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Modular Integrated Construction for High-rise Buildings in Hong Kong: Supply Chain Identification Analyses and Establishment

Reference Material for Practical Guide on MiC Adoption

香 港 大 學
THE UNIVERSITY OF HONG KONG

Centre for Innovation in Construction & Infrastructure Development

Modular Integrated Construction for High-rise Buildings in Hong Kong: Supply Chain Identification, Analyses and Establishment

Reference Material
Practical Guide on MiC Adoption

Authors

Ir Prof Wei PAN; Ir Prof Thomas NG; Ir Prof George HUANG;
Ir Prof Sam CHAN; Ir Prof Francis AU; Ir KL TAM; Dr Louis CHU;
Mr Zhenjie Zheng; Dr Yi YANG; Dr Mi PAN
The University of Hong Kong

Enquiries

Any enquiries may be made to the CIC Secretariat at:
CIC Headquarters
38/F, COS Centre, 56 Tsun Yip Street, Kwun Tong, Kowloon, Hong Kong
Tel: (852) 2100 9000
Fax: (852) 2100 9090
Email: enquiry@cic.hk
Website: www.cic.hk

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1. Introduction

1.1 Background

Modular Integrated Construction (MiC), one of the most advanced off-site construction methods, is defined as "*a game-changing disruptively-innovative approach to transforming fragmented site-based construction of buildings and facilities into integrated value-driven production and assembly of prefinished modules with the opportunity to realise enhanced quality, productivity, safety and sustainability*" (Pan and Hon, 2018; Pan et al., 2019).

For the purpose of public works policy and regulatory building control, the Government of the HKSAR has defined MiC as a construction method that employs the technique of having freestanding volumetric modules (with finishes, fixtures, fittings, etc.) manufactured off-site and then transported to site for assembly (see PNAP ADV-36 and DEVB TC(W) No. 2/2020).

MiC offers substantial advantages over the conventional construction methods, prefabricated components and two-dimensional panelised systems (Pan and Hon, 2018). Typically, the modular units are fully factory prefinished internally and possibly externally, and most of the on-site works are transformed into the factory with prefabricated modules integrated with structural, architectural, and building service works. The benefits from MiC adoption have been well demonstrated, which include a shortened construction period, improved health and safety, enhanced productivity and quality, and minimised construction waste (Pan et al., 2019).

The intrinsic features of MiC determine its critical success factors which include:

- Project-level partnering between the client and its professional advisors and supply chains from the preliminary design stage on, particularly the early involvement of the contractor and MiC supplier;
- Integrating the Design for Manufacture and Assembly (DfMA) theory and advanced manufacturing and logistics technologies into supply chain solutions;
- Structural stability, wind load resistance, and connection details as the prominent considerations for high-rise MiC solutions; and
- Embracing systems thinking and lifecycle approach for design chain and supply chain management, such as considering module materials' durability and modular buildings' long-term performance in building design.

MiC offers an innovative solution with a high potential of benefits (CIC, 2019). However, to date in Hong Kong, this emerging form of construction has not yet gained enough momentum. Partially, this can be attributed to two significant factors in relation to the supply chain: (1) the industry's fragmented knowledge about MiC, and (2) the lack of supply chain development for MiC in Hong Kong.

1.2 Purpose and scope

This Practical Guide is produced as one of the deliverables of the Research entitled "*Modular Integrated Construction for High-rise Buildings in Hong Kong: Supply Chain Identification,* *Analyses and Establishment*", which aims to improve the Hong Kong construction industry's understanding of MiC and to help de-risk MiC adoption in Hong Kong by identifying and analysing the challenges in establishing MiC supply chains, among others, for buildings in Hong Kong in order to enhance construction productivity, quality, safety and sustainability.

This Practical Guide aims to offer a referential basis to technical and managerial professionals without sufficient MiC knowledge about the essentials to be considered in MiC adoption within the regulatory, geographical and socio-economic contexts of Hong Kong. The Practical Guide was designed to consider the main life cycle stages of a MiC project (Figure 1-1), which include project planning, procurement, design (including architecture, structure, mechanical, electrical and plumbing, and fire safety), module production, transportation and logistics, installation and construction, maintenance, as well as essential issues of quality assurance and quality control (QAQC) and cost estimation and cost code. Particularly, the Practical Guide provides general guidance on how MiC should be planned, procured, designed, produced, transported, installed and maintained, as well as how quality should be controlled and cost be estimated. Besides, the Guide suggests specific actions to critical stakeholders within a project context.

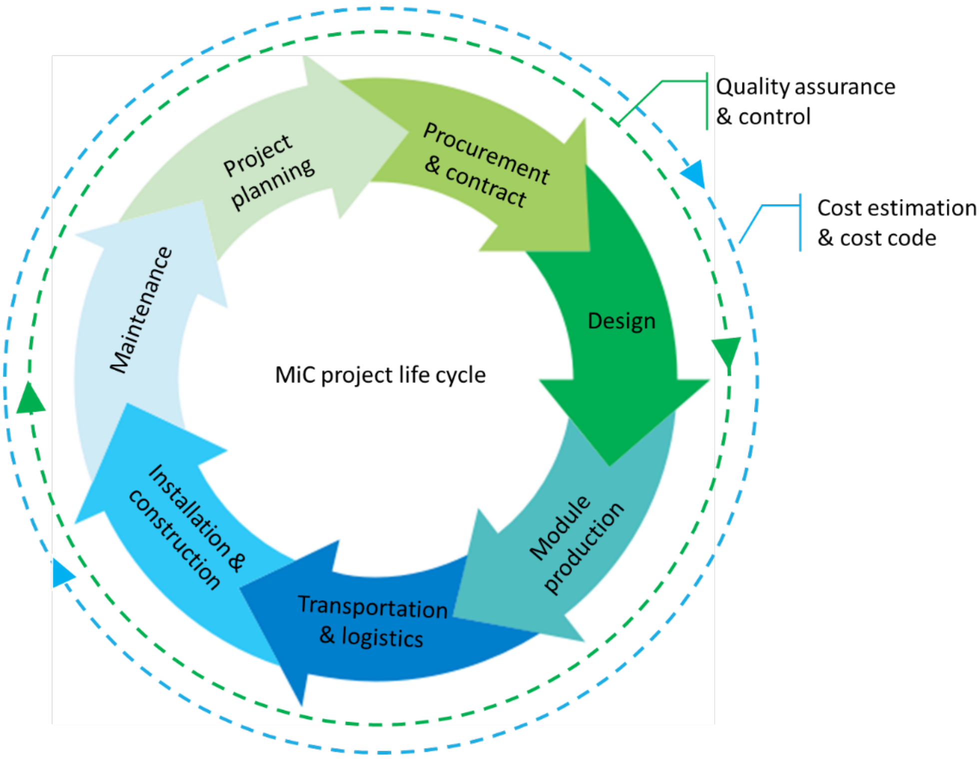

Figure 1-1 The main stages of and general issues along the life cycle of MiC projects addressed in this Practical Guide

1.3 Project team

Table 1-1 lists the basic information about the project team including the Principal Investigator and Co-Investigators. The project team also includes a team of researchers with expertise in MiC, cost analysis, and supply chain management.

Table 1-1 Project team

Role	Name	Position
Principal Investigator	Ir Prof Wei Pan	Professor and Executive Director, CICID, HKU
Co-Investigator 1	Ir Prof Thomas Ng	Professor & Associate Dean, Department of Civil Engineering, HKU
Co-Investigator 2	Ir Prof George Huang	Chair Professor & Head, Department of Industrial and Manufacturing Systems Engineering, HKU
Co-Investigator 3	Ir Prof Sam Chan	Associate Director, CICID, HKU
Co-Investigator 4	Ir Prof Francis Au	Professor & Head, Department of Civil Engineering, HKU
Co-Investigator 5	Ir KL Tam	Director, Estates Office, HKU
Co-Investigator 6	Dr Louis Chu	Assistant Director, Estates Office, HKU

1.4 Structure of the Guide

Following this introductory chapter, Chapter 2 explains the methods adopted for developing this Practical Guide. Chapters 3 to 11 provide general guidance to the practitioners and suggest specific actions to critical stakeholders, in terms of project planning, procurement, design (including architecture, structure, mechanical, electrical and plumbing, and fire safety), module production, transportation and logistics, installation and construction, maintenance, QA/QC and cost estimation and cost code. Chapter 12 summarises the Practical Guide with clarifications to potential users. Appendix I provides a list of regulations, web-links and documents pertinent to MiC adoption as references for practitioners.

1.5 How to use this Guide

This Practical Guide can be used as a reference for potential MiC practitioners by offering a comprehensive coverage of the critical issues along the life cycle of MiC projects. The guidance of how to use this Practical Guide is provided in Figure 1-2. Besides, useful information which can facilitate the planning, design and construction of MiC, including local MiC projects, project consultants and contractors, and MiC suppliers and systems with the Buildings Department's in-principle acceptance (IPA), can be found in the CIC's MiC Resources Centre (http://mic.cic.hk/en/Home). The CIC has also published reference materials to facilitate the implementation of MiC projects, viz. Reference Material on the Statutory Requirements for Modular Integrated Construction Projects (CIC, 2020a) and Reference Material on Logistics and Transport for Modular Integrated Construction Projects (CIC, 2020b).

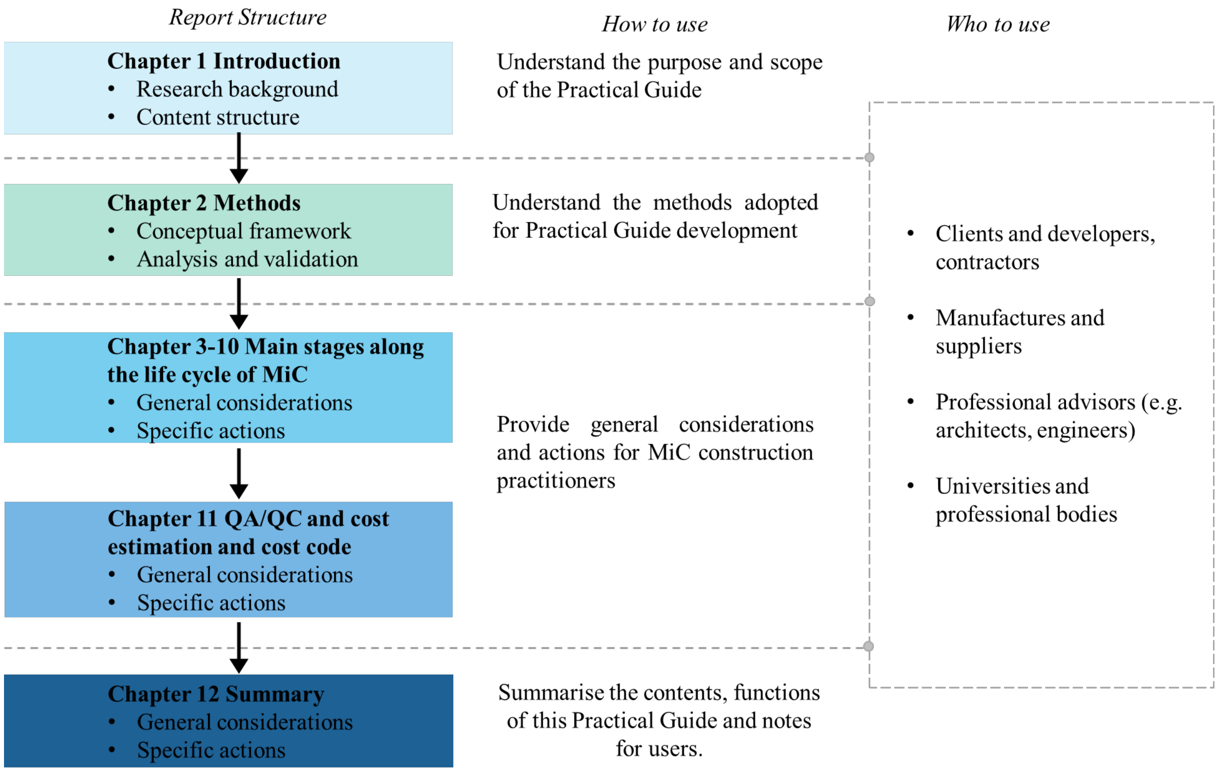

Figure 1-2 User guidance for the Practical Guide

2. Methods

This Practical Guide was developed through the use of combined methods including document review and analysis, expert consultation and focus group meeting.

Document review and analysis

A comprehensive review and analysis of relevant documents was carried out, which aimed to understand the status quo of MiC and the challenges being faced by the construction industry in Hong Kong, and to elicit learning from international experiences of modular construction. The reviewed documents included government documents (e.g., practice notes), industry reports, published materials, relevant websites accessible in the public domain, and the reports delivered in this study including:

- Case Study Report (with leaflets)
- Supply Logistics Report
- Cost Estimates of MiC
- Stakeholder Seminar Report
- Market Analysis Report

Expert consultation

The Practical Guide has gone through an intensive process of discussing with and commenting by CIC. In doing so, a number of meetings between CIC and HKU were conducted, which enabled in-depth discussion on the contents of and issues addressed in the Practical Guide. These consultation meetings mainly included the following agenda items:

- Briefing by the project team on the project requirements, and main considerations for developing the Practical Guide.
- Discussion on the contents of the Practical Guide and the potential use of such a Guide for MiC practitioners.
- Discussion on the recommendations for improving the Practical Guide for better practicability and usefulness.
- Debriefing and summary sessions.

The Practical Guide has also been circulated to relevant government departments and industry organisations for views and input, including the Joint Working Group on MiC, relevant Departments of the HKSAR government and parties (e.g., Architectural Services Department, Buildings Department, and Housing Authority), and CIC Committee on Productivity. Their comments have been addressed and integrated into this Guide.

Focus group meeting

A final focus group meeting was designed to further verify and enrich the Practical Guide. The participants covered the key stakeholder groups of government, client, contractor, consultant and institution.

During the meeting, the project team first explained the developed Practical Guide within the context of the project. The focus group participants raised enquiries and provided comments and suggestions. The focus group meeting lasted two hours for effective discussion. The discussion was audio-recorded with permission from the participants, and then transcribed. Transcription and notes taken during the focus group discussion were analysed using the thematic contents analysis methods.

3. Project planning

3.1 General guidance

In general, MiC project planning should cover the following aspects.

- Suitability
  - Site selection, e.g. appropriate site for logistics and module delivery, with particular consideration of hoisting set up on site for module installation and transportation of modules to site.
  - Project scale, in terms of the quantity of MiC units for economical production (e.g. around 50 and 150 modules for each production line in respect of steel (hybrids) and concrete modules respectively).
  - Project type, in terms of building typology (e.g. residential, hotels/hostels, commercial/retail, schools and office) with adequate repetition.
- Project planning
  - Project programme, i.e. to identify the overall project programme and time frame, the date of design freeze and the date of project completion/occupation permit.
  - Package programme, including technical feasibility stage, design stage, production stage, construction stage (site formation programme, foundation programme, ELS programme, superstructure programme and regulatory submission and approval programme).
  - Contract form to be used, i.e. design-bid-build or design & build, and the designer and design responsibility of the MiC parts, the non-MiC parts and the interfaces between them.
  - Consultant engagement, i.e. consider the appropriate timing to seek professional advice and the scope of service, e.g. study on site logistics, module delivery routes (marine and road transport) and module delivery constraints.
  - Contractor engagement, i.e. engage contractor and MiC supplier at appropriate time. Adoption of design & build will facilitate Early Contractor Involvement (ECI) which could bring time and cost benefits. For such cases, the design & build contractor will be the designer and carry the design responsibility under the contract. If it is considered beneficial to the project, the project client could arrange for his consultants to be novated to the appointed contractor.

3.2 Specific actions

To safeguard MiC project success, specific actions for the client on project planning are recommended below.

- The client should have or acquire a good understanding of MiC. For example, the client can refer to *Modularisation for Modernisation: A Strategy Paper Rethinking Hong Kong Construction* that illustrates the concept, history and vision of MiC (Pan et al, 2019) and *A Glossary of Modular Integrated Construction* that gives detailed illustrations of MiC terminology (Pan et al., 2020).
- For suitability of MiC, the client can learn from successful experiences from the government-funded pilot projects (Pan et al, 2020).

- The client should identify effective strategies for procurement, such as ECI as well as MiC-ready design strategy which has been demonstrated in the HKU Wong Chuk Hang student hostel project.
- The client should make reference to the useful information available in CIC's MiC Resources Centre (http://mic.cic.hk/en/Home).

4. Procurement and contract

For successful MiC project delivery, it is important to adopt appropriate procurement strategies that enable early engagement and collaboration between the project consultants, the contractor and the MiC supplier.

4.1 General guidance

In general, procurement strategies should cover at least the following aspects:

- Contractual requirements that promote a collaborative/inclusive environment amongst the key project team members should be considered to best ensure the buildability of the development. Provisions, such as target cost and pain/gain share mechanism, would encourage collaboration between project parties.
- The DfMA design approach and the Building Information Modelling (BIM) with appropriate level of detail (LOD) or level of information need (LOIN) should be implemented to facilitate a collaborative approach along the entire supply chain.
- The use of BIM should underpin the collaborative and innovative culture of off-site manufacturing. BIM uses, such as quantities-take-off and design coordination, should be adopted.
- Contractors' input into design should be encouraged.

The term Early Contractor Involvement (ECI) has been used as a concept to describe procurement strategies that involve the contractor during the design phase as design and build (DB), management contracting or construction management (Finnie, 2018). When a client has decided to adopt MiC, ECI is important to ensure the project's buildability, i.e. the building can be built in the way intended in the detailed design, in accordance with the project timescale and cost plan.

When adopting ECI, the following aspects should be considered:

- **Design freeze.** MiC by its nature integrates design and manufacturing, which necessitates early design freeze before production begins. The building life cycle to ensure success of the project should be considered comprehensively in the detailed design. Particularly, the following principles should be followed during the design: DfMA, design for manufacture, design for assembly on site, and design for operation and maintenance. The end user (and the sales team, for build-for-sale buildings) should be consulted early). Ideally, the design should be frozen after the ECI phase.
- **Project team interface**. Early engagement of the key project members (including MiC supplier) could facilitate a strong partnership amongst the project team, and establish the interface required to achieve early design freeze.
- **Formalising ECI**. Traditional single-stage procurement methods do not accommodate ECI as the contractor and MiC supplier are not involved in the design development phase. Hence, single-stage procurement methods have limitations to realise early design freeze and early engagement of the key project team members and end users. Therefore, formal two-stage procurement methods are recommended for high-rise modular

buildings in order to realise the benefits of ECI in MiC projects. *In Stage 1*, the contractor should be engaged as soon as the feasibility of the project has been determined and an outline design and the associated specification have been developed. The contractor's work will be to develop and optimise the design in conjunction with the design team, conduct construction planning and procurement activities that lead to physical construction works and to give an optimised and accurate estimate of the construction cost. If the refined design and construction cost is acceptable to the client, the contractor would be instructed to proceed with Stage 2 construction. This arrangement allows the client to retain flexibility to seek other contractors (through competitive tender) for the construction, and at the same time, compensating for the design input by the original contractor. Examples of contracts that can be used to achieve two-stage procurement are listed as follows:

- The supplementary ECI clause issued by New Engineering Contract (NEC) for use with NEC EEC contracts (options C and E) provides basic pre-construction provisions.
- The Joint Contracts Tribunal (JCT) Pre-Construction Services Agreement (General Contractor or Specialist) contracts are intended to supplement the JCT standard forms of construction contract (whether traditional or DB).
- Bespoke pre-construction services agreements can be prepared in order to address the specific risk factors and practical difficulties of a particular development.
- The use of NEC4 contracts in off-site manufacturing (it is assumed that the contractor will be contracting with the MiC supplier rather than the project client).

Currently, MiC is still in its infancy nature in Hong Kong. For public-funded MiC projects, the "MiC-ready" tendering strategy is recommended to minimise project risks and cost (Ng and Ng, 2019). "MiC-ready" tendering strategy was originally developed by the HKU Estates Office and has been successfully adopted in the Wong Chuk Hang (WCH) project. The core methods of "MiC-ready" tendering strategy are given as followed (Tam and Chu, 2019):

- Clients provide MiC-ready solution, typically prepared by a design consultant engaged separately, for the Buildings Department's approval.
- MiC-ready solution clearly demarcates the design responsibilities between the contractor/MiC supplier and the design engineer showing the MiC modules and cast in-situ structural portions (non-MiC parts).
- IPA (In-Principle Acceptance) approval from the Buildings Department is not required to maximise competitiveness at the tendering stage. (Note: Prerequisite or prequalification, such as IPA, is not recommended as it will undoubtedly lengthen the whole tendering process and no significant benefit could be gained to reduce any statutory approval risk. The capability of the proposed MiC supplier can be assessed by the MiC specialist consultant/designer who will advise whether there are any significant challenges for the proposed MiC system to comply with the local building regulations and identify the high risk items for inclusion in the final tender assessment).
- A sufficiently long tendering period (4 months in the HKU WCH project), i.e. tenderers can have sufficient time to team up with their chosen MiC supplier and carry out the MiC tender design.

- Allow all types of MiC system, i.e., facilitate different types of MiC supplier to participate in the tendering exercise which increases competition, and thus secures the MiC unit pricing in the returned tenders.
- MiC supplier is not specified at tender submission stage, i.e. there is flexibility for the contractor to have a better bargaining power for negotiation.
- Provide adequate briefing sessions, i.e. tenderers can have a thorough understanding of the tender requirements and can clarify uncertainties to avoid over-pricing the tender with unnecessary risks.
- Down payment to be released, i.e. advanced payment to the MiC supplier to ease his financial burden during off-site fabrication and a more competitive price can be expected in the returned tenders.

New ways of payment and payment schedule should be considered in the procurement stage of MiC. As the costly module production process is conducted ahead of on-site module installation, which differs from that in conventional construction, new ways of payment schedule should be introduced. The interim payment schedule should take the module production process into consideration rather than only on-site building milestones. The key considerations are listed below:

- The risks for the client in terms of advance payments made in respect of off-site materials/products/goods should be well noted. The client should establish ownership of goods purchased with such payments or require payment security to remove such risks.
- Ownership can be established by requiring the contractor to issue a vesting certificate in respect of those off-site materials/products/goods accepted and purchased.
- Security can be provided by a third party (e.g. the maintenance of an effective bond to cover such goods) as an alternative means of protecting advance payments.
- Commercial risks in terms of trading with overseas/international MiC supplier should be noted, such as the applicable law with regard to the contract.

For international/cross-boundary transportation, payment arrangements, cash flow concerns, finance and security arrangements, additional insurance requirements, transfer of title issues and currency fluctuations should be well considered. Ownership of the MiC modules should be transferred to the project client upon their delivery to the site and contract acceptance.

In addition, taxation and liability of in-bound and out-bound supply chain should be addressed. Additional considerations from a logistical and contractual perspective arise where contractors or clients are required to trade with overseas/international MiC supplier. For example, modules might integrate components and sub-assemblies procured from overseas, and then finished modules must be imported into Hong Kong for assembly on site. Such considerations are important where the overseas MiC supplier is situated outside Hong Kong, notably in the aspects of the taxation and liability, import and export licences, customs issues, jurisdictional considerations and enforcement concerns of in-bound and out-bound supply chain.

Finally, procurement for innovation and performance should be encouraged as a tool to improve the performance of the MiC project. Encouraging digital technologies in the procurement is central to improving the design, construction and performance of buildings. Digitisation will increase design efficiency and accuracy, reduce material consumption and carbon emission, and ensure the full resilience of the assets. An example of procurement for performance is to consider key performance indicators for quality control, site progress, safety and social benefits.

4.2 **Specific actions**

To safeguard MiC project success, specific actions for different stakeholders on procurement and contract are recommended below.

For the Client:

- The client should carefully select the procurement strategy considering the funding source. Generally, MiC-Ready approach is suitable for public-funded projects, where the client has sufficient resources and expertise (either in-house or through design consultants) to develop a sufficiently mature design, whereas ECI approach is generally suitable for private-funded projects.
- The adoption of ECI approach requires close collaboration among different project team members in the early design stage.
- The client should adopt a value-for money based procurement approach and increase the technical weighting in the tender assessment criteria in order to reduce the technical risk of delivering high-rise modular buildings.
- Suitably high weighting should be allocated to innovations and technical competence in the technical evaluation. Focus should be put on the scoring method for technical assessment to ensure only the competent contractors teamed up with competent designers and contracturally-binded core personnel can pass the technical assessment, with relatively less score given to generic items, such as reference projects of the company.
- The client should consider off-site works in the payment stage. A maximum 70% of the total construction cost excluding preliminaries and contingency allowance could be considered for off-site works in the project delivery process (Ng and Ng, 2019).
- The client should require a Building Maintenance Manual to be prepared by the designer covering for the MiC parts.

For the Contractor:

- The contractor should team up with the MiC supplier for bidding the contract. A stable and close partnership between the contractor and MiC supplier can help identify and solve technical problems early, which increases the chance of success in both technical and financial aspects.

5. Design

5.1 General guidance

5.1.1 Architecture

The architectural design of MiC should consider the following aspects:

- Responsibility for the overall modularisation coordination and planning between different disciplines and full utilisation of the DfMA approach and BIM in the project;
- Building functions, i.e. the suitability and capability of serving an intended purpose (e.g. residential buildings for dwelling purpose, office buildings for business activities);
- Layout modularisation, i.e. Module dimension design should consider the constraints imposed by supply chains (e.g. transport regulations and feasibility) and construction (e.g. crane capacity, site accessibility);
- Construction materials, i.e. consider wide variety of building materials which complies with specification/building compliance proposed by the MiC supplier or contractor to suit MiC production;
- Construction tolerance, i.e. practical variations related to the functions of the materials or finished works; within an acceptable range.

The regulatory requirements on the building design of MiC can be referred to:

- Practice Note for Authorised Persons, Registered Structural Engineers and Registered Geotechnical Engineers: Advisory-36 (PNAP ADV-36: Appendix C, Section1);
- Buildings Ordinance;
- Building (Construction) Regulations.

5.1.2 Structure

The structural design [1] of MiC (particularly for high-rise buildings) should consider the following aspects:

- Stability, i.e. the ability of structural components to resist the stabilising forces and horizontal forces, especially in extreme conditions such as strong wind;
- Robustness and integrity, i.e. structural components are fit for purpose under normal operation conditions and are safe when conditions exceed the original design intent;
- Wind load resistance, i.e. structural design of modular buildings should comply with related regulations in order to resist strong wind load (e.g. typhoon);
- Joints and gaps, i.e. compared with the traditional in-situ construction method, MiC may have more joints and gaps. In order to achieve the ultimate benefits of MiC, the design of structural connections between MiC modules should take into consideration the following aspects: 1) simplified details which can be measured and recorded for proper installation process to meet QA requirements, 2) installation tolerance to allow sufficient adjustment for slight misalignment during the installation process while ensuring the design intent and structural performance, and 3) installation methodology

[1] Please refer to Shan et al. (2019) for the general structural analysis process for MiC, Wang and Pan (2020) for structure innovation for hybrid modules, and Wang et al. (2020) for structure innovation for concrete modules.

to ensure occupational safety;
- Water-tightness. Water-tightness of each module should be tested in factory and re-tested on-site before installation;
- Construction materials, i.e. use of different construction materials should comply with Building (Construction) Regulations (B(C)R) and take the advantages offered by the MiC supply chain;
- Construction tolerance.
- Alteration and de-mobilisation requirements if needed;
- Inspection and maintenance requirements.

The regulatory requirements on the design and construction of reinforced concrete, precast concrete and structural steel buildings also apply to MiC elements. Details can be referred to:
- PNAP ADV-36: Appendix A, Section 3;
- Code of Practice for Structural Use of Concrete;
- Code of Practice for Precast Concrete Construction;
- Code of Practice for Structural Use of Steel;
- Code of Practice on Wind Effects in Hong Kong;
- Code of Practice on Design for Safety - External Maintenance.

5.1.3 Mechanical, electrical and plumbing
The design of mechanical, electrical and plumbing (MEP) systems of MiC should consider the following aspects:
- MEP functions
  - Heating ventilation and air conditioning systems are used to maintain internal air quality, and regulate internal temperatures and internal humidity;
  - Electrical systems provide power supply and distribution, interior and exterior lighting, security and access control, information and telecommunications and so on;
  - Plumbing systems refer to any system that allows the movement of fluids. Pipes are typical elements of a plumbing system.
- DfMA, i.e. maximise off-site components at design stage to minimise site installation works.
- Combine MEP services into a modularised system with modular fixings, and maximise factory-installed MEP services.
- Construction materials, i.e. the use of different construction materials should comply with B(C)R and the advantages offered by the MiC supply chain;
- Coordination of MEP services, i.e. modules are finished in the factory with complete MEP systems; all types of MEP works should be closely coordinated and conducted in a modular factory;
- Impacts of MEP services to structural and fire integrity;
- System integrity of MEP services;
- Accessibility for MEP installation, inspection and maintenance;
- Design and construction error tolerance.

The design and installation of MEP systems of MiC should comply with the following guidance notes and codes:

- PNAP ADV-36;
- Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method;
- Guidance Note on Household Electrical Products with Modular Integrated Construction Method;
- Guidance Note on Gas Supply Installations;
- Guidance Note on Supply of Energy Label Prescribed Products at MiC Projects;
- Water Supply for New Buildings adopting Modular Integrated Construction;
- Guide to Application for Water Supply published;
- Electricity Ordinance;
- Gas Safety Ordinance;
- Energy Efficiency (Labelling of Products) Ordinance.

5.1.4 Fire Safety

The design of MiC should comply with fire safety requirements by considering the following aspects:

- Fire residence rating of materials in terms of stability, integrity and insulation;
- Fire resistance of MiC structure in terms of stability, integrity and insulation;
- Protection and warning system;
- Construction tolerance.

The design of MiC considering fire safety should comply with the following guidance notes and codes:

- PNAP ADV-36: Appendix A, Section 1;
- Fire Service Department (FSD) Circular Letter No.1/2020;
- FSD Circular Letter No.3/2019;
- FSD Circular Letter No.1/2015;
- FSD Circular letter No.1/2007.

5.2 **Specific actions**

To safeguard MiC project success, specific actions for critical stakeholders on MiC design are recommended below.

For the Client:

- The client or his/her representatives should be physically and actively engaged in the design process, so as to better understand the ongoing project challenges for reasonably adjusting their requirements.
- The client should decide on the contract form early and identify the designer and design responsibility of the MiC parts, non-MiC parts and the interfaces between them.
- Confirm the design and production of modules at the early project stage.

For the Contractor:

- The contractor should closely coordinate with the MiC supplier on design in sequence to improve the design approval efficiency by the client's design team.
- The contractor should provide necessary input to the feasibility of implementing proposed design ideas, e.g. the maximum weight of modules in light of the lifting capacity of cranes.
- Adopt a BIM collaboration platform to connect project teams, reduce rework, improve productivity and accelerate project delivery.

For the Consultant/Designer:

- The consultants/designer should adopt the DfMA approach using BIM during the whole design stage.
- Increase the degree of modularisation and increase the size of modules to lower the cost per square metre while ensuring the technical feasibility, especially the feasibility of transporting to and logistics on site.
- Pay attention to design for toilet that usually has the highest cost per metre.
- Integrate more furnishings into a module within the weight limits for transportation.
- Propose innovative connection design to overcome the constraints related to wind load and fire rated requirements in the technical aspects.
- Adopt innovative materials such as light high-strength materials for high-rise modular building.
- Adopt innovative structural design for high-rise modular buildings.
- Adopt design for safety principles, especially design for safety on external maintenance.

6. Module production

In the global modular construction market, nearly 90 MiC suppliers were found to be capable of supplying MiC products and services for building projects. Most are from the UK (31), followed by Singapore (26) and Australia (14), with a few from Mainland China (11) and the US (6). Some MiC suppliers have their own factories[2], while others choose to partner with overseas MiC supplier for cost and space savings.

6.1 General guidance

To facilitate the wider use of MiC in Hong Kong, the Buildings Department (BD) has set up a pre-acceptance mechanism for granting in-principle acceptance to MiC systems/components. As of August 2020, there have been 14 steel and 4 concrete MiC systems/components in the pre-accepted list[4]. The following issues should be carefully examined when identifying eligible MiC supplier:

- Factory capability, e.g. production rate and capacity, facilities and level of automation;
- MiC supplier's qualification. The production of modular units should be conducted by a factory with ISO 9001:2015 or equivalent quality assurance certification;
- Product types and features;
- Factory location and its impact on the mode of transport;
- Labour source, skills and training, e.g. plumbing work training using virtual reality or module prototypes;
- Quality assurance and quality control (QA/QC) system;
- Health and safety management measures;
- Financial stability;
- Previous experience in MiC.

Relevant guidance notes and codes, especially for QA/QC in production, are summarised as follows:

- PNAP ADV-36: Appendix B;
- Code of Practice for Structural Use of Concrete;
- Code of Practice for Precast Concrete Construction;
- Code of Practice for Structural Use of Steel;
- Pre-acceptance Mechanism;
- Practice Notes for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers: Administration-8 (PNAP ADM-8);
- Practice Notes for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers: Application of the Buildings Ordinance and Regulations-143 (PNAP APP-143);
- Buildings Ordinance: Item 6 in Section 17(1).

[2] For more information about automation and robotics in modular factory, please refer to Yang et al. (2019)

6.2 Specific actions

To safeguard MiC project success, specific actions for different stakeholders on module production are recommended below.

For the Client:

- The client is suggested not to change the design after module production commences. The design should be approved before consent to commence production is given.
- The factory QA/QC procedures should be in place before the factory is engaged and before production can commence. (Note: The QAS has to be submitted to BD at least 14 days prior to the commencement of the production).
- The client should send representatives to conduct quality checking on module production process in the factory.
- The client is suggested to require and review a mock-up and a trial assembly of the MiC modules at the factory before the mass production for performance and quality assurance checking.

For the Contractor:

- Coordinate with MiC supplier on module production progress to meet the requirements of the on-site installation schedule.
- Coordinate with MiC supplier on equipment, materials and other services required for smooth flow of the project.
- Make the best use of the mock-up, as it provides a trial run for the production and assembly workflow of MiC units from production, transportation to installation.

For the MiC Supplier:

- Adopt lean manufacturing method for the management of module production.
- Increase the automation level in the factory rather than simply transfer construction workers from site to factory especially for local MiC factories in Hong Kong, e.g. using robotic arms, automatic guided vehicles, 3D-laser scanning and computer vision technology.
- Provide a mock-up to test out QA/QC workflow, conduct trial assembly and make any further improvement to ensure quality assurance.

7. Transportation and logistics

For the transportation and logistics of modules, it is important to allow early engagement of a logistics provider to establish a feasible route, identify the traffic constraints along the route, and if needed to help overcome the constraints.

7.1 General guidance

In general, the following issues should be carefully considered:

- A comprehensive study of logistics[3], in terms of feasibility, constraints and coping measures, during the design and planning stage, to investigate:
  - Geographical conditions of the project site, e.g. lane width, traffic conditions, bridges, site area and accessibility, in order to identify critical constraints to module design;
  - Road conditions related to transport safety, e.g. turning radius, steep roads;
  - Maximum transport envelopes to determine maximum module sizes for specific route;
  - Requirements for the temporary storage of modules during transport;
  - Partnering with third-party service providers, such as logistics firms, shippers, warehouse service providers, and agencies;
  - Regulatory compliance requirements and their impacts on logistics performance, e.g. impacts of night-time delivery, feasibility of daytime delivery and temporary traffic management schemes;
  - Manufacturing and installation schedule, and their impacts on logistics performance;
  - Available modes of transport, and their impacts on logistics performance;
  - Constraints and risks related to cross-border transport, taxation and customs clearance of cross-border material supplies;
  - On-site logistics, site gantry locations and temporary storage;
  - The transport of modules should comply with the following guidance notes and codes[4]:
- MiC suppliers and contractors work together to determine a comprehensive logistics plan, which should clearly define the following issues:
  - Transport solution, which should include mode of transport, routing, schedule,

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[3] Referential information can be found in the HKU Research Report entitled *'Modular Integrated Construction for High-rise Buildings in Hong Kong: Supply Chain Identification, Analyses and Establishment: MiC Logistic Report',* HKU CICID, with CIC Research Fund, which includes:

(a) A summary of relevant transport regulation, authorities and official websites
(b) Limitation of the cargo at the major land crossings control points in Hong Kong
(c) Comparative analysis of land crossings for MiC logistics
(d) Comparative analyses of using different ports for MiC
(e) Comparison of different transport modes for MiC

[4] Referential information can be found in the HKU Research entitled '*MiC for High-rise Buildings in Hong Kong: Supply Chain Identification, Analyses and Establishment: MiC Logistic Report'*, HKU CICID, with CIC Research Fund, which includes a summary of relevant transport regulations, authorities and official websites.

transport duration per delivery, required handling equipment, contingency plans for emergent occasions, escort arrangement, documents required for temporary traffic arrangements (TTA) application, etc.;
    - Equipment and facilities, such as heavy cranes, specialised trailers;
    - Human resources, e.g. trained operatives to handle loading and unloading of heavy lifting with extra safety precautionary measure.

To achieve just-in-time (JIT) delivery of modules, temporary storage is critical, as it could balance the production in the factory and the installation on site, which should be planned and considered at the design stage. Storage solution should include storage area location and capacity, schedule, and required handling equipment. There are generally two approaches to developing temporary storage for MiC projects in Hong Kong which are provided below:

- *Development of temporary storage areas for an individual project on a case-by-case basis.* For specific MiC projects, the selection of temporary storage area is more complicated and requires case-by-case discussion according to project-specific requirements and conditions, which should be planned ahead and taken into account at the design stage. Nevertheless, the following steps are suggested to facilitate the search and selection of temporary storage yards:
    - When there is enough space at the construction site:
    The space at the construction site should be used.
    - When there is not enough space at the construction site:
    If the modules are transported from Mainland China (e.g. the Greater Bay Area) by road, due to the customs clearance issues, temporary storage would be necessary. The selection of temporary storage areas should carefully consider that:
        - the location of the storage areas should be on or close to the transport route;
        - the size of the storage areas should be enough to tackle the gap between module supply and demand on-site;
        - the storage areas should provide enough operating space for lifting devices;
        - the storage areas should provide enough space for entrance/exit of trailers; and
        - the rental cost of the storage areas should meet the logistics budget, and meet the basic requirements for safety, noise and environmental protection.

    If the modules are transported to site from terminal/dock depots (see Table 1) or certain storage yard, additional storage is not necessary as it is not difficult to achieve JIT delivery.

- *Use of existing container depots.* Modules are similar to containers in terms of dimensions and weight. There are also some steel MiC systems directly developed from the container manufacturing industry. In this regard, container depot is the most suitable place for the temporary storage of modules. There are a total of 13 container depots in Hong Kong (see Table 1), including 11 container depots that are located close to the major terminals (container terminals and the River Trade Terminal), and 2 inland container depots in Yuen Long. There are several advantages and disadvantages of using container depots as temporary storage yards for modules.
    - Advantages:

- Compared with other storage areas, the container depots can provide enough storage space for cumbersome modules;
- There are well-established container depots in Hong Kong, and it is thus not necessary to spare additional land for MiC logistics;
- Container depots are usually close to the terminals, which makes it easy for cross-border transport of modules by sea;
- Container depots can provide enough devices for the transport, lifting and stacking of modules;
- Container depots have a well-established digital system to manage the cargos; and
- Utilising container depots can make the best use of free storage services (usually 7 days) provided by the terminal.

o Disadvantages:
- It is not convenient for cross-border MiC logistics through land checkpoints from Mainland China to use container depots for temporary storage purpose;
- Although similar in size and weight, there are still many differences between modules and containers, especially the concrete types;
- Due to the abovementioned differences, the operational devices of containers may not be suitable for modules;
- Due to the abovementioned differences, the free storage period policy may not apply to module transport; and
- Containers can be stacked several layers (as high as 7 layers in Hong Kong), which might be difficult for modules if the temporary connection is not considered in module design; thus the storage of modules will take more areas compared with containers if modules cannot be stacked on each other.

Table 1. List of container depots in Hong Kong

ID	Company	Depot address
1	Hong Kong International Terminal	Terminal 4, Container Port Road South, Kwai Chung, H.K.
2	Modern Terminals	Terminal 1, Kwai Chung, H.K.
3	Goodman DP World Hong Kong	Berth 3, Kwai Chung Container Terminal, Kwai Chung
4	Eng Kong Container Services Limited	DD125, Lot No.447, Fung Kung Tsuen, Kai Pak Ling, Yuen Long, N.T.
5	Singamas Terminals (Hong Kong) Limited	Gate 2, River Trade Terminal, 201 Lung Mun Road, Tuen Mun, N.T
6		DD125, Lot No.447, Fung Kung Tsuen, Kai Pak Ling, Yuen Long, N.T.
7	Sun Power Container Logistics Limited	Zone 1, River Trade Terminal, 201 Lung Mun Road, Tuen Mun, N.T.
8	PCL Container Services Limited	No. 3784 Tsing Ko Road, Tsing Yi
9	Floata Consolidation Limited	Lot No. 479, Stonecutters Island, Kwai Chung, N.T.
10		STT3589 Hong Wan Road, Tsing Yi Island, N.T.
11		Mei Chung Road, Kwai Chung Container Port Road South, N.T.
12		Area 29, Cheung Fai Road, Tsing Yi Island, N.T.
13		River Trade Terminal, 201 Lung Mun Road, Tuen Mun, N.T.

Relevant guidance notes and codes for module production, are summarised as follows:

- PNAP ADV-36;
- PNAP ADV-34;
- Code of Practice for Precast Concrete Construction (Item 3.15);
- Road Traffic (Traffic Control) Regulations.

7.2 Specific actions

To safeguard MiC project success, specific actions on MiC transportation and logistics are recommended below.

For the Contractor:

- Adopt buffer storage yard, back-up storage yard and site-nearby yard to reduce the risks of module transportation and secure just-in-time performance.
- Adopt scenario-based approach for logistics plan comparison and analysis (Niu et al., 2019).
- Design at least two backup routes for module transportation to increase the robustness of logistics plan.
- Conduct trial run of the delivery route.
- Adopt advance technology to identity road constraints on module dimension, e.g. truck motion planning methods and 3D truck simulation tools.
- Adopt real-time tracking technology to track module status on road and site, e.g. global positioning system (GPS) to track transportation location, inertial measurement units (IMU) to track vibration and surveillance cameras to track installation process (Zhang et al., 2020).

8. Installation and construction

8.1 General guidance

For module installation[5], it is necessary to consider the aspects including but not limited to the following:

- Crane selection, i.e. lifting capacity (load weight, lift height, moving distance, etc.), crane type, cost and noise should be considered when selecting a crane. (Note: Mobile cranes have a greater lifting capacity than tower cranes. They can be located at the optimal locations to minimise the reach from the lifting point to the installation position. However, consideration should be given to the capacity of the bearing ground to support the outriggers, adequacy of working space, the height limit to which the MiC modules can be lifted and the building height. Tower cranes with a lifting capacity of 25T at a reach of 30 metres are quite common in Hong Kong. However, tower cranes with a higher lifting capacity such as up to 42T at a reach of 30 metres are very limited in number at present and it is recommended to secure their availability early);
- Preparation works for module lifting
  - Loading point;
  - MiC delivery truck running in and out of the project site;
  - Application of lifting frame;
  - Safety guardrail;
  - Optimisation of setup/preparation time/ module installation sequence levelling and shimming of the base fixing points to receive the modules;
  - Worker and site supervisor qualifications;
- Quality checking works during module installation
  - Construction tolerance
  - Vertical and horizontal alignments;
  - Water-tightness;
  - Fire cavity barrier treatment;
- Safety and on-site audit check
  - Design of safe working platform for lifting and connection installation,
  - Worker safety equipment, e.g. safety belts, safety shoes, hardhats;
  - Safety supervision plan;
  - On-site audit check, i.e. design a checklist for module components like furniture, equipment and contingency plan for lifting equipment failure.

Relevant guidance notes and codes for the module installation and construction, are summarised as follows:

- PNAP ADV-36;
- PNAP ADV-34;
- Building (Administration) Regulations (B(A)R);

[5] For more information about the established and innovative methods of lift planning and optimisation, please refer to Zhang and Pan (2020)

- Buildings Ordinance;
- Code of Practice for the Structural Use of Steel;
- BS EN ISO 6892-1:2009.

8.2 Specific actions

To safeguard MiC project success, specific actions on MiC installation and construction are recommended below.

For the Contractor:

- Adopt BIM-supported virtual reality technologies to train construction workers for MiC, especially for the module installation process.
- Adopt smart technologies to improve the productivity and safety levels of construction sites, e.g. smart crane monitoring systems for module lifting, digital systems for monitoring activities of construction workers and vehicles.
- Adopt 3D-laser scanning technologies to assist the levelling and alignment of module installation.

9. Maintenance

9.1 General guidance

For the maintenance of buildings built with MiC, it is essential to consider the aspects in design including but not limited to the following issues:

- Inspection and maintenance plan, e.g. regular walls and roof, windows and doors, flooring and electrical and mechanical utility inspection;
- Access points for inspection, repair and replacement of critical elements;
- Renovation guidance, e.g. procedures, appropriate tools, renovator qualification;
- Availability and supply of spare parts;
- Homeowner user manual, e.g. safety notices, instruction for use, structure, layout, cleaning and maintenance advice;
- Decommissioning and demobilisation, e.g. activities, personnel, equipment and operating supplies needed for decommission and demobilisation.

Relevant guidance notes and codes for modular building maintenance, are summarised as follows:

- PNAP ADV-36
- PNAP APP-93
- PNAP ADV-14
- Building Maintenance Manual

9.2 Specific actions

To safeguard MiC project success, specific actions for different stakeholders on MiC maintenance are recommended below.

For the Client and the Maintenance Contractor:

- Refer to Building Maintenance Manual for regular maintenance;
- Use Artificial Intelligence of Things (AIoT)-supported digital twin for maintenance and management, e.g. structural health monitoring system.

For the User:

- Users should seek recommendations from renovation guidance or qualified professionals prior to the commencement of renovation works.
- Report tears, leaks and cracks leak immediately to the facility management company for instructions and repair arrangements.

10. Quality assurance and quality control

10.1 General guidance

For the quality assurance and quality control (QA/QC), it is necessary to consider the aspects including but not limited to the following:

- Quality Assurance Scheme (QAS), i.e. the MiC supplier usually is required to submit a QAS before the commencement of the production work in the prefabrication factory;
- Module supplier qualification, i.e. modules produced by a factory with ISO 9001:2015 or equivalent quality assurance certification;
- The Contractor, Authorised Persons, Registered Structural Engineers and Registered Geotechnical Engineers also hold the responsibility of carrying out in-factory quality supervisions in specific frequencies by themselves or their representatives on the product compliance and conformity as required by the PNAP ADV-36.
- Define acceptance criteria in the contract documents. When this is not the case, it would be necessary to identify them and possibly to achieve agreement between the project client and the contractor prior to the commencement of the contract.
- Apart from Hold and Witness Points in prefabricated and in-situ cast construction, typical Hold and Witness Points in MiC would include module dimension, squareness, verticality, connections, etc. For example, the levelling and alignment of a module shall remain within the tolerance limits after its production in factory and installation on site.
- QC inspectors with specific duties and involvement in the inspection activities should be trained prior to the commencement of production and construction work.
- Special tests (e.g., magnetic particle inspection and ultrasonic examination in steel MiC, compressive strength of concrete cylinders in concrete MiC) should be conducted by laboratories accredited under the Hong Kong Laboratory Accreditation Scheme (HOKLAS) or other laboratory accreditation bodies which have mutual recognition agreements with HOKLAS for the particular test concerned, as required by the PNAP ADV-36.
- For inspection works outside of Hong Kong, the contractor and the project client should organise authorised representatives to conduct inspection in the factory.

Relevant guidance notes and codes for QA/QC, are summarised as follows:

- PNAP ADV-36: Appendix B;
- PNAP APP-158;
- FSD Circular Letter No.1/2020;
- FSD Circular Letter No.3/2019;
- FSD Circular Letter No.1/2015;
- FSD Circular Letter No.1/2007;
- Water Supply for New Buildings adopting Modular Integrated Construction;
- Guidance Note on Fixed Electrical Installations with Modular Integrated Construction
- Method;
- Guidance Note on Household Electrical Products with Modular Integrated Construction Method

- Buildings Ordinance: Item 6 in section 17(1);
- (B(A)R (Regulation 10);
- Code of Practice for Structural Use of Concrete;
- Code of Practice for Precast Concrete Construction;
- Code of Practice for Structural Use of Steel.

10.2 Specific actions

To safeguard MiC project success, specific actions on QA/QC are recommended below.

For the Contractor:

- Inspections works can be organised according to the production, transportation and site installation workflows. The inspection check sheet should include item, description, location, method, frequency, responsibility, acceptance criteria, contact, follow-up and remarks, etc. The quality targets to be achieved should meet the requirements of regulation and customer scope.
- Adopt mock-up sample to 1) verify selections made under sample submittals, demonstrate aesthetic effects and where indicated, qualities of materials and execution, review coordination, testing and operation, 2) show interface between dissimilar materials, 3) demonstrate compliance with specified installation tolerances.
- Adopt a Cloud-based Workflow Management System (CWMS) and digital technologies for QA/QC, e.g. use QR code or Radio-frequency identification (RFID) to record quality checking and progress information in factory production, transportation and on-site production.
- Adopt BIM supported virtual reality technologies to train inspectors with specific duties and involvement in the inspection activities.
- Adopt remote sensing and living technologies for some inspections works outside of Hong Kong, e.g. checking roughness of walls.
- Adopt 3-D laser scanning technologies for levelling and alignment inspections.
- A QA/QC Plan Table sample is recommended as shown in Table 2.

Table 2. Quality Assurance/Quality Control Plan Table

	Project Title:	
	Contract No:	
	Reference No.:	

Item No.		Activity Description	Location	Type of Control	Hold (H) and Witness (W) Points								Contract Requirement/ General Specification/ Acceptance Criteria	Type of Record Table	Remark
					Contractor		MiC Supplier		Client		Third Party				
					H/W	ROI	H/W	ROI	H/W	ROI	H/W	ROI			
Factory	1	Check module dimension	A Working Area	I	H	All	W	All	W	25%	W	25%	Tolerance Description	Table I	Inspection before painting
	2														
	…														
Site	1														
	2														
	…														

Notes:

H = Hold Points W = Witness Points ROI = Rate of Inspection

11. Cost estimation and cost code

11.1 General guidance

For the cost estimation of a MiC project, it is necessary to consider the aspects including but not limited to following:

- The principles of MiC cost estimation include:
    - *Controllability*: The preparation of the cost estimation is based on the cost control capability of the responsible unit (e.g., the client, contractor, MiC supplier, etc.). Any cost that can be controlled by the responsible unit should be listed as the content of the unit's cost estimation. For the uncontrollable cost of the responsible unit, it should be regarded as another controllable unit of responsibility.
    - *Consistency*: The cost estimation should be prepared in full accordance with the responsibilities of the responsible unit, ensuring that the content of the cost estimation is consistent with its responsibilities.
    - *Rationality*: The cost estimation should be prepared on an objective and practical basis, and should comply with relevant laws and regulations, guidance notes and codes.
    - *Adjustability*: In case of the absence of drawings and design changes, the cost estimation should be dynamically adjusted according to the actual situation.

The following activities should be included in the cost estimation process:

- Pre-cost estimation work
    - To identify responsible units for the cost estimation;
    - To identify contract type (e.g. Design and Build);
    - To obtain relevant cost data with due adjustment;
    - To obtain quotations for each construction activity.
- During cost estimation work
    - To develop cost centres according to the given drawings;
    - To take off quantities and develop Bills of Quantities (BoQ) according to the drawings and method of measurement.
- Post-cost estimation work
    - To adjust the BoQ according to design changes, force majeure, etc.;
    - To collect and store the quotation of construction activities.

For systems cost estimation for MiC projects, it is advisable to leverage on the well-established cost estimation system in the building construction industry, which encompasses:

- Model BoQ for Building Works;
- Hong Kong Standard Method of Measurement of Building Works (SMM);
- Drawing on standards provided by relevant regulatory bodies, e.g. the Civil Engineering and Development Department (CEDD) [6], the Architectural Services Department

[6] CEDD Standard Drawing: https://www.cedd.gov.hk/eng/publications/standards-spec-handbooks-cost/stan-drawing/index.html

(ArchSD)[7], the Drainage Services Department (DSD)[8], the Water Supplies Department (WSD)[9].

11.2 Specific actions

The CICID of The University of Hong Kong (HKU) developed Cost Code[10] of MiC, which can be used by practitioners for cost estimation and benchmarking. The cost codes cover all cost items related to MiC construction at the project level. Various levels of costs are provided for systematic and effective cost analysis and benchmarking. The cost model consists of:

- There are four major cost codes, i.e., Net Building Cost, Gross Building Cost, Net Project Cost and Gross Project Cost (ASD, 2015).
- The Gross Project Cost is broken down into 9 minor cost codes. These are Preliminaries, Substructure, Superstructure, Mechanical & Electrical Services, External Works & Drainage, Site Development, Stores, Furniture & Equipment, Consultant's Fees and Contingency.
- Within each minor cost code there are various elements. Each element represents a function of the building or its environs. There are 20 elements in the model.
- To allow finer control over the apportionment of cost, some elements are further divided into sub-elements. There are 93 sub-elements representing the major cost centres of the project. Each of them is provided to further explain the components in its corresponding element.
- Cost items permit cost significant parts of the sub-elements to be monitored in some details. 319 cost items are identified in this cost model. For example, the sub-element, Structure, is divided into frame, roof, upper floors, etc.
- Within each cost item, there are several sub-cost items. In total, 546 sub-cost items are identified to elaborate the definitions of its corresponding cost item.

The cost codes developed are supposed to be used to evaluate the cost of MiC projects in comparison with their traditional counterparts. Some key considerations are highlighted as follows:

- It should be noted that the unit rates of sub-cost items are much associated with the costs of labour, materials and equipment, and are highly influenced by productivity and level of technological innovations in industries. Thus, the users of the cost codes are suggested to update the unit rates according to their specific project contexts for producing effective cost estimation. Nevertheless, the provided cost code structure should be used for meaningful cost benchmarking and learning.
- The cost of module production is usually provided by the MiC supplier as a total unit

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[7] ArchSD Standard Drawing: https://www.archsd.gov.hk/media/15056/e152.pdf

[8] DSD Standard Drawing: https://www.dsd.gov.hk/EN/Technical_Documents/Standard_Drawings/index.html

[9] WSD Standard Drawings: https://www.wsd.gov.hk/en/publications-and-statistics/guidelines-reports-drawings-specifications/standard-drawings/index.html

[10] HKU CICID (2019). *MiC for High-rise Buildings in Hong Kong: Supply Chain Identification, Analyses and Establishment: MiC Cost Code*. HKU CICID, CIC Research Fund.

cost. The cost of module transportation is usually provided by the logistics service provider as a total unit cost. The cost of module installation should be evaluated based on actual installation works undertaken by the contractor or relevant subcontractors/service providers.

- The cost codes provide a structured approach to evaluating and benchmarking costs of MiC projects. The cost codes support customisation to meet specific requirements in different MiC projects.

12. Summary

This Practical Guide provides general guidance and recommends specific actions on MiC adoption in Hong Kong. The Practical Guide considers the main life cycle stages of a MiC project, which include procurement, design (including architecture, structure, mechanical, electrical and plumbing, and fire safety), module production, transportation and logistics, installation and construction, and maintenance, as well as addresses the key issues with quality assurance and quality control (QAQC) and cost estimation.

The Practical Guide was produced based on the results of the other deliverables of this study, which include the case studies, the logistics report, the market report, and the cost analyses report. The Practical Guide should help to support the Hong Kong construction industry in their MiC adoption with a better understanding of the two following aspects:

- The Practical Guide summarises an array of essential considerations and regulatory requirements to be considered in delivering a MiC project, covering the aspects of design, manufacturing, transportation and logistics, installation and construction, maintenance, and cost estimation and control. The Practical Guide also includes a series of referential documents and supplementary information.
- The Practical Guide provides recommendations on how to overcome the challenges in establishing MiC supply chain. This will help stakeholders to formulate practical and robust supply chain solutions in terms of their supplier selection, module manufacturing, logistics planning, and regulatory compliance.

The Practical Guide has taken into consideration the established modular construction practices overseas as well as the relevant codes and regulations locally in Hong Kong. Nevertheless, the users of this Practical Guide should pay attention to the following notes:

- This Practical Guide is provided for general guidance rather than for specific prescriptions, and so the guidance provided will then need to be contextualised to specific projects for effective use.
- Stakeholders when considering MiC adoption should refer to the details of the documents listed in this Practical Guide. Nevertheless, such list is by no means exhaustive, but other statutory and technical documents may need to be considered as per specific project conditions and requirements and new statutory and technical documents may be introduced.
- Stakeholders when considering MiC adoption should also check the latest version of the relevant codes, standards, and documents listed in this Practical Guide as they may be updated from time to time.

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Appendix I: List of standards, guidance notes and regulations

No.	Standards, guidance notes and regulations	Issued by	Publication Date	Reference links
1.	Model Bills of Quantities for Building Works	ArchSD	2017	https://www.archsd.gov.hk/media/93722/model_bill_2012_rev.pdf
2.	ArchSD Standard Drawing	ArchSD	Feb 2011	https://www.archsd.gov.hk/media/15056/e152.pdf
3.	Hong Kong Standard Method of Measurement of Building Works	ArchSD	Nov 2018	https://www.hkis.org.hk/ufiles/smm4-201811.pdf
4.	Code of Practice for Precast Concrete Construction	BD	Apr 2016	https://www.bd.gov.hk/doc/en/resources/codes-and-references/code-and-design-manuals/cppcc2016e.pdf
5.	Code of Practice for Structural Use of Concrete	BD	Feb 2013	https://www.bd.gov.hk/doc/en/resources/codes-and-references/code-and-design-manuals/CoP_SUC2013e.pdf
6.	Code of Practice for the Structural Use of Steel	BD	May 2010	https://www.bd.gov.hk/doc/en/resources/codes-and-references/code-and-design-manuals/SUOS2011.pdf
7.	PNAP ADV-14	BD	Jul 2012	https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/ADV/ADV014.pdf
8.	PNAP ADV-34	BD	Sep 2016	https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/ADV/ADV034.pdf
9.	PNAP ADV-36	BD	Dec 2017	https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/ADV/ADV036.pdf
10.	PNAP APP-158	BD	Nov 2016	https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/APP/APP158.pdf
11.	PNAP APP-161	BD	May 2019	https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/APP/APP161.pdf
12.	PNAP APP-93	BD	May 2014	https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/APP/APP093.pdf
13.	Pre-acceptance Mechanism	BD	Nov 2017	https://www.bd.gov.hk/en/resources/codes-and-references/modular-integrated-construction/index.html
14.	Building Maintenance Guidebook	BD	Dec 2020	https://www.bd.gov.hk/en/resources/codes-and-references/codes-and-design-manuals/bmg.html
15.	CEDD Standard Drawing	CEED	Jul 2019	https://www.cedd.gov.hk/eng/publications/standards-spec-handbooks-cost/stan-drawing/index.html
16.	Guidelines on the Statutory Requirements for Modular Integrated Construction Projects	CIC	Sep 2020	http://mic.cic.hk/files/Information/1/File/Reference_Material_2020.pdf
17.	Technical Guide on Effective Design and Construction to Structural Eurocodes: EN 1993-1-1 Design of Steel Structures	CIC	Mar 2015	http://www.cic.hk/files/page/148/Technical%20Guide%20EN1993_Prof.KF%20CHUNG.pdf
18.	Building (Administration)	Department	Jan 1960	https://www.elegislation.gov.hk/hk/cap123

No.	Standards, guidance notes and regulations	Issued by	Publication Date	Reference links
	Regulations	of Justice (DOJ)		A
19.	Building (Construction) Regulations	DOJ	Dec 2012	https://www.elegislation.gov.hk/hk/cap123B
20.	Building Ordinance	DOJ	Sep 2011	https://www.elegislation.gov.hk/hk/cap123
21.	Electricity Ordinance	DOJ	Nov 1990	https://www.elegislation.gov.hk/hk/cap406
22.	Energy Efficiency (Labelling of Products) Ordinance	DOJ	May 2008	https://www.elegislation.gov.hk/hk/cap598
23.	Gas Safety Ordinance	DOJ	April 1991	https://www.elegislation.gov.hk/hk/cap51
24.	Road Traffic (Traffic Control) Regulations	DOJ	Aug 1984	https://www.elegislation.gov.hk/hk/cap374G
25.	DSD Standard Drawing	DSD	Aug 2001	https://www.dsd.gov.hk/EN/Technical_Documents/Standard_Drawings/index.html
26.	Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method	EMSD	Jun 2019	https://www.emsd.gov.hk/filemanager/en/content_444/GN_FEI_Modular_Integrated_Construction_Method.pdf
27.	Guidance Note on Gas Supply Installations	EMSD	Jun 2019	https://www.emsd.gov.hk/filemanager/en/content_287/Guidance_Note_on_Gas_Supply_Installations.pdf
28.	Guidance Note on Household Electrical Products with Modular Integrated Construction Method	EMSD	Jun 2019	https://www.emsd.gov.hk/filemanager/en/content_444/GN_HEP_Modular_Integrated_Construction_Method.pdf
29.	Guidance Note on Supply of Energy Label Prescribed Products at MiC Projects	EMSD	Jun 2019	https://www.emsd.gov.hk/energylabel/en/doc/Guidance%20Note%20on%20Supply%20of%20Prescribed%20Products%20at%20MiC%20Projects_ENG(201906).pdf
30.	FSD Circular Letter No. 3/2019	FSD	Mar 2019	https://www.hkfsd.gov.hk/eng/source/circular/2019_03_eng_20190327_160959.pdf
31.	Modularisation for Modernisation: A Strategy Paper Rethinking Hong Kong Construction	HKU CICID	May 2019	
32.	BS EN ISO 6892-1:2016	ISO/TC 164/SC 1 Uniaxial testing	Jul 2016	https://www.sis.se/api/document/preview/920653/
33.	Water Supply for New Buildings adopting Modular Integrated Construction (MiC)	WSD	Apr 2020	https://www.wsd.gov.hk/en/customer-services/application-for-water-supply/water-supply-for-new-buildings-adopting-mic/index.html
34.	Guide to Application for Water Supply	WSD	Oct 2019	https://www.wsd.gov.hk/filemanager/en/content_1805/guide-to-application-for-water-supply-e.pdf
35.	WSD Standard Drawings	WSD	Oct 2020	https://www.wsd.gov.hk/en/publications-and-statistics/guidelines-reports-drawings-specifications/standard-drawings/index.html