  - Accurate
  - Very fast
  - Quality
  - Most practical (e.g.; furniture, cabinet etc)
  - Other shapes; Round

- Process in factory
  - Prepare very fast
  - Quality control
  - All machinery

- Past & current problems faced in IBS: MC was too rigid (cannot be generalized and apply to other projects)

- Most practical (e.g.; furniture, cabinet etc)
  - Circle unused space

- Going up but very slow because of the limitation of manufacture interest to do MCS projects; all projects were different size MC; too rigid, inflexible

- We can do over here.

| Company D | - Build in control env. (factory).
|          | - Infancy
|          | - Lack interest among developers
|          | - Transport & delivery
|          | - Ready to use within the day
|          | - Build in controlled env.
|          | - Cheaper to construct

|   | - Cheaper to plan & fit out.
|   | - Lesser need for very skilled workers.
|   | - Use machinery & tools (less labor)

- Cost controlled

- Needs to have market

### Company D

- Infant
  - Build in control env.
  - - Easy to control on time management/schedule & quality.
  - - Cost controlled

- Infancy
  - - Labor cheaper cost
  - - Use machinery & tools (less labor)

- Cheaper to construct
  - - Easier to plan & fit out.
  - - Lesser need for very skilled workers.

- Most practical (e.g.; furniture, cabinet etc)

- Circle unused space

- We can do over here.

### 5. Findings

The results showed that the combinatorial concept for modular design has a potential to widened the opportunity for affordable housing in Malaysia as it offers alternatives design layout, cost effective and time saving compared to the conventional system. Moreover, the product of MCS is highly reliable in quality as the manufacturing process is under a controlled environment involving tools and machineries. MCS is considered as high quality product because 80% of the process is conducted in the factory supported by 14% experts recommended the MCS for fast track project which is high in demand. However, a thorough research to adapt MCS in architectural heritage is yet to be define (Ar. Mastor, 2015)

The objective of promoting combinatorial concept to develop effective design strategies, standard guidelines, specifications and procedures aiming for cost reduction and efficiency is achievable through equipment modularization and standardization with process simplification. The products of combinatorial providing a repetition of identical units, both in the building dimensions and building layout.

As suggested by experts, Pattern A and B were the best shape for house pattern arrangement. Therefore, the researcher proposed five (5) combinatorial way of most practical pattern for
arrangement. The pattern proposed is based on a single unit of high rise home. The method proposed by the researcher entitled as Combinatorial Concept of design. The combinatorial tiling is defined as a process or technique to figure out the floor plan and pattern composition by repeating the modules in the given square area.

Figure 1 indicates the best shape for MCS of public housing design. 75% experts agreed pattern B is the most practical shape of affordable home design. Meanwhile, only 25% selected pattern A as the second best shape design for MSC in Malaysia. Pattern A and B are considered to be the best in economic aspects and practicality. Other patterns are not favourable as it is less economical, has larger footprint and offer poor ventilation when it comes to space arrangement and orientation.

In order to relate the concept of green shape, the researcher discovered, that Pattern B was the most practical shape of affordable home design for high-rise. The second most practical shape is Pattern A. The experts claimed that square or rectangular is a commonly used shape in construction. They suggested rectangular is considered as a green shape because it is economical and has less wastage of materials compared to other shapes. Besides that, rectangular shape is synonyms in architectural design as it is proven that this design is functional and flexible, and has been used and fully utilized in architectural history for a long time. All these patterns have been proposed using block arrangements and Combinatorial Concept. However, the experts agreed that MCS in Malaysia needs to improve IBS issues according to building players in the construction industry and the end user.

In addition, to promote MCS in Malaysia, it is not recommend to follow exactly what other countries use for modular construction. Experts claimed that in other countries such as in the United Kingdom, Australia, and United States of America, the cost of labour is expensive. Therefore, these countries resulted in using prefab and MCS as a solution to overcome the high cost of labour. Malaysians are looking for versatility in home design. They want something unique but cost saving and can be constructed in a shorter period of time. MCS is one of the solutions for this home design. The experts agreed that the future of MCS in Malaysia is bright. There is a demand among Malaysians in using MCS for construction. However, there are still is a few issues that need to be tackled such as home price of MCS within home of Conventional System.

The experts also remarked that it is possible to implement MCS in the Malaysian construction industry but the government should play a big role in supporting building players in the IBS field itself. The suitability of MCS to be a new construction system for affordable homes could still be achieved if the MCS house is priced at a fair rate compare to conventional house design.

![Figure 1. Best Shape for MCS of Public Housing Design](image-url)
6. Recommendations and Conclusions
Suggested of the Combinatorial Concept for MCS might be able to cover issue product modularity in sustainable shape design especially. As Pattern A and B most practical and economical shape for home pattern, experts agreed rectangular is considered as a green shape because it is economical and has less wastage of materials compared to other shapes. This concept will improve user decision making e.g. building players in order to look for appropriate methods before to proceed with any decision of prototype, testing and hands-on construction at site. Thus, with the concept proposed by the researcher it may be able to promote user friendly design, fast track construction, and quality based product, less wastage and varied of design selection can be chosen of the user. The Combinatorial Concept was developed based of economization of product and risk management approach (based on Literature Review) with direct engagement from practitioner in construction industry to choose best shape of design to look for in MCS. Despite this Combinatorial Concept not been testing yet unto real world consideration, should future research to look into account this method for further research and assessment. Area to be considered in order to sustain of the concept development in future such as computational software based. Due to the formulation of affordable home based on combinatorial probability and combinatory code. As combinatory code has been used in field of Artificial Intelligence (AI) and Internet of Things (IOT) The objective was to develop to necessary strategies, standards, designs, specifications, and procedures for cost reduction through equipment modularization, equipment standardization and process simplification. The products of combinatorial providing a repetition of identical units, both in the dimensioning building spaces, as well as in the layout of the building. With this theory, it might be provided more idea in producing affordable home in the near future. Through the reuse of formwork, sustainable and inexpensive designs can be attained. The system allows for the customization of designs, while maintaining the benefits of a regular prefabrication product, so their cost and performance can be improved over time [15]. Challenge of MCS in Malaysia is vastly complex but to apply this alternative construction system in near future is inevitable action. So, the right track and steps of conceptual and construction technique certainly can help narrow down suitable solution of current problem faced by building players to apply MCS in construction industry. In short, the combinatorial design was an experimental design to find out the sustainable shape and economic way of design.

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