IPC 2020

Proceedings of the 8th International Conference on

Innovative Production and Construction (IPC 2020)

"Towards Advancement in Technologies and Processes for Smart Buildings and Construction"

7th-8th December 2020, Hong Kong

Edited By:

Jack C.P. CHENG and Moumita DAS

The Hong Kong University of Science and Technology

Effectiveness of BIM Enabled Modular Integrated Construction in Hong Kong: Applications and Barriers

Lee Ka Wing, Salman Tariq & Tarek Zayed
The Hong Kong Polytechnic University, Hong Kong

ABSTRACT: *In recent years, the Hong Kong government has been actively encouraging the construction industry to use Building Information Modelling (BIM) for enhanced productivity and sustainability. This study has thoroughly examined the effectiveness of BIM for the local MiC industry by identifying the list of potential applications and barriers which are closely examined and discussed. Interviews of local construction experts confirmed the validity of the list, and the subsequent questionnaire survey analysis revealed the relative significance of applications and barriers. The results showed that the use of BIM would be more effective in the design phase rather than the latter MiC project phases. The overall output of this study would facilitate stakeholders in understanding the benefits of BIM-enabled MiC technology for Hong Kong and in formulating better strategies to overcome the barriers towards its successful implementation.*

KEYWORDS: *building information model, BIM, modular integrated construction, MiC, off-site construction*

1. INTRODUCTION

Modular integrated construction (MiC) is a game-changing innovative disruptive technique that transforms the fragmented on-site construction into a value-driven production and assembly of prefabricated modules (Zhai et al. 2019). In a typical MiC project, the prefinished modules (with complete fittings and fixtures) are manufactured in an off-site factory environment and are transported to the construction site for assembly and final installations (Wuni and Shen 2019). The perceived benefits of MiC include shortened construction span, ameliorated labor safety, enhanced construction quality, minimized waste, and improved productivity (Pan and Hon 2018). These advantages make MiC especially suitable for regions dealing with housing shortage problems (Zhai et al. 2019). Hong Kong is one of the world's most densely populated metropolis (Jaillon and Poon 2008) which triggers the development of high rise buildings to address space and dwelling constraints. However, Hong Kong's construction industry faces acute problems such as aging workspace, reliance on expensive local labor, and escalating construction costs. In order to uplift construction productivity and sustainable growth, HKSAR (Hong Kong government) has brought forward MiC as the new policy initiative (Pan and Hon 2018). As a part of the policy, HKSAR has established a construction technology and innovation fund to promote MiC and digitization.

MiC has been an established construction approach in modern countries e.g., Japan, the UK, the USA, Singapore, and New Zealand. Successful delivery of MiC requires three main pre-requisites: 1) consistent information delivery, 2) well-coordination between stakeholders, and 3) smooth supply chain (Zhai et al. 2019). MiC, a relatively new concept in Hong Kong, inevitably necessitates meticulous arrangements from AEC (architects, engineers, and contractors) professionals right from the early stages such as the adoption of new digital technologies aiming to facilitate information exchange during the whole project lifecycle. Building information modeling (BIM) is one such technology that has been promoted by HKSAR for several years. For example, a technical circular issued by the Hong Kong Development Bureau made BIM technology mandatory for capital works projects exceeding HK$30million.

In contrast to the traditional construction, several challenging tasks are encountered in MiC such as the coordination and fabrication of MEP (mechanical, electrical and plumbing) systems particularly in the congested spaces to avoid interference and to comply with the operation criteria (Lu and Korman 2010). BIM appears to be an effective approach to circumvent these challenges. However, the integration of BIM with MiC in Hong Kong is still in the preliminary stages (Darko et al. 2020) and its effectiveness remains to be explored thoroughly. This research, therefore, aims to fill this knowledge gap using literature, interviews, and surveys from local AEC professionals. Rest of the article is organized as follows: Section 2 provides an overview of BIM background in general and its implementation in Hong Kong; section 3 explains the research methodology adopted for this study; section 4 summarizes the applications and barriers of BIM in MiC from the literature review and a case study; section 5 elaborates the details on the interviews from experts to finalize the questionnaire survey; section 6 and 7 presents survey analysis; and section 8 provides the conclusions, recommendations, and future research directions. The overall output of this study would facilitate stakeholders in understanding the benefits of BIM-enabled MiC technology for Hong Kong and in formulating better strategies to overcome the barriers towards its successful implementation.

2. BIM BACKGROUND AND IMPLEMENTATION IN HONG KONG

BIM is commonly defined as a process of generating a virtual 3D model to facilitate data sharing among the construction and design teams. The model contains relevant building data such as precise geometry, design details and specifications, scheduling and estimations, quality of materials, etc. to support the entire project phases including design, on-site installations, and operation-maintenance. Compared to the conventional 2D modeling which depicts graphical entities in terms of lines and arcs, BIM technology enables the formation of smart digital semantic models, containing the complete physical and functional information, of the entire building system including walls, beams, slabs, columns, and MEP systems. In short, BIM creates a visualize model with explicit details to enhance communications and collaborations between designers and builders for successful project delivery. Moreover, BIM allows integrations with other technologies such as Geographical Information Systems (GIS), Radio-Frequency Identification and Geometry (RFIG), and even 3D printer to keep up with the changing innovation requirements.

Since the past few years, HKSAR has been proactively promoting BIM for higher production efficiency and to reduce the on-site labor requirements. The Public Housing Authority (HKHA) has adopted BIM in different ventures for 1) site planning and sequence simulation, and 2) financial control and progress tracking. The Mass Transit Railway Cooperation, Airport Authority, and the Architectural Service Department have also utilized BIM in important projects e.g., Shatin to Central rail link, Express rail link, Midfield Concourse, CX Cargo Terminal, 3D Laser Scanning and Photogrammetry for Heritage Information Management, Kai Tak Nullah Improvement Works, etc. (Poole 2014). Among private developers, some major companies have started hiring BIM professionals extensively and are even expending on equipping their employees with necessary tools and pieces of training to catch up with the advanced development trend. Furthermore, the use of BIM has become mandatory for public projects worth more than HK$30million, following the detailed directive issued by the Development Bureau in December 2017. A revised technical circular was issued a year later in response to the feedback of the Works Department to further enhance the adoption of BIM in public works projects. These initiatives indicate the government's seriousness in the implementation of BIM. Moreover, Hong Kong BIM stakeholders are also collaborating with the CIC towards the strategic adoption of BIM in the Hong Kong construction industry. CIC is using both push and pull strategy to advocate clients and contractors to utilize BIM technology (Poole 2014). This research aims to provide government authorities and the private sector an insight into the possible applications of BIM in MiC and the barriers that need to be addressed through a greater commitment of construction industry stakeholders.

3. RESEARCH METHODOLOGY

This study has taken a systematic research approach (Figure 1), combining the literature review, a case study, interviews, and survey analysis. While the details are mentioned in the relative sections, the overall process can be summarized as follows. Firstly, a thorough literature review was conducted to understand the benefits and issues related to the implementation of BIM in general and then in relation to the MiC industry. This step led to the shortlisting of possible applications of BIM in MiC and the barriers. Secondly, a case study of a BIM-enabled MiC project was carried out to further corroborate the applications from a real project. Thirdly, interviews were taken from four industry experts in Hong Kong to validate the findings from the literature which also led to the finalization of the questionnaire survey. Fourthly, a survey analysis based on the responses of local AEC professionals was conducted to find the relative significance of the shortlisted applications and barriers.

4. BIM EFFECTIVENESS IN MiC

Lawson et al. (2014) reported that the momentum behind MiC popularity in the past decade can be attributed to 1) off-site production of modules during the execution of sub-structure resulting in overall construction time-savings, 2) reduction in labor requirements making the construction site less crowded, improving the working environment and site safety, 3) minimization of usage and wastage of construction materials and re-utilization of modules from dismantled MiC building ensuring sustainability, 4) realization of higher construction quality control, better acoustic and thermal insulation, and fire safety due to the double skin nature of modules, and 5) reduction in noise and disruption during the construction period. Although MiC technology has the potential to deliver several advantages over traditional construction methods but certainly has limitations e.g., requiring higher accuracy in design, better coordination between the project parties, better planning on transportation, etc. To overcome the limitations, BIM integration provides a digital platform to optimize the benefits of MiC technology.

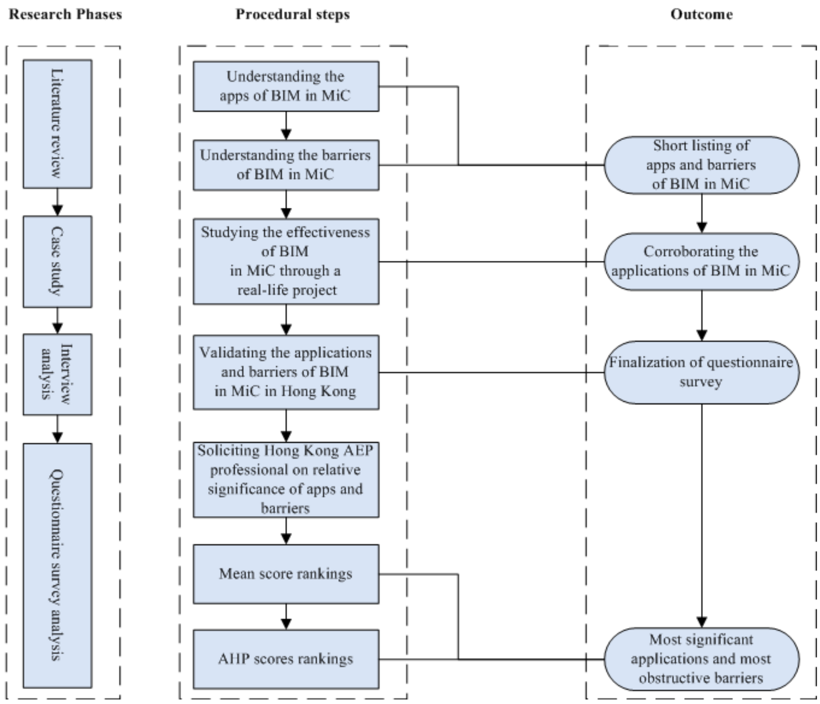

Fig. 1: Research Methodology

4.1. BIM Applications in MiC

4.1.1. 3D Visualization

BIM allows the designer to generate 3D models with the user inputs. At the conceptual phase, the designer can illustrate different 3D models to the client which makes decision making easier at the early stage. Rendering feature generates the pictures of the final product (both internal and external design) which fully resembles the photos as if taken from the real world. If required, BIM has made the whole process of amendments and visualizing the effects of amendments on the final product easier. To facilitate the overall design work, such an early decision making is particularly useful for MiC projects (Johansson et al. 2014).

4.1.2. Clash Detection

In the traditional 2D construction drawing method, clearance of all the clashes between MEP and structure at the design stage is difficult. Clash clearances are typically conducted at the construction stage resulting in variations from the original design (Tatum and Korman 2000). Such variations could be a disaster for MiC projects since the modules are produced off-site, and on-site modifications may lead to cost overruns. BIM clash detection feature helps to sort out the construction clashes in the design phase, thus ensuring an error-free model before off-site manufacturing of modules. For instance, in Aquarium Holton Garden Inn Project, Atlanta, cost-savings, and time-savings were estimated to be US$0.2M and 1,143hrs, respectively, owing to the BIM-enabled detection of 590 collisions between the structure and MEP system in the design phase (Azhar 2011).

4.1.3. Better Communication and Coordination

Goh et al. (2014) reported that BIM enables better communication and coordination among project parties which ultimately improves productivity. In MiC projects, early design completion is a critical success factor for which effective communication is inevitable. BIM creates a central sharing mechanism allowing project parties to work on a single model simultaneously. Ease in updating and exchanging information results in improved interoperate-ability between project team minimizing communication costs and design errors.

4.1.4. Analysis, Simulation, and Optimization

BIM provides analysis and simulation functions such as structural analysis, fire evacuation simulation, lighting simulation, acoustic analysis, energy efficiency analysis, MEP optimization, etc. (Lu and Korman 2010). In the AEC industry, it is common to presume that the tolerance/variation during the execution complies with the design and building codes to eliminate the need for checking (Garrigo et al. 2017). However, the simulations and optimizations in BIM resolve tolerance issues before manufacturing modules. Therefore, through adding such a piece of information in the form of textual data in BIM, the tolerance can be checked effectively.

4.1.5. Parametric Modelling

BIM-based parametric modeling permits the architects to design a model that links every element with its function and other criteria together as a system. Through this function, the designer can create intelligent models which let other parameters to be adjusted automatically when one parameter is changed (Shang and Shen 2014). For example, if a rule is created that the wall shall reach the ceiling height, then the wall height is adjusted automatically in accordance with any change in the floor to ceiling height.

4.1.6. Quantities Take-off and Cost Estimation

In traditional cost estimations, the quantities are measured from a set of drawings such as architectural, structural, MEP, civil, and landscape drawings. The process is not only time consuming but also dependent on the accuracy of the drawings; any discrepancy requires amending the errors and revising the measurements (Andersson 2016). BIM has enabled the quantities to be extracted directly from the model and any revisions can be calculated automatically. This feature, in combination with parametric modeling, establishes a reliable platform for the MiC project to forecast the budget requirements efficiently.

4.1.7. Improved Pre-Fabrication Levels

Due to the discrepancies in traditional 2D drawings, the client generally feels less confident in adopting MiC due to its low error tolerance. The production of error-free BIM models minimizes off-site pre-fabrication risks. Ezcan et al. (2013) argued that a higher level of IT integration is required for streamlining the off-site manufacturing process. BIM provides easy integration with other information systems such as numerically controlled computer machinery to improve the design, detailing, fabrication, and erection of MiC modules.

4.1.8. Scheduling and Logistic Planning

BIM allows the contractor to simulate and evaluate construction sequencing, and coordinate trade activities on site. The project team can identify construction progress at any time and compare the planned schedule with the actual schedule. In MiC projects, with the utilization of BIM, the contractor and manufacturer can coordinate the delivery of modules, determine feasible delivery routes, plan site logistics, and test the delivery plan. BIM can also be used to develop a lifting and hoisting plan for modules. For sites with limited storage, Just-In-Time delivery can be employed through BIM. Further, BIM-RFIG integration can help track the construction sequencing to avoid misplacement of modules (Staub-French et al. 2018).

4.1.9. Assembly Training with BIM

One of the important functions of BIM is to produce walkthrough animations. With the help of BIM 4D models, the construction sequences can be visualized in the form of animation videos. This feature can be used to train workers and operator for a greater familiarization with the construction logistics (BCA 2016). Together with Virtual Reality technology, employers new to MiC execution can experience on-site working in a reality-based simulated environment which may eliminate the possibility of creating costly mistakes (Sampaio 2018).

4.2. A Case Study to Validate the BIM Applications in MiC

The effectiveness of BIM-enabled MiC established through literature was further validated through a case study of a real-life project. A project from Singapore was selected due to the 1) socioeconomic similarities between Hong Kong and Singapore, and 2) vast experience of Singapore in similar projects. North Hill Student Residence Hall, Nanyang Technological University (NTU), Singapore (Sacks et al. 2018) was chosen for this purpose. The project was executed using MiC technology, however, the podium, transfer slab, and the central core were cast using the in-situ concrete construction method. BIM was employed in this project right from the beginning to facilitate the design and to optimize the benefits from MiC throughout the construction phase. The case study analysis found at least six (i.e. 3D visualization, clash detection, parametric modeling, analysis and optimization, communication and coordination, and scheduling and logistics planning) of the nine reported BIM applications. The success of this project proves the usefulness and effectiveness of applying BIM in MiC.

4.3. BARRIERS TO THE IMPLEMENTATION OF BIM IN MiC

4.3.1. AEC Industry Resistant to Change

The construction industry, in general, is not aware of the importance of BIM and hesitant to accept this new technology. The industry is used to 2D drawings of construction methods for ages and considers current software inefficient in handling construction projects. BIM adoption means changing the work environment but most construction companies, not yet convinced of the promised BIM value, are observing the outcomes rather than taking the risks of embracing BIM (Ahmed 2018).

4.3.2. High Initial Cost

In order to adopt BIM, the construction industry not only needs to invest in the software and replacement of hardware to support the software but also in the staff training and professional recruitments. Small and medium enterprises are incapable of bearing such a financial burden. In large companies, shareholders are only concerned about profits and are not willing to invest in a technology that requires large upfront expense but no guarantee of the return (Hasan and Rasheed 2019).

4.3.3. Insufficient Training and Lacking BIM Professionals

Although governments including HKSAR is promoting BIM for several years still the local industry in most countries do not find themselves at ease in embracing such innovative technology. Finding and recruiting BIM experts is difficult due to high salary demands. Salaries offered are sometimes not that attractive to overseas experts. A further dilemma surrounds the fact that not enough academics are trained in BIM and therefore, only a handful of educational institutes offer BIM courses. Companies' reluctance in paying for extra money for employees' training is another hurdle. Generally speaking, as of now, there is a shortage of BIM professionals globally (Sacks et al. 2018).

4.3.4. Legal Responsibilities and Liability Issues

Compared to the traditional contract documents, using BIM raise suspicions on insurance coverage, confidentiality exposure, intellectual property rights and ownership, and model control, etc. For instance, suppose architect, structural engineer, and building service engineer collaboratively produce a model and then pass the final product to the contractor. Later, the contractor might make some amendments to facilitate work with sub-contractors. In case of any unfortunate event in the future, no party would like to be held responsible for the damages and it would be difficult to distinguish the liable party (Lu and Korman 2010)

4.3.5. Lack of Collaborations Between Parties

In traditional construction projects, experts from different disciplines are involved in designing their own parts. However, adopting BIM means putting efforts into collaborating with other project parties but it can be difficult in the sense that each party might be involved in multiple BIM projects simultaneously. Architects, engineers, etc. in such a case would prefer the subordinates to complete the design first rather than discussing with other parties each time a discrepancy arises (Staub-French et al. 2018).

5. EXPERTS' INTERVIEWS AND FINALIZATION OF QUESTIONNAIRE

In order to validate the findings in relation to MiC technology in Hong Kong, structured interviews of four highly experienced local AEP experts were carried out (Table 1). All the four experts were involved in the construction industry for more than 10 years, and have at least 1 year of BIM experience. Three experts, including two architects and one structural engineer, were working in the public sector, whereas one expert was employed as a BIM specialist in a private architect firm. Such knowledgeable and experienced experts provide the necessary credibility to the interview results. Experts were asked to provide feedback on the list of applications and barriers with respect to the implementation of BIM in the Hong Kong MiC industry. As a general rule of thumb, it is established that any application/barrier failing to acquire at least 50% consensus from the experts will be excluded from the list. Agreements and remarks of experts about each application and barrier are given in Table 2. In summary, experts 1, 2, and 3 agreed that applying BIM in MiC would be highly effective for the Hong Kong construction industry since this technology integration would facilitate 1) early coordination and confirmation of design, and 2) the subsequent production and fabrication in a factory. Expert 1 stated that BIM usage in MiC would result in quicker and more sustainable construction. Expert 4 also agreed on the effectiveness of BIM in MiC, however, pointed out that BIM is more effective in the design stage than in the construction stage, therefore, BIM may not meet governments' expectations. Besides, some functions such as 'analysis, simulation, and optimization' and 'scheduling and logistic planning' require extra work in inputting a substantial amount of data to maximize benefits. From the interview analysis, all the applications and barriers were found satisfactory to be included in the questionnaire survey for further validation and analysis.

Table 1: Background information of experts

Experts	Organization	Occupation	Experience in the Construction Industry	Experience in BIM
Expert 1	Public Sector	Architect	10-20 years	1 year
Expert 2	Public Sector	Architect	10-20 years	4 years
Expert 3	Architect Firm	BIM Specialist	10-20 years	17 years
Expert 4	Public Sector	Structural Engineer	10-20 years	6 years

6. QUESTIONNAIRE SURVEY

An online questionnaire is conducted to solicit professionals from Hong Kong AEC industry on the significance of applications and barriers. Professionals were selected on the basis of their experience in the construction industry and their emails were collected through companies' websites, snowball techniques, and personal requests to the HR departments. Professionals were first, asked to rate the applications and barriers on a Likert scale of 1 to 5, with 1 being 'less effective' and 5 being 'very effective'. Secondly, due to the fact that in the Likert scale questions, respondents rate single factors without considering the relative importance of other factors, the experts were also asked to rate applications and barriers with respect to other applications and barriers on an AHP scale for analytical hierarchical process analysis. Email invitations were sent to the professionals; 47 professionals chose to respond to the survey. Most of the respondents were government officials i.e. 35. Out of the remaining, 8 were consultants and 4 were contractors. Professionals represented diverse fields of expertise, the highest number of respondents were quantity surveyors i.e. 15. Besides, architects, structural engineers, building service engineers, and building surveyors represented the rest of the groups of professionals. Around 70% of the experts had more than one year of work experience in BIM (Table 3).

7. SURVEY ANALYSIS

7.1. Mean Score Ranking Technique

The well-established technique of mean score ranking was used to rank the factors (Tariq and Zhang 2020). In this technique, the average score of ratings given by respondents on each factor is calculated using the formula:

$$\text{Mean score} = \sum_{i=1}^{N}(f_i \; x \; S_i)/N \text{ , } 1 \leq \text{Mean Score} \leq 5$$

Where N = no of respondents; f = frequency of ratings (1-5) given by the respondents on ith factor; S = score given by the respondents on ith factor. The threshold mean value for the most significant factors is taken as 4. As an example, 32 experts rated 'clash detection' as 5, 7 rated it as 4, and 8 others rated as 3. The overall mean score as a result came out to be 4.51.

7.2. Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a structured technique developed by Prof. Thomas L Saaty in 1970 for decision making by quantifying the weights of criteria (Triantaphyllou 2000). This method utilizes the experts' experience through pair-wise comparison of each factor/criterion. A nine-point scale is typically used for AHP to determine the significance of one factor/criterion over the other. A comparison matrix is then developed from the respondents' pair-wise ratings which are normalized in the next step. The average normalized scores are used to rank the factors/criteria in the final step, as shown in Figure 2. To simplify the questionnaire, this research assumed that the respondents' decisions are consistent and used only one factor for pair-wise comparison with other factors. Pair-wise scores of all the other factors with each other are then calculated using geometric mean values (GMV). The average of normalized GMVs was then used to sort out the significance order.

Table 2: Experts' Agreement on applications and barriers of BIM in Hong Kong MiC industry

Functions	Agreement					Remarks
	Expert1	Expert2	Expert3	Expert4	Consensus	
Applications of BIM in Hong Kong MiC industry						
3D Visualization	✓	✓	✓	✓	100%	Expert 2 regarded 3D visualization a common and useful application for all types of projects including MiC.
Clash Detection	✓	✓	✓	✓	100%	All the experts stated that this function would help to minimize the design errors in the initial stages.
Better Communication & Coordination	✓	✓	✓	✓	100%	Expert 2 shared that this function is facilitating his construction team greatly in a current MiC project.
Analysis, Simulation, and Optimization	✓	✓	✓	✓	100%	Expert 4 believed that this function is useful but highly time-consuming because all the manual data needs to be inputted in BIM.
Parametric Modelling		✓	✓	✓	75%	Expert 1 mentioned that the benefits of this function are not so obvious and can be used for a less complex system.
Assembly Training with BIM			✓	✓	50%	Experts 3 and 4 suggested that this function can enhance the worker's readiness on working in MiC projects through watching animations. Contrary to this, expert 1 disagreed and said that the actual implementation can only be learned through hands-on experience. Expert 2 pointed to the fact that the local contractors are experienced in pre-fabrication works and dealing with MiC would not be much problem.
Quantities Take-off and Cost Estimation	✓	✓	✓		75%	Expert 1, 2, and 3 agreed that this function can assist quantity surveyors in taking off quantities quicker but modifications and standards are required for accurate measurements. Expert 4 showed his disagreement by commenting that not everything can be measured through BIM such as reinforcement.
Scheduling and Logistic Planning	✓	✓	✓	✓	100%	All the experts showed 100% agreement on this function, however, they stated that not everything goes as planned especially due to traffic congestion and unforeseen events.
Improved Pre-fabrication Level	✓	✓	✓	✓	100%	All the experts agreed that BIM can lead to an improvement in the prefabrication of modules by producing accurate drawings and by integrating advanced mechanical fabrication technologies with BIM. However, experts also asserted that fabricators in Hong Kong are highly experienced so this benefit is not so obvious.
Barriers to the BIM implementation in Hong Kong MiC industry						
Insufficient Training and Lacking BIM Professionals	✓	✓	✓	✓	100%	Experts regarded this barrier as one of the most critical barriers due to which Hong Kong is far behind in implementing BIM than many developed countries.
Legal Responsibilities& Liability Issues	✓	✓	✓	✓	100%	All the experts agreed on the significance of this barrier.
High Initial Cost	✓	✓	✓	✓	100%	Experts mentioned that the license fee is expensive and Hong Kong companies generally are not willing to invest in the training of their employees.
AEC Industry Resistant to Change	✓	✓	✓	✓	75%	All the experts agreed on the significance of this barrier. They stated that the BIM trend will ultimately take over and will change the current industry culture and contractual relationships between the project stakeholders.
Lack of Collaborations between Parties	✓	✓	✓		75%	Same as the previous remark.

7.3. Most significant applications and barriers

Mean score values and AHP values of BIM applications and barriers are given in tables 4 and 5, respectively. From table 4, it can be noted that 'clash detection', '3D visualization', and 'better coordination and communication' are the most significant factors as per the mean score rankings. These rankings are consistent with the interview analysis as all the interviewees agreed on the importance of these applications. However, there are some differences in means score and AHP rankings. AHP suggested 'clash detection' and 'better coordination and communication' as the two most significant applications; and ranked 'analysis, simulation, and optimization' higher than '3D visualization'. This is due to the opinion of some experts believing that '3D visualization' is a common application and should not be regarded as a special application for MiC. Nevertheless, '3D visualization' should be regarded as an effective application as its benefits are direct. To obtain benefits from 'analysis, simulation, and optimization', huge data is needed to be inputted which means extra workload.

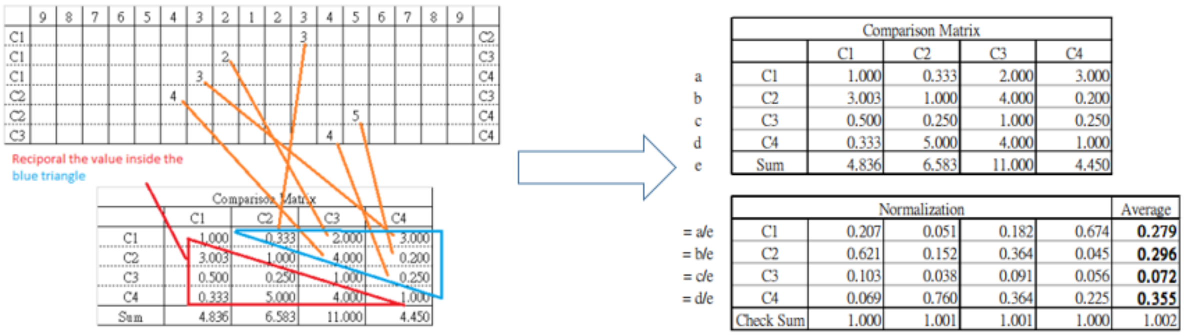

Fig. 2: AHP based calculation of average scores and rankings

Table 3: Background information on local AEC professionals

Background Questions	Responses	No. of respondents	Percentage
Type of organization	Government	35	74.5%
	Consultant	8	17%
	Contractor	4	8.5%
Professional fields	Quantity Surveying	15	31.9%
	Architecture	13	27.7%
	Structural Engineering	8	17%
	Building Service Engineering	6	12.8%
	Building Surveying	5	10.6%
Working Experience	Less than 10 years	39	83%
	10-20 years	7	14.9%
	More than 20 years	1	2.1%
BIM Experience	Less than a year	14	29.8%
	1-2 years	27	57.4%
	2-5 years	5	10.6%
	5-10 years	1	2.2%
	Total	47	100%

Table 4: Ranking results of BIM applications in Hong Kong MiC Industry

BIM apps in MiC	Mean score values	Rank	AHP values	Rank
3D Visualization	4.19	2	0.11	4
Clash Detection	4.51	1	0.19	1
Better Communication and Coordination	4.17	3	0.17	2
Analysis, Simulation, and Optimization	3.70	4	0.13	3
Parametric Modelling	3.06	5	0.10	5
Quantities Take-off and Cost Estimation	2.68	6	0.09	6
Improved Pre-Fabrication Level	2.23	8	0.07	7
Scheduling and Logistic Planning	2.32	7	0.07	7
Assembly Training with BIM	2.19	9	007	7

From table 5, 'insufficient training and lacking BIM professionals' and 'high initial cost' came out to be the most obstructive barriers from both types of ranking techniques. The mean score value of 'high initial cost' is very close to 4, therefore it is also regarded as one of the most obstructive barriers. These ranks are also consistent with the interview analysis.

In addition to scaled survey questions, the AEC professionals were also asked to comment on the overall effectiveness of BIM in the Hong Kong MiC industry. More than 60% of the AEC professionals believed that BIM-MiC integration would be effective, and the remaining 40% suggested otherwise. The reasons for disagreement might be similar to those suggested by the interviewees that BIM is focused more on the design stage, and benefits in the later stages are not direct requiring extra work. This general bias can also be confirmed from the rankings of the applications focusing on the construction stage such as 'scheduling and logistic planning' and 'assembly training with BIM' are lower than the applications focusing on the design stage.

Table 5: Ranking results of the barriers to the implementation of BIM in Hong Kong MiC Industry

BIM barriers in MiC	Mean score values	Rank	AHP values	Rank
AEC Professionals Resistant to Change	3.55	3	0.14	4
High Initial Cost	3.94	2	0.26	2
Insufficient Training and Lacking BIM Professionals	4.15	1	0.30	1
Legal Responsibilities and Liability Issues	2.83	5	0.10	5
Lack of Collaborations Between Parties	3.47	4	0.19	3

8. CONCLUSIONS, RECOMMENDATIONS, AND FUTURE RESEARCH

This research conducted a thorough investigation of the effectiveness of applying BIM in the Hong Kong MiC industry. The applications and barriers were established first through literature. A case study analysis of NTU's student residential hall is carried out to further explore the applications of BIM in MiC. The findings were then validated through structured interviews from four field-experts. After finalizing the questionnaire survey as per the interview results, the relative significances of applications and barriers were identified through a questionnaire survey analysis based on the responses of local AEC professionals. Interview and survey results revealed that BIM would be more effective in the MiC design stage than the later stages. The most effective applications were: 'clash detection', '3D visualization', and 'better communication and coordination'. And, the most obstructive barriers were: 'insufficient training and lacking BIM professionals', and 'high initial cost'.

Based on experts' suggestions, recommendation on BIM's adoption in Hong Kong MiC industry can be summarized as to 1) provide more training to the AEC professionals in educational institutes and in the industry; 2) offer governmental incentives to the industry such as GFA concession, tax waiver, extra technical scores, etc.; 3) share benefits from the real cases to the construction industry professionals; 4) establish an online platform for knowledge sharing and technical support, and 5) collaborate with Autodesk and other developers to make the software user-friendly and tailor-made to the specific needs of the Hong Kong such as merging the functions of BIM in a single software.

Although this article explored the BIM effectiveness in MiC through the combination of literature, case study, interviews, and survey there were certain limitations to the research design. Firstly, only 1 case study was conducted and that too was not from Hong Kong. Secondly, only 47 respondents completed the questionnaire; a large sample size would have given more credibility to the results. Based on the limitations, future research will firstly, try to incorporate local case studies and secondly, more experts having vast experience in BIM will be invited to participate in the survey. Comparison with other advanced countries will also be beneficial to provide recommendations on the improvement of the existing industry situation in Hong Kong.

Acknowledgment: The authors would like to thank the Chinese National Engineering Research Centre for Steel Construction (CNERC), Hong Kong Branch, at the Hong Kong Polytechnic University, for funding this research.

REFERENCES

Ahmed S. (2018). Barriers to implementation of building information modeling (BIM) to the construction industry: A review, *Journal of Civil Engineering and Construction*, Vol 11 No. 2, 107-113.

Andersson L. Farrell K. Moshokovich O. and Cranbourne C. (2016). *Implementing virtual design and construction using BIM: current and future practice*, Routledge.

Azhar S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry, *Leadership and Management in Engineering*, Vol 11 No. 3, 241-252.

Darko A. Chan A. P. Yang Y. and Tetteh M. O. (2020). Building information modeling (BIM)-based modular integrated construction risk management–Critical survey and future needs. *Computers in Industry*, Vol 123, 103327.

Ezcan V. Isikdag U. and Goulding J. S. (2013). BIM and Off-Site Manufacturing: Recent Research and Opportunities, In *CIB World Building Congress, Netherlands.*

Garrigo A. G. Mahdjoubi L. and Brebbia C. A. (2017). *Building Information Modelling (BIM) in Design, Construction and Operations II,* WIT Press.

Goh K. Goh H. Toh S. and Peniel Ang, S. (2014) Enhancing communication in construction industry through BIM, In *Proceedings of the 11th International Conference of Innovation and Management (ICIM 2014), Vaasa, Finland.*

Hasan A. N. and Rasheed S. M. (2019). The Benefits of and Challenges to Implement 5D BIM in Construction Industry, *Civil Engineering Journal*, Vol 5 No. 2, 412-421.

Jaillon L. and Poon C. S. (2008). Sustainable construction aspects of using prefabrication in dense urban environment: A Hong Kong case study, *Construction Management and Economics*, Vol 26, No. 9, 953-966.

Johansson M. Roupé M. and Viklund T. M. (2014). From BIM to VR-Integrating immersive visualizations in the current design process, In *Fusion-Proceedings of the 32nd eCAADe Conference-Volume 2* (261-269).

Lawson M. Ogden R. and Goodier C. (2014). *Design in modular construction*, CRC Press.

Lu N. and Korman T. (2010). Implementation of building information modeling (BIM) in modular construction: Benefits and challenges, In *Construction Research Congress 2010: Innovation for Reshaping Construction Practice* (1136-1145).

Pan W. and Hon C. K. (2018). Modular integrated construction for high-rise buildings, In *Proceedings of the Institution of Civil Engineers-Municipal Engineer*, Thomas Telford Ltd, 1-5.

Poole K. (2014). BIM initiatives by Construction Industry Council, *Construction Industry Council*, Hong Kong.

Sacks R. Eastmam C. Lee G. and Teicholz P. (2018). *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*, Wiley & Sons, Inc.

Sampaio Z. (2018). *Enhancing BIM Methodology with VR Technology*, Intechopen.

Shang Z. and Shen Z. (2014). Critical success factors (CSFs) of BIM implementation for collaboration based on system analysis, In *Computing in Civil and Building Engineering (2014)* (1441-1448).

Staub-French S. Poirier P. E. A. Calderon F. Chikhi I. Arch M. Zadeh P. Chudasma I. D. and Huang S. (2018). Building Information Modeling (BIM) and Design for Manufacturing and Assembly (DfMA) for Mass Timber Construction, *BIM TOPiCS Research Lab, University of British Columbia*.

Tariq S. and Zhang X. (2020). Critical Failure Drivers in International Water PPP Projects, *Journal of Infrastructure Systems*, Vol 26, No. 4, 04020038.

Tatum C. B. and Korman T. M. (2000). Coordination Building Systems: Process and Knowledge, *Journal of Architectural Engineering*, Vol 6 No. 4, 116-121.

Triantaphyllou E. (2000). *Multi-criteria Decision Making Methods: A Comparative Study*, Springer.

Wuni, I. Y., and Shen, G. Q. (2019). Barriers to the Adoption of Modular Integrated Construction: Systematic Review and Meta-Analysis, Integrated Conceptual framework, and Strategies, *Journal of Cleaner Production*, 119347.

Zhai Y. Chen K. Zhou J. X. Cao J. Lyu Z. Jin X. Shen G. Q. Lu W. and Huang G. Q. (2019). An Internet of Things-enabled BIM platform for modular integrated construction: A case study in Hong Kong, *Advanced Engineering Informatics*, Vol 42, 100997.