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Benefits and Challenges of Modular Integrated Construction in Hong Kong: A Literature Review.

Sherif Abdelmageed[1], Sherif Abdelkhalek[2], Tarek Zayed[3]

[1] *MSc student, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong SAR,* E-mail address: sherif.mohamed@connect.polyu.hk

[2] *PhD student, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong SAR,* E-mail address: sherif.abdelkhalek@connect.polyu.hk

[3] *Professor, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong SAR,* E-mail address: tarek.zayed@polyu.edu.hk

Abstract
Modular Integrated Construction (MiC) has gained quite momentum as it provides solutions for several problems in the construction sector, particularly in Hong Kong. MiC is converting the building into modules and erecting them easily on site providing various benefits, such as cost and time savings, better quality, lower risk, higher sustainability, less injuries and accidents, etc. The MiC is considered the best alternative to traditional construction approaches in solving the huge housing demand problem in many cities all over the world due to the time-saving privilege. The utilization of MiC is facing a lot of challenges, which are considered obstacles to the wide acceptance of this technique in the construction industry in Hong Kong. This, in turn, has led the interests of the research community to investigate its benefits and challenges aiming at addressing several solutions to harness the benefits of this technique and to tackle these challenges. The present research aims to review the main concept of MiC and to determine the benefits and the challenges of implementing MiC in construction industry. The findings of this research highlight the advantages and limitations of incorporating MiC technique in Hong Kong, which will help the stakeholders to effectively utilize this technique in the construction industry.

Keywords: Modular Integrated Construction (MiC), benefits and challenges.

1. INTRODUCTION

Prefabrication, the umbrella under which Modular Integrated Construction (MiC) takes place, is not a new invention; it goes back to the 17th century [1] where houses were built in England and shipped all the way through the Atlantic Ocean to a village named “Cape Ann” back then. England was clearly a hub for prefabrication at those ages. In 1790, simple shelters where sent to settlements in Australia in order to be used as hospitals, cottages and storages. Similar structures were noticed in Africa, particularly in Sierra Leone and South Africa. Despite the aforesaid structures were not completely prefabricated, it provided a noticeable reduction in the labor force required [1].

In the year 1830, the Manning Colonies in Australia developed a new system as an improvement for the original one. In 1833, the light balloon frame system appeared in the United States, particularly in

Chicago but such system had a problem that it caught fire too quickly which led to the disastrous Chicago fire. Taylor [2] discussed the development of prefabrication starting in 1830 at Manning's portable colonial cottage to 1890 where standard cast iron catalogues were used at Macfarlane's Saracen Foundry in Glasgow, and how the architecture evolved from ad hoc buildings to planned production.

In 1851, a unique building named "Crystal Palace" was designed and built using the prefabrication technique, the materials used were iron, wood and glass. This building was designed by Sir Joseph Paxton in less than two weeks and constructed in only few months, the building was presented in Britain's Great Exhibition during that year. Another unique building was built in the United States, in the 1930s, named Aladdin and known for its' erection just in one day, the new design was promoted due its low cost per foot and high utilization of timber lengths. In 1932, George Fred Keck utilized the metal sandwich panel wall system to build "House of Tomorrow" and "Crystal House", and present them in Chicago World's Fair in 1933. The idea was implemented in the single-family homes in the United States, as they were built as module on a chassis in manufacturing facilities, this technique idea compromised 25% of this type of houses between years 1954 to 1968 [1].

Another famous building, the Hilton Palacio Del Rio Hotel in San Antonio, Texas is considered a prefabrication landmark as it was finalized from design to occupation in just 202 working days, the hotel consists of 21 stories, the first four stories were constructed using conventional technique, while the remaining stories, which were 496 prefabricated modules, were erected in 46 days [1]. According to [2], the utilization of off-site construction or prefabrication increased after World War II (WWII) as it provided a solution for the increasing demand of housing and provided a more dynamic solution compared to the traditional method. In the 90s, the world started adopting MiC in several functions such as hotels, prisons and houses. The 90s were evolutionary days for MiC, in 1999, the research community started discussing the financial benefits of automation and mechanization in construction.

From the 17th till the 21st century, prefabrication existed in the construction sector in various ways; it was adopted for its speed of erection and to cover the demand for housing after wars, like what happened after WWII. The widespread usage of prefabrication occurred starting from the beginning of the 21st century and MiC started to gain momentum in the last two decades, therefore, this research aims at reviewing the main features of MiC. First, a brief introduction will be provided to figure out the differences between various expressions used in this area. Second, the benefits of MiC will be discussed. Third, the challenges of MiC are going to be presented. Finally, we will present how MiC progressed in Hong Kong and what we concluded from our research.

2. DEFINITIONS

Prefabrication, hybrid systems, panelized system, modular construction technique, industrialized building system, pre-assembly, off-site construction and many other expressions can be found when researching about prefabrication and modular integrated construction; what really matters is the meaning of each expression and how the construction sector views each expression. Table (1) provides definition for these expressions. From Table 1, it can be concluded that prefabrication, industrialization, and off-site construction give the same indication when used or the same construction concept, all of them are referring to using manufacturing facilities away from site to construct building components then transport them back to site for installation. On the other hand, preassembly is another process which is concerned with putting together various components during manufacturing in order to reduce the amount of work on site. In general, building construction can be done using one or various types of prefabricated elements (i.e. hybrid systems). These elements can be 2D elements (i.e. panelized elements such as walls, floors, roofs, and columns) or/and 3D fully furnished modules that contains everything needed.

3. BENEFITS OF MiC

In this section we are going to demonstrate how MiC can enhance the construction sector of any given market and how various researchers were able to analyze and track the benefit of MiC and come up with facts and conclusions. Figure 1 represents the number of papers in each construction market that have previously discussed MiC and prefabrication. While, figure 2 represents how many references support each benefit of MiC benefits; which can be considered as an indicator for how common such benefits can be achieved and reflect a common agreement on certain benefits among the research community worldwide.

Table 1. Definitions of Scientific Expressions

Expression	Reference	Definition
Prefabrication	[2, 3]	"Prefabrication" which consists of two parts; the first is "Pre" which means something that was previously prepared or made and the second part is "fabrication" which indicates the manufacturing process itself and accordingly the word when utilized in a construction setting such as prefabricated buildings it shall mean buildings that were already manufactured.
Industrialization	[4-7]	A term used when relying on factories/manufacturing facilities to build parts of a building or the whole building, similar to prefabrication, and it is commonly used in Malaysia
Off-Site Construction	[2, 3]	Performing activities away from the construction site itself, which is the core concept of prefabrication as an idea, in order to enhance quality and save time, building components are manufactured in off-site facilities and then transported to site for installation/erection.
Preassembly	[2, 3]	Process which is concerned with putting together various components during manufacturing in order to reduce the amount of work on site
Modular construction	[1, 4, 6]	Modular Buildings or Modular structures that are built using the MiC technology which is the manufacturing of 3D fully furnished modules that are volumetric and box like that contains everything needed. This type offers very limited site operations which decreases the time of construction.
Panelised construction	[1, 4]	A system in which buildings that are manufactured from 2D elements which constitute walls, floors, roofs and columns. Ex: A famous hotel in China named Dongting Lake.
Hybrid construction	[1, 4]	It is a combination between Modular and Panelized systems, a famous example for it is the Meridian First Light House in New Zealand.

3.1. Time

MiC technology offers a benefit of time saving because it allows rapid construction. Simply, modules are brought to site then erected, and it overlaps the work on site with the work in the manufacturing facility [4, 8, 9]. Furthermore, MiC can eliminate almost 80% of the construction site activities hence, eliminating a huge amount of delay due to resource management and weather problems [4, 10]. Using the manufacturing facilities provides a smooth flow of activities in a linear way for repetitive work, even better than performing linear activities on site. The use of machines and automation technologies also helps in enhancing this process and in decreasing the time. In addition, it helped solve the skilled labor shortage problem occurring in countries like Malaysia [11]. Navaratnam, et al. [10] believes that due to better delivery arrangements of materials to the manufacturing facilities and due to the eliminated delays of weather conditions and disruptions, the time saving achieved when using MiC can reach 40%

compared to traditional/conventional construction methods, which means early operation of the project and accordingly a decrease in interest payments for capitals [12].

3.2. Risks, Health and Safety

MiC moves almost 90% of the construction activity to manufacturing facilities which eliminates a lot of risks like; weather condition, disruptions, equipment problems, labor low productivity and other sorts of risks that would make the project suffer more delay and incur extra costs [9, 12, 13]. The reduction in on site activities makes the site tidier [11] and decreases the occurrence of accidents among labors which enhances the construction industry and makes it safer [9, 11-13]. Kamali and Hewage [14] mentioned that when using MiC reportable accidents was reduced by 80% compared to conventional methods. In addition, the reduction in usage of equipment, mainly in MiC we use lifting equipment only, the risk of damage to private properties due to the presence of huge amount of large equipment decreases.

3.3. Cost

In general, the benefits of MiC from the cost point of view can be concluded easily. First, time is money [14] so as project duration is reduced the time-dependent costs are reduced such as crane renting cost [10, 11, 14]. Second, the site preparation and mobilization for MiC projects are much simpler, leading to a reduction in costs [12, 14, 15]. Third, the percentage of rework compared to the conventional methods would decrease to only 10 to 20% as a consequence of minimal on site activities, resulting in cost reduction for owners and less risk of budget overruns for contractors [9, 16]. Furthermore, during the bidding stage, a contractor will evaluate the risks of MiC to be lower than the traditional methods, as these methods include higher health and safety precautions [13], bigger exposure for adverse weather conditions [13], bigger risk of poor workmanship from labors resulting in more rework and finally, risk for damage to property is much higher [14]. This will reduce the risk percentage the contractor is taking into account during bidding stage.

In addition, it is standard procedure in projects that the contractor insures the project with various types of insurance policies as per the contract conditions. When using MiC, the feature of the project is different, it is much safer now which can lead to reduction in cost of insurance policies' premium. Furthermore, from the owner's perspective, the project shall not suffer from variation orders like the traditional ones, the MiC technique obliges all parties to a certain time after which no changes are allowed which leads to much lesser variation orders or no variation orders. By numbers, Kamali and Hewage [14] and Hong, et al. [17] stated that cost reduction in capitals when using modular construction can reach 10% while, Navaratnam, et al. [10] and Kamali and Hewage [14] discussed the benefit of lower material prices due to bulk orders when using MiC. Kamali and Hewage [14] mentioned that MiC reduces the labor cost by 25% compared with the traditional method.

3.4. Sustainability

Prefabrication or Off-site construction (OSC) helps in decreasing the wastage of material and provide cleaner environment [5, 9-14, 18]. Navaratnam, et al. [10] stated that OSC has great environmental positive impact from noise reduction and decrease in disruption by 30 to 50%. In addition, OSC buildings are known to promote recycling specially when using steel structure modules, Kamali and Hewage [14] reported that 76% of researchers confirmed the ability of MiC system to reduce construction wastage. Marjaba and Chidiac [18] stated that OSC, which ranges from prefabrication of cladding to prefabrication of complete modules, offers less wastage in material, reduction in environmental impacts compared to conventional method, and ability to build according to higher specification if needed. Furthermore, OSC allows the application of lean production principles which improves sustainability. In fact, OSC would result in wastage less than 5% [18], and it would also decrease the carbon emissions resulting from transportation due to the reduction of transportation required, particularly in MiC [14, 18]. In general, MiC provides positive impacts on the three aspects of sustainability; environmental, social and economic.

3.5. Quality

Quality enhancement is one of the most guaranteed benefits of MiC, the manufacturing facilities provide adequate fabrication [5, 8, 12] for all components in a better work environment with more advanced production lines, machines and automation technologies. The precision available in factories reflects in higher quality, better efficiency and easier application of higher specifications or standards [5, 9, 13]. The application of quality control (QC), quality assurance (QA) and total quality management (TQM) in manufacturing facilities is much better [8] and effective compared to its application on site, which paves the way to the application of lean production /Construction. The off-site production process allows close monitoring by multiple specialized persons and shall result in better quality for products [5, 10, 11, 13]. Kamali and Hewage [14] demonstrated two further benefits for MiC, first, the workers will have better learning curves when working in factories compared to site activities because of small tasks assigned to each worker which promotes "work specialization". Second, all of the material will be away from severe or harsh weather conditions, thus, the final products will have high quality building finishes.

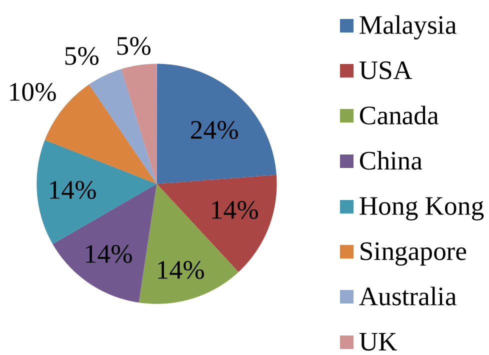

Figure 1. Various markets of previous studies.

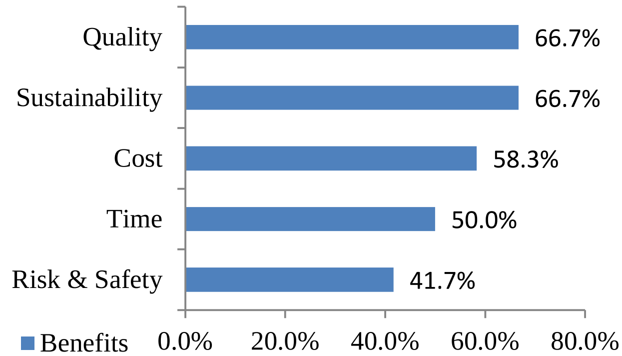

Figure 2. No. of papers mentioning each benefit

4. Challenges of MiC

Albeit the benefits of MiC, its' spreading in various construction markets lagged in the last decade, and Hong Kong city is a clear example for that. The reason behind this problem is that there are challenges crippling MiC from spreading. In this section, we focus the light on the details of these challenges. Figure 2 represents the number of references mentioning each challenge facing MiC, the numbers can be indicative of how common problems are occurring in various countries and markets.

4.1. Initial Investment Cost

Chai, et al. [4] stated that the application of MiC requires a large amount of initial investment cost to cover the expenses of the plant, machinery, moulds, formwork and suitable transportation arrangements. This, in turn, requires that the demand on such new business is good enough to make it feasible economically [9, 11, 14, 19]. Molavi and Barral [8] and Navaratnam, et al. [10] believed that the costs of design and engineering will increase when using MiC, in addition, MiC structures require more materials to sustain a safe structural system [8], which adds extra costs. Furthermore, the shortage of specialized contractors may lead to additional costs due to scarcity of required experience. Haron, et al. [12] stated that the high capital investments and high interest rates used when using MiC are not justified in the competition with traditional methods that offers lesser investment costs. Zhang, et al. [20] studied the barriers affecting the prefabricated housing in china and provided an order of importance for all these barriers from most important to least important, the result of this study concluded that the high initial cost barrier is the most crucial barrier holding the wider spread of MiC in the residential housing industry.

From the financing point of view, Velamati [21] believes that the financial sector is still familiarizing itself with the concepts of MiC and how it works. Lenders are still very cautions when dealing with MiC projects and they are more concerned about the completion of the project. This problem is occurring due to the scarcity of firms specialized in fabricating modules, so the lenders believe it is risky to fund these projects because if the modules manufacturer goes bankrupt they may lose their money. In other words, they believe that the risk of losing their money is high, consequently, they demand more guarantees which limits the fund. Hwang, et al. [19] studied the constraints facing MiC and how to mitigate them, the initial cost problem was ranked 5th according to his statistical study and the possible mitigation for it, are to implement feasibility studies, to develop software/systems that perform economic studies and to use BIM technologies.

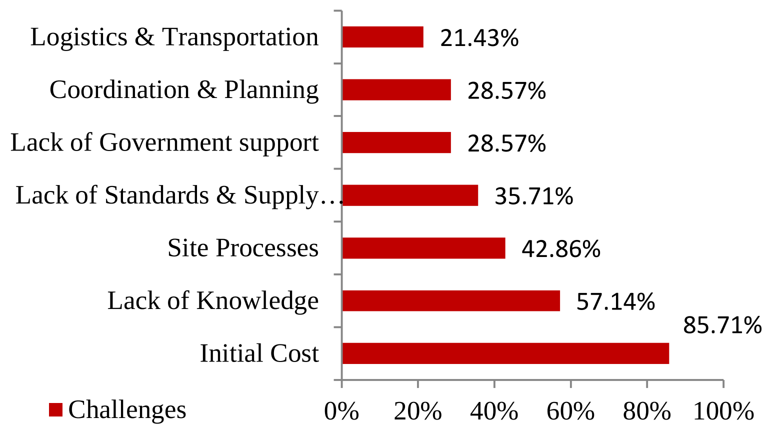

Figure 3. No. of papers mentioning each challenge

Schoenborn [13] mentioned the cost problems facing MiC and believed that the industry should push towards complete mechanizing of the manufacturing process, eliminate on site work and maximize the usage of recycled material in order to make MiC more cost effective. Rahman [22] believes that the need to purchase all the materials at the beginning of the project is burdening MiC and believes that if the demand is fluctuating this can lead to cost increase that would make MiC less cost effective compared to traditional methods. This study concluded similar results and ranked the high initial cost problem 2nd among other barriers identified in UK and China.

4.2. Logistics and Transportation

Each project has its own unique location and feature, and this will result in facing different traffic regulation and transportation regulation. Over populated areas will hinder the movement of modules or even restrict it, some roads may not be primarily designed to carry the load of the modules [14, 19, 22]. On the other hand, some module manufacturers allow maximum transportation distance in order to maintain the wellbeing of the module itself from damage [14]. In case of transporting to distant locations, the cost of this process must be studied well and the proper permits should be issued in order to prevent any delay that would negatively influence the benefits of MiC [14]. Shipping is another deal; it will require various procedure and regulations to prevent any damage to the modules and make sure all of them arrive to site with no damage. In addition, this whole process will have its restrictions in terms of size, weight and dimensions of the modules [14]. Rahman [22] ranked the transportation issue the 7th among other barriers in his study on UK and China, while Hwang, et al. [19] ranked the transportation problems the 8th among several constraints being studied and they suggested that the manufacturing facility should be placed close to the site to minimize the transportation costs and problems.

4.3. Coordination, communication and planning

The fragmented nature of MiC and the diverse nature of its stakeholders require an immense amount of coordination and planning in order to avoid technical and cost overrun problems [9, 12] as the design of MiC project is different from the conventional design. The modules itself require extra work to be accurately designed and fit for its purpose. Furthermore, a clear scope must be defined from the beginning in order to avoid any changes later on as changes are very hard or even impossible during the construction stage of the project. Detailed plan with a clear scope should be present as early as possible [14], in order to enhance the coordination and communication. Planning between the manufacturing facility and the site management is crucial in MiC, idle expensive equipment or large stock of modules on site can complicate the cost status of the project leaving all parties with losses and delays. For better control of the process it is recommended that the main contractor charges the responsibility of elements assembly on site and subcontracts the manufacturing facility work in order to have the upper hand in planning and coordination of the flow of work [21]. Furthermore, when using MiC in residential high rise buildings, the owner would require to occupy multiple stories while the project is not yet finished, others would rather occupy the building after all the on site activities are finalized. This process must be well planned and communicated among project parties in order to avoid any losses to any party [21]. As a solution, BIM can be a useful tool to enhance coordination, communication and planning between all stakeholders.

4.4. Lack of awareness and knowledge

Lack of knowledge about MiC leads to various complications for all participants, some of them fail to do their part effectively due to this problem while others provide poor quality outputs for the same reason [11, 12]. The problem gets even more inflated when owners are not aware of what MiC is and how it works so they tend to avoid it or sometimes neglect its benefits [14, 19]. In other cases, they know the benefits but lack the knowledge, so the process is not done correctly and therefore, they lose the benefits of MiC, mainly time and cost reduction. Similar concept was discussed by Navaratnam, et al. [10] who concluded that the knowledge of MiC needs proper communication and enhancement in order to allow for better implementation. Furthermore, the educational sector should step in and support spreading the knowledge and awareness related to MiC. In the same context, engineers being unaware of the essential elements for designing MiC building [9] decreases the probability of harvesting the MiC benefits. What makes things worse is the lack of research and development (knowledge) that identify the proper ways of implementing MiC. Another factor that contributes to the problem is the lack of awareness from the end users/ occupants/clients [14] which may affect the sales/rentals of the project and affect the cash flow of the employer. Furthermore, lack of awareness formed a suspicious attitude towards the performance and quality of MiC and a wrong belief that MiC buildings are of low quality due to its light weight [22].

4.5. Site processes

Site conditions in MiC may be simpler than traditional site conditions but it has additional requirements to fulfill its purpose correctly, such as additional space to be used for storage, mobilization and proper circulation for equipment. Thus, constituting a constrain in applying MiC. In addition, installation of modules requires advanced equipment and skilled labor which burdens the process even more [11]. Various literature mentioned that the lack of skilled labor forms a major problem and a challenge in spreading MiC [4, 9, 12, 14, 20].

4.6. Lack of codes, standards, standardization and supply Chain

Standardization is important for the stability of any industry; this can allow MiC to gain edge over other methods of construction. Component standardization is reported in the literature as a key factor affecting MiC [11, 12, 22]. The concept is to help decrease initial costs of design and mouldings. Furthermore, it is thought that standardization would be critical to the idea of reuse [23], and this shall help MiC become more sustainable by decreasing its life cycle wastage. In contrary, the lack of standardization is believed to cause wastage in materials and additional costs [12]. A study carried out in China by Zhang, et al. [20], ranked the challenges facing prefabrication in general and it ranked the lack of supply chain as the 4th most important challenge and lack of standardization as the 5th most important. The supply chain problem is due to the fact that the industry is fragmented and consisting of various types of trades [20, 22] and, it makes it hard to realize which components are available locally and which are not, making the planning and design stages even more complex and putting the project at risk of delays. MiC in each country, and in China specifically, needs more standardization, serialization, and scaling to establish the required supply chain of components and trades that shall promote MiC [20].

Lack of technical standards formulates a main barrier facing MiC and stopping it from spreading, some volumetric parts in projects were customized only for such projects and became one of its kind. These types of practices force redesigning every time and increases material waste. A solid reliable base must be established so that all parties can refer to during their work [20].

4.7. Lack of incentive and government support

Despite the numerous benefits of MiC, adopting MiC concept in the construction industry is slightly growing. One of the main reasons for this situation is the lack of support the governments are showing, and how they failed to provide enough incentives for owners/employers/investors to adopt MiC in their projects [12, 20]. Zhang, et al. [20], mentioned that there is insufficiency of promotive and incentive actions that would promote MiC. In addition, possible policies and facilitating regulatory mechanisms are not provided. In fact, it's part of the governments' roles as the mentor, supervisor and facilitator of the whole system to make sure that if new technologies are beneficial, they are well promoted among consumers. The situation may even get worse without the required incentives and promotions, the public perception of MiC is defensive, and they believe that MiC technique provides projects with lower quality. In addition, other companies have certain mindsets and they don't want to try anything new, this type of thinking is reluctant to innovate or change to MiC without proper incentives [22].

One of the incentives that can be done is to provide some tax relief measures to promote for the adoption of MiC, this can lessen the initial costs of the projects and encourage companies to adopt MiC, and this can help in overcoming the challenges facing MiC. Furthermore, many countries lack special legalization and international standard specifically made for MiC, the pioneer in this action is the Danish government who made the world's first modulus system legalization and standards [20, 24]. In this section, we tried to cover the important and common challenges that are hindering the growth of MiC, but this doesn't mean that these are the only challenges existing. The literature mentioned more challenges like lack of experience in module installation, lack of design experience, decreased flexibility for late design changes, requirement of early commitment [19], lack of large capacity hoisting equipment, product quality problems [20] and lack manufacturing capability [9, 20].

In addition, it is worth mentioning that we have discussed the details of challenges that were present in multiple literature not a specific one. Some advanced studies identified the challenges in certain markets and ranked those challenges then discussed possible solutions. Table 2, provides the ranking of different challenges to adopt MiC in two studies in two different countries; one was carried on prefabrication in general for the Chinese market [20] while the other studied MiC challenges in Singapore [19].

Table 2. Ranking of Challenges based on specific studies in different construction markets

Market Location	China	Singapore

Challenges	Zhang, et al. [20]	Hwang, et al. [19]
Initial Cost	1st	5th
Logistics & Transportation	N/A	3rd & 8th
Coordination, Communication & Planning	N/A	1st & 10th
Lack of Knowledge	N/A	13th
Site Processes	N/R	9th
Lack of Standards & Supply chain	4th & 5th	N/A
Lack of Government support	6th	N/A

Notes: N/A: Not Applicable N/R: Not ranked/Out of ranking

5. MiC in Hong Kong

In April 2018, an International Conference on Modular Integrated Construction was organized by the Construction Industry Council (CIC) and the Development Bureau (DEVB) in Hong Kong, many experts from all over the world were invited. The aim of the conference was to build an understanding of this new method trends worldwide along with the development opportunities and challenges facing it [25]. In the fiscal year 2018-2019, the Hong Kong Special Administrative Region (HKSAR) represented by its financial secretary proposed USD one Billion as Construction Innovation and Technology Fund (CITF). MiC was one of the new technologies that the aforesaid fund supports. This aims to promote the usage of MiC because of how this method can offer in terms of productivity, quality and sustainability [25]. In January 2019, the CIC organized a “Client Contractor Supplier Forum on MiC”. Speakers were invited from the various Housing parties and academic experts as well. The aim of this forum is to draw a road map for the development of MiC and its challenges. The forum had a session for discussion between construction parties to help smoothening the project processes, such as; planning, design, procurement and government regulations [25].

MiC had a ground breaking in Hong Kong with its first pilot project starting in September 2018, this new project is a disciplined services quarter for the Fire Services Departmental at Pak Shing Kok, Tseng Kwan O. The project consists of 5 quarter blocks, each of height 16 to 17 stories, each floor shall contain around 8 modules and the total shall be 648 modules. Around 50 m2 will be dedicated for three bedrooms, a living room, a dining room, a kitchen and a bathroom. Building facilities will include building management office, covered walkways and recreational spaces such as multi-function room, an outdoor playground for children, car park, etc. The project is expected to be finished in 2021 [25]. The second MiC project in the history of Hong Kong is the students’ residence at Wong Chuk Hang site owned by the University of Hong Kong. It is expected to be completed before the fourth quarter of 2023. The project consists of two 17-story residential towers on top of a three-story podium structure. It will contain single rooms of an area 6.5 m2 utilized by students and staff, also the building includes recreational spaces, canteen, car park, etc [25].

6. CONCLUSION

From our review, we can conclude that MiC is the most modern technique available for the construction of buildings and it represents the future of construction, with its various benefits and what it can offer to the construction sector we can say that this method can be relied on in solving the problems of our industry, such as; sustainability, quality, time, etc. In addition, MiC can provide a universal solution for housing problems in some countries and cities like Hong Kong, its rapid execution feature increases its competitiveness against other methods. Nevertheless, the challenges facing MiC are crucial and can prevent this technique from spreading, that's why providing solutions for these challenges is a must. We aim that this paper provides the Hong Kong construction sector insights on how to benefit from MiC and alerts regarding the possible challenges that they might face during the implementation.

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