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Project Title: Relocatable Housing by Modular Integrated Construction

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Project Outline:

Local building industry in Hong Kong has just commenced to adopt the modern technology of "Modular Integrated Construction" (MiC), in response to current challenges faced by the industry and transform it to a new era. MiC in Hong Kong is defined as an innovative construction method with the concept of "*factory assembly followed by on-site installation*", aiming to improve productivity, quality, safety and environmental performance of construction projects (Construction Industry Council Hong Kong). Recently, applications of MiC are found mostly in residential developments, including students and youth hostels, government staff quarters and transitional social housing (TSH, for families in distress or extended waiting list of public rental housing). In the 2019 Policy Address, the HKSAR government had pledged to provide 10,000 TSH units in the next three years, utilizing idle land parcels of short-term tenure. The government lands are typically granted for a period of five year use, after that the TSH units are supposed to be relocated unless an extension is offered.

In order to address to the unprecedented challenge of transitional housing, the study aimed at identifying key technical issues and proposing an adaptable solution in form of a relocatable MiC building system prototype. The main objectives were: (a) To provide a series of modular housing units design and low-rise structural/building system which is fully relocatable, reusable and environmentally self-sustainable (with maximized optional off-grid capacity). (b) To explore the scope of adaptable MiC modules for different occupants needs such as accommodation (size/no. of bedrooms/bathrooms), functional configuration for site and terrain constraints (stacking, cascade) and other associated ancillary use of residential complex.

Keywords— modular integrated construction, prefabricated prefinished volumetric construction, relocatable housing, transitional social housing.

Scope of Works:

The study initially reviewed the MiC technology and its current application in Hong Kong, focusing on projects in the housing sector. Literature review on comparable MiC applications and exemplary national guidelines (global) were conducted to provide a reference point and basis for evaluation against local context including industry practices, manufacturing and logistics, building code compliance, etc. Qualitative survey and focus groups were conducted with industry key stakeholders, academia, government departments and user groups to identify key challenges and possible solutions. Value engineering assessment was also introduced to evaluate cost effectiveness of options on module sizes, layout and configuration such as no. of storeys, provision of communal facilities, etc. Modularized units were applied to the entire building system, including corridor, staircase, building envelope (roofing/façade), building services and foundation.

Project Deliverables:

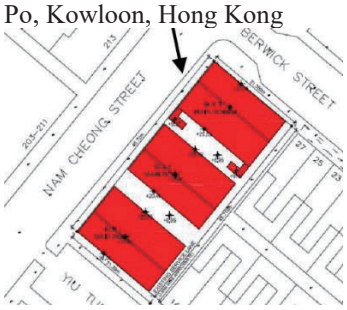
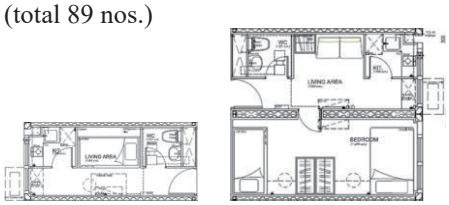
Expected deliverables include (i) Design prototype of MiC volumetric residential modules of different configurations; (ii) Prototype design of a relocatable MiC building system, including structural (foundation and superstructure), building components (horizontal & vertical circulation, façade, roofing, amenities), essential building services and sustainable environmental systems (energy, water, thermal, septic, etc.); (iii) Prototype building cost and time program for construction planning purpose; (iv) Working and presentation models to illustrate (i) and (ii) above; (v) Knowledge dissemination -

public and industry seminars, presentation at industry conference: (vi) Evaluation - public and industry Public and industry feedback, recommendation of way forward.

Project Progress:

Literature review

Comparable projects search was conducted on electronic data base and general search engine including English and Chinese data base. (Keywords – relocatable homes, social housing, modular housing). Search results indicated that there are only limited comparable examples locally and overseas for the relocatable form of low-rise social housing projects. Most relocatable homes found are single free-standing units, and most social housing are of permanent type. Two comparable built examples were identified below for comparison:

Project	Hong Kong Council of Social Services (Operator - Tung Wah Group) 	"Ladywell" Pop Up Scheme for Homeless Families 
Location	202-220 Nam Cheong Street, Shum Shui Po, Kowloon, Hong Kong 	Lewisham Council, London UK 
Time Program	"Design & Built" Contract 4/2019 – Q2/2020 (365 days) Land tenure overall 5 years (2017-2022)	Design, construction 2014-2016 Land tenure 4 years (2017-2020)
Structure	4 storey steel framed (2.5m wide modules)	4 storey timber framed
Unit type	1 person, 2 persons, 3 persons flat @13.36 – 20 - 26.73 sqm respectively (total 89 nos.) 	4 person (2 bedrooms) flat @80 sqm approx. (total 24 nos.) 
No. of occupants	150 approx. @> 7.5 sqm approx.	96 approx. @ 20 sqm approx.
Construction cost	HKD$ 400,000/ unit approx. (total project HKD$ 37.5 mil)	£ 1,200/sqm. (total project £ 4.98 mil)
Redeployed	Not known, Design life up to 20 years	5 more times, Design life 60 years

Overseas national design guide for Construction of Modular Housing

- Canada:
    - **National Building Code of Canada:** CSA Z240 MH "CSA National Standard for Manufactured (Mobile) Home Construction" is in effect a building code for manufactured (mobile) homes. CSA A277 Standard is a Certification Standard (not a building code) used to certify the residential building in compliance to the National Building Code (NBC) as adopted by the provinces, and applied via CSA A277 Procedure for Certification of Prefabricated Buildings, Modules and Panels, where the home will be located.
    - **The BC Housing Design and Construction Standards (2019):** Currently, BC Housing provides general guidance on modular construction in a section called "Modular Construction Methods" within the Design Guidelines and Construction Standards. According to the guidelines, the acceptable building forms are: (1) walk-up apartments up to 3 storeys and (2) four to six storey apartments. The types of units to be designed fall under three categories: (a) self-contained studio units (30sqm in size); (b) emergency shelter units, from single-bed to four-bed sleeping configurations (ranging 11sqm – 18sqm in size); or (c) wheelchair accessible units which must constitute at least 5% of the total provisions of units. As to material, the use of wood is generally required as the primary construction material. Transportation regulations indicate that vehicles must not exceed 4.9m in width and 18.3m in length (BC Housing, 2014).

- Australia:
    - **Handbook for the Design of Modular Structures (Monash University, 2017):** This Handbook is intended to form a Guide for Modular Construction and DfMA in relation to the considerations and expectations required of the various stakeholders – the Developer, the Designer, the Manufacturer, the Materials Supplier, the Builder. The information is presented as a detailed list of considerations along with cross references to the National Construction Code of Australia.

      These considerations provide integrated solutions and experiences to industry, government and the community across key chapters: "Structure", "Building Services, Fire, Acoustics and Sustainable Thermal Regulation", "Façades", "Architecture", "Materials and Manufacturing", "Durability", "Safety", "Transportation", "Compliance", "Disassembly and Recyclability", "DfMA, Digital Engineering and Lean Manufacturing". The Handbook also delineates the types of off-site construction offering an important concept of the continuum of prefabrication between volumetric and non-volumetric which is defined by "the extent of prefabrication." Transportation regulations require prefabricated components to be under 3.5m in width, 4m in height, 16.5m in length and 22 tonnes in weight (p147).

- UK:
    - **UK Building Regulations (Approved Documents)**: Currently, there is no specific guidance on the modern methods of construction in the UK. All modular design projects are expected to meet (and even exceed) or comply with the items found in the UK Building Regulations (UK Parliament, 2019). Most modular buildings up to 30sqm floor area are exempt from the majority of building regulations as long as they are not used for sleeping accommodation. Otherwise it will require full building regulations approval.
    - **Modern Methods of Construction (MMC): Introducing the MMC Definition Framework**: The Definition Framework was launched by the Ministry of Housing in

2019 with an aim to define "Modern Method of Construction" (MMC) so that these terminologies could be better understood across the industry. According to the Definition Framework, there are 7 MMC categories according to its structural characteristics. According to the transportation regulations, the modules are required to remain under 5 metres in width, 4.2 metres in height and 14 metres in length (Lawson et al., 2012; RICS, 2019) which is the maximum for motorway transport in the UK.

- Singapore
    - **Design for Manufacturing and Assembly (DfMA) - Prefabricated Prefinished Volumetric Construction (PPVC) 2018:** Singapore's Building and Construction Authority (BCA) partnered with the industry to develop detailed code of practice on PPVC for suppliers and manufacturers to follow. The guidebook provides simple and step-by-step tips on how PPVC is designed, manufactured, inspected, transported and assembled. It places emphasis on having early involvement of contractors before deciding on which types of PPVC modules (concrete or steel) to be used. The material of the construction will dictate the size and weight of the modules and is therefore critical for the next considerations in terms of transportation requirements, module configurations and the type of hoisting machinery required on site. According to BCA, for every typical 2-bedroom unit layout, approximately 48sqm in size, 3.5 modules are required (ratio 1:3.5). In terms of transportation, the controlled parameters are to be under 4.5m in height, 80 tonnes in weight and no more than 3.4m in width.

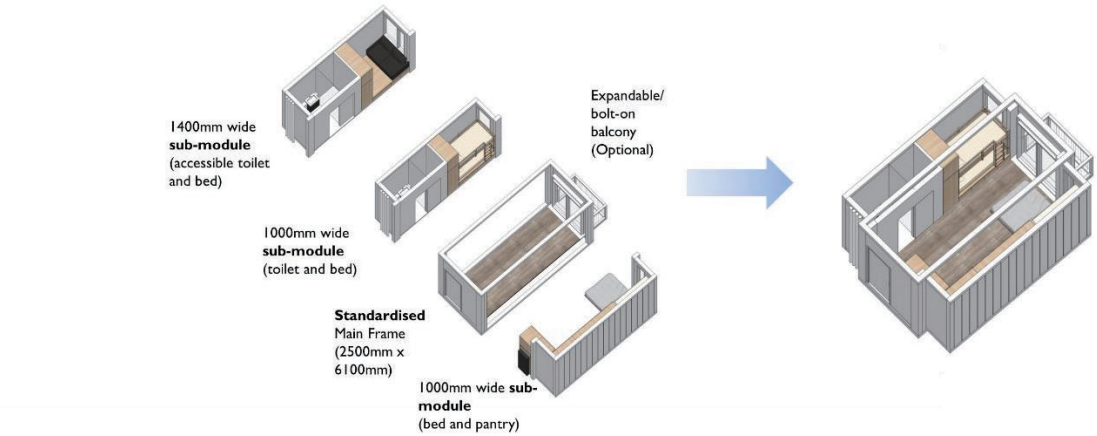
- Countries Comparison - Table 1

Items	Canada	Australia	UK	Singapore
MiC-Specific Regulations	Yes	No	No	Yes
Transportation Requirements	< 4.9m (Width) < 18.3m (Length)	< 3.5m (Width) < 4m (Height) < 22 tonnes (Weight)	< 5m (Width) < 4.2m (Height)	< 3.4m (Width) < 4.5m (Height) < 80 tonnes (Weight)
% of Modular Housing /Year	12.5%	5%	15%	35%

Architectural design

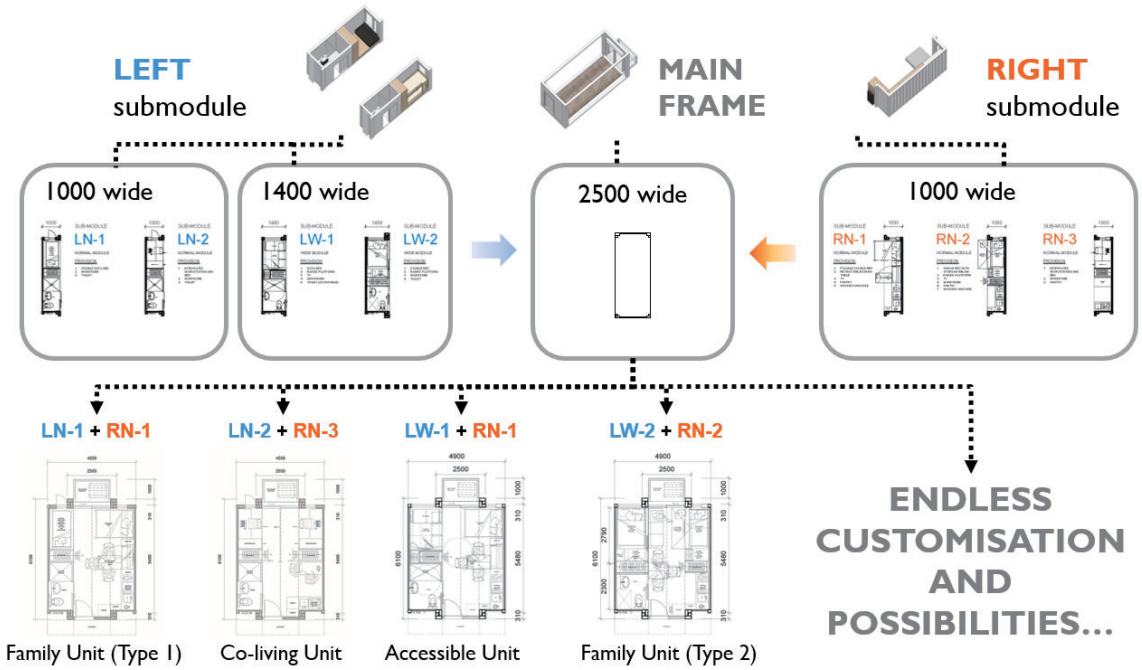
Architectural design concept

- Expandable MiC prototype module to overcome road transportation limitation - packaged to 2.5m wide & transported during daytime. Expand on-site to 4.5m to 4.9m wide – create efficient unit layout optimized for living to meet different occupants' needs.
- Volumetric construction - minimize in-situ works
- Expandable module is more efficient in GFA compared to conventional MiC (3% higher efficiency) due to the fact that the extent of internal wall between adjoining modules is eliminated.
- Modular building system including circulation (corridors, staircases) and typical plant room modules (electrical, lift, fire services, etc.)
- Adaptable façade and roofing system for custom design as per site/project requirements.
- Allow maximum potential for future reuse



Module Standardization & Built-in flexibility

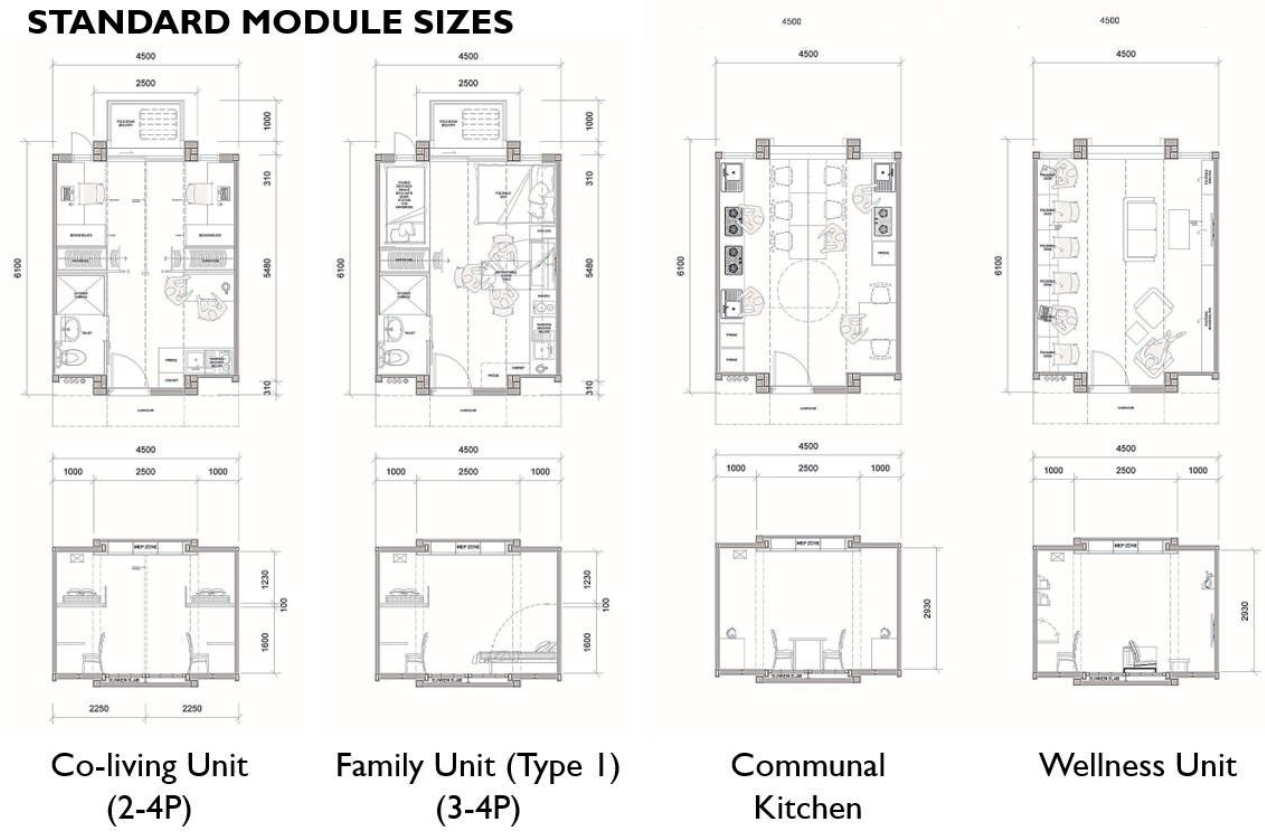
- In order to achieve optimal cost effectiveness, all unit types are fabricated by fitting customizable submodules on two sides of a standard main frame/centre module. The cost effectiveness is further enhanced by eliminating mirrored units to reduce variation of submodule types.



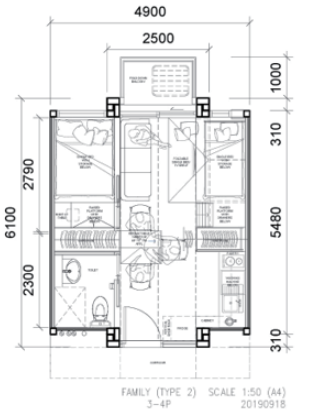
- Module matrix - An optimum combination using one single main frame (2.5m wide) with 3 submodules (2 left side submodules of 1m and 1.4m wide, 1 right side submodule of 1m wide) allows optimal flexibility and customization to generate 6 occupancy layouts without sacrificing economic efficiency:

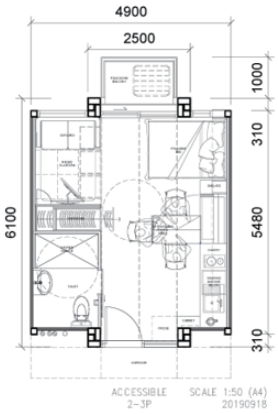
    - Twin/co-living unit (4m wide O/A) - shared unit for 2 people. Bedrooms can be separated for private living space. Share bathroom, living room & open kitchen.
    - Family unit type 1 (4m wide O/A) - Versatile unit for young couple with 1-2 kids (3 to 4 persons). Fold-up furniture: Couch/Double bed and TV Shelf/Single bed – create more clear space to be both a bedroom and a living room.

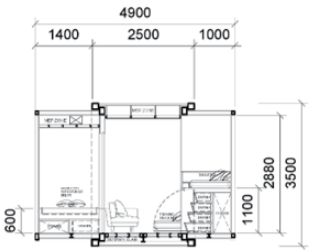
- Family unit type 2 (4.5m wide O/A) - Versatile unit for young couple with 1-2 kids (3 to 4 persons). Fold-up furniture: Couch/Double bed and TV Shelf/Single bed – create more clear space to be both a bedroom and a living room.
- Accessible unit (4.5m wide O/A) - Designed for assisted living of older couples with one care giver. Fully wheelchair accessible (bed space, kitchen, shower, cabinets) + elderly friendly/Universal Design features. Fold-up Furniture - Couch/Double bed and TV Shelf/Single bed enables more clear space
- Communal kitchen (4m wide O/A) - As all living modules only provide small pantry with portable electric cooktops, it is required under BO that a communal kitchen shall be provided due to non-provision of kitchen within unit. Features multiple electric worktops to allow spontaneous use, with shared appliances incl. fridge, microwave, oven, etc. Flexible table arrangement (1-8 pax) encourage social interactions among residents. Similarly, a smaller laundromat module may also be provided as required for each block.
- Common Wellness (4m wide O/A) - The Wellness Unit is designed to provide communal space for leisure that fosters interactions within neighbourhood. Flexible seating arrangement to encourage a variety of uses/spaces for different groups - up to 7-8 people also accessible to all residents including wheelchair-bound users. Furniture: Bookshelves, newspaper racks, board games, water pitchers/snacks, plants.

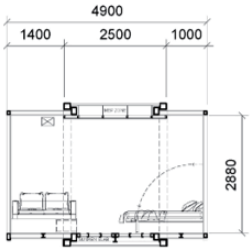


OVERSIZED MODULE SIZES (4900mm WIDE)







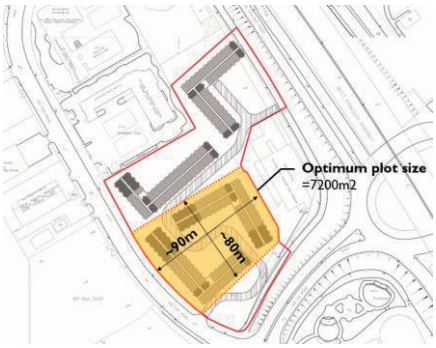


Family Unit (Type 2)
(3-4P)

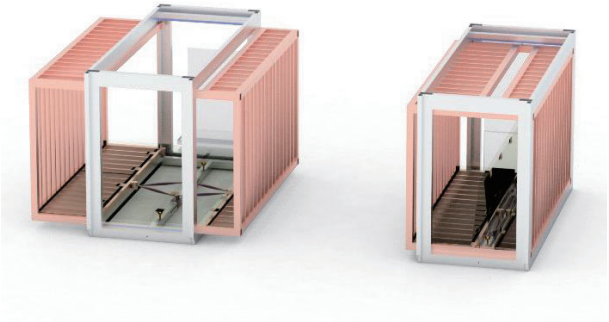
Accessible Unit
(2-3P)

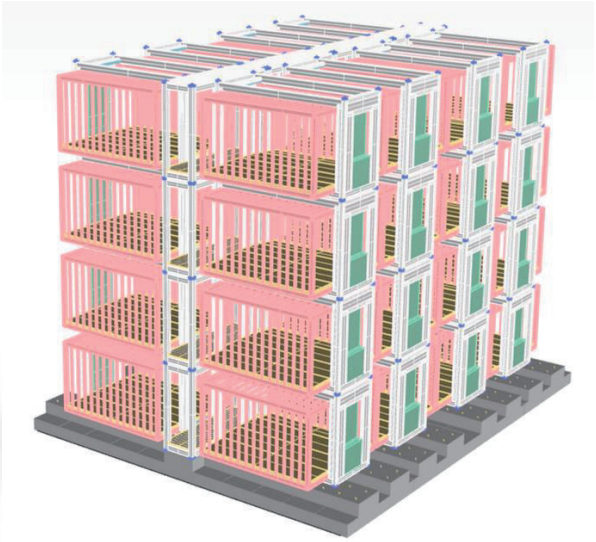
Cluster design

- An optimum ratio of a residential cluster (10 units per typical floor cluster) was established by taking account of basic circulation criteria, including functional and statutory egress distances.
- With reference to local and international benchmarks (approx. 12% for supporting communal facilities from a database of multiple social housing projects globally), one Communal kitchen and Wellness room were proposed to each typical floor cluster.
- Based on consideration of local context and usage pattern, one laundromat module was proposed (on ground floor) per block of residential cluster (typically 4 storey high).



Structural design





Structural steel of grade S355 has been adopted as the primary structural frame of the modules and the overall modular building after the modules are stacked on each other. The advantages of the structural steel material for the expandable MiC application are:

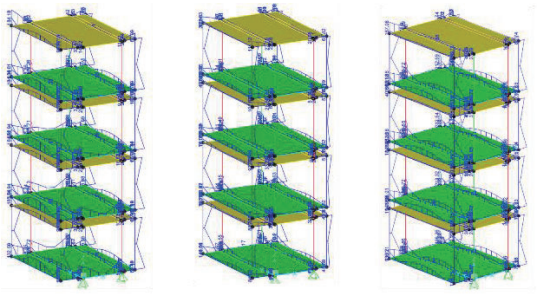
- Lighter structure and more compacted structural element size by comparing with reinforced concrete structure.
- Fabrication tolerance and accuracy can be controlled to meet a stringent requirement which is essential for the expandable mechanism.
- Fabrication process is relatively faster than that using reinforced concrete structure.
- Bolted connection at the module connection point can be designed and fabricated easily which enable the removal of individual module if required by loosening the connected bolts between modules.
- It is more environmentally friendly than the concrete structure as it can be recycled.

Superstructure & foundation

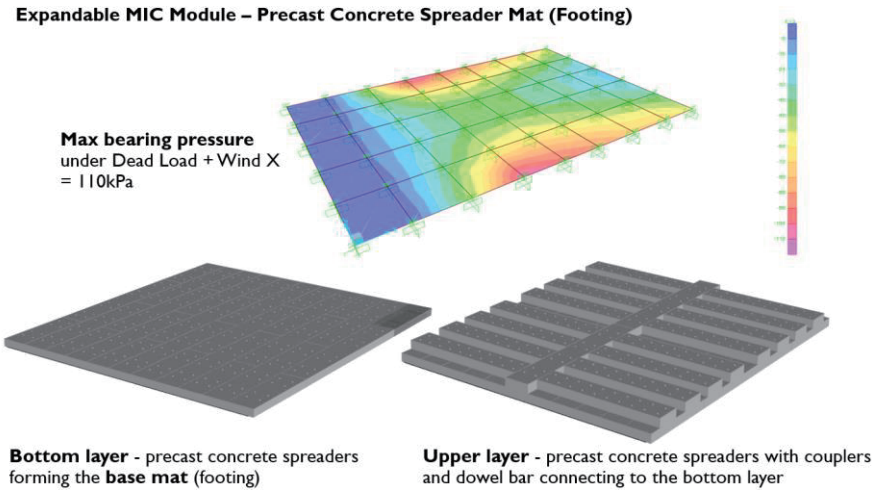
- Freestanding 4 storey building (or taller subject to ground bearing capacity and integration w/lateral resisting structural elements such as staircase and lift core)
- Volumetric module of Structural Steel Portal frame w/slide-out sub-module & fold-out balcony (optional), galvanised for outstanding corrosion protection
- Fully demountable module connection
- Relocatable precast concrete foundation (spreader mat & base slab with maximum bearing pressure 100 kPa for 4 storey building)

Max. Displacement under Wind X
= 24mm (H/583) OK

Max. Displacement under Wind Y
= 45mm / 2 = 22.5mm (H/622) OK



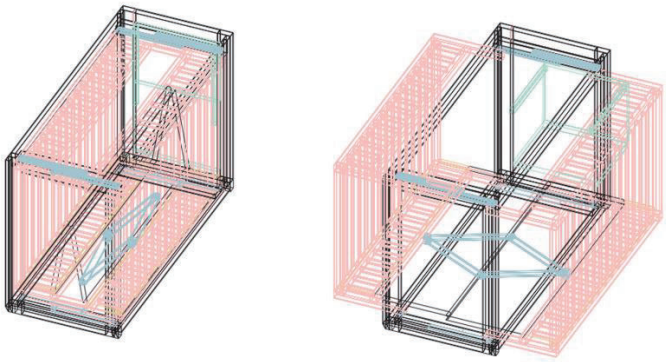
Wind X + DL + LL Wind Y + DL + LL DL + LL only
Maximum Stress among these load cases within 300MPa < 345 MPa



Expansion mechanism

The Expandable MiC represents ideal solution for a large variety of places. Following characteristics for its expansion mechanism will be considered during the design process.

- The capacity to multiply two times its net area by symmetrical extension
- Low operation and installation cost should be considered
- Low self-weight and low maintenance cost
- Allow the mechanism to unfold and fold easily and quickly
- Symmetrical extension by manual or electromechanical extension
- Based on the slider-crank mechanism, a new lever-based system where a series of interconnected linkages counterbalance one another is developed
- The expansion parts retain their integrity and only a small amount of power is needed to move them whose self-load is heavy.
- As all of the levers are pin jointed and triangulated, the unfolded structures are extremely strong while remaining durable and easy to use.



Building services

Proposed optimum off-grid MEP provisions include:

Electrical -

- Off-grid power supply by Bio-diesel Generators
- Specific Process license is required for total generators capacity exceeds 5 MW
- High operation and maintenance cost
- Air pollution and noise pollution
- Underground fuel tank shall be provided
- Higher running cost and less reliability than power company

No. of Flat Units	**100**	**200**	**300**
Estimated Load	1,201 kVA	4,409 kVA	3,363 kVA
Installed Capacity of Biodiesel Generator	1 x 1,500 kVA	3 x 1,500 kVA	2 x 1,800 kVA
Genset Room Size	100 sqm	300 sqm	220 sqm
Fuel Tank Capacity for 48-hr Operation	25,000 L	75,000 L	58,000 L
Estimated Initial Cost	HK$2.5M	HK$6M	HK$5.8M

Plumbing –

- Centralized Solar Hot Water System
- Hot water stored in storage tank, backup from electric heating is required.
- Centralized plant need additional pipework and equipment with extra plant room space.

No. of Flat Units	**100**	**200**	**300**
Area of Solar Hot Water Panel Required	270m²	540 m²	810 m²
Hot Water Storage Tank Quantity	7nos. of 3000L Tank (1.5m⌀ x 2.7m(H))	14nos. of 3000L Tank (1.5m⌀ x 2.7m(H))	21nos. of 3000L Tank (1.5m⌀ x 2.7m(H))
Centralized Plant Area	60m²	120m²	180m²

Drainage –

- Package Type Sewage Treatment Plant - Per EPD Guide, use small sewage treatment plant for development with population >50 person
- Treated effluent can discharge to utility storm water system directly
- Regularly maintenance to remove sludge
- Underground installation, space saving

No. of Flat Units	**100**	**200**	**300**
Sewage Treatment Plant Dimension	2nos. “2.5m⌀ x 11m”	3nos. “3m⌀ x 12m”	4nos. “3m⌀ x 12m”

Table 2. Comparison Summary of Conventional vs Expandable MiC

Types of MiC	Conventional MiC	Expandable MiC
O/A module width	2.5m (normal) / 2.8m–3.1m (desirable but subject to TD wide load permit)	2.5m (during road transportation) / 4.5m–4.9m (expand on site after installation)
Transportation Restriction of module	2.5m wide - no restriction >2.5m wide - subject to TD wide load permit & restrictions	No restriction
Transportation Cost	Additional cost due to greater number of modules and escort for modules wider than 2.5m	Nominal cost as standard transportation
GFA Concession	6% for qualified MiC schemes	6% + 3% improved efficiency w/o double walls
Fabrication Cost	Additional cost for double wall, extent of structural frame and fire protection work for each individual modules.	Additional cost for the expandable mechanical device and foldable furniture.
Approach to allow customization	By adjusting main module.	By sub-module (standardization with optimum layout and functional flexibility)
Challenge on statutory approval	Depends on if adopted MiC system is in BD pre-approved IPA list.	Fire separation requirement between the sub module slab soffit and ceiling.
Technical challenges to be resolved in detail design	Less unforeseen technical challenge if adopting systems from BD's IPA pre-acceptance list.	Expandable mechanism (ball bearing guided rail system)
Acoustic performance between modules	Potential flaking noise transmission through module connection in both vertical and horizontal direction	Potential flaking noise transmission through module connection in vertical direction only.
Seal up joint between modules	Provide weather seal and fire stop between modules	Not required
Setting out tolerance between modules during installation	Tighter tolerance control required	Not required
On-site installation time	Longer – require seal up joint between modules & tolerance adjustment	Envisaged half of the installation time
Complexity of dismantle MiC	Higher - remove seal up joint between modules, install temporary weather protection to openings of demounted modules.	Minimum effort. No exposed module openings required to be protected.
Cost and time of disassembling	Relatively higher cost and longer period due to complexity of site work	Relatively lower cost and shorter period

Knowledge dissemination

Event - Construction Innovation Expo 2019 *"InnoTalk Forum - Innovation on Planning and Building Transitional Social Housing with MiC (Modular Integrated Construction)*", jointly hosted by the JC Design Institute for Social Innovation, PolyU and Construction Industry Council.

Date: 20 December 2019 (Friday)

Time: 11:00am–12:30pm

Venue: Hong Kong Exhibition & Convention Centre (Hall 1C – 1E)

Background: The importance and urgency of transitional social housing (TSH) has been heavily emphasised in the latest Government Policy Address. Rising property prices and long waiting times for public housing mean needy families require a place for shelter.

Challenge: Transitional social housing is much more than just about providing temporary accommodation however. The initiative aims to create a stronger bond among neighbourhoods, restore family values, revitalise local communities and develop a sustainable society.

Objective: To allow an exchange of opinions from key stakeholders (NGOs, architects and engineers, contractors) who wish to influence the future quality of transitional social housing (TSH) in Hong Kong, and visit the MiC prototypes at the "InnoTalk Forum" at the CI Expo.

Methodology: The preliminary design prototype of expandable MiC scheme was initially presented as an advance possible solution to introduce the key issues of TSH both socially and technically (design and construction). A "Mentimeter" survey was conducted on site with real time results and feedback from guests and participants, which were divided intentionally to 3 groups (NGO, Designers, Builders) to assess areas of differences in expectation and views.

Results: Total 89 participants (29 from Builders, 36 from Designers and 24 from NGO sectors) took part in the "Mentimeter" survey. Results were now being summarized for further analysis. Findings will be used as a guide to evaluate and develop the preliminary design prototype.

Project Significance:

1. The prototype design may provide potential real case application in selected sites for NGOs involved in the delivery of TSH. NGO had expressed interest in adopting the design scheme.
2. The prototype design may be used to participate in Hong Kong Construction Association's "Eco-TH-Village MiC Design Competition".
3. The prototype design provides a solid basis for the future pre-approval application of BD "In-Principle Acceptance" pre-approval application w/AP & RSE, subject to fund availability. https://www.bd.gov.hk/en/resources/codes-and-references/modular-integrated-construction/mic_acceptedList.html

Future work:

The next stage will focus on developing necessary component details and getting feedback from industry and public such as NGO sectors.

1. Building Ordinance statutory compliance check – e.g. MoE, FSI
2. Study of modular unit junction details (external and internal)
3. Structural and MEP Integration
4. Sample façade & roof design
5. Fine-tune interior design
6. Green / sustainability features (energy, water, septic, ect.)
7. Production of working & physical models
8. Public & industry evaluation

Appendix

MiC Design Prototype Interim Presentation ppt 20/12/2019