Technologies in Modular Integrated Construction

Chapter 1 Introduction

This dissertation investigates the application of Building Information Modelling (BIM), Internet of Things (IoT), cloud computing on Modular Integrated Construction (MiC) in Hong Kong. MiC is one of the latest forms of construction technologies. Because of the complexities of the offsite module manufacturing of MiC and the joining of modules to form a building, BIM, IoT, and cloud computing are indispensable to MiC. MiC is a new construction technology. However, it needs high level of information flow to ensure successful implementation. It is thus crucial to investigate how to enhance the effectiveness and efficiency of MiC construction. Therefore, a full picture is needed to know how BIM, IoT, and cloud computing can be integrated.

1.1. Background of this Study

1.1.1. The Nature of MiC

MiC uses modules premanufactured in factories from distance and integrates the modules to form a building (HKBD, 2018). When compared with traditional form of prefabricated construction, the modules are built to greater details. Instead of just integrating a wall to a building, it encompasses finishes, fixtures, and fittings of a building (Smith, 2010, Lacey et al., 2018). Specifically, there are two major steps in MiC. The first one is to manufacture the modules that need to be integrated to a building at a distant factory. The second one is to integrate the modules to form a building (PolyU, 2020). Figure 1 offers a clear view of the process of MiC construction. The left-hand side of the picture show the manufacturing of modules in MiC in a factory. The right-hand side of the picture shows how heavy equipment can be used to move the block and install them to form a building.

usage and integration of IoT, BIM, and cloud computing in MiC is to ensure seamless and complete collection, sharing, and processing of information needed for MiC.

Currently, the use of BIM, IoT, and cloud computing in MiC has many rooms for improvement. According to Tang et al. (2019), the integration of BIM, IoT, and cloud computing is a powerful method of improving the efficiency and effectiveness of construction and operation. However, Tang et al. (2019) also suggested that there are many rooms for improvement in such technologies, for example, real-time model update based on IoT device readings, use of other leading technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). Other suggestions include providing standards for information integration and management for the use of BIM, IoT, and cloud technology and ensuring real-time big data analytics, BIM and IoT data storage, and using cloud-based IoT integration portal for BIM (Tang et al., 2019). Therefore, the use of BIM, IoT, and cloud computing in MiC has plenty of rooms for improvement.

Overall, because of the need for more information sharing and processing from MiC and the imperfect usage, this research aims at building a knowledge framework on the application of BIM, IoT, and cloud computing of MiC in Hong Kong currently and in the future.

1.2. Aim, Objectives, and Research Questions

This research aims at building a knowledge framework on the application of BIM, IoT, and cloud computing of MiC in Hong Kong currently. This research aim is supported by the following objectives:

- To identify the latest requirements and information technology infrastructure of using BIM, IoT, and cloud computing of MiC,
- To explore the construction processes before adopting BIM alone in construction or MiC construction,
- To investigate the construction process improvements after adopting such technologies in MiC construction, and

Chapter 2 Literature Review

There are several sections in this chapter. They are a more detailed introduction of MiC, the process of BIM, the use of IoT and cloud computing in construction, the barriers, and risks of MiC in construction, facilitating factors for MiC in construction, the way that such techniques improve construction, and the current application status of MiC in construction.

2.1. MiC Construction

This section has several sub-sections. They are about how MiC differentiates from other prefabricated construction techniques, materials used in MiC construction, and the method of how to connect the joint used in MiC construction.

2.1.1. The Differences between MiC and other Techniques for Prefabrication Construction

Lacey et al. (2018) and Lacey et al. (2019) provided detailed descriptions of the construction sequence, materials utilized, and processes employed to manufacture MiC. According to Lacey et al. (2018), MiC is a construction method that involves the manufacturing of components called modules in factories off the construction site. It is a process for generating off-site building components that are about volumetric units in size and may function as a structural part of a project (Lacey et al., 2018). MiC structures are composed of a range of structural approaches and materials, rather than using only one type. The major advantages of MiC are shorter building time, potentially better quality, and lower waste in building materials.

More importantly, MiC must be differentiated from other categories of prefabricated construction methods that use two-dimensional panels built within the construction site. First, instead of using two-dimensional panels, MiC uses three-dimensional (3D) panels that are manufactured off the construction site. They are then used as modules and installed to a building on site (Ecoliv, 2017). Second, instead of only using constructing simple structures such as panels and walls which are two-dimensional (2D), MiC features three-dimensional and more

2.1.2. Construction Materials used in MiC

Module classification, per Lacey et al. (2018), comprises a range of MiC types. The first is a steel structure with a modular design. The first is a steel structure with a modular design. It is employed in the building of hotels and residential units. Due of its greater robustness, this technology is well-suited for high-rise building. It is, however, caustic, and devoid of design requirements. The second is a light steel steel-frame module. It is lighter in weight and is often utilized in structures with fewer than ten storeys. The third one is the steel-container module It is primarily employed following disasters, military operations, and residential construction. It is incredibly portable and is used to recycle shipping containers. However, further reinforcement is required to assure the container's stronger and tenser when the wall apertures are cut (Lacey et al., 2018).

MiC also uses concrete apart from steel. Precast concrete modules are used in hotels, prisons, and guarded housing. In hotels, jails, and guarded housing, precast concrete modules are employed. It protects against fire, provides acoustic insulation (soundproofing), and has a great performance in thermal condition. Moreover, it has a higher mass to ensure compliance with vibration regulations and a higher capacity. As a result, it is significantly heavier than steel buildings and more prone to shatter at the side (Lacey et al., 2018).

Apart from the previous two, timber framing is also used in MiC. However, it is less popular It is typically utilized in constructions with one to two stories, educational institutions, and dwellings. Due to its ease of cutting and malleability, it may be a sustainable material that alleviates manufacturing challenges. However, it is very combustible and has a limited shelf life (Lacey et al., 2018). Last, there are also use of composite materials in building MiC module. Lacey et al. (2018) discusses the following materials as potential composites for MiC in a number of applications in the following table 2.

connection system is to connect modules to the ground foundation of a building. They include in-situ or precast concrete footings, and augured steel piles (Lacey et al., 2019).

2.2. The Barriers and Risks, and Facilitating Factors of MiC in Construction

Scholars have conducted many research studies on the barriers, risks, and facilitating factors for using MiC in construction (such as Wuni et al. (2020b), Wuni et al. (2019), Hussein and Zayed (2020), Darko et al. (2020)). The adoption of MiC is essential in Hong Kong since there are tremendous housing needs. However, Hong Kong experiences a shortage and aging of construction workers. First, because of the declining productivity of labours, projects of the same monetary amount need 16.67% more workers in 2018 than before comparing with 1997 (HKGov, 2019). Besides, the median age for construction workers in Hong Kong was 51.4 in 2017 (HKGov, 2019). Third, the younger generations are reluctant to enter the construction industry since it is physically demanding. Therefore, there is a need to seek an alternative construction method to reduce the demand for labours. Since MiC uses few labours and offers potentially better quality and durability (Lachimpadi et al., 2012), it is selected as a new construction method.

Although MiC uses fewer labours, it has many barriers and risks. According to Wuni et al. (2019), major barriers include the (1) difficult requirements for integrating the supply chains for transporting the modules to the construction sites, (2) delay in delivery of the modules to construction site, (3) high initial capital costs for the investment in module manufacturing plants, (4) information gap and inconsistency in the supply chain, (5) managerial complexity, and (6) limited experience and expertise in MiC construction. According to Wuni et al. (2020a), the multiple barriers or risk factors of MiC can be classified in three categories. They are stakeholder and supply chain risks, design and capabilities risk, financing risks, and regulatory risks (Wuni et al., 2020a). Examples of stakeholder and supply chain risks are stakeholder fragmentation and management complexity and supply chain information gap and inconsistency (Wuni et al., 2020a). Examples of design and capabilities risks are errors in installing the modules to the building, complex rectifications and rework needed once installation errors occur, constant change of design or

2.6. Other New Technologies of MiC in Construction

There are other new technologies using BIM-MiC-Cloud Computing in MiC. First, there are new technologies in helping constructors to track the production processes in MiC factories. It also helps constructors to identify deficiencies in production processes earlier. Martinez et al. (2019) suggested a vision-based method of comparing real-time MiC steel frames in production with its BIM drawing to detect any deficiencies. Besides, Arashpour et al. (2020) used laser scanning to collect information on the module produced and compared them with the BIM models. It helps constructors to identify discrepancies between design and production early. Furthermore, An et al. (2020b) and An et al. (2020a) proposed a BIM-based approach to assess the ability of a machine in MiC factories to produce a construction product. Last, Rashid and Louis (2020) showed the use of audio information generated from different production activities such as hammering, drilling, and nailing to automate the tracking of production activities in real-time.

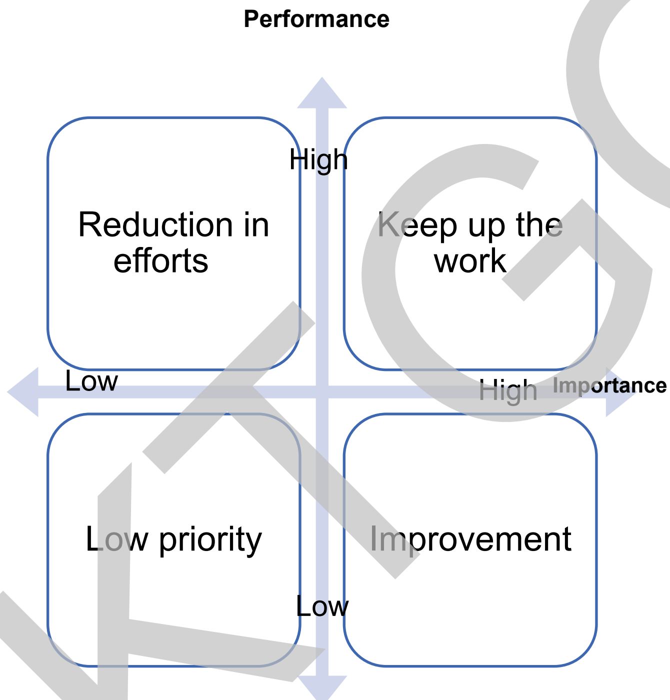
Besides, new technologies can also help with integrated supply chain management for optimal scheduling, equipment planning, and transportation. For example, Lee and Hyun (2019) have used simulation model to find a near-optimal production sequences, number of transportation trucks, and on-site installation schedules of MiC modules to minimise modules stacked on-site. Besides, Hsu et al. (2019) developed an optimisation model to find the optimal production and logistics decisions at the minimal costs at different stages of the supply chain. Last, there are technologies in helping to visualise the damage or distress in the structure of MiC building using sensors (Valinejadshoubi et al., 2019).

2.7. Research Gap and Chapter Conclusion

This chapter discusses the nature of MiC, the use of raw materials and systems of joining the modules, the barriers, facilitators, and advantages of using MiC in construction over the conventional construction method. Most important, it discusses the current research study of the use of MiC in integrating BIM, IoT, and cloud computing. By summarising the above discussion, the aim of the integration of BIM, IoT, and cloud computing is to ensure seamless synchronisation of information for MiC construction. At the

The second part uses the methodology of importance-performance analysis. According to Feng et al. (2014), importance-performance analysis (IPA) is to investigate which actions require maintenance of practice, improvements, having low priority or too many efforts on. The result of the IPA is divided into four zones plotted on a figure (See Figure 4).

Figure 4 The Four Zones in IPA Analysis



Source: Feng et al. (2014).

The four zones are "keep up the work," "reduction in efforts," "improvement," and "low priority". They vary in levels of importance and performance. "Keep up the work" means high importance and high performance. "Improvement" means high importance but low performance. "Reduction in effort" means low importance but high performance. "Low priority" means low importance and low performance. The result of this analysis means that the organisation needs to focus their efforts on areas of "keep up the work," and "improvement."

According to the semi-structured interviews of construction personnel who are familiar with MiC, the geographical distance, communication, and cultural problems between the Hong Kong construction sites and the Mainland China prefabrication factories are often problematic. There is substantial geographical distance, differences in language and culture that hinders the communication, coordination, and supply chain between the two parts. Besides, there is no quarantine-free border crossing between Hong Kong and Mainland China now because of the COVID-19 pandemic. It makes it difficult for Hong Kong personnel to go to Mainland China to conduct physical inspection and coordination between Hong Kong and China. Although the Hong Kong construction personnel try to resolve this problem by having staff members to stay in Mainland China for a long time to conduct such tasks, it is still less desirable to do so unless the quarantine-free border crossing between Hong Kong and Mainland China resumes. The following quotation from one interviewee sums up the difficulties of such communication and coordination:

"Given the current situation, it is extremely difficult to implement MiC in Hong Kong in a very large scale. It is very costly to set up any MiC prefabrication factories in Hong Kong because of the lack of land, high land price, and lack of expertise and personnel in such areas. We must rely on the factories located in the Greater Bay Area (GBA) region to conduct such prefabrication tasks. However, there are several problems in this approach.

First, there are different building specification requirements in Hong Kong and Mainland China. It is sometimes difficult to communicate and explain such requirements to them to ensure that they comply fully with such requirements to achieve the quality needed in Hong Kong. Second, there are often language barriers between the personnel in the Mainland China factories and the Hong Kong staff because we speak different dialects.

Third, the border between Mainland China and Hong Kong has been closed for almost two years (at the time of interview). It is difficult for us to afford a large number of our team members to physically go to the factories located in the Greater Bay regions. We cannot conduct very thorough physical inspection, communication with those operators and workers in the factories in selecting those prefabrication factories. Often, in substitute, we must rely on few staff members that stay in the

Apart from the synchronisation of data on site, they also hope for better technology to improve the coordination of their collaborators off the site such as the prefabrication factories located in GBA of Mainland China. Some of the interviewees heard of the new technologies in other IoT as documented in Section 2.4.1 and Section 2.6 in helping them to track the progress in those plants such as laser scanning, LiDAR, audio information. However, they are still not deployed in practice.

4.4. Research Question 4: The Processes of MiC Construction Using BIM, IoT, and Cloud Computing

This research question is about the current processes of MiC construction using BIM, IoT, and cloud computing in Hong Kong construction sites. The optimal stage, as planned by the constructors, is to promote data synchronisation from the use of IoT downwards at the construction sites to the synchronisation, processing of data at the middle. The final product is a greater level of automation of status tracking at the construction site and decision-making. They want greater automation in the planning of production of modules, transportation scheduling of modules, equipment planning, crane operations, workforce planning and safety, inspection of modules, and processes of assembling the modules, cost management and budgeting, etcetera.

Their description of such target system of BIM-IoT-Cloud computing resembles the logic of system-building as shown in Figure 3 and Section 2.5 in Chapter 2. However, the current processes are still far from the desirable taget system. First, the scanning of RFID code, QR Code and NFC sometimes does not work, making complete real-time synchronisation of data difficult to achieve. Second, the BIM and cloud computing software and system architecture take time to configure and tune for the best automation of processing. Areas such as more automation of transportation scheduling, planning of module production with the worksite situation, equipment planning, and crane operations are the most difficult to configure. Sometimes, bugs and system errors are inevitable. Third, there are serious financial cost concerns in the building of such BIM-IoT-cloud computing system. Without achieving economies of scale by now, there are doubts of whether