October 2023

CONSTRUCTION INDUSTRY COUNCIL
建造業議會

TECHNICAL REPORT

on the Deconstruction, Relocation and Reinstallation of MiC units in Nam Cheong 220 Transitional Housing Project

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Research Report to the Construction Industry Council, Hong Kong

Project Number: PRMIC2023000049

Technical Report on the Deconstruction, Relocation and Reinstallation of MiC modules in Nam Cheong 220 Transitional Housing Project

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October 2023

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Abbreviations

AP	Authorized Person
BIM	Building Information Modelling
CCTV	Closed-circuit Television
CIC	Construction Industry Council
DfD	Design-for-Disassembly
DMP	Digital Material Passport
FM-900	Fire protection paint
F.S.	Fire Service
P&D	Pick-up & Delivery
MEP	Mechanical, Electrical and Plumbing
MiC	Modular integrated Construction
MPI	Magnetic Particle Inspection
NC220	Nam Cheong 220
QR	Quick Response
SWHC	Standard Working Hours Committee
TMB	Temporary Modular Building
RHS	Rectangular Hollow Section
RSE	Registered Structural Engineer
UV	Ultraviolet
VAHA	Vancouver Affordable Housing Agency
VD	Virtual Deconstruction
3D	Three Dimension

Executive Summary

Using Modular-integrated Construction (MiC) method to build transitional housing can achieve earlier occupancy, owing to its faster on-site project delivery when compared with traditional in-situ construction. As these temporary housing projects are normally developed on vacant government or privately-owned land with limited duration of land tenure, the adapted MiC method shall also allow efficient disassembly and future reuse/reinstallation in their subsequent life cycles. Otherwise, if these temporary MiC housing projects are scrapped and disposed of as construction waste, the adverse environmental impact relative to the period of use may be much greater than that of permanent buildings. To optimise the environmental sustainability and economic value of temporary MiC housing, it calls for a shift from demolition to deconstruction, a process of disassembly, relocation, and reuse.

MiC, if designed appropriately, has high reuse potential because proper modular designs allow for ease of disassembly without causing damage to building components and materials, and enable efficient reinstallation to reproduce the original building performance. Overseas example has shown that MiC modules can be flexibility reused as individual units to become part of other new buildings. In Hong Kong, Nam Cheong 220 (NC220 in short) is the first local MiC transitional housing project disassembled when its land tenancy was terminated in early 2023. Owing to the design of bolted connections, NC220 modules have been dismantled and reused in a different project. The existing building was deconstructed to individual modular units, transported, stored, inspected, refurbished and reinstalled in a new location to produce the entire original building. The processes were highly efficient and only took eight months overall to achieve practical completion. NC220 has successfully become one of the first MiC projects that have been relocated and reused in the world as a complete four storey building.

Given that MiC relocation research and practice are deemed lacking, this study aims to investigate and document the technical details of MiC disassembly, relocation, and reuse, using NC220 as a case study. This study will highlight the key issues pertaining to the disassembly process, reusability of MiC components, and manpower and equipment used throughout the relocation process, with a view to shaping good practices on MiC relocation and reuse. The research team adopted mixed methods to investigate the technical aspects of MiC disassembly, relocation and reuse. They were on-site visual observations, semi-structured interview, and a questionnaire survey. The research team conducted seven site visits at Nam Cheong Street (pre-deconstruction, dismantling), Hung Shui Kiu storage yard (inspection, touch-ups, relocation), and Wong Yu Tan site (delivery, reinstallation). Subsequently, a semi-structured interview with the NC220 project team was carried out to gain an in-depth insight into the MiC reusability, structural appraisal, and site management. A questionnaire survey was then administered to the NC220 project team to collect the data relevant to the allocation of manpower and equipment used during the disassembly, touch-up, and reinstallation processes (refer to Appendix B for details). Finally, the findings of good practices and potential challenges of the case study were presented. Lastly, recommendations for enhancing the MiC relocation process were formulated.

It is worth noting that the deconstruction process is a reversible construction process. The lifting plan, site supervision plan, logistic plan, and safety precautionary measures adopted for MiC assembly were adapted to the MiC disassembly process. Simulation and trials were conducted by the NC220 project team before the deconstruction works commenced to ensure that disassembly could be executed safely. Comprehensive condition survey of the reusable MiC modules was carried out by the Contractor's project team before disassembly, after disassembly, and before reinstallation, to determine the reusability and touch-up/refurbishment plan, ensure structural integrity and all other building compliances to meet statutory requirements. Site observations were carried out by the research team before disassembly and after disassembly to investigate the exterior and interior conditions of MiC modules and assess the reusability of MiC modules.

Key findings on reusability were:

i. In general, the MiC modules, as individual volumetric units consisting of prefabricated structure and finishes, were found to be in good condition after use for 2 years, indicating a high overall reusability rate of 95% to reproduce the complete original building in a new location.

ii. More specifically, it was found that there were no visible deformations of the MiC modules, and all of them could maintain their shapes and verticality, also without significant damage to finishes caused by transportation handling or lifting stress.

iii. Structural steel members and inter-module connections remained 100% reusable after being in use for 2 years, without any signs of corrosion or deformity. Only 2% needed touch-ups (e.g., re-coating, rectification, and polish) to enhance fire-resistant coating protection due to normal use. 95% of module-foundation connections were reusable, and the touch-up rate was 5%. This was because welded connections were employed to link the ground-floor modules with the raft foundation, leading to the necessity of employing flame-cutting techniques when disconnecting the ground-floor modules.

iv. After 2 years of use, the roof structure was 100% reusable with a 10% touch-up rate made to enhance protective coating. Firestop systems exhibited 100% reusability, with an overall touch-up rate of less than 2% attributed to normal use.

v. The external envelope, including windows and side walls, was 100% reusable after minor touch-ups. For instance, less than 1% of external elements required touch-ups due to normal use. Approximately 10% of façade walls were repainted to adapt to the architectural design of the new transitional housing project.

vi. Over 90% of the internal finishes were found to be reusable, while the remaining (10%) were made-up to clean and recondition the internals. Notably, as an upgrade or non-essential touch-up, 90% of the interior walls are repainted to welcome the new incoming occupants.

vii. More than 95% of built-in fixtures and 90% of mechanical, electrical, plumbing (MEP) and fire services inside MiC modules were reusable, subject to final testing and commissioning as a complete building/building system. A new plumbing and drainage system outside MiC units would be reinstalled concerning hygiene issues. In the dissected corridors, the electricity cables, lighting and fire services would be fully replaced/reinstalled at the new site.

The relocation and reuse of NC220 provide a valuable reference and good practice for implementing sustainable development in the Hong Kong construction industry through reducing demolition waste, avoiding the consumption of virgin materials, maximizing the value of public money, and ultimately achieving sustainability of MiC projects. All MiC modules of NC220 are reusable after minor touch-ups, fostering local and international practices on MiC reuse. Learning from this case, this report formulates viable recommendations for reuse practice in future relocatable MiC projects by streamlining the design-procurement-maintenance-disassembly-reinstallation process. It has also established the high reusability as a complete building, as well as the flexibility of potential adaptation of individual MiC modules for other uses when the transitional housing project ceased to operate and release over 20,000 transitional housing modules in the next five to ten years.

Strategic technical recommendations for relocatable MiC buildings were:

I. **Include Design-for-Disassembly (DfD) solutions in early design phase** - It is recommended that early involvement of MiC suppliers and deconstruction professionals is essential for developing DfD solutions during the design stage of relocatable MiC buildings, as intermodular joint connections play a crucial role in determining the feasibility of disassembling and reusing interconnected MiC elements. The design of MiC connections shall consider the locked-in stress induced after a period of time of use. Interlocking connections that ensure structural integrity without compromising the ease of disassembly are thus recommended. Research & Development on DfD solutions addressing the technical feasibility of assembly and disassembly will enable engineers to design MiC connections efficiently.

II. **Provision of MiC User Manual from original designers** - As roles and responsibilities have drastically changed under DfD, a MiC User Manual should be contributed by all project stakeholders during the design documentation stage. The Manual shall include all essential information about DfD solutions, material inventory, maintenance instructions, and disassembly procedures. By doing so, deconstruction experts, especially those who have not been involved in the design stage, can access the Manual to understand method statements on the disassembly of MiC modules. The contractor can then follow the designated maintenance instructions to procure proper replacement materials and carry out corresponding touch-ups. It may also help to reduce uncertainties or risks during tender pricing of the relocation works.

III. **Pilot the innovative Design-Build-Deconstruction (DBD) contract** - In construction procurement strategy, existing methods mainly focus on the completion of a new building, such as Design-Bid-Build, or Design-Build. Such a linear procurement process excludes the end-of-life phase of the building without early consideration of pricing, scheduling, and risk management in MiC relocation. It is recommended that a life cycle approach by integrating the three major phases of relocatable MiC projects, namely, design, assembly, and disassembly, shall be adopted. The DfD solutions and MiC relocation should be considered at the procurement stage as a provisional service. It is proposed that a DBD contract can be piloted in future to support the client in procuring practical DfD solutions, MiC production, and relocation in an integrated approach within an agreeable time frame, incorporating the early consideration of the end-of-life scenarios of MiC projects. It will help the client plan relocatable MiC projects on a multi-use cycle basis and manage the relocation process efficiently, especially when these projects are funded and developed centrally by a single agency.

IV. **Establish BIM-based disassembly models** - The existing disassembly planning in NC220 relies on manual procedures by determining the key topological interrelations between MiC modules. Notably, Building Information Modelling (BIM) technology has become an efficient tool not only for supporting the design and construction processes but also for facilitating the disassembly planning process. BIM-based disassembly models that specify the disassembly parameters of BIM elements can provide the information necessary for a disassembly process in an efficient way, overcoming errors arising from manual procedures. Virtual deconstruction (VD) technology using a three-dimension (3D) BIM disassembly model can further be developed to digitally plan out and simulate all aspects of a deconstruction project. These technologies, however, remain in their infants. It calls for future research looking into the development and implementation of BIM-enabled disassembly planning tools.

V. **Develop BIM-based Digital Material Passport (DMP) to facilitate life cycle analysis of multiple reuses** - NC220 took the initiative to use quick response (QR) codes for each MiC module. The QR codes incorporated details relevant to the information about disassembly, delivery, and installation. It is recognized as a good start for the industry to engage with digital practice and to further the change to harvest its benefit. It is recommended that more detailed information, including quantities, material properties, reusability, and touch-up records, can be further documented using QR codes. In particular, material properties, such as life spans, origins, and embodied carbon, can be gathered and compiled into a material inventory database. It is further suggested to integrate the upgraded QR codes with BIM, the so-called Digital Material Passport (DMP). The BIM-based DMP, as a whole life cycle tracking system, can create digital platforms for the life cycle management of MiC modules and materials, thereby supporting the efficiency of reusing MiC modules in future projects. Such approach may significantly facilitate life cycle analysis of relocatable MiC buildings during multiple reuses. Further effort should be dedicated to the development and implementation of harmonized and standardized DMP in future relocatable MiC projects.

VI. **Provision of MiC maintenance manual to housing operators** - Proper maintenance planning during operation stage can keep the building in good condition and improve its reusability. Building occupants and users may have a profound impact on the building conditions, especially frequent changes of tenants are anticipated in transitional housing. Thus, property management needs to improve their MiC building users' engagement to avoid unexpected degradation, as well as to encourage them to report faults immediately and display a high level of awareness for maintaining MiC modules in excellent condition. In view of this, it is recommended to provide information on how to maintain MiC-built transitional housing at optimal levels and ensure that all users both know and understand how the MiC maintenance works and act to keep its optimum reusability.

This report represents one of the pioneering studies documenting the technical aspects of MiC building's disassembly, relocation, touch-ups, and reinstallation, which has received limited prior attention. By offering comprehensive technical details and insights into the good practices and useful lessons on the relocation processes of the NC220 project, this study contributes to enhancing the reusability and relocation efficiency of MiC buildings. The findings offer valuable references for construction practitioners, guiding them to adopt good practices and utilize design guides to enhance the reusability of MiC components and efficiency of MiC relocation. Although the government has recently announced that no more MiC transitional housing projects will be built in the future, the strategic recommendations above may apply to the existing MiC transitional housing and probably upcoming Light Public Housing projects [note].

[note:] *PolyU Jockey Club Design Institute for Social Innovation releases interim findings on the Study on Effective Transitional Housing Delivery in Hong Kong with multiple policy recommendations | Media Releases | Media | PolyU*. (n.d.). The Hong Kong Polytechnic University. Accessed 30 August 2023 https://www.polyu.edu.hk/media/media-releases/2023/0817_polyu-jockey-club-design-institute-for-social-innovation-releases-interim-findings/

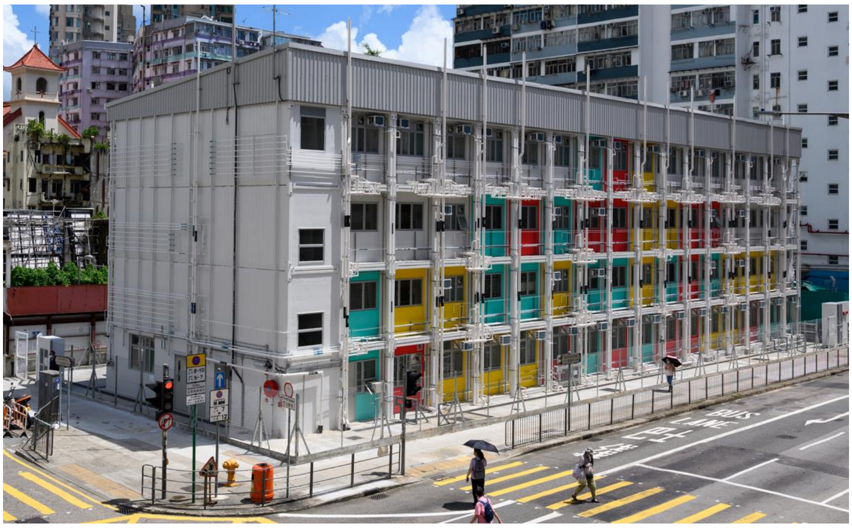
1. Introduction

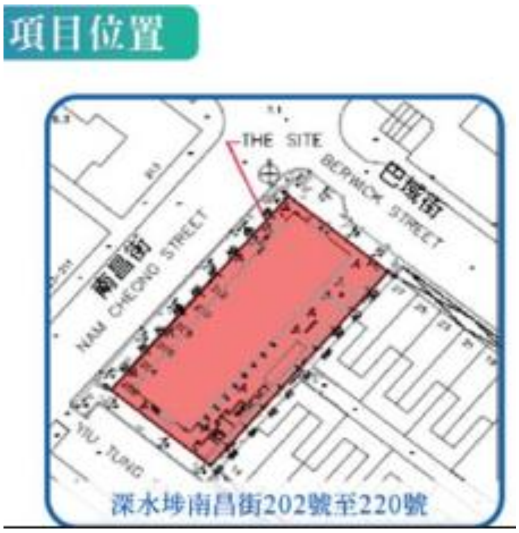
1.1 Background

The past decades saw significant growth in the demand for building products by off-site construction and modular integrated construction, owning to its performance in the accelerated overall speed of production, improved construction quality, reduced waste and environmental impacts, and simplified on-site assembly works [1–4]. There are numerous benefits of adopting MiC, for instance, greatly accelerating the construction speed [5–7]. Moreover, the use of MiC could achieve a higher quality compared to traditional buildings due to the controlled assembly lines where the components are built. The quality of components can be improved by repetitive processes and operations in the factory, as well as automated machinery. Furthermore, because of the ever-changing nature of on-site work, MiC has a higher level of safety because most of the work is completed in the factory. It is reported that modular construction can reduce on-site accidents by 70% when compared to on-site construction [8]. In addition, evidence has shown that MiC can effectively reduce construction waste compared with traditional in-situ construction [9, 10]

Smith [11] divided MiC into two distinct types: permanent and relocatable. MiC, if designed properly, has high reuse potential. Commonly, the MiC module made of steel frames can be reused for at least seven more lifecycles if maintained regularly [12]. Relocatable MiC is a rapid solution to provide a comfortable indoor housing environment for homeless people [11]. MiC reuse can reduce the consumption of virgin materials, retain economic and environmental value, and achieve higher levels of sustainability and circularity. Despite this potential, uncertainties surround the initiative of MiC reuse, particularly due to a lack of knowledge of the details of the disassembly process and due to lack of knowledge required to determine reuse quality. Previous research mainly focused on the design, manufacture, and construction processes of permanent MiC buildings, while MiC disassembly, relocation, and reuse have received scant attention. Although several temporary MiC properties have been built worldwide, MiC relocation practices remain lacking.

In Hong Kong, where an estimated 20,000 MiC housing modules will be required to be deconstructed and relocated within the next five to ten years' time, NC220 was the first transitional housing project built in Hong Kong in 2018 with relocatable MiC modules (Fig. 1). It is also the first of its kind to be relocated due to expiration of land tenure in 2023.





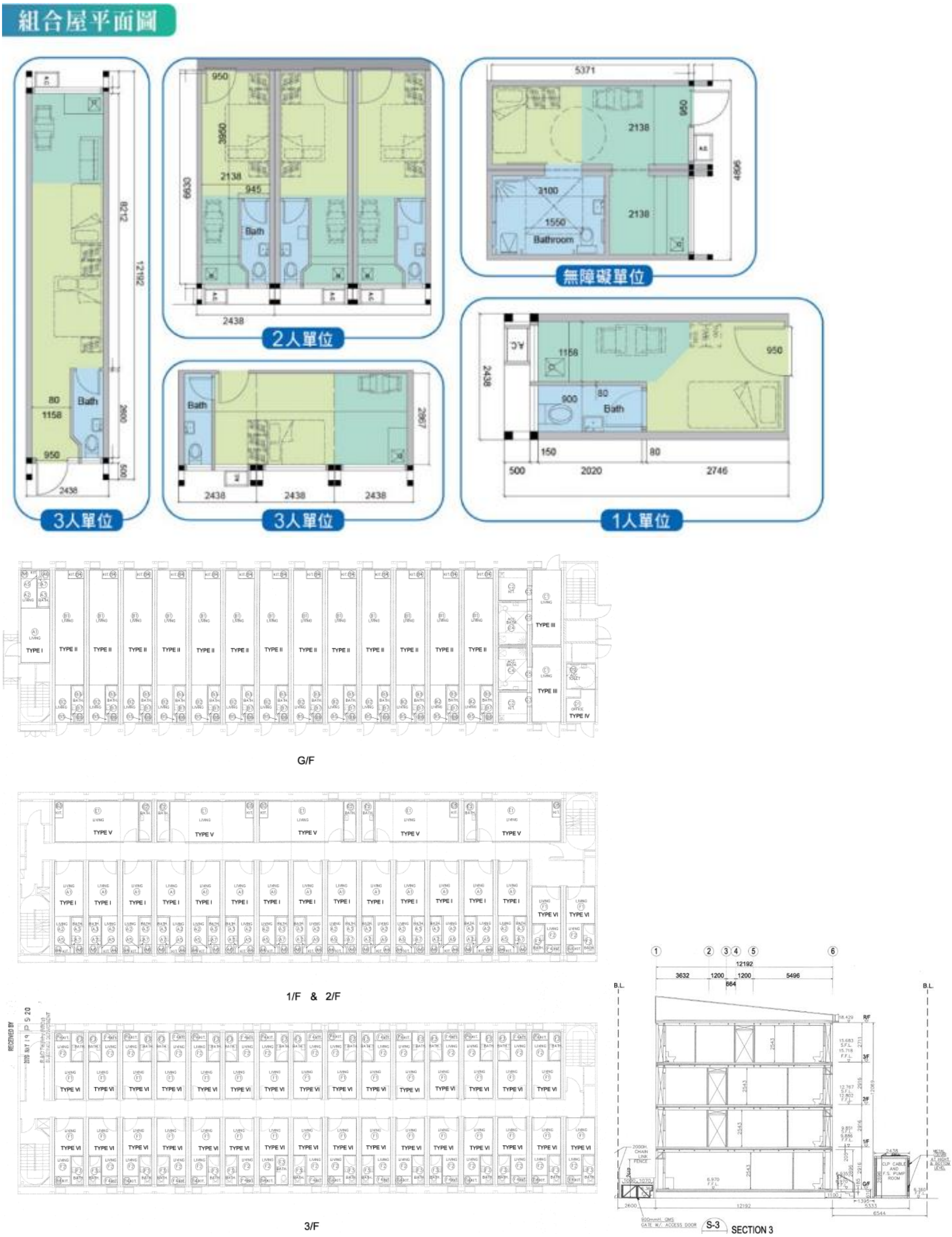


Fig. 1. NC220 exterior and module layout*; floor plans and section#.)
(Source: *Hong Kong Council of Social Services, #Wilson & Associates)

1.2 Objectives

Given that MiC relocation research and practice are deemed lacking, this study aims to investigate and document the technical details of MiC disassembly, relocation, and reuse using the relocation project located at Nam Cheong Street no. 220 as a case study. The disassembly process and the conditions of MiC modules were inspected. The degree of reusability of building components was assessed. Built upon an evidence-based understanding of the benefits and challenges of MiC relocation, this study will contribute to developing good MiC relocation practices that inform future project teams in planning suitable (de)construction methods at the design stage and improve the efficiency of MiC relocation and reuse.

1.3 Methodology

i. Literature review on relocatable modular building technology and similar projects overseas;
ii. Data collection of project details and plans from contractors and consultants;
iii. On-site visual inspections with photographic and video recording;
iv. Semi-structured interview with the Contractor's project team;
v. Questionnaire survey about the allocation of manpower and equipment;
vi. Data analysis and estimation of reusability of MiC building components;
vii. Formulate recommendations on good practices and design guides to improve MiC reusability.

Literature review was conducted on electronic data base and internet search engines. Data including project details, general layout plans and work method statements were collected from the contractor's consultant. The research team conducted a total of seven visits at Nam Cheong Street (pre-deconstruction, dismantling), Hung Shui Kiu storage yard (inspection, touch-ups, relocation), and Wong Yu Tan site (delivery, reinstallation). The timeline of the site visits is illustrated in Fig. 2.

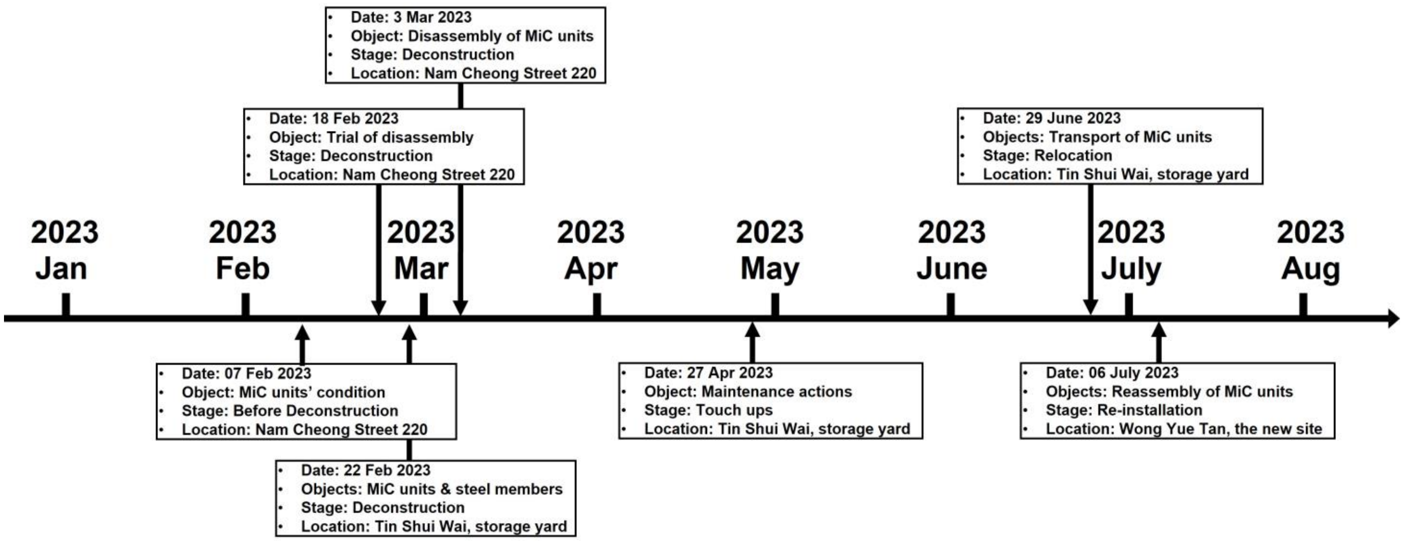


Fig. 2. Timelines of site visits conducted by the research team

During the site visits, we photographed and videotaped the pre-deconstruction works, disassembly of MiC modules, transport, lifting, and touch-up works. We carried out detailed visual inspections of MiC modules in storage to examine any deformation, bulking, and corrosion after use for 2 years. Subsequently, we carried out a semi-structured interview with the project team to gain an in-depth insight into the MiC reusability, structural appraisal, and site management. We also investigated the general conditions of the roof system and MEP services, and fire protection systems.

Based on site-based observation and semi-structured interviews, the research team developed a MiC component inventory for reusability assessment. Assessment results from three researchers and two consultants of the project were triangulated. Disagreements in the results were discussed and verified. The verified result of each component's reusability assessment is presented in Appendix A. Finally, we presented our findings of good practices adopted in NC220 relocation and formulated recommendations for enhancing the MiC relocation process in the future.

2. Literature Review

2.1 Keywords & inclusion criteria

Electronic database search was carried out on ProQuest, EbscoHost, ScienceDirect, Springer Link, ICONDA CIB Library, Google Search, and Google Scholar using the following keywords to identify existing studies and real-life MiC examples – "temporary housing, modular housing, relocatable reusable buildings, verplaatsbare modulaire woningen (Dutch), flytbart modulhus (Danish), 可重配置模块化集成房屋(Chinese), 再配置可能なモジュラー ハウジング (Japanese), 재배치 가능 주택 (Korean)."

To ensure compatibility for technical assessment, the inclusion criteria were set to be:

- **(i)** Modular volumetric modules primarily for residential use;
- **(ii)** Relocatable or reusable construction method;
- **(iii)** Three stories or above.

Therefore, permanent or non-relocatable structures, single/double story or mobile homes/site offices, or prefabricated flat-pack construction were excluded. Some institutional buildings were included as they mainly consist of similar functional areas such as living spaces and washroom amenities (e.g., aged-care homes, schools).

2.2 Existing cases of relocatable modular buildings

Most of the world's MiC building is permanent, with only a few temporary MiC buildings serving homeless people in Canada, UK, and Europe [13]. These identified examples all share the commonality of (i) consisting of pre-finished modular modules as the basic building and structural component, without additional exo-structural framing support; (ii) employing relocatable or reusable construction methods to allow future dismantling and relocation with high efficiency; (iii) majority of four or five-story building without lift service; (iv) highly standardized interior and typical floor layout with mainly living, bedroom and washroom amenities, and some are classrooms spaces. It was found that these MiC buildings were designated to last three to ten years before relocation, depending on regulations, project planning, and land use permits. However, only one deconstructed MiC project in Little Mountain of Vancouver has been partially reused and reinstalled in two other new projects developed by the Vancouver Affordable Housing Agency (VAHA), and the relocation and reuse processes have not been well documented. In addition, a number of temporary MiC housing projects in Vancouver are currently undergoing renewal or extension of land use, and considered to become a more "permanent" status by the government BC Housing.

2.2.1 Canada

In the past decade, the Vancouver Affordable Housing Agency (VAHA) in Canada has commenced building affordable housing with modular modules (all steel framed MiC), all on government land with short-term availability in view to relocate to other available sites in the near future. VAHA has now completed 17 temporary MiC housing projects (over 800 modules) with 9 underway, all in the urban area of Vancouver. Back in 2017, VAHA constructed Canada's first temporary modular building (TMB) on City-owned land at

220 Terminal Avenue (Fig. 3(a)) [14]. The building has three floors with 40 modules, each of which is approximately 25 square meters, and has a combined bedroom, living room, kitchenette, and private bathrooms that ensure individual residents' privacy and independence. The building was governed as temporary modular housing and held only a time-limited development permit for 10 years [15]. In another case, the City of Vancouver used an industrial site at 1580-1582 Vernon Drive in 2021 to construct two three-story TMBs for approximately 100 homeless people, totalling 98 single-occupancy modules (Fig. 3(b)) [16]. These two projects are expected to last for ten years and are still in use. They will be deconstructed and relocated when their land permits expire. In the coming years, the Vancouver government will continue to provide TMB to displaced people to meet their housing needs. In 2023, the provincial government is expected to provide these displaced people with 2 single-story TMBs at 1500 Main Street, which contain 90 individual rooms [17]. The only project that was relocated was the Little Mountain project (224 modules), built in 2018 and deconstructed in 2021. Some of the modular modules were subsequently deployed to two separate projects of BC Housing in 2023, while the remaining modules were still kept in storage (Fig. 3(c)).

(a) (b) (c)

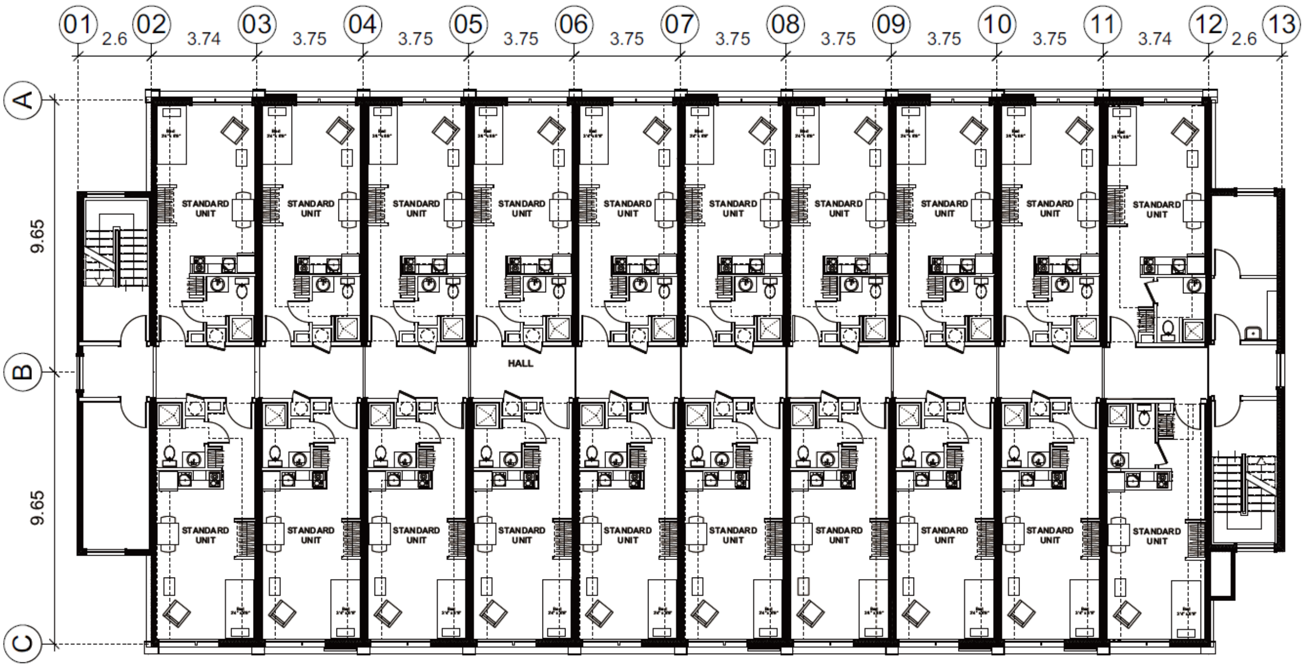


Fig. 3. TMBs as affordable housing in Canada – Exterior and typical layout plan (Source: VAHA, Canada)

2.2.2 UK and Europe

In UK, there were only three comparable TMB examples found – Parkview (2021), Ladywell Place (2016), and Y-Cube (2015) in London (Fig. 4 (a)-(c)), some built with timber or steel framed MiC. The scale was not extensive (total 99 modules) and not systematically planned by the local Council. Although off-site construction has been a major shift of construction methods in UK for over two decades, there was little relocatable or reusable structure built for the housing sector.


(a)


(b)


(c)

Fig. 4. TMBs for houseless people in UK – Exterior and typical modular modules

(Source: Rogers Stirk Harbour + Partners, UK)

In Europe, apart from providing temporary accommodation for homeless people, TMBs built by standard ISO containers were also used for student housing up to five stories. For example, Tempohousing has built five student housing in Europe, including the world's first and largest container campus for students in Amsterdam, Netherlands, where the total number of modular reached 1034 with an overall area of 31,020 m^2 (Fig. 5 (a)) [18, 19]. The project was supposed to be at its original location for five years, but the relocation was postponed until the end of 2018. Between January and February 2018, the first 249 houses (Buildings A and B) were demolished, and they have all been sold and rebuilt elsewhere [19]. The remaining 751 homes (Buildings C to

F) were used until December 2019, including two office buildings, a supermarket, and a café [19]. In addition, there was an assembled student house in Diemen built to address the shortage of student housing (Fig. 5(b)) [20]. The building has an area of approximately 7560 m^2 and five floors with 250 modular modules. Although it was intended to be a temporary solution for only five years, it was approved as a permanent structure in 2013. It is unknown when the project will be relocated. Finally, an assembled hotel named "Labour" had 5-story and 25 modules [21]. The typical housing module was built with a recycled shipping container from China, so it is easy to transport by truck and has the possibility to relocate. The project was designed to last only five years, but as of 2013, the owner has decided to keep the building in place for an extended period.

(a) (b) (c)

Fig. 5. TMBs built with ISO containers for student campus housing in the Netherlands and UK (Source: Tempo Housing, Netherland)

Similar shelter for the homeless was also built in Brighton UK by converted 40-foot shipping containers (Fig. 5(c)) [22]. The 60 containers are stacked up to 5 levels; each container is 12 meters in length and 2.4 meters in width, which is about 30 m^2. The container homes were built in a social factory in Amsterdam, and the shelter was completed in less than eight weeks [22]. An interesting hybrid TMB example was found in Amsterdam, built by the 'Salvation Army' for homeless people (Fig. 6). It comprises 3 separate buildings and 60 suite modules [23]. This design is technically unique because the ground floor is built with concrete columns to provide a large open space, and the 2nd and 3rd floors were assembled using the typical modular housing modules [23]. These TMB housing projects serve primarily homeless people and last three to ten years, depending on regulations, project planning, and land use permits. In addition, most TMB projects are still in the non-relocation phase, with few cases documenting relocation and reuse progress.

Fig. 6. Hybrid TMB (Concrete ground floor and steel MiC modules) in Amsterdam

2.3 Deconstruction methods

2.3.1 Purpose of deconstruction

Deconstruction, also known as disassembly, differs from demolition in that it involves recovering individual parts for recycling or reuse [24, 25]. From the environmental and economic aspects, the deconstruction phase of securing components is crucial since removing components from outdated buildings can reduce manufacturing impacts and costs in the subsequent life cycle [26, 27]. Dismantling, reuse, and relocation are essential parts of temporary MiC buildings, directly affecting the environmental load and economic efficiency [28, 29]. As a result, from the design stage, the processes of deconstruction and recovery of building components must be considered [26].

2.3.2 De-constructability

Deconstruction assessment is the most important aspect of TMBs, as it directly determines how the components are treated after removal. In this regard, it is essential to indicate the level of reusability of components, which will determine the corresponding value retention processes and the environmental and economic impacts. Prior studies used quantifiable scores to illustrate the de-constructability and reusability of building components. For example, Mattaraia et al. [30] combined disassembly difficulty and potential damage to evaluate the deconstruction performance of building components. The disassembly difficulty ranges from 0 to 1, with 1 indicating the greatest possibilities of disassembly and reuse. Also, a weight between 1 and 3 was assigned based on the material functions and the possible damage to other materials during disassembly. Similarly, Akinade et al. [31] and Basta et al. [32] developed the de-constructability assessment score comprising two recyclability and de-constructability categories. On the other hand, Durmisevic [33] derived a transformation capacity index showing the potential for reuse and recycling components. Although this index was not designed to assess the deconstruction performance of a building, it is applicable to assess the individual component. Besides, some researchers used digital technology to determine deconstruction performance. For instance, Xiao et al. [34] developed a deconstruction evaluation model for predicting deconstruction feasibility using image maximum laser scanning technology and the BIM platform. Sanchez et al. [35] presented a computational deconstruction model using a visual programming language and a BIM application programming interface. The above studies emphasize the importance of deconstruction assessment for TMBs. A proper assessment facilitates classifying a certain component based on its condition and taking appropriate treatment.

3. Documentation on the deconstruction, relocation and reinstallation processes

3.1 Pre-deconstruction planning

3.1.1 NC220 has a total of 89 residential modules of transitional housing for approximately 162 residents. 12 types of MiC modules are used (total = 68 modular modules). The modular modules are made of structural steel frames (tubular hollow sections) and precast concrete slabs, erected on reinforced concrete raft slab foundation and protected under a steel truss pitch roof. The entire building was deconstructed and reassembled in its original layout to form an identical complete building on another site at Wong Yue Tan. Upon the completion of disassembly, MiC modules shall be delivered to a temporary storage yard in Tin Shui Wai for inspection, renovation, and maintenance. Then all MiC modules were relocated and transported to Wong Yue Tan for reassembly. The relocation programme is shown in Fig. 7.

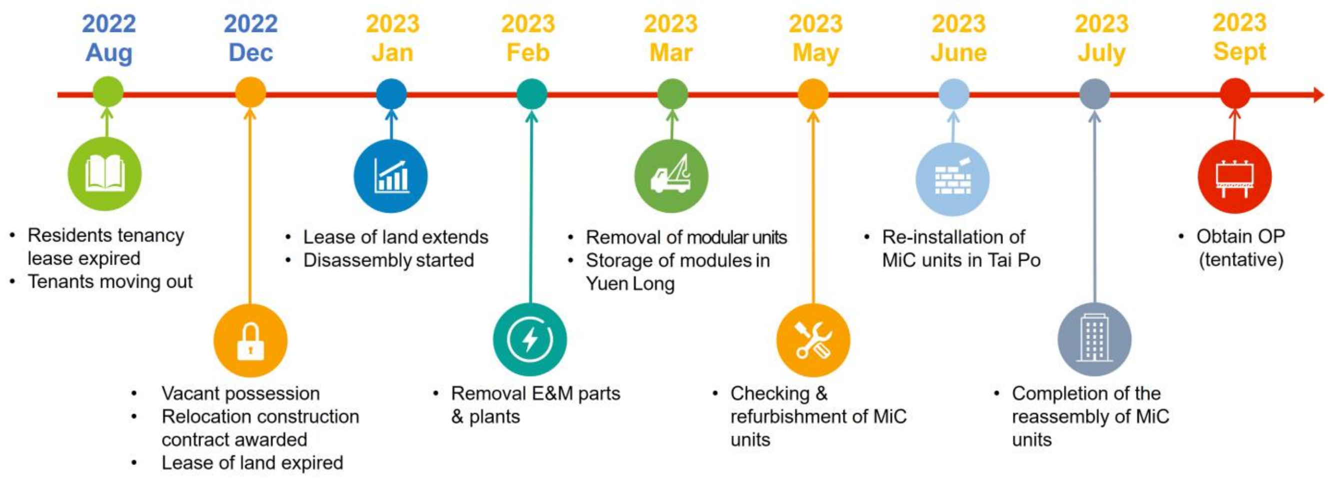


Fig. 7. Relocation programme of NC220 transitional housing

3.1.2 Following confirmation of designated project relocation of NC220 to Lok Sin Tong's transitional housing project at Tai Po around mid-2022, the relocation work was tendered out as part of the overall construction contract for Wong Yue Tan, Tai Po. Construction contract was awarded in November 2022 to Woon Lee Construction (the Contractor) in form of a "Design and Build" contract, in which the entire building of NC220 would be deconstructed, refurbished, and reinstalled to the new site location according to the terms of the contract.

3.1.3 The Task Force of Transitional Housing of the Housing Bureau (the Task Force) was appointed to act as technical coordinator to facilitate the execution of the relocation works with other government authorities and monitor the construction process on behalf of Lok Sin Tong, who will be responsible for the future operation and maintenance of the transitional housing project.

3.1.4 In the pre-deconstruction phase, planning of the following was carried out by the Contractor and the associated consultant team (Authorised Persons/Registered Structural Engineers, etc.):

(i) Preparation, submission, and obtaining approval of site related advance works - hoarding, site access, scaffolding and protection;

(ii) Liaison, preparation, submission and obtaining approval from lending authorities on construction works programme with potential impact due to noise, waste, pollution, traffic etc.;

(iii) Preparation, submission and obtaining approval of dismantling and removal of building components;

(iv) Preparation, submission and obtaining approval of installation of relocated building at the new project site, including General Building Plan, revised In-Principle-Acceptance of modular modules, etc.

3.1.5 NC220's resident leases expired in August 2022, and land permits expired in late 2022. In January 2023, the land lease was extended, and deconstruction works commenced.

(i) The E&M parts were removed in February 2023, after which the connections and MiC modules were disassembled.

(ii) The entire building was deconstructed within one month. Upon the completion of disassembly, MiC modules were transported to a temporary storage yard located at Hung Shui Kiu, Yuen Long, for inspection and touch-up/rectification.

(iii)Then all MiC modules were relocated and placed in Wong Yue Tan, Tai Po, and reassembled within two weeks.

3.2 Pre-deconstruction works

3.2.1 Prior to the deconstruction works of MiC modules, the following advance works were carried out:

(i) Temporary hoarding, covered walkway, and catch platform structure;

(ii) Site access/entrance gate for construction equipment and vehicles;

(iii) Scaffolding and protections;

(iv) Site logistic plan;

(v) Mobile crane setup;

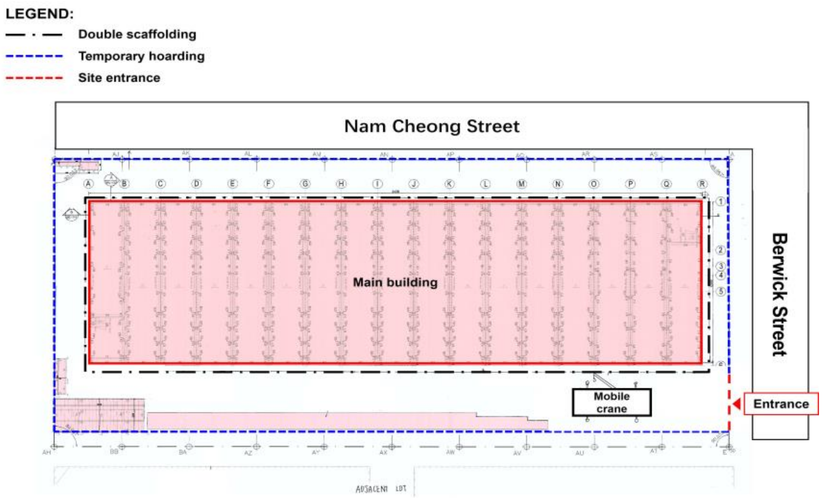
(vi) Utilities and services disconnection and cap-off;

(vii) Building exterior and interior inspection;

(viii) Removal of external plumbing and drainage pipes outside modular modules;

(ix) Module interior finishes partial removal to expose inter-module joints and connections.

3.2.2 The layout of the construction site is illustrated in Fig. 8 (a)-(b). Safety precautionary measures were carried out in strict accordance with the respective applications and statutory approvals granted by the regulatory authorities (completed in January 2023). Temporary hoarding was erected, acting as a physical barrier that separated the construction site from pedestrian and vehicular traffic. This helped limit unauthorized access, thereby preventing potential accidents and ensures the safety of both workers and passerby. A covered walkway and a catch platform were constructed to encircle the site perimeter. Furthermore, a designated site entrance was established to manage the vehicular traffic and prevent unauthorized access.



(a). Layout of deconstruction site

(b). Completed hoarding and site entrance

Fig. 8. Pre-deconstruction works

3.2.3 Temporary metal scaffolds were constructed to providing safe access and egress for workers while dismantling MiC modules. Safety nets were installed to provide fall protection and mitigate the risk of injuries or fatalities resulting from working from heights. Additionally, safety belts were mandatorily worn by all personnel involved in working from height, ensuring that they remained securely anchored.

3.2.4 The disassembly of MiC modules was carried out within a limited work space. A precise logistic plan was implemented accordingly. The site layout was designed for temporary material storage, lifting zones, and movement of vehicles. Figure 8(a) illustrates how the materials and equipment were placed on the site. Water tanks were removed first to allow sufficient working space for the mobile crane. Vehicular traffic was managed within and around the construction site, enabling that the disassembled MiC module was timely moved out according to the scheduled sequence. Since only one traffic pathway was available onsite, just-in-time loading and delivery became essential for MiC disassembly. A four-stage delivery plan was therefore implemented to ensure the smooth movement of vehicles (Appendix C).

3.2.5 Wood timbers or engineered crane pads were positioned beneath the crane's outriggers (Fig. 9) could provide a stable and level foundation for the mobile crane, minimizing the risk of tilting or overturning due to uneven or unstable ground conditions. Moreover, when the mobile crane lifted a MiC module, heavy loads could be spread over more evenly, thereby maintaining the stability of the crane. This is an essential safety measure of mobile crane operation.

Fig. 9. Placement of timber mats and blocks

3.2.6 All the electrical and mechanical works for the modular modules were disconnected before deconstruction. The MiC module's building service equipment, including reticulation pipes and cables outside the modules and inside the corridors, was disconnected and removed before deconstruction. Besides, all sealed joints between the MiC module were removed.

3.2.7 A comprehensive inspection and record of the building's exterior and interior was carried out and recorded accordingly. There was no report of substantial defect found. Minor water leakage was found on the first-floor corridor in zone 1, between the second and third modules. The cause of the leakage (suspected rainwater seepage from compromised weather-seal joints on the vertical façade on upper floors) was identified in the next phase.

3.2.8 As the removal of external plumbing and drainage pipes did not require statutory approval, it was carried out in advance of the deconstruction works of the modular modules. As illustrated in Fig. 10, all external plumbing and drainage pipes have been cut and loaded to facilitate the dismantling of the MiC module. None of these pipes were reusable and were disposed of at the treatment plant. A new plumbing and drainage system was designed and installed in the next project concerning hygiene issues.

Fig. 9. The main type of waste – external plumbing and drainage pipes

3.2.9 MiC module's interior conditions (including internal finishes and fixtures) were found to be generally good. Interior finishes over the joint areas (floor and wall covering, ceiling finishes) were partially removed to expose the joint, ready to facilitate joint removal between adjoining modular modules (Fig. 11 (a)-(d)). All interior fittings and equipment were left in their original installed positions during removal, including kitchen sink and cabinets, toilet-shower fittings, fixtures and electric water heaters, window-type air-conditioning modules and metal support frames. Each modular module was assigned a unique quick response (QR) code to aid in identifying the position when it is reinstalled in the future.

(a). Partial removal of wall finish over joints

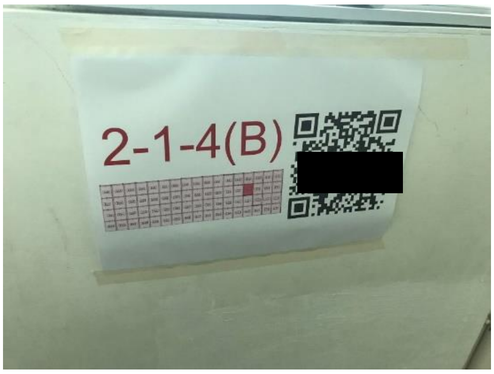
(b). Exposed joints between modules

(c). Partial removal of floor covering over joints

(d). Partial removal of ceiling finishes at joints

Fig. 10. Interior conditions of MiC modules

3.2.10 Each MiC module was given a QR code that documents the basic information about the module, such as dimensions, position, and deconstruction and re-installation details (Fig. 12(a)). On-site engineers can quickly obtain module information by scanning QR codes, which assists in locating the MiC module's initial location and facilitating reassembly. Details relevant to the disassembly information, including disassembly time, mobile crane information, and lifting frame information, are also recorded (Fig. 12(b)). Such data assist project personnel in tracking the relocation process and efficiently managing the reuse of MiC modules. Furthermore, delivery and installation details from the reinstatement plant to the new assembly location were electronically recorded. This electronic tracking system was designed to assist practitioners in tracking MiC module information, promoting site management, and improving the efficiency of disassembly and reassembly. This is a good start for the industry to engage with digital practice and to further the change to harvest its benefit.



Project Name	Nam Cheong 220 Relocation (under Project : Transitional Housing at Wong Yue Tan, Tai Po)			
Module Code	2-1-2			
Module details	Dimension	Structure	Floor	Function
	(W) (L) (H)	Steel MiC	2/f	Residential Unit
Dismantle Details	Date and time of Dismantle	Name of Supervisor	Serial no of the Mobile Crane	Serial no of the lifting frame
Delivery Detail-01 (from Nam Cheong 220 to reinstatement yard)	Date and time of Delivery	Delivery Truck car plate no	Date and time of arrival	Name of Recipient
Delivery Detail-02 (from reinstatement yard to Wong Yue Tan)	Date and time of Delivery	Delivery Truck car plate no	Date and time of arrival	Name of Recipient
Installation Detail	Date and time of start of Installation	Date and time of completion of Installation	Name of Supervisor	
	Serial no of the Mobile Crane	Serial no of the lifting frame		

ı) QR code assigned to each MiC modul (b). Information sheet linked to the QR Code

Fig. 11. Digital system for tracking MiC modules

3.3 Practice on a condition survey of MiC structure before disassembly

3.3.1 The NC220 project team had carried out structural inspection of MiC before the disassembly work, as requested by the Buildings Department. The scope of the condition survey included:

- Examine the physical condition and degree of corrosion of the existing building;
- Check for any structural abnormalities such as cracking and deformation;
- Examine the presence of any unauthorized building works;
- Verify the correctness of structural information available (Source: Wilson & Associates).

3.3.2 The survey results revealed the generally good condition of MiC structure before disassembly (Source: Wilson & Associates). The condition of MiC structure before dismasting work shall be compared with that after disassembly (see Section 4.1), as required by the Buildings Department. Therefore, the project team should maintain plenty of site photo records and documents before and after disassembly.

3.4 Deconstruction works

The deconstruction work of NC220 MiC modules commenced in February 2022, right after obtaining all required statutory approval from the lending authorities. In accordance with the deconstruction plan, the first trial of MiC module removal took place on February 18, 2023. Around 6 to 8 modules were disassembled per day. All MiC modules were removed in three weeks' time. All deconstruction works including in-situ and MiC were completed in one month as scheduled. It is worth noting that the deconstruction process is a reversible construction process. The lifting plan, site supervision plan, logistic plan, and safety precautionary measures adopted for MiC assembly were adapted to MiC disassembly. Simulation and trials were conducted by the NC220 project team before the deconstruction works commenced to ensure that disassembly could be executed safely.

3.4.1 Master deconstruction sequence

In the pre-deconstruction phase, external plumbing and drainage pipes were cut to ease MiC module dismantling. Subsequently, the building service equipment, encompassing pipes and cables both outside the modules and within the corridors, was disconnected and removed. Following this, interior finishes in joint areas (floor and wall coverings, ceiling finishes) were partially removed to expose the joint for the removal of adjoining modular modules. Lastly, the MiC module connections and module-foundation connection were disassembled (Refer to section 3.2 for details).

The deconstruction works were conducted in three stages, as illustrated in Fig. 13. The first stage involved the removal of the existing fiber glass water tanks. In the subsequent stage, the steel structures near the main building were disassembled. The final stage was to remove the metal roof and MiC modules of the main building. The disassembly sequence planning was adopted with a view to ensuring the structural safety and stability of the load-bearing structures.

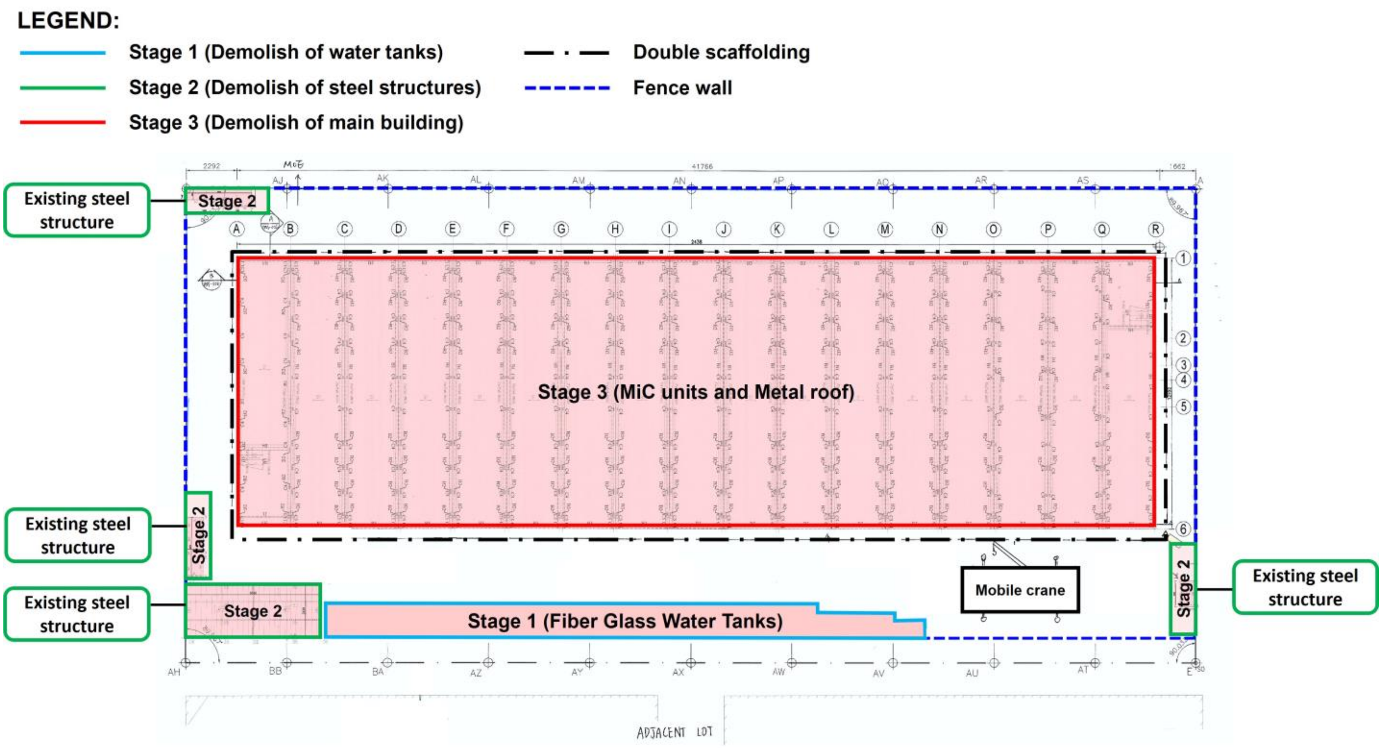


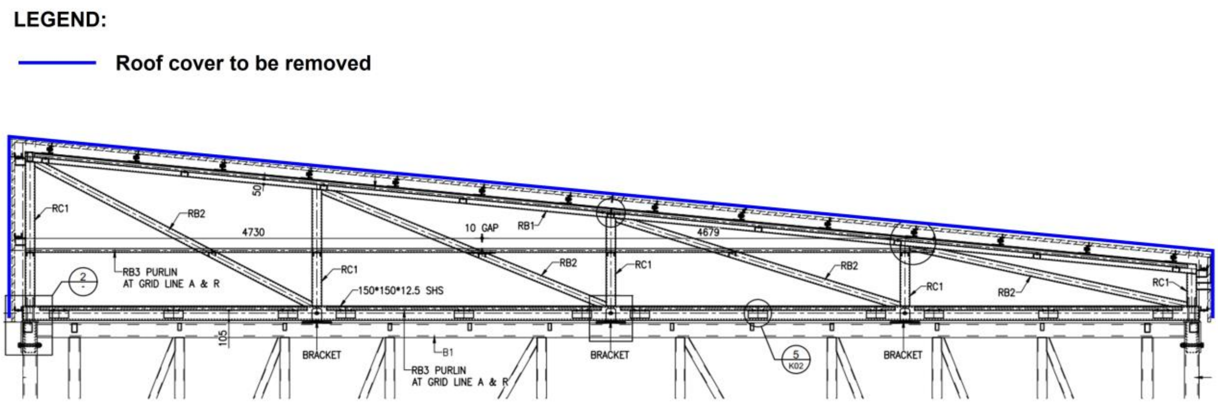
Fig. 12. Master demolition sequence of NC220 project
(Source: Wilson Cheung & Associates)

3.4.2 Roof removal

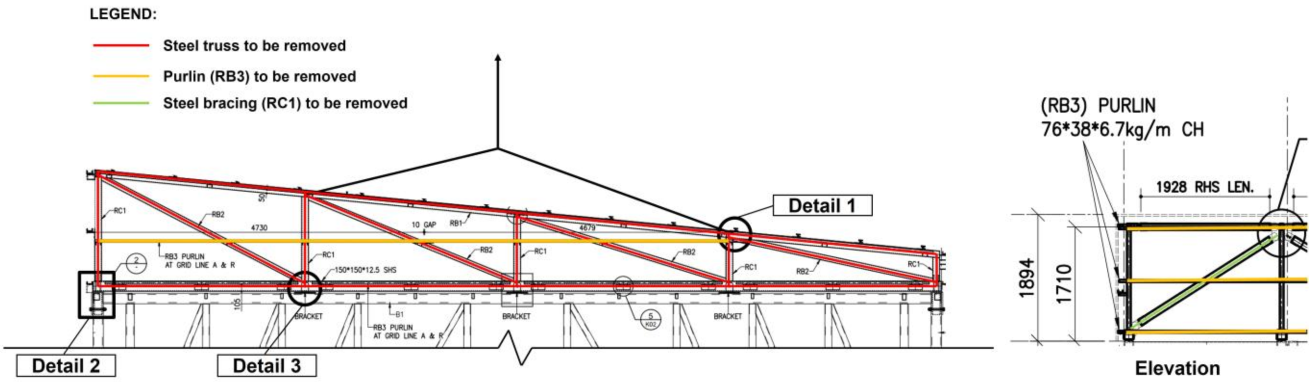
Prior to removing MiC modules, the roof structure was disassembled. A fall arrest system (i.e., double scaffolding) was adopted throughout the disassembly of the roof structure as a good practice. The typical steps for removing the roof structure include:

- Removal of roof cover (Lysaght Trimdek roof) by removing self-tapping screws. (Refer to Fig. 14(a))
- Install lifting wire onto the steel truss.
- Removal of purlin (RB3) members by loosening bolt-nut (Refer to Fig. 14(c) and Fig. 14(d))
- Removal of bracing RC1 by loosening bolt-nut. (Refer to Fig. 14(b))

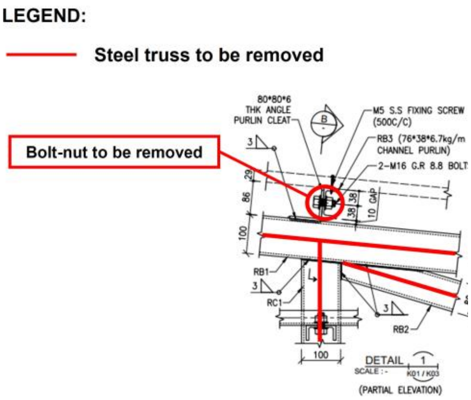
- Removal of connection by loosening of bolt-nut. (Refer to Fig. 14(d) and Fig. 14(e))
- Removal of the main steel truss by lifting.



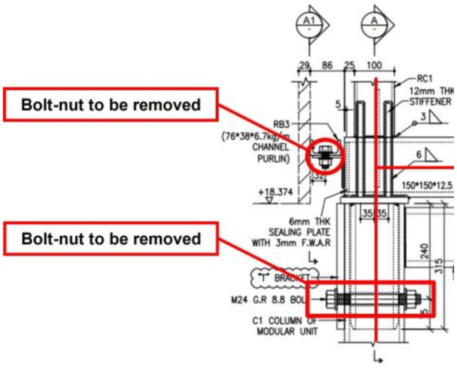
(a) Removal of roof cover



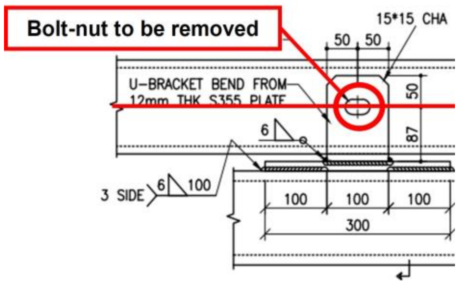
(b) Removal of main steel truss



(c) Detail 1



(d) Detail 2



(e) Detail 3

Fig. 13. Roof removal details
(Source: Wilson Cheung & Associates)

3.4.3 Disassembly of MiC modules

The MiC modules were removed zone by zone, namely from zone 1 to zone 4 (Fig. 15). In each zone, all MiC modules at upper floors were firstly disassembled, followed by those at lower floors. The specific sequence of disassembly of the main building is depicted in Table 1. For illustration purposes, zone 1 was chosen as an example. The procedures for dismantling MiC modules and roof systems include:

a. Remove metal roof of grid line R to L at zone 1.
b. Remove the MiC module at 3/F.
    i. Disconnect the connection joints between modules. (Refer to section 3.4.4)
    ii. Remove modules 3-1-1 to 3-1-5 one by one by lifting.
c. Remove modules 2-1-1 to 2-1-4 one by one at 2/F, following the same process as step b.
d. Remove modules 1-1-1 to 1-1-3 one by one at 1/F, following the same process as step b.
e. Disconnect joints between modules and footing. (Refer to section 3.4.5)
f. Remove modules G-1-1 to G-1-2 one by one at G/F, following the same process as step b.

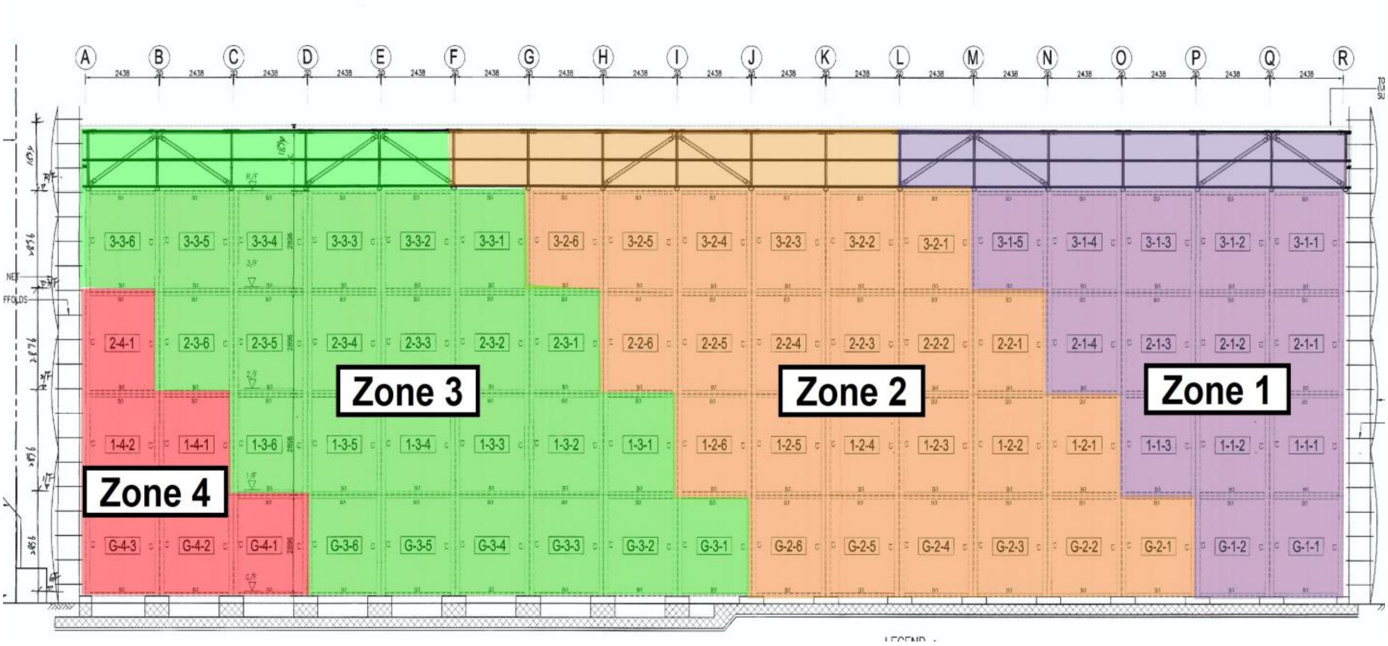


Fig. 14. Deconstruction zones of the main building.
(Source: Wilson Cheung & Associates).

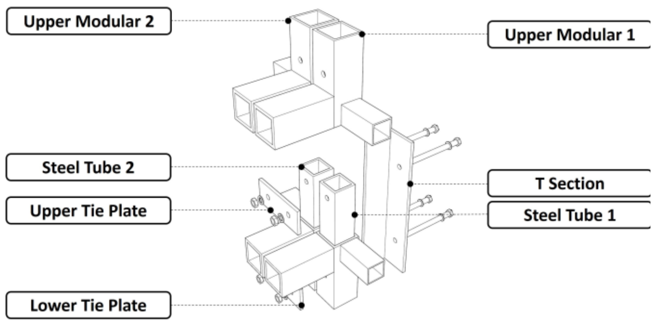
Zone	Sequence	Area	MiC unit mark
1	1	R/F Zone 1	R/F Grid R To L
	2	3/F Zone 1	3-1-1 To 3-1-5
	3	2/F Zone 1	2-1-1 To 2-1-4
	4	1/F Zone 1	1-1-1 To 1-1-3
	5	G/F Zone 1	G-1-1 To G-1-2
2	6	R/F Zone 2	R/F Grid L To F
	7	3/F Zone 2	3-2-1 To 3-2-6
	8	2/F Zone 2	2-2-1 To 2-2-6
	9	1/F Zone 2	1-2-1 To 1-2-6
	10	G/F Zone 2	G-2-1 To G-2-6
3	11	R/F Zone 3	R/F Grid F To A
	12	3/F Zone 3	3-3-1 To 3-3-6
	13	2/F Zone 3	2-3-1 To 2-3-6
	14	1/F Zone 3	1-3-1 To 1-3-6
	15	G/F Zone 3	G-3-1 To G-3-6
4	16	2/F Zone 4	2-4-1
	17	1/F Zone 4	1-4-1 To 1-4-2
	18	G/F Zone 4	G-4-1 To G-4-3

Table 1.
Removal sequence of MiC modules

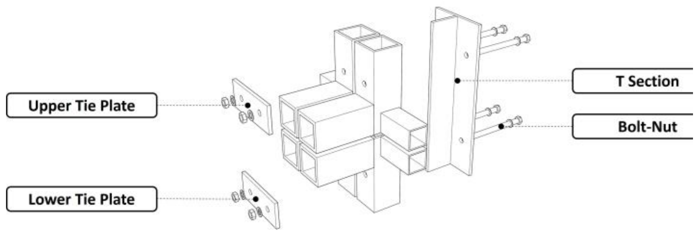
3.4.4 Disconnecting joints between MiC modules (Inter-module connection)

The next task was to loosen the connection joint that tightly holds the adjacent four MiC modules before lifting out the modular module in the prescribed sequence. Fig. 16(a) depicts a typical MiC module connection, which consists of two steel tubes, two tie plates, one T-section, and bolts and nuts. The bolts are used in the area connected to the steel plate, steel tube, and T-section. The procedures for dismantling MiC connections between modules include:

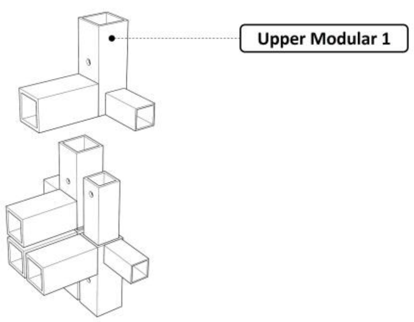
- Step 1: T-section, and upper and lower tie plates were loosened first by removing bolts and nuts (Fig. 16(b)). While removing bolts and nuts, the T-section should be temporarily held tightly by workers to prevent the upper and lower tie plates from sliding off. Meanwhile, the MiC module was slightly hoisted by a lifting frame to prevent it from unexpected collapse due to the removal of connections.
- Step 2: After removing connections, the upper modular-1 module was disassembled by lifting (Fig. 16(c)). We observed that the tie plate, steel tube, and T-section were tightly connected, implying the structural integrity of the MiC connection system. Despite this, it is worthy of investigation to further explore new connection systems that ensure structural integrity without compromising the ease of disassembly.
- Step 3: Steel tube #1 was removed thereafter (Fig. 16(d)). It is critical to avoid possible deformation of steel tubes due to lock-in stress arising from permanent load during heavy lifting operations. In such a circumstance, workers may need to use a hammer to release the lock-in stress between the steel column and steel tube.
- The upper modular-2 was removed following the same procedure.



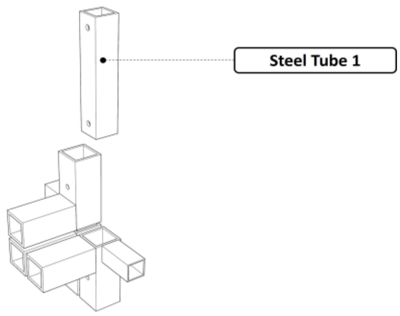
(a) Typical steel connection



(b) First step of disassembly



(c) Second step of disassembly

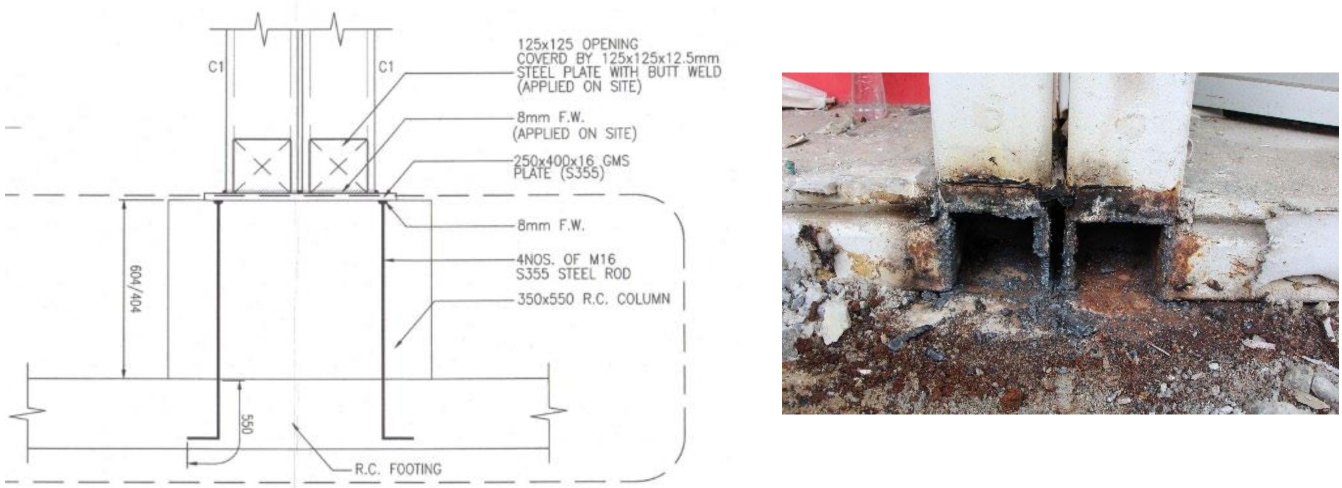


(d) Third step of disassembly

Fig. 15. Typical joint connection (a) and disassembly sequence (b)-(d)

3.4.5 Disconnecting joints between modules and footing (module-foundation connection)

The base plate connection system of the ground-floor MiC modules to the footing is depicted in Fig. 17(a). A base plate was welded to the side column and attached to the concrete footing with four steel rods. The steel rods were cast into the concrete footing and bent to prevent pull-out. According to this design, the side columns of the ground-floor MiC modules were originally welded to base plates. Flame cutting had to be carried out to disconnect the welded connections between side columns from base plates (Fig. 17(b)). Consequently, the affected side columns should be inspected and rectified before reuse. It is therefore recommended that dry connections should be used to improve the ease of disassembly of the ground-floor MiC modules.



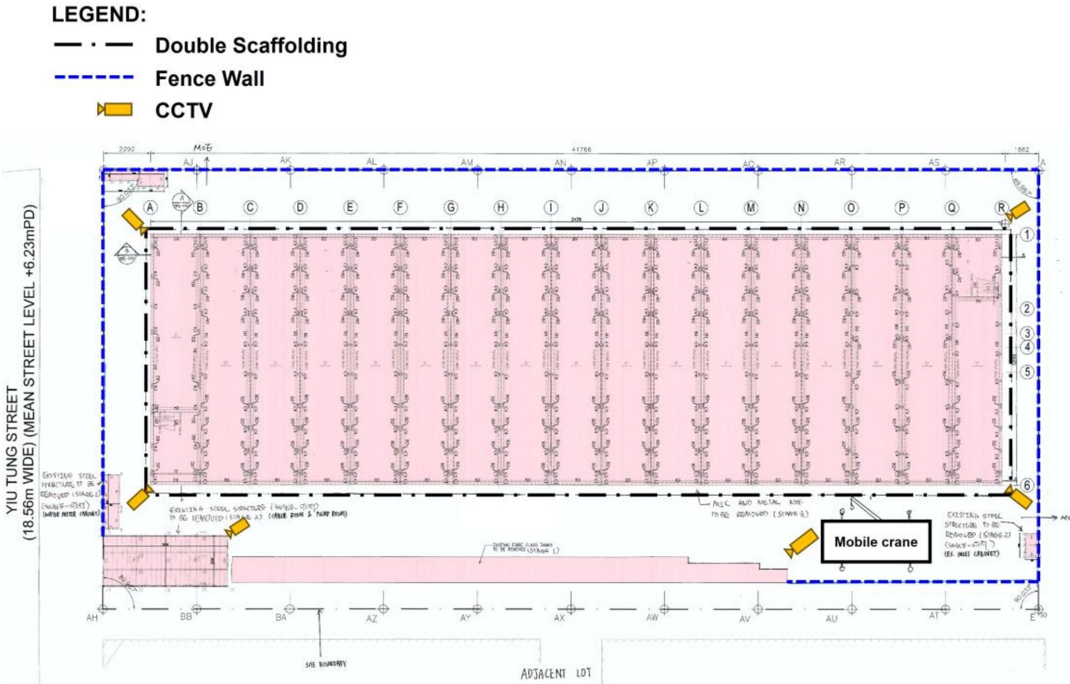
(a) Side column originally welded to a base plate (b) Side column after flaming-cut

Fig. 16. Disconnecting joints between modules and footing

3.4.6 Lifting plan for removing MiC modules

The layout plan for lifting is shown in Fig. 18(a). Video cameras were installed at each demolish site to record the entire process for the purposes of supervision and review. Heavy lifting operations for dismantling MiC modules were carried out using a mobile crane with a lifting frame. Each MiC module was lifted and placed on a truck. The loading capacity of the mobile crane is 230 tons, while each MiC module typically weighs around 20 tons. The wire rope sling can be used to lift loads of less than 10 tons. Each MiC module has four lifting eyes. They were hooked by four-leg chain slings with shackles during lifting operations (Fig. 18(b)). In any circumstance, the angle between any two leg slings should not exceed 120 degrees, i.e., the safety working load. Every lifting gear, chain sling, block chain, shackle, and master link should be inspected by a competent person on each occasion. A signalman using a walkie-talkie would assist the crane operator in lifting the MiC module. Each of the four riggers held a guide rope simultaneously to control the heavy MiC module and prevent unintended load arising from shaking to accurately place it on the truck (Fig. 18(c)). Details of heavy lifting operations can be referred to a reference material of Construction Industry Council (CIC) [36].

We observed that a few lifting eyes of the MiC module were slightly deformed after lifting (Fig. 18(d)), although they did not affect structural integrity. This is probably because compression forces acted on the long span of the MiC module when a module was lifted by the lifting frame. It is suggested that two additional lifting eyes can be added at the midpoint of the upper long-span beams to evenly distribute the lifting load and avoid possible deformation of the lifting eyes.



(a) Layout Plan for Lifting

(b) Lifting eyes located at front and end sides of MiC modules

(c) Workers using guide ropes to stabilize MiC module during lifting

(d) Slight deformation of lifting eyes

Fig. 17. Lifting and removal of MiC modules

3.4.7 Main types of waste

We observed that most of the on-site demolition waste included drainpipes on the exterior wall (Fig. 19), which were prior to MiC disassembly. The plumbing system would be redesigned and reinstalled concerning hygiene issues. The electricity cables in the corridors were cut off and would be reinstalled on the new site. The findings indicated that the disassembly of MiC modules induced minimal demolition waste, thereby, significant reusability was achieved.

Fig. 18. The main type of wastes: pipes and power cables

3.5 Site safety supervision for deconstruction works

This section reports the general practice of safety supervision conducted by the project team. The latest version of Code of Practice of Site Supervision and The Demolition Code and Building were referred [37, 38]. The supervision plan was submitted to the statutory authority.

3.5.1 Supervisory staff

All demolition work shall be overseen by authorized persons (AP), registered structural engineer (RSE), registered specialist contractor, and technically competent personnel. The site supervision should align with the supervision plan that has been submitted to the statutory authority.

3.5.2 Site safety supervision

- Precautionary measures and temporary support must undergo daily inspections by the representatives of the AP and RSE, as well as the contractor. Regular removal of any accumulated building debris on catch fans and platforms is required.
- Before departing the deconstruction site, the contractor is responsible for identifying and rectifying unsafe conditions, including partially demolished structural elements and damaged temporary supports.
- Proper illumination and protective measures are essential for all workplaces, approaches, and hazardous openings to ensure the safety of employees and others.
- Flammable materials must be securely stored, and firefighting equipment should be readily accessible in visible locations.
- All site personnel are required to undergo a comprehensive training program to understand project and site safety requirements. Daily safety meetings are to be conducted to reinforce the safety protocols.
- During typhoon signals, the contractor must inspect all externally exposed work and reinforce any loose connections. Following the typhoon, a competent person should inspect and confirm the safety of all externally exposed structures.
- Video cameras were installed at each demolish site to record the entire process for the purposes of supervision and review.

3.6 Site reinstatement

3.6.1 Under the terms of land use agreement, all building works and infrastructure must be entirely removed and return the site to the landowners at an agreed date (in this case the private land developer Henderson Land Properties Ltd.) in its original state and conditions.

3.6.2 In NC220 relocation project, the deconstruction program was slightly delayed due to statutory approval process on road closure at Berwick Street to allow daytime set-up of mobile crane-truck for zone 1 removal. After all modular modules were removed from site, ground level was cleared out of previous raft foundation and external plantrooms were all dismantled and removed.

3.6.3 By the end of March 2023, all removal works were completed, and the site was handed back to the landowners. The actual deconstruction work took less than two months, while the overall removal period was around four months from vacant possession to handover back to landowner.

3.7 Transportation and storage of MiC modules

After all MiC modules were transported to the storage yard, they were laid flat for inspection and maintenance to assure the modules' safety and integrity. At the storage yard, a mobile crane was used to lift MiC modules (Fig. 20(a)-(b)) from the trailer to a pre-designated spot. Normally, one crane operator and four coworkers perform lifting activities. The modular modules were placed on leveled steel beams anchored to the ground, which was about 200 mm. The layout of the storage yard followed the sequence of removal (i.e., from zone 1 to 4 in descending order) (Fig. 21). It facilitates future reinstallation when the modules are being transported to the new project site in the reverse order of assembling. The MiC units were placed with protective film covered after touch-ups, which helped reduce further deterioration under extreme weather such as heavy rain in the worst-case scenario.

(a). Placement of MiC modules in sequence (b). Lifting of MiC modules by a mobile crane

Fig. 19. Placement of MiC modules in the storage yard

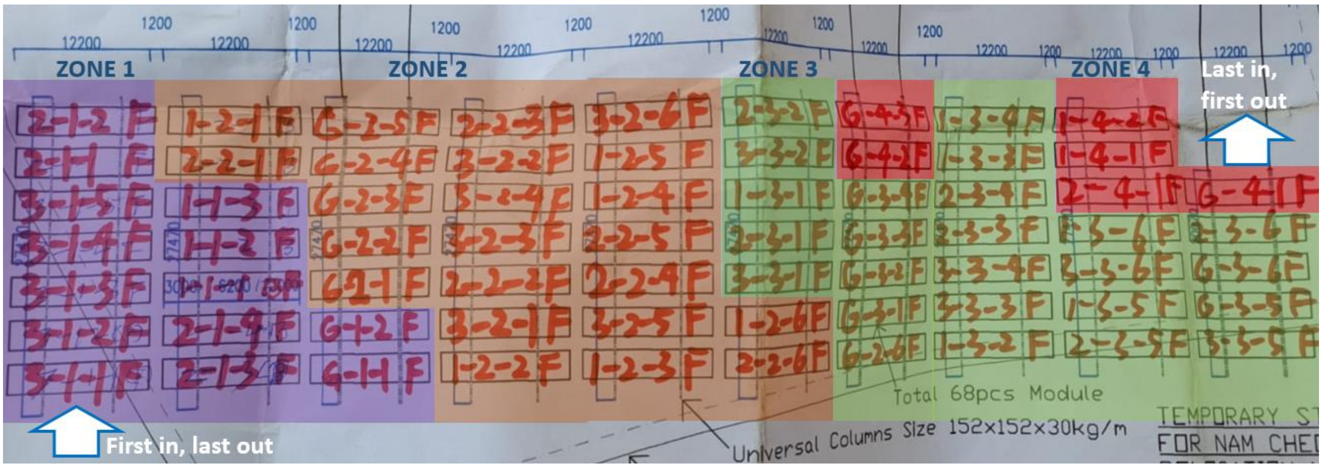


Fig. 20. Layout plan of MiC modules at the storage yard

3.8 Manpower and equipment

3.8.1 Labour (disassembly, touch up and reinstallation)

In general, the NC220 project team adheres to the working time policy set up by Standard Working Hours Committee (SWHC). The working hours were restricted to 8 hours per day. The detailed results of the questionnaire survey about the allocation of manpower and equipment are presented in Appendix B.

The NC220 relocation project can be divided into three phases: demolition, touch-up, and reinstallation. In the demolition phase, a diverse range of workers was engaged, encompassing pick-up & delivery(P&D) workers, electric workers, fire service (F.S.) workers, scaffolders, and other skilled labourers. Among these, P&D workers were primarily responsible for material and waste handling on the construction site, electric workers cut unnecessary cables in the corridor, F.S. workers removed the fire sealant from the MiC module connections, and scaffolders were tasked with scaffold installation and dismantling. During the touch-up phase, the contractor also hired painters and plasterers to repair the damaged MiC modules. The reinstallation phase was expected to take one and a half months, involving various types of workers; the specific numbers and working hours are shown in Table 2.

Site(stage)	Trades	Amount	Working days	Man-day/CFA
NC220 project site (Demolition)	P&D worker	4	20	0.024
	Electric worker	4	20	0.024
	F.S. worker	3	20	0.018
	Scaffolder	8	14	0.034
	Labourer	8	30	0.073
Storage yard (Touch-up)	Painter	8	30	0.073
	Plasterer	8	30	0.073
	P&D worker	4	10	0.012
	Electric worker	4	10	0.012
	F.S. worker	4	10	0.012
	Labourer	4	30	0.037
Wong Yue Tan (Reinstallation)	P&D worker	8	45	0.110
	Electric worker	8	45	0.110
	F.S. worker	4	45	0.055
	Painter	8	30	0.073
	Plasterer	8	30	0.073
	Scaffolder	8	14	0.034
	Labourer	4	45	0.055

Table 2. Manpower engaged in the NC220 relocation project

3.8.2 Equipment (disassembly, touch up and reinstallation)

During the NC220 relocation, various machines and equipment were used. The specific quantities, duration, and specifications are depicted in Table 3. In the demolition phase, a mobile crane was utilized to lift MiC modules from their stacked positions onto trucks. Four 12-meter-long trucks shipped the disassembled MiC modules to the storage yard. Flame-cut machines were used to separate MiC modules on the ground floor from the concrete foundation. In the touch-up stage, a loading capacity of a 130-ton mobile crane was used to position MiC modules within the storage yard. Similar to the deconstruction, four trucks were employed to transport the refurbished MiC modules to the new project site, and a loading capacity of a 230-ton mobile crane was used for assembly during the re-installation process.

Site(stage)	Machine/Equipment	Type	Amount	Working days
NC220 project site (Demolition)	Trucks (from the site to the yard)	12m-length	4	16
	Mobile crane	230-ton	1	16
	Flame-cut machine	N.A.	2	16
Storage yard (Touch-up)	Mobile crane	130-ton	1	16
Wong Yue Tan (Reinstallation)	Trucks (from the yard to the new site)	12m-length	4	14
	Mobile crane	230-ton	1	14

Table 3. Equipment and machines used in the NC220 relocation project

4. Inspection of reused MiC modules

This section introduces the normal workflow of the NC220 project team adopted to examine the conditions and structural integrity of MiC modules for statutory authorities' inspection, comment, and approval (Fig. 22). In addition, the reusability of MiC modules was investigated through site observations carried out by the research team.

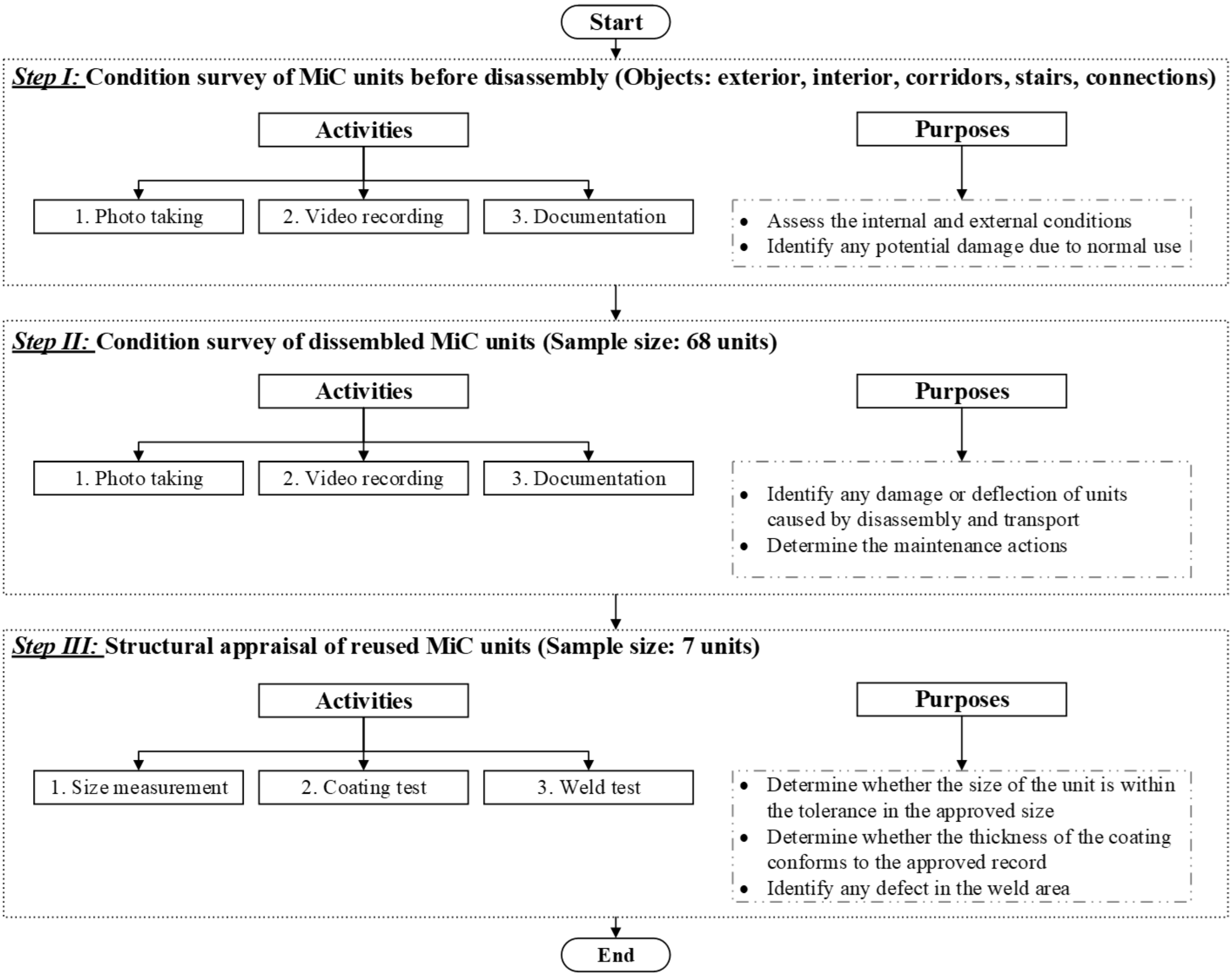


Fig. 21. Inspection processes for MiC modules

4.1 Practice on a condition survey of dismantled MiC modules

The condition survey of disassembled MiC modules conducted by the NC220 project team was similar to that before disassembly (see Section 3.3), using a site photo recording and documentation approach. Notably, it was required that the eight sides (A – H sides) of each module shall be taken records (Fig. 23), generating over 500 photos for statutory authorities' inspection, comment, and approval. It was reported that the conditions of MiC modules before and after disassembly remained similar, indicating no observable damage or deflection of module in the process of dismantling and transportation to the temporary storage site (Source: Wilson & Associates). It was thus concluded that most of the structural members are in good condition and no replacement or maintenance is required (Source: Wilson Cheung & Associates).

The existing condition surveys should be carried out before and after disassembly of MiC modules, requiring plenty of photo records and documentation. In the near future, it is expected that 29 MiC transitional housing projects (including 10 completed and 19 under construction). Numerous site photos (each module with 8 sides) are expected to be recorded for statutory authorities' inspection, comment, and approval.

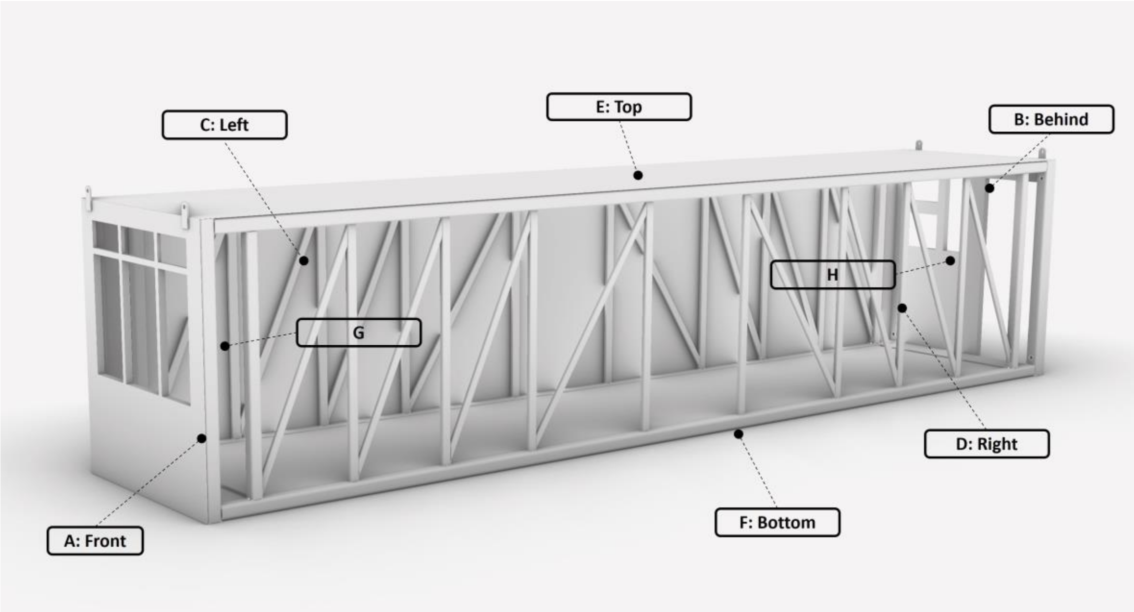


Fig. 22. Photo records and documentation taken from 8 sides of each MiC module
A, B, C, D, E, and F sides are the exterior sides, while H and G are the interior sides

4.2 Practice on a detailed structural appraisal of reused MiC modules

Prior to the reuse of MiC modules, a detailed structural appraisal should be conducted for statutory authorities' inspection, comment, and approval. The sampling size adopted for detailed structural appraisal was 10%, meaning that 7 modules out of 68 were chosen (Fig. 24). The detailed structural appraisal consists of dimensional measurement, measurement of coating thickness, and weld test.

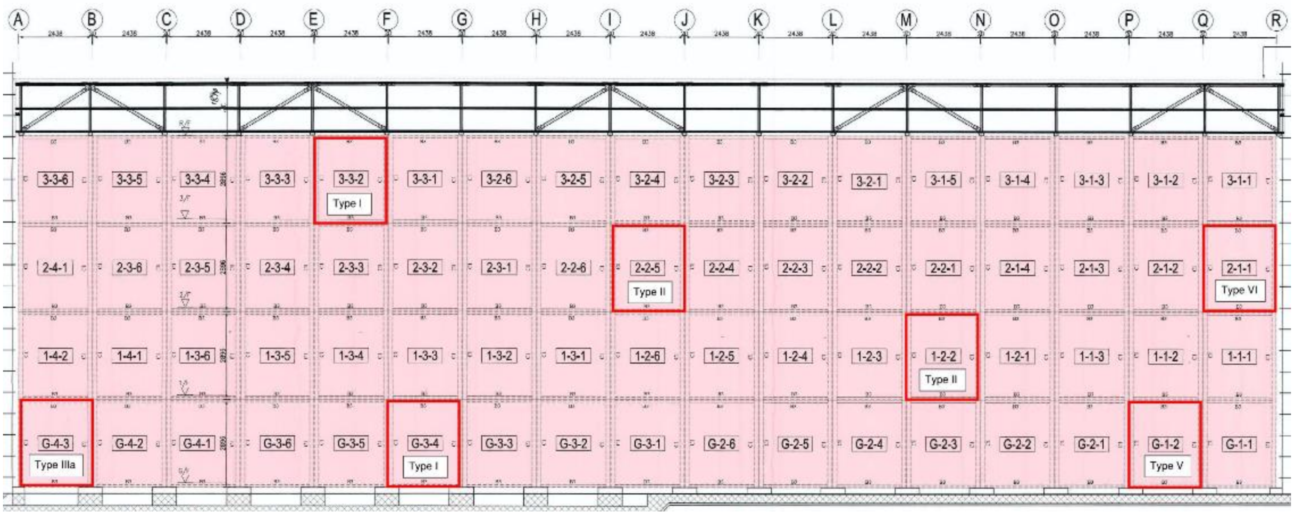
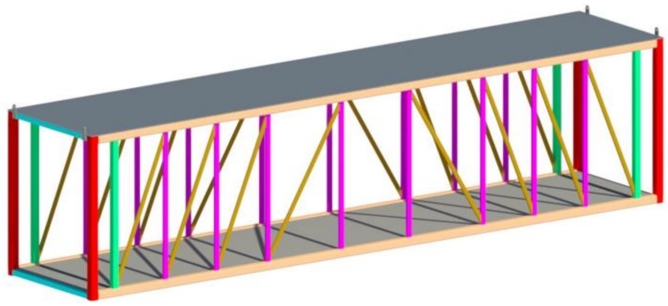


Fig. 23. Selected MiC modules for detailed structural appraisal

(Source: Wilson & Associates)

As depicted in Fig. 25, the steel frame of the MiC modules is composed of multiple steel members, and the total thickness of each member (including the member thickness and coating thickness) is not consistent. During the measurement process, only the exposed steel members (i.e., B1, C1, C4) were measured, while those members inside the envelope were not measured. The protective coating of the steel members consists of a zinc primer (Thickness: 0.2mm) and fire coating (FM900). The specific thickness of the fire coating and the expected total thickness of each steel members are detailed in Table 6. For detailed comparison of measured size with the approved member size, please refer to Appendix D.



Member Mark	Colour	Member Size	Total Size (with coating)
B1		150*150*16	152.06*152.06*17.03
B2		80*40*6.3	87.95*47.95*10.27
B3		100*100*8	104.14*104.14*10.07
C1		150*150*12.5	152.06*152.06*13.53
C4		100*50*6.3	107.51*57.51*10.06
C5		120*120*10	123.34*123.34*11.67

Fig. 24. Steel members mark

	Member Size	FM900	Primer	Expected Total Thickness
C1	150 x 150 x 12.5	0.832	0.2	152.06 x 152.06 x 13.53
C4	100 x 50 x 6.3	3.556	0.2	107.51 x 57.51 x 10.06
C5	120 x 120 x 10	1.472	0.2	123.34 x 123.34 x 11.67
B1	150 x 150 x 16	0.832	0.2	152.06 x 152.06 x 17.03
B2	80 x 40 x 6.3	3.774	0.2	87.95 x 47.95 x 10.27
B3	100 x 100 x 8	1.872	0.2	104.14 x 104.14 x 10.07
B4	100 x 100 x 6.3	3.556	0.2	107.51 x 107.51 x 10.06
J1	100 x 60 x 8	1.952	0.2	104.30 x 64.30 x 10.15
-	120 x 120 x 12.5	0	0.2	120.4 x 120.4 x 12.7

Table 4. Expected total thickness (mm) of each steel member
(Source: Wilson & Associates)

4.2.1 Dimensional measurement

The detailed structural appraisal consisted of dimensional measurement, coating thickness measurement, and weld test. The NC220 project team used a calibrated digital vernier to measure the dimensions of steel members and a calibrated tape measure to record the overall dimension of disassembled MiC modules in terms of length, height, and width. For illustration purposes, MiC module "2-2-1" was chosen as an example. The measured dimensions of this module were carefully checked against the design records (12192 mm (L) × 2438 mm (W) × 2896mm (H)) (Fig. 26(a)-(c)). The results were within acceptable tolerance ± 3 mm according to the approval record of NC220. Also, measurements were taken for the sectional dimensions and thickness of the steel member "2-2-1 Column C1" (Fig. 26(d)-(e)). It was found that the differences in sectional dimension and thickness between the test results and the approval plan were within 1 mm and thus, it was concluded that the tested members are in good condition for reuse (Source: Wilson & Associates).

(a) Measured length of MiC module: 12195mm, difference = +3mm	(b) Measured width of MiC module: 2440mm, difference = +2mm	(c) Measured height of MiC module: 2896mm, difference = 0mm	(d) Measured sectional dimensions of the member: difference = +0.56mm	(e) Measured thickness of the member: difference = +0.22mm

Fig. 25. Dimensional measurement of steel members
(Source: Wilson & Associates)

4.2.2 Measurement of coating thickness

The thickness of the galvanized coating and fire protection paint (firecut FM-900) were measured before reuse, using a calibrated coating thickness gauge with a measurement accuracy of 1 mm. For illustration purposes, the steel member "MiC module 2-2-1, Column C1" was chosen as an example (Fig. 27). It was observed that the measured coating thickness (FM-900 + zin primer = 1.05 mm) of the steel member "Column C1" is larger than the approved thickness (1.032 mm), enhancing fire and anti-corrosion protection. Accordingly, the measured overall dimension of steel section members (Steel section + FM-900 + zin primer = 152.24 mm) is larger than the approved overall size (152.064 mm)(Source: Wilson & Associates).

Fig. 26. Coating thickness of the steel member "Column C1, Location L"
(Source: Wilson & Associates)

4.2.3 Weld test

Non-destructive test of welded joints using magnetic particle inspection (MPI) was employed to detect any surface and near-surface flaws in welded joints. After thoroughly cleaning the welded joints, magnetic particles were uniformly applied to the surface of welded joints (Fig. 28(a)-(b)). These particles can be attracted to areas of magnetic flux leakage caused by any surface or near-surface flaws such as cracks, laps, seams, or porosity. Accordingly, the particles can form visible patterns at the locations of the defects. After testing the fillet weld length (0-150 mm) of 14 welded joints, the results of MPI indicate that no defects were found in welded joints (Source: Wilson & Associates), proving the reusability of MiC joints.

(a) Magnetic Particle Test of MiC module 2-1-1 upper weld

(b) Magnetic Particle Test of MiC module 2-1-1 lower weld

Fig. 27. Magnetic particle test
(Source: Wilson & Associates)

4.3 Site observations

The exterior and interior conditions of MiC modules were observed before disassembly on February 07, 2023. An initial batch of 10 modular modules, including the roof structure, were transported and stored at the storage yard for visual inspections conducted on 3 March 2023 by the research team. A follow-up 2-hour site visit was carried out on 27 April 2023, and 8 typical MiC modules, connection joints, and disassembled metal roofs were observed during the visit.

This section shows the findings of on-site observations carried out by the research team. It covers the basic conditions of the relocated MiC modules, such as signs of deformation and damage (if any), waste generation, and relevant on-site activities. The components that needed touch-ups (if any) were identified as well.

4.3.1 Metal roof

The roofing system in NC220 was also fully relocatable and reusable, consisting of single pitch steel roof trusses, profile aluminum roofing and rainwater gutter (Fig. 29(a)-(c)). They were generally found to be in good condition and reusable for reinstallation.

(a) Steel roof trusses

(b) Detail of roof truss sleeve-bolt connection

(c) Aluminum roofing and gutter

Fig. 28. Conditions of the roofing system

Only a minor touch-up was required to clean rust stains inside a Rectangular Hollow Section (RHS) sleeve at one location of the roof truss connections (Fig. 30(a)). This minor spot rusting indicated that moisture penetration was evident at this particular roof/façade junction. This may be the likely cause of water seepage to the second-floor module below. Despite this, such rust stains would not cause substantial damage to the roofing system. Touch-ups were done through cleaning and coating to enhance corrosion resistance. Fig. 30(b) shows that an on-site worker was using a vernier calliper to measure the thickness of the RHS sleeve to determine its dimensional tolerance.

(a) Rust stains inside an RHS sleeve

(b) On-site measurement to check dimensional tolerance

Fig. 29. Conditions of roofing system (II)

4.3.2 External condition of MiC modules

In NC220, the modular modules form an integrated façade without any additional cladding or adaptive façade features (i.e., no sunscreen or other shading panels). The external surfaces of the MiC modules observed were generally in good condition, without any signs of damage or water penetration. There was no remarkable discoloration or staining on the walls, floors, or roofs. No cracks, exposed gaps on the exterior wall or broken seals between inter-module junctions were found. There were minor scratches to the fire-proofing coating of the structural steel frame, possibly during removal of weather seals during deconstruction, which was carried out manually by workers.

Only minor surface rust stains were found at the vertical inter-module joint of a third-floor module (Fig. 31(a)), and on the top cover panel (Fig. 31(b)) and inter-module joint of one second floor model labeled as 2-1-1 (Fig. 31(c)). This was possibly due to minor rain ingress driven through the gap between the roof and module top, then subsequently seeped downward towards the third-floor and second-floor inter-module joints. The intrusion gap likely corresponded to the small rust stain found inside the RHS sleeve of the roof truss in 4.2.1 above, suggesting moisture penetration at this particular roof-module junction. This observation may likely explain the water leakage found on the corridor floor of the second-floor corridor at the corresponding module location during the tenancy period. These minor surface rust stains have no negative effect on the performance of the building components. Minor touch-ups were required to re-condition the surface. No rust stains were found in other observed modules.

(a) vertical steel frame of a third-floor module

(b) top cover panel of a second-floor module

(c) top joint of a second-floor module

Fig. 30. Surface rusting (minor rust stain) on external surface of MiC module

To adapt to the architectural design of the new transitional housing project in Taipo, the exterior of the existing MiC modules was repainted with new colour (Fig. 32(a)-(b)).

(a) Elevation (b) Left side

Fig. 31. New architectural design of transitional housing project

4.3.3 Connections between modules

Inter-module connections were dismantled and stored in the storage yard. The connections, including bolts, nuts, steel tubes, and tie plates, were visually examined to detect any sign of damage, deformation, and corrosion. During the site visit, the connections were found to be in good condition without significant cracks or bending. No sign of corrosion was detected at the internal/external tie plates. However, localized rust was found at the back of T-section over the inter-module connections (Fig. 33(a)). Water stored at the gaps between the T section and the steel columns might have caused corrosion. It should be noted that these inter-modular connectors were not galvanized, but fire-protective paints (in white) were applied. Touch-ups were carried out to clean the rust stains and apply protective zinc coating at these areas.

We discovered that a few bolted holes in some of these steel tie plates were slightly elongated due to bearing (Fig. 33(b)). The deformation of these holes was slight and had no main effect on structural integrity. Since almost all connections can be reused in the next project, the bolts, nuts, steel tubes, and tie plates were marked and paired, allowing ease of tracking and reassembly.

(a) Surface rusting on the back of T-section (b) Bearing of the steel connection

Fig. 32. Conditions of steel connections

4.3.4 Structural steel members

During the site inspection, the steel structural members examined were found to be in good condition, without visible deformation or local buckling observed (Fig. 34(a)-(b)). This is evidenced by the good condition of the pink fire-rated board and fixing crews without the tendency to warp. Minor paint peeling and surface rusting were identified inside beams and columns of the MiC modules "2-1-2," "2-1-1," "1-3-2," "G-2-5," "3-1-3," and "3-1-5." The locations are shown in Fig. 35.

(a) Front side of the typical MiC module (b) One side of the typical MiC module

Fig. 33. Conditions of exposed steel members

Fig. 34. Overview of locations of MiC modules with surface rusts as observed

Surface rusts were observed in highly localized areas near the beam-column joints of the modules exposed to weather (Fig. 36(a)). They were believed to be caused by the long-term presence of water in the gaps between the steel beams and the adjacent modules. Besides, surface rusts were identified in a steel member probably because of rainwater seepage (Fig. 36(b)), and in a ground-floor MiC module exposed to ground moisture (Fig. 36(c)). It might be caused by insufficient waterproofing applied to the footing system and steel members. In addition, we also observed that the painting was peeled off from 4 steel members and caused surface rusting. It was possibly caused by the scratch between MiC modules during assembly or disassembly (Fig. 36(d)), or the scratch between the module's steel member and the lifting eye of the upper or lower adjacent module (Fig. 36(e)). Notably, the very slight surface rusting did not induce significant damage to steel members. Touch-ups were made to remove the rust stains and repaint the affected steel members using corrosion-resistant and fireproofing coating.

(a) Surface rusts near the column-beam junctions

(b) Surface rusts due to water seepage

(c) Surface rusts due to ground moisture

(d) Paint peeling due to modules collision

(e) Paint peeling due to scratch with lifting eye

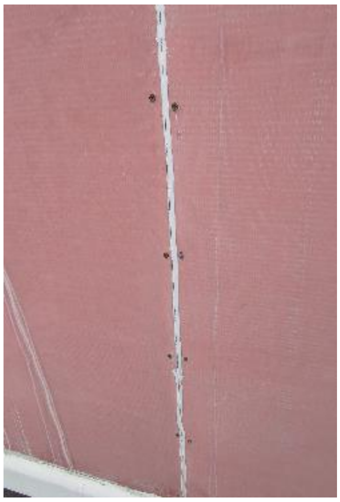
Fig. 35. Surface rusting on steel members

4.3.5 Fire protection system

The fire protection system adopted in MiC modules consisted of fire-rated boards (pink in color), fireproof coating, and rock wool. All steel members were provided with fire-rated coating. Fire-rated boards were installed in wall panels. Brackets used for supporting fire-rated boards were installed at a spacing of roughly 500 mm to offer an effective fire protection system. Rock wool was provided on the wall and ceiling of the modules.

During the site inspection, the fire protection system was found to be in good condition after 2 years of use. The observed fire-rated boards could maintain their positions without signs of distortion (Fig. 37(a)). Almost all the fixing screws of these boards had no sign of tilting or bearing (Fig. 37(b)). Touch-ups were made to replace gemtree boards and fire sealants in the highlighted areas due to normal use (Fig. 37(c)-(e)), whereas fireproof coating was repainted for all steel members to enhance the protection for future use.

(a) Supported fire-rated boards

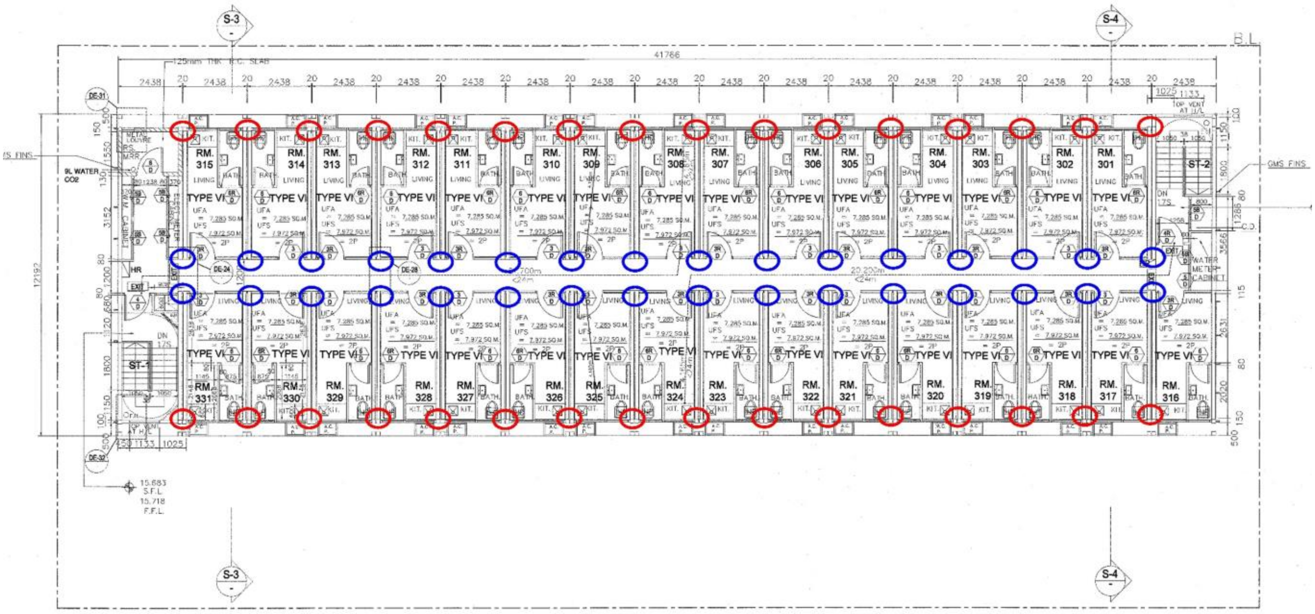


(b) Fixing screws in good condition

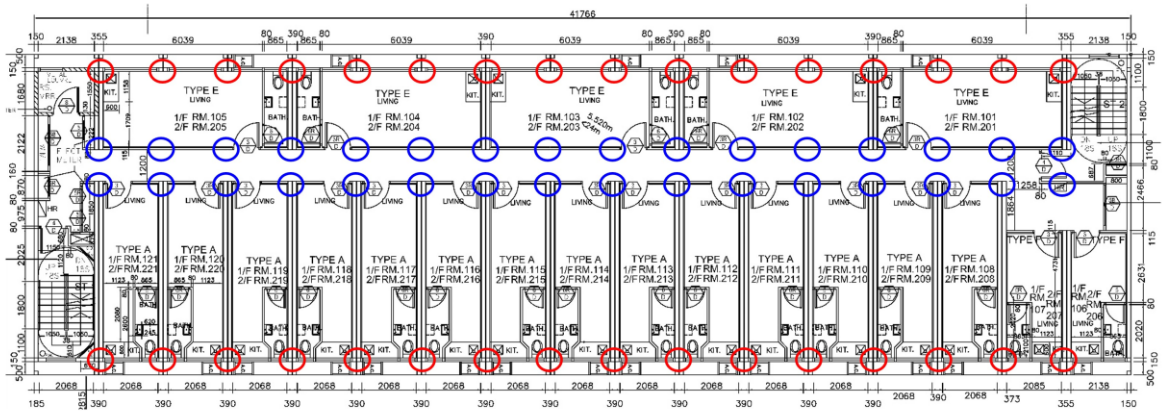
LEGEND:

Replace fire stop acrylic sealant

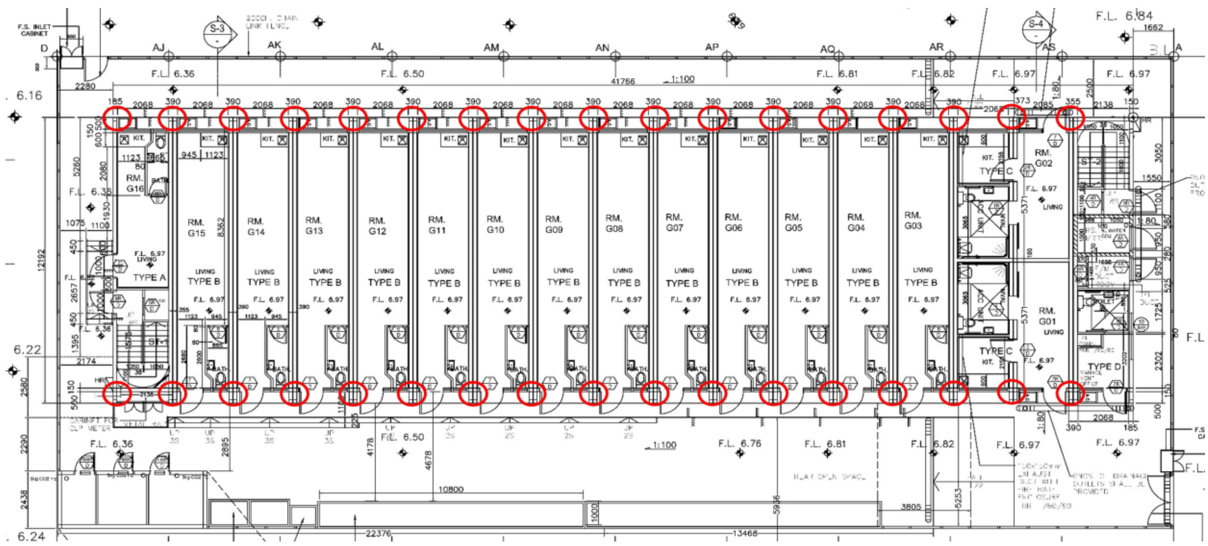
Replace 12mm THK Gemtree board



(c) Replacement of fire sealants and gemtree boards on 3/F floor



(d) Replacement of fire sealant and gemtree boards on 1/F and 2/F floor



(e) Replacement of fire sealants on G/F floor

Fig. 36. Conditions of fire protection system (Source: Wilson & Associates)

4.3.6 Internal finishes

We observed that the floor, wall and ceiling finishes inside the modules and corridors were generally in good condition. A small quantity of the wall and floor tiles in the toilets showed signs of cracking and peeling due to normal use. These wall and floor tiles were removed and re-laid. (Fig. 38). There was no significant blistering and peeling of paint on the internal walls and ceiling. No mildew growth on the interior surfaces of walls and ceiling was observed, indicating a minimal chance of water seepage inside the MiC module.

Fig. 37. Tile resurfacing

4.3.7 Built-in fixture, fittings and equipment

The kitchen cabinets, bathroom sanitary ware and window-type air conditioners are the main built-in fixtures of the MiC module. Most of the fixtures examined was found generally in decent condition and could be used as it was for the second life cycle. A few kitchen cabinets were found partially damaged, with minor surface blemishes that might need to be repainted. The toilet water closet, washbasin, hand shower, and ventilation fans were the bathroom's fixtures; most of them were durable with minimal substantial damage. At the storage yard, we observed workers cleaning the interior of the suite, including the bathroom sanitary ware and kitchen fixtures. The research team also checked the conditions of exposed fixtures, including windows, doors, ironmongery and air conditioner (AC) aluminum racks. These exposed fixtures were in good condition.

4.3.8 Building services (MEP)

In the exterior wall of the MiC modules, cracks were observed on the some external pipes, which might be caused by ultraviolet (UV) radiation (Fig. 39(a)). All external water supply and drain pipes were removed and disposed of to avoid hygiene issues. A new external plumbing and drainage system using new pipe materials was designed and would be installed in the new project site. Inside the MiC modules, water and drain pipes, surface mounted electrical conduits, switches, sockets and lighting fixtures were all retained while most of the electricity cables were cut off during the pre-deconstruction phase (Fig. 39(b)). They would be reconnected at the new project site. Sprinkler heads and smoke detectors were also retained. The air-conditioners were found to be in satisfactory condition and ready for reuse in the next project (Fig. 39(c)). In the corridor, all electric conduits, sprinklers pipes and light fixtures were all removed to facilitate joint removal between modules. These items would be replaced by new installation during reassembling stage.

(a) Crack on surface of exposed pipe (b) Disconnected wiring (c) Air-conditioner & support frame

Fig. 38. Conditions of MEP building services

4.3.9 Summary of site observations

In general, the MiC modules, including steel members and joints, were found to be in good condition, determining their high reusability. No replacement or maintenance was required.

a. The studied MiC modules, including the steel frame and connection systems are dismountable and reusable, given that they were found in good condition after use of 2 years.
b. There were no visible deformations of the MiC modules, and all of them could maintain their shapes and verticality.
c. Surface rusting (minor rust stains) was found but without causing severe damage. Touch-ups were required to clean rust stains and repaint protective coating due to normal use.
d. Many internal and external connections were found to be in good condition, and well protected with galvanization and coating. Slight surface rusts were found at the inner side of the cover plates over the inter-module connections. Touch-ups were required only to clean rust stains and apply protective zinc coating.
e. The conditions of the inner side and outer surface of MiC modules were found to be in good condition.
f. The fire protection system was found to be in good condition; however, touch-ups were necessary to replace plasterboard and fire sealants in specific areas due to normal use. Additionally, the fireproof coating on steel members needed repainting to enhance the protection for future use. External drainpipes will be reinstalled, as well as electricity cables.
g. The built-in fixtures were found to be in good condition and ready for reuse.

5. Reusability of MiC modules

This section presents the methods to determine the reusability of MiC modules and concludes the reusability rate of MiC modules based on the research team's site observations that were validated by the NC220 project team.

5.1 Methods used to assess the reuse rate and touch-up rate of MiC modules.

The assessment of the reuse rate and touch-up rate was based on site observation and inspections conducted by the research team during the process of deconstruction, storage and reinstallation. In addition, a semi-structured interview was carried out with the NC220 project team to verify the assessment.

5.1.1 In this study, "reuse rate" is defined as the degree or overall percentage of reusing the building component fit for its original intended purposes, function and performance criteria without substantial repair, alteration or replacement in part or in whole. "Touch-up rate" refers to "*the degree or overall extent of additional works aim to improve or perfect the building conditions by small areas of making good or minor alterations*" [39], for example, spot coating and surface repainting. The estimated percentage (%) is by area or number unless otherwise stated, corresponding to the normal measuring unit of the items and rounded up to the next whole percentage.

5.1.2 Overall, the area of surface rusting over area of all steel members is approximately 0.83%. Among all levels, modules at the ground level had the highest percentage of rust area, which is approximately 2%. Taking the MiC modules on the ground floor as an illustration, we noted that 14 out of 17 modules with rust stains (Fig. 40 (a)-(b)). We further estimated that the reuse rate of the side columns of the ground MiC modules is approximately 99%. This estimation was based on the affected flame-cutting area, which accounts for around 1% of the total area of the side columns. The touch-up rate was estimated based on the flaming-cutting length of the side column, which accounts for 5% of its total length.

(a) Rust stains on the beam of MiC module G-3-4 (Front side)

(b) Rust stains on the beam of MiC module G-3-4 (Left side)

Fig. 39. Rust stains on the MiC modules
(Source: Wilson & Associates)

5.2 Reuse rate and touch-up rate of MiC modules

Overall, the MiC modules of NC220 can achieve an overall reuse rate of more than 95%. The overall reuse rate and touch-up rate of the structural frame, external envelope, internal finishes, built-in fixtures, and MEP services are shown in Fig. 41. Detailed information on the reuse rate for each component and the corresponding touch-up rate can be found in Appendix A.

5.2.1 The structural frame of the MiC modules remains in good condition, and the main steel frame can be fully reused after 2 years of use. There were no visible deformations of the MiC modules, and all of them could maintain their shapes and verticality, also without significant damage to finishes caused by transportation handling or lifting stress.

5.2.2 Steel members and inter-module connections were 100% reusable. Only 2% needed touch-ups (e.g., re-coating, rectification, and polish) to enhance coating protection due to normal use. 95% of module-foundation connections were reusable and the touch-up rate was 5%. This was because welded connections were employed to link the ground-floor modules with the raft foundation, leading to the necessity of employing flame-cutting techniques when disconnecting the ground-floor modules.

5.2.3 While the roof structure was 100% reusable with a 10% touch-up rate made to enhance protective coating, the roof covering would be replaced due to normal use. Firestop systems exhibited 100% reusability, with an overall touch-up rate of less than 2% attributed to normal use.

5.2.4 The external envelope, including windows and side walls, was 100% reusable after minor touch-ups. For instance, less than 1% of external elements required touch-ups due to normal use. Approximately 10% of façade walls were repainted to adapt to the architectural design of the new transitional housing project.

5.2.5 More than 90% of the internal finishes were reusable, with an overall touch-up rate of around 10%. Notably, 90% of internal walls were repainted due to normal use to refurbish the interior conditions for new occupants in the future.

5.2.6 More than 95% of built-in fixtures and mechanical, electrical, plumbing (MEP) and fire services inside MiC modules were reusable, subject to final testing and commissioning as a complete building/building systems. A new plumbing and drainage system outside MiC units would be reinstalled concerning hygiene issues. In the corridors, the electricity cables, lighting and fire services would be fully replaced/reinstalled at the new site.

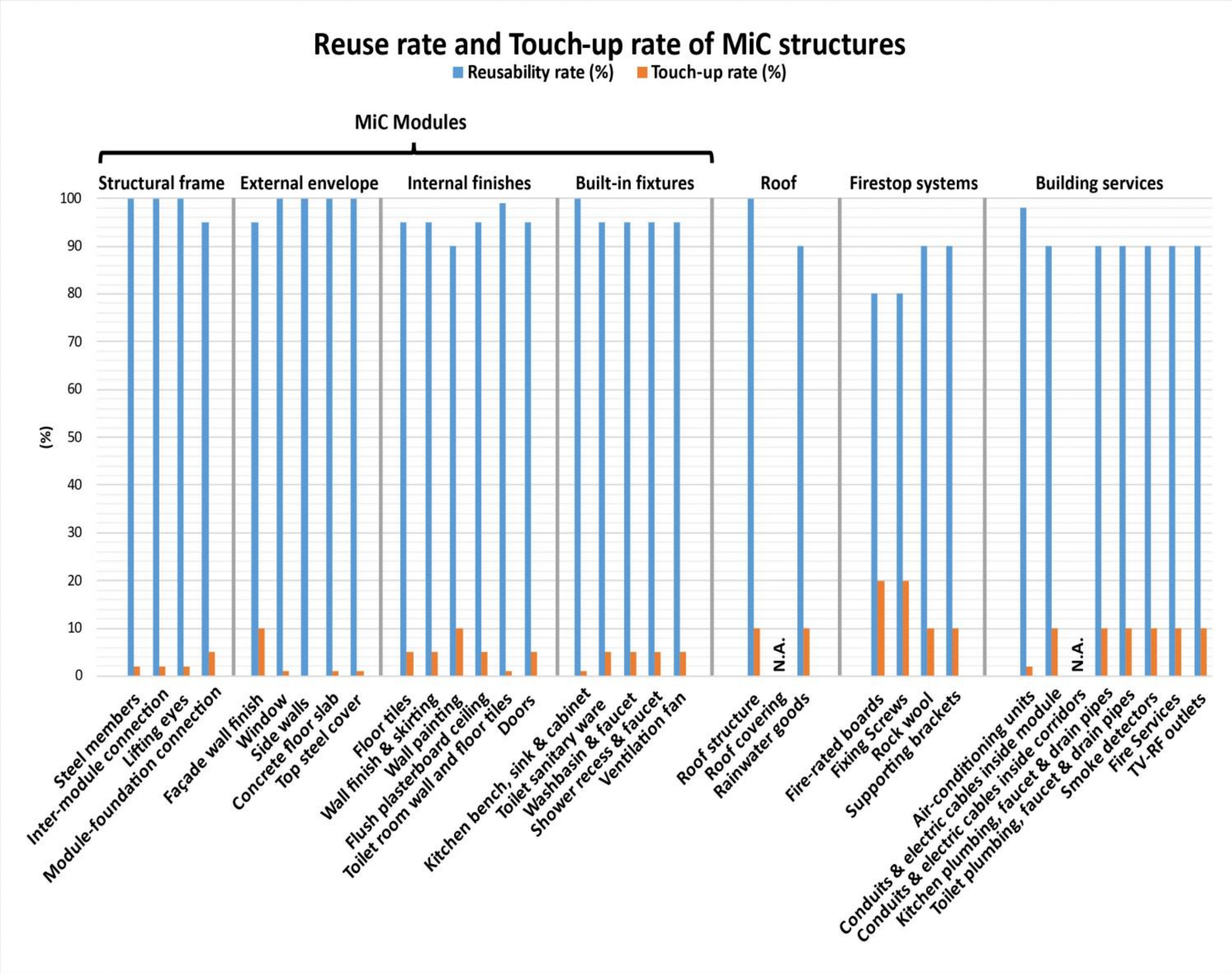


Fig. 40. Reuse rate and Touch-up rate of MiC modules

6. Recommendations

The relocation and reuse of NC220 provide a valuable reference and good practice for implementing the circular economy in the construction industry, thereby reducing demolition waste, avoiding the consumption of virgin materials, maximizing the value of public money, and ultimately achieving sustainability of MiC projects. To the authors' best knowledge, NC220 is one of the first MiC projects globally that has been disassembled, relocated, and reused entirely as a complete building. (In Vancouver, one VAHA project "Little Mountain," was deconstructed and put in storage for two years before dispatching some modules for reuse in two separate locations.) All MiC modules of NC220 are reusable after minor touch-ups, fostering local and international practices on MiC reuse. Learning from this case, this report formulates viable recommendations for reuse practice in future relocatable MiC projects by streamlining the design-procurement-maintenance-disassembly-reinstallation process. Strategic technical recommendations are formulated below to enhance the delivery of MiC relocation projects.

6.1 Include Design-for-Disassembly (DfD) solutions in early design phase

As a general principle on design, it is recommended that early involvement of MiC suppliers and deconstruction professionals in the early design phase is essential for developing DfD solutions. All project stakeholders (clients, architects, structural and mechanical engineers, builders, deconstruction professionals, etc.) should contribute to the DfD solutions and ensure that initial consultation of DfD has taken place [40]. It will allow the MiC suppliers and deconstruction professionals to contribute their expertise knowledge and experience in disassembly during the design stage to achieve higher reusability of MiC modules [41].
[42]
This section reviews and compares the existing DfD solutions adopted in NC220 and other projects, providing references for improving the ease of disassembly in future relocatable MiC projects.

6.1.1 *Module connections*

Connections play a crucial role in determining the feasibility of disassembling and reusing interconnected elements [40]. It is widely acknowledged that welded connections, binding agents, and sealing agents are less conducive to reusability [43]. Regarding the connections between MiC modules, the issue of locked-in stresses in NC220 was addressed in Section 3.4.4. In lieu of a bolted connection utilizing a connection plate, interlocking connections are recommended for projects in the future [44]. Fig. 42 illustrates a typical interlocking connection mechanism characterized by two strips featuring geometric elements such as tongues and grooves [45]. These elements ensure the tightness of the connection and the overall structural integrity. The MiC modules can be assembled and disassembled by pushing along the side of adjacent modules.

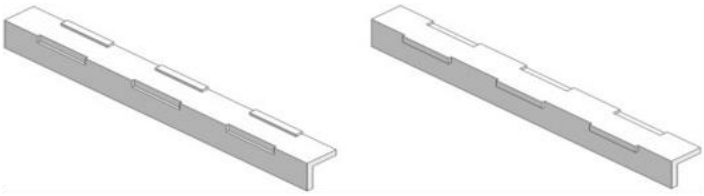


Fig. 41. Recommended connections for MiC modules
(Source: Interlocking system for enhancing the integrity of multi-story modular buildings)

6.1.2 *Footing system*

Foundations that are suitable for designing structures with disassembly in mind include pads, piles, or ground beams, as indicated in the literature. Conversely, construction methods involving the extensive use of concrete for strip, trench, or raft foundations, such as observed in the case of NC220, are less favourable for disassembly purposes [44]. In the specific context of NC220, welded connections were employed to link the ground-floor modules with the raft foundation, leading to the necessity of employing flame-cutting techniques when disconnecting the ground-floor modules. The difficulty in removing welded connections and the need for additional procedures, such as flaming cuts, contribute to their limited reusability. An instance of this challenge is evident in the case of NC220, where a flaming cut was necessary to separate the welded connection between the side column of the ground floor module and the base plate on top of the concrete footing. Unfortunately, the use of a flaming cut not only damages the bottom of the side column but also prolongs the disassembly process. As an alternative, mechanical connections utilizing bolts, nuts, screws, dowels, and clamps are highly recommended due to their ease of disassembly [40]. A typical example is a bolted base plate depicted in Fig. 43, comprising a steel plate and anchor bolts embedded into a concrete foundation [46]. Through a bolted connection, the MiC modules situated on the ground floor can be disconnected from the foundation simply by removing the top nut. This type of connection circumvents the damage to the side column caused by a flaming cut and significantly enhances the efficiency of the disassembly process. It is thus recommended that the implementation of straightforward, regular, rectilinear grids of supports (or support attachments) be employed, providing a foundation solution that allows for the assembly and disassembly of columns using mechanical connections [44].

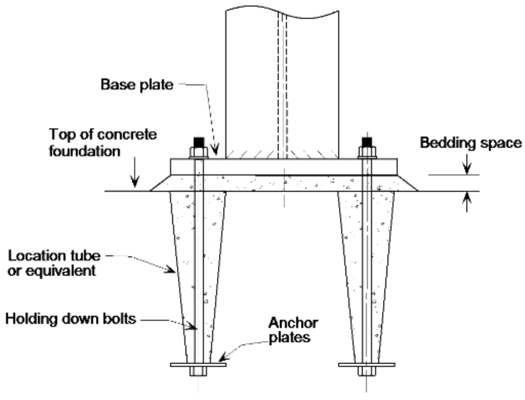


Fig. 42. Recommended connection for the concrete footing
(Source: Structural engineering forum of India)

6.2 Pilot the innovative Design-Build-Deconstruction (DBD) contract

In construction procurement strategy, existing methods mainly focus on the completion of a new building, such as Design-Bid-Build, or Design-Build. Such linear procurement process excludes the end-of-life phase of the building, without early consideration of pricing, scheduling, and risk management in MiC relocation. It is recommended that a life cycle approach by integrating the three major phases of relocatable MiC projects, namely, design, fabrication, and disassembly, shall be adopted. The approach shall take the DfD solutions and MiC relocation into account at the procurement stage. This Design-Build-Deconstruction (DBD) contract [42] will support the client in procuring DfD solutions, MiC production, and relocation in an integrated approach, with the early consideration of the end-of-life scenarios of MiC projects. It will help the client plan relocatable MiC projects on a life cycle basis and manage the relocation process efficiently.

6.3 Provision of MiC User Manual from original designers

As roles and responsibilities have drastically changed under DfD, a MiC User Manual should be contributed by all project stakeholders during the design stage. The Manual shall include all essential information about **DfD solutions, maintenance instructions, disassembly procedures, and digital material inventory**. By doing so, deconstruction experts, especially those who have not been involved in the design stage, can access the Manual to understand method statements on the disassembly of MiC modules. The MiC supplier can then follow the designated maintenance instructions to procure proper replacement materials and carry out touch-ups.

6.4 Provision of MiC maintenance manual to housing operators

Proper maintenance planning at the design stage can enhance MiC's maintainability and improve future maintenance practices during the operation stage of the MiC building to minimize building maintenance work and costs [47], thereby keeping the building in good condition and improving its reusability. To avoid the effects of improper design on maintenance work, maintenance planning should be accomplished by integrating the building design and future maintenance processes. Designers shall also determine mandatory building inspections to maintain the building elements in good condition.

Building occupants and users may have a profound impact on the building conditions. Based on a study conducted by Au-Yong et al. [48], deteriorating building components may depend on how much care is given to the facilities by buildings' users rather than the effectiveness of maintenance operations. Hence, buildings' users' interactions must be positive and responsible for the conservation and maintenance of buildings. Favorable interactions can be fostered by building management raising their awareness of the importance of the proper use of the building and its maintenance. Thus, building management needs to improve their building's users' engagement to keep buildings safe for occupancy and to avoid degradation, as well as to encourage them to report faults immediately and display a high level of awareness for maintaining buildings in excellent condition [47]. The MiC User Manual should therefore address the needs of its users and increases their understanding of the building's function, provides information on how to maintain it at optimal levels, and ensure that all users both know and understand how the building maintenance works and act to keep it reusability at optimal levels. A user guideline could be formulated: "Occupants shall not drill holes in the walls."

6.5 BIM-enabled disassembly sequence planning

The existing disassembly planning in Nam Cheong 220 relies on manual procedures by determining the key topological interrelations between MiC modules. Notably, Building Information Modelling (BIM) technology has become an efficient tool not only for supporting the design and construction processes but also for facilitating the disassembly planning process [49, 50]. BIM-based disassembly models that specify the disassembly parameters of BIM elements can provide the information necessary for a disassembly process in an efficient way, overcoming errors arising from manual procedures [50]. Virtual deconstruction (VD) technology using a three-dimension (3D) BIM disassembly model can further be developed to digitally plan out and simulate all aspects of a deconstruction project. These technologies, however, remain in their infants. It calls for future research looking into the development and implementation of BIM-enabled disassembly planning tools.

6.6 Digital material inventory

The QR codes have been adopted in NC220, which provide basic information about MiC modules' relocation. However, more detailed information, such as quantities, material properties, reusability, and touch-up records, is absent. Individual building materials have differing expected time spans of use, which determine their reusability in future life cycles. Such information should be gathered and compiled into a database, thus creating an inventory of available materials suitable for reuse [44]. With the assistance of the material database, MiC suppliers can trace the material origins and procure proper replacement when carrying out touch-ups. Information such as material type, classification (load-bearing, insulation or façade), previous history (production, supplier warranty and donor building details), dimensions, shape, presence of additional material (coatings, renders, binders, sealants) and embodied carbon can be documented [44]. Once the MiC modules are disassembled, extensive information recorded for inspecting and repairing should be updated accordingly.

It is further suggested to develop a whole life cycle tracking system that integrates BIM with an upgraded QR code, so-called Digital Material Passport. By linking DMP with the BIM model [51], all project stakeholders can retrieve real-time information, such as the material's expected lifetime, inspection results, and reusability rate. The BIM-based DMP can create digital platforms for the life cycle management of MiC modules and materials, thereby supporting the reuse of MiC modules towards a circular economy in the construction industry. It is thus recommended the implementation of harmonized and standardized DMP in future relocatable MiC projects.

7. Conclusion

In Hong Kong, a number of 20,000 MiC modules are expected for deconstruction and relocation within the next five to ten years. Despite the existence of numerous studies on MiC buildings, the research and practical aspects concerning the relocation and reuse of MiC buildings remain underexplored. Consequently, a comprehensive investigation and documentation of the processes, including the dismantling, relocating, repairing, and reinstalling of relocatable MiC buildings has become imperative. This study endeavors to fill this knowledge gap by conducting a meticulous analysis of the first transitional housing project NC220 in Hong Kong, to enhance the understanding of this critical domain. The NC220 project demonstrates the great potential of MiC buildings in terms of relocation and reuse, as they can be disassembled, refurbished, and reinstalled within a mere six-month timeframe. The significance of relocatable MiC lies in enhancing the reuse rate of building, reducing resource wastage causes by the demolition of traditional buildings, addressing urban development challenges and housing requirements, improving the living conditions of low-income individuals, and benefiting multiple regions simultaneously. This study further indicates that the structural frame, envelopes and supporting facilities of the MiC modules almost remained intact after two years of use, exhibiting no visible signs of damage. The overall reusability rate of the relocatable MiC building can reach 95% after undergoing touch-up. Among them, most MiC elements demonstrate a reusability rate exceeding 95%, with low touch-up requirements, while only a few components fail to attain this level of reusability.

Drawing from the experiences from the NC220 relocation project, this study offers valuable recommendations to enhance the efficiency of relocating and reusing MiC buildings. We suggest adopting interlocking or gravity connections in future projects. Specifically, utilizing gravity or interlocking connections to attach new structural members to existing structural frames would enable convenient assembly and disassembly processes. To enhance the efficiency of foundation disassembly, an approach would be to adopt straightforward, regular, rectilinear grids of pads or piles, allowing columns to be easily disassembled using dry mechanical connections. Various building materials have distinct expected lifespans, influencing their potential for reuse in future life cycles. The data on building materials should be collected and compiled into a comprehensive database, facilitating the creation of an inventory of available materials suitable for reuse. Designers should not only establish mandatory building inspections to uphold the building elements in good condition but also focus on enhancing user engagement in building management to ensure safety and prevent facility degradation. To enhance the efficiency and effectiveness of deconstruction projects, we recommended considering developing Virtual Deconstruction technology using a 3D BIM disassembly model for digital planning and simulation. This advancement will greatly facilitate the deconstruction process. We also recommend adopting dimensional and geometric tolerance strategies and implementing transport loading simulation models within the project. The utilization of building information technology can effectively minimize damage and dimensional variability, leading to improved project outcomes. Finally, it is suggested to develop a whole life cycle tracking system that integrates BIM with an upgraded QR code, the so-called Digital Material Passport.

This report represents one of the pioneering studies documenting the technical aspects of MiC building disassembly, relocation, repair, and reinstallation, which has received limited prior attention. By offering comprehensive technical details and insights into the good practices and useful lessons on the relocation processes of the NC220 project, this report offers valuable references for construction practitioners, guiding them to adopt good practices and utilize design guides to enhance the reusability of MiC components and improve the efficiency of MiC building relocation and reuse in future.

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Acknowledgement

This technical report was funded by the Construction Industry Council, Hong Kong.

The study team is grateful to the generous support and information provided by the following organisations and individuals:

(in alphabetical order)
Construction Industry Council, Hong Kong
Housing Bureau – Task Force for Transitional Housing, HKSAR government
Ir. Paul Chung
The Hong Kong Council of Social Services
Wilson Cheung and Associates
Woon Lee Construction Ltd.
Vancouver Affordable Housing Agency, Canada BC

Appendix A. Estimate of building components to be reused

Note: Estimation was based on site observation and inspections conducted by the research team during the process of deconstruction and relocation. In addition, semi-structure interview was conducted with contractor's project team and consultants to verify and carry out adjustments as deemed necessary.

"Reusability rate" is defined in this report as the degree or overall percentage of reusing the building component fit for its original intended purposes, function and performance criteria without substantial repair, alteration or replacement in part or in whole.

* "Touch-up rate" refers to the *degree or overall extent of additional works aim to improve or perfect the building conditions by small area of making good or minor alterations* [1], for example, spot coating and surface repainting. Estimated % is by area or number unless otherwise stated, which corresponds to the normal measuring module of the item, and round up to the next whole percentage.

Building components	**Items**	**Reusability rate# (%)**	**Touch-up rate* (%)**	**Details of Touch-up works**
Sub-structure				
1. Foundation	Raft slab on ground (in-situ reinforced concrete); concrete columns with steel plate & cast-in anchor bolts	0	N/A	N/A
MiC modules / modular units				
2. Structural frame	Steel columns, beams & lateral bracings	100	2	Small area repair of fire protection coating mainly to beams
	Inter-module connection (between MiC modules) – SHS sleeves, tie plates and bolts	100	2	Polish & new top coat painting
	Lifting eyes	100	2	Rectified slight bending
	Module-foundation connection (between ground floor modules and footing) – SHS sleeves welded to steel plate	80	20	Rectify bottom part of side columns of GF modules
3. External envelope	Façade wall finish	95	10	New top finish coat to façade to suit new architectural scheme
	Window – anodized aluminum frame, glazing, hinges & handles	100	1	Minor adjustment of hinges and handles (due to normal use)

	Side walls - fire-rated boards & rock wool protection	100	0	
	Horizontal and vertical joints between modules	0	N/A	Replace all seals between module gaps (backer rods and sealant) as normal reinstallation practice
	Concrete floor slab	100	1	Replace floor drain outlets & traps for accessible modules due to removal to facilitate transportation
	Top steel plate/cover	100	1	Cleaning & minor spot painting to small areas of surface rust stains
4. Internal finishes	Module, corridor & stairs floor tiles	95	5	Making good and reinstall floor tiles to exposed floor joints between modules; general cleaning/polishing
	Module, corridor & stairs wall finish & skirting	95	5	Making good and reinstall wall boards over exposed vertical joints between modules
	Internal wall painting	90	10	Due to normal use + additional new top finish coat to all module interior, corridor and circulation areas for new tenancy
	Module flush plasterboard ceiling	95	5	Making good and reinstall ceiling boards over exposed joints between modules; partial repainting
	Wet areas - shower-toilet room wall and floor tiles	99	1	Replace damaged tiles (due to normal use)
	Module, corridor, stairs external and internal doors, door hardware and ironmongery	95	5	Minor adjustment to door hardware and locksets (due to normal use)
5. Built-in fixtures furniture & equipment	Kitchen bench, sink & cabinet	100	1	Minor repair (due to normal use)
	Toilet sanitary ware	95	5	Replacement damaged fittings due to normal use
	Washbasin & faucet	95	5	ditto
	Shower recess & faucet	95	5	ditto
	Ventilation fan	95	5	ditto
6. MEP services	Room type air-conditioning	98	2	Minor maintenance due to

inside modules, corridor & stairs	modules, aluminum support frame & condensate pipe			normal use
	Electrical switches, power outlets and exposed conduits/cables inside module modules	90	10	Minor maintenance due to normal use (assessed after connecting to main and testing/system commissioning)
	Kitchen plumbing, faucet & drain pipes; exhaust fan	90	10	ditto
	Toilet-shower plumbing, faucet & drain pipes	90	10	ditto
	Smoke detectors inside module modules	90	10	ditto
	Fire sprinkler heads & pipes inside module modules	90	10	ditto
	Exposed conduits/electric cables, lighting fixtures, fire sprinkler heads & pipes inside corridors	0	N/A	Replaced for practical purpose after module installation to form the complete length of the corridor
	Fire hydrants	0	N/A	Replaced as normal reinstallation practice
	Fire Services Installations – portable fire extinguishers	0	N/A	ditto
	TV-RF outlets	90	10	Minor maintenance due to normal use
Roof				
7. Roof structure	Single-pitch steel truss & SHS-bolted connections	100	10	New top coat painting to roof truss and connections
8. Roof covering	Aluminum profile roofing & flashing	0	N/A	Replace with new roofing for practical purpose to ensure weatherproofing performance.
9. Rainwater goods	Aluminum box gutter & PVC downpipes	90	10	Minor maintenance due to normal use
Firestop systems				
10. Fire-rated partition/wall	Fire rated board	80	20	
	Fixing Screws	80	20	
	Rock wool	90	10	
	Supporting brackets	90	10	
Main building services				

11. Mechanical ventilation	Stairs, corridor & plantrooms (inside MiC modules)	70	30	Minor maintenance due to normal use
12. Electrical/ power supply	Electrical rooms with main switches & distribution boards (inside MiC modules)	90	10	Minor maintenance due to normal use (Assessed after connecting to main and testing/system commissioning)
13. Fire detection	Smoke detectors/FS control panel (inside MiC module)	90	10	ditto
14. Plumbing	External potable water supply pipes, storage tanks, filters & pumps (outside building block)	0	N/A	Replaced and connect to new main as normal reinstallation practice
15. Waste water drainage	External drain pipes & stacks for kitchen sink, hand basin, shower drains.	0	N/A	ditto
16. Sewage disposal	Toilet sewer drain pipes & stacks	0	N/A	ditto
17. Fire protection	Fire services tanks and pumps (outside building block)	0	N/A	ditto
18. Lightning protection	Conductor bands & earthing devices	0	N/A	Replaced as normal reinstallation practice
19. Master Antenna & TV	Antenna & cabling	20	N/A	ditto

Appendix B. Machine/equipment/worker involved

Note: The specific amount and working days of machines and workers were provided by the main contractor of NC220 relocation project.

Location (Stage)	Machine/ equipment/ workers	Type	Quantity	Working hours per day per equipment or per worker	Working days (mean)
NC220 project site (Disassembly)	Truck (from site to storage yard)	12m-length truck	4	8 hr	16 days
		Truck crew	2		
	Equipment & tools for joint disconnection	Flame cut machine	2	8 hr	16 days
		Work crew	4		
	Crane	300 ton mobile crane	1	8 hr	16 days
		Crane crew	8		
	Trade workers	P&D workers	4	8 hr	20 days
		EL workers	4	8 hr	20 days
		F.S. workers	3	8 hr	20 days
		Scaffolder	8	8 hr	14 days
		Labourer	8	8 hr	30 days
Storage yard (Touch-up)	Crane	130 ton mobile crane	1	8 hr	16 days
		Crane crew	4		
	Trade workers	Painter	8	8 hr	30 days
		Plasterer	8	8 hr	30 days
		Labourer	4	8 hr	30 days
		P&D workers	4	8 hr	10 days
		EL workers	4	8 hr	10 days
		FS workers	4	8 hr	10 days
Wong Yue Tan (Reinstallation)	Truck (From storage yard to Wong Yue Tan)	12m-length truck	4	8 hr	14 days
		Truck crew	2		
	Crane	300 ton mobile crane	1	8 hr	14 days
		Crane crew	8		
	Trade workers	P&D worker	8	8 hr	45 days
		EL worker	8	8 hr	45 days
		F.S worker	4	8 hr	45 days
		Painter	8	8 hr	30 days

		Plasterer	8	8 hr	30 days
		Labourer	4	8 hr	45 days
		Scaffolder	8	8 hr	14 days

Appendix C. Logistics schedule for module delivery.

Stage	Module No.	Date		Time	拖架車牌	approval	site	Tons
Stage 1	3-1-1	2/18/2023	Sat			1	1	
	3-1-2	2/18/2023	Sat			2	2	
	3-1-3	2/18/2023	Sat			3	3	
	3-1-4	2/18/2023	Sat			4	4	
	3-1-5	2/20/2023	Mon	9:26	JL849	5	5	15.5
	2-1-1	2/20/2023	Mon	11:15	SX8884	6	6	15.5
	2-1-2	2/20/2023	Mon	11:40	JL849	7	7	15.5
	2-1-3	2/20/2023	Mon	13:35	SR446	8	8	15.5
	2-1-4	2/20/2023	Mon	14:33	SX8884	9	9	15.5
	1-1-1	2/20/2023	Mon	15:15	JL849	10	10	15.5
	1-1-2	2/22/2023	Wed	9:10		11	11	15.5
	1-1-3	2/22/2023	Wed	10:00		12	12	15.5
	G-1-1	2/22/2023	Wed	15:30	PZ156	13	15	16.5
	G-1-2	2/22/2023	Wed	17:00	SR446	14	16	15.5
Stage 2	3-2-1	2/25/2023	Sat	11:35	:SX8884	15	21	15.5
	3-2-2	2/27/2023	Mon	9:00	JL849	16	25	16
	3-2-3	2/25/2023	Sat	14:50	SX8884	17	23	15.5
	3-2-4	2/25/2023	Sat	15:50	PZ156	18	24	15.5
	3-2-5	2/27/2023	Mon	10:15	KU6818	19	28	16
	3-2-6	1/3/2023	Tue	9:25	:KU6818	20	36	16
	2-2-1	2/22/2023	Wed	10:35	SR446	21	13	15.5
	2-2-2	2/25/2023	Sat	14:20	PZ156	22	22	15.5
	2-2-3	2/27/2023	Mon	9:20	SX8884	23	26	16
	2-2-4	2/27/2023	Mon	11:10	JL849	24	29	16
	2-2-5	2/27/2023	Mon	11:50		25	30	15.5
	2-2-6	1/3/2023	Tue	9:45	SR446	26	37	15.5
	1-2-1	2/22/2023	Wed	11:30	JL849	27	14	15.5
	1-2-2	2/24/2023	Fri	14:05	SR446	28	19	15.5
	1-2-3	2/27/2023	Mon	9:40	PZ156	29	27	16
	1-2-4	2/27/2023	Mon	13:25	PZ156	30	31	15.5
	1-2-5	2/27/2023	Mon	13:45	KU6818	31	32	15.5
	1-2-6	1/3/2023	Tue	10:10	JL849	32	38	15.5
	G-2-1	2/24/2023	Fri	11:05		33	17	15.5
	G-2-2	2/24/2023	Fri	11:25	PZ156	34	18	15.5
	G-2-3	2/24/2023	Fri	14:45		35	20	15.5
	G-2-4	2/27/2023	Mon	14:05	JL849	36	33	16
	G-2-5	2/27/2023	Mon	15:05	PZ156	37	34	16
	G-2-6	2/27/2023	Mon	15:30	KU6818	38	35	16
Stage 3	3-3-1	1/3/2023	Tue	15:30	JL849	39	40	15.5
	3-3-2	1/3/2023	Tue	17:25	JL849	40	43	15.5
	3-3-3	2/3/2023	Fri	11:37	KU6818	41	47	15.5
	3-3-4	2/3/2023	Fri	13:20	JL849	42	48	15.5
	3-3-5	3/3/2023	Fri	9:50	PZ156	43	55	15.5
	3-3-6	3/3/2023	Fri	14:45	RX9897	44	60	16.5
	2-3-1	1/3/2023	Tue	15:55	KU6818	45	41	15.5
	2-3-2	2/3/2023	Fri	9:00	SU1121	46	44	15.5
	2-3-3	2/3/2023	Fri	13:47	SX8884	47	49	15.5
	2-3-4	2/3/2023	Fri	14:00	SU1121	48	50	15.5
	2-3-5	3/3/2023	Fri	11:45	RX9897	49	56	15.5
	2-3-6	3/3/2023	Fri	15:20	SX8884	50	61	15.5
	1-3-1	1/3/2023	Tue	15:55	SR446	51	42	15.5
	1-3-2	2/3/2023	Fri	9:20	KU6818	52	45	15.5
	1-3-3	2/3/2023	Fri	14:31	KU6818	53	51	15.5
	1-3-4	3/3/2023	Fri	9:10	JL849	54	54	15.5
	1-3-5	3/3/2023	Fri	13:40	SX8884	55	57	15.5
	1-3-6	3/3/2023	Fri	15:46	JL849	56	62	15.5
	G-3-1	1/3/2023	Tue	11:00	KU6818	57	39	15.5
	G-3-2	2/3/2023	Fri	9:40	JL849	58	46	16
	G-3-3	2/3/2023	Fri	14:55	JL849	59	52	15.5
	G-3-4	2/3/2023	Fri	15:40	SU1121	60	53	15.5
	G-3-5	3/3/2023	Fri	14:00	JL849	61	58	16
	G-3-6	3/3/2023	Fri	14:20	PZ2156	62	59	16
Stage 4	2-4-1	4/3/2023	Mon	9:45	JL849	63	64	16
	1-4-1	4/3/2023	Mon	10:45	PZ156	64	65	15.5
	1-4-2	4/3/2023	Mon	13:15	PZ156	65	67	15.5
	G-4-1	4/3/2023	Mon	9:05	PZ156	66	63	16
	G-4-2	4/3/2023	Mon	11:20	JL849	67	66	16
	G-4-3	4/3/2023	Mon	14:30	SX8884	68	68	17

(Source: Wilson & Associates)

Appendix D. Measured results of steel members.

Module ID	Module Type	Location	Member Mark	By Digital Vernier Measured Member Size			Approved Member Size (including FM900, Primer)				By Coating Thickness Guage	Approved Thickness		
				a	b	t	a	b	t		FM900 +Primer	FM900	Primer	FM900 +Primer
2-2-1	VI	L	C1	152.24	152.62	13.75	152.064	152.064	13.532	ok	1.05	0.832	0.2	1.032
		R	C1	152.65	152.84	14.1	152.064	152.064	13.532	ok	1.15	0.832	0.2	1.032
		D	B1	152.9	/	/	152.064	152.064	17.032	ok	1.3	0.832	0.2	1.032
		L	B1	155	/	/	152.064	152.064	17.032	ok	1.35	0.832	0.2	1.032
		D	C4	57.79	/	/	57.512	107.512	10.056	ok	3.81	3.556	0.2	3.756
		E	C4	57.76	/	/	57.512	107.512	10.056	ok	3.79	3.556	0.2	3.756
		D	-	120.84	121.28	13.16	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
		B	-	121.55	121.64	12.97	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
G-1-2	V	L	C1	152.39	152.68	13.77	152.064	152.064	13.532	ok	1.05	0.832	0.2	1.032
		R	C1	152.22	152.28	13.57	152.064	152.064	13.532	ok	1.35	0.832	0.2	1.032
		D	B1	154.97	/	/	152.064	152.064	17.032	ok	1.5	0.832	0.2	1.032
		L	B1	153.94	/	/	152.064	152.064	17.032	ok	1.1	0.832	0.2	1.032
		A	-	121.95	121.44	12.96	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
		C	-	120.74	120.71	12.79	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
1-2-2	II	L	C1	152.68	152.7	13.76	152.064	152.064	13.532	ok	1.2	0.832	0.2	1.032
		R	C1	152.47	152.55	13.77	152.064	152.064	13.532	ok	1.3	0.832	0.2	1.032
		D	B1	154.95	/	/	152.064	152.064	17.032	ok	1.05	0.832	0.2	1.032
		R	B1	152.32	/	/	152.064	152.064	17.032	ok	1.4	0.832	0.2	1.032
		D	C4	57.6	/	/	57.512	107.512	10.056	ok	3.91	3.556	0.2	3.756
		E	C4	57.98	/	/	57.512	107.512	10.056	ok	3.86	3.556	0.2	3.756
		D	-	121.07	120.74	12.88	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
		B	-	121.54	120.47	12.8	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
2-2-5	II	L	C1	152.48	152.57	14.53	152.064	152.064	13.532	ok	1.45	0.832	0.2	1.032
		R	C1	152.35	152.36	14.09	152.064	152.064	13.532	ok	1.1	0.832	0.2	1.032
		D	B1	154.42	/	/	152.064	152.064	17.032	ok	1.35	0.832	0.2	1.032
		L	B1	154.47	/	/	152.064	152.064	17.032	ok	1.25	0.832	0.2	1.032
		A	-	121.12	121.18	13.2	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
		C	-	121.93	121.9	13.02	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
3-3-2	I	L	C1	152.94	153.21	14.09	152.064	152.064	13.532	ok	1.1	0.832	0.2	1.032
		R	C1	152.79	152.81	13.83	152.064	152.064	13.532	ok	1.05	0.832	0.2	1.032
		D	B1	155	/	/	152.064	152.064	17.032	ok	1.1	0.832	0.2	1.032
		R	B1	154.91	/	/	152.064	152.064	17.032	ok	1.2	0.832	0.2	1.032
		D	C4	57.99	/	/	57.512	107.512	10.056	ok	4.18	3.556	0.2	3.756
		E	C4	57.93	/	/	57.512	107.512	10.056	ok	3.87	3.556	0.2	3.756
		D	-	122.7	120.82	13.14	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
		B	-	121.2	120.94	13.34	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
G-3-4	I	L	C1	152.34	152.84	13.86	152.064	152.064	13.532	ok	1.25	0.832	0.2	1.032
		R	C1	152.54	152.81	13.83	152.064	152.064	13.532	ok	1.1	0.832	0.2	1.032
		D	B1	154.47	/	/	152.064	152.064	17.032	ok	1.2	0.832	0.2	1.032
		L	B1	154.42	/	/	152.064	152.064	17.032	ok	1.9	0.832	0.2	1.032
		A	-	120.68	121.3	12.8	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
		C	-	121.13	121.18	13.27	120.4	120.4	12.7	ok	0.2	0	0.2	0.2
G-4-3	IIIa	L	C1	152.17	152.45	14.41	152.064	152.064	13.532	ok	1.05	0.832	0.2	1.032
		R	C1	152.73	152.74	13.83	152.064	152.064	13.532	ok	1.1	0.832	0.2	1.032
		D	B1	155.02	/	/	152.064	152.064	17.032	ok	1.15	0.832	0.2	1.032
		R	B1	155.01	/	/	152.064	152.064	17.032	ok	1.1	0.832	0.2	1.032
		D	-	122.4	122.01	12.93	120.4	120.4	12.7	ok	0.3	0	0.2	0.2
		B	-	121.38	121.27	12.88	120.4	120.4	12.7	ok	0.2	0	0.2	0.2

(Source: Wilson & Associates)