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Modular Integrated Construction for High-rise Buildings: Measured Benefits

PLUS

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Ir HON Chi-keung
Chief Executive and Secretary

Highlights of 2020

All hands on deck towards a better society

Looking back at what we achieved in 2020, and the ebb and flow of the COVID-19 pandemic, we rose to the challenge by working incessantly in fighting the coronavirus while sustaining our belief in the theme for this Session, that is, "Believing is seeing - Innovation for transformation", as underpinned by the President.

As a unique engineering institution in Hong Kong, we stand with the community in this unprecedentedly difficult time. We have spared no efforts in deploying our engineering expertise; worked in many ways by offering our professional views and sharing innovative suggestions to facilitate public understanding of topical issues via media enquiries and interviews. Throughout the year, we used our best endeavours to help cheering people up and support industry practitioners. We distributed masks to members, raised funds for the Construction Industry Council (CIC)'s campaign to help those local industry practitioners in need, and stood together with the people of Hong Kong through thick and thin.

In accomplishing our mission of advancing the engineering profession at all levels with particular emphasis on innovation and transformation, we held our first tailor-made talk for primary students under the School Ambassadors Programme in January; co-organised with the Institution of Civil Engineers Hong Kong Association to carry out the "Proud to be Women in Engineering Photo Challenge"; concluded the HKIE Colouring and Photo Competitions in June; and most importantly kicked off our innovative programmes for Session 2020/2021 in September.

These were just some highlights of 2020. Now, if we look ahead to the brighter tomorrow, we will be embarking on a number of actions to invigorate the Institution including pursuing digitalisation, enhancing service to members, boosting professionalism, facilitating innovation and undertaking governance review. So please stay tuned with the upcoming developments and make your contributions to what will affect the Institution in the years to come.

Together, let's bring all hands on deck and set sail to a brighter future for our Institution, the engineering profession and our beloved community.

January

- The Institution of Civil Engineers (ICE) paid a courtesy visit to the Institution on 7 January 2020.

- The HKIE New Members' Reception cum Prize Presentation Ceremony of Session 2019/2020 was successfully held on 10 January 2020 at the Hong Kong Club. Various awards were presented.

- The Institution extended the HKIE School Ambassadors Programme to primary schools and the first tailor-made talk was organised for St Stephen's College Preparatory School on the topic of "What is an Engineer?" on 17 January 2020.

- After a series of revamp to enhance the reading experience, the new face of *Hong Kong Engineer* and its digital version of the Hong Kong Engineer Online were rolled out with the January 2020 issue. Many members have switched to the digital version since then, helping the Institution reduce paper consumption and its carbon footprint to protect the environment.

March

- As a supporting member of the proposal of the World Engineering Day for Sustainable Development and a member of the World Federation of Engineering Organisations, the Institution promoted via the media the establishment of the World Engineering Day which is on 4 March of every year.
- In early March, the Institution participated in the production of a song named "疫境同行" with the hope of filling everyone with positive energy to fight against COVID-19.

- The Institution distributed the masks passed on by Ir Dr The Hon W K Lo from donors to HKIE members.
- To support workers of the construction industry through the difficult times, HKIE members were encouraged to support the CIC's fundraising campaign, and Ir Ringo Yu, President for Session 2019/2020, offered to match the donation made by HKIE members on a dollar-for-dollar basis up to a maximum of HK$300,000.
- The Institution was awarded the Caring Organisation Logo for the 16th consecutive year from the Hong Kong Council of Social Service, in recognition of the Institution's commitment to caring for the community, the employees and the environment over the past years.
- The Institution was awarded the "Construction Caring Organisations" logo launched by the Construction Industry Sports & Volunteering Programme of the CIC, in recognition of the Institution's commitment to serving the industry and community, and devotion to promoting corporate social responsibility.
- The renewal of Reciprocal Recognition Agreements (RRAs) with the Society of Operations Engineers (SOE) was completed and took effect from 1 March 2020. The Environmental Discipline was newly included in the RRA at Associate Member level, which also covered the Building Services, Control, Automation & Instrumentation, Electrical, Manufacturing & Industrial (now Manufacturing, Industrial & Systems) and Mechanical Disciplines.

April

- Ir Ringo Yu, President for Session 2019/2020, joined hands with government departments and the construction sector once again to record another song named "抗疫同舟" to support industry practitioners to overcome the difficult times.
- A new e-service was launched for Graduate Members undergoing Scheme "A" Training, enabling current Graduate Members who commenced their Scheme "A" Training on or after 1 April 2010 to retrieve a computer-generated copy of their Scheme "A" record from the Member Login Area of the HKIE website.
- A survey report studying the training and development needs of engineers was prepared and published online.

June

- The 45th Annual General Meeting was held on 23 June 2020. President Ir Prof P L Yuen highlighted some of his work plan for the new Session with members.

- The Manufacturing & Industrial Division/Discipline were renamed as "Manufacturing, Industrial & Systems Division (MI Division)/Discipline (MIS Discipline)" respectively effective from the commencement of Session 2020/2021.
- A new Student Chapter in the Technological and Higher Education Institute of Hong Kong was set up as the 11th Student Chapter of the HKIE.
- The International Women in Engineering Day (INWED) takes place annually on 23 June. Under the theme of "Shape the World", the HKIE Task Force on Women in Engineering co-organised the "Proud to be Women in Engineering Photo Challenge" (#ProudToBeWIE) along with the Institution of Civil Engineers Hong Kong Association.
- The International Engineering Alliance Meetings 2020 and Seoul Accord Mid-term Meeting 2020 were organised virtually on 22 - 26 June 2020 and 25 - 26 June 2020 respectively.
- The HKIE "Engineering Our Future" Colouring Competition for primary school students and "The Engineer's Vision" Photo Competition for the public and HKIE members were joyfully concluded at a Prize Presentation Ceremony held on 27 June 2020.

Prizes were presented to the winners at the Ceremony. The award-winning entries were exhibited on the same day.

A roving exhibition of the winning entries of the Competitions was organised from July to October 2020 at the Main Lobby of the Hong Kong Science Museum, the MTR Community Art Gallery at Wan Chai Station, Foyer Exhibition Area at the Hong Kong Cultural Centre and the Covered Piazza at Times Square Hong Kong.

- Experts from relevant Disciplines contributed to the updating of the booklet "公眾安全系列指南：樓宇保養維修" to assist the public in dealing more effectively with common problems of drainage pipes, sewage pipes and other building services.

July

- 12 young members were selected as President's Protégés to shadow and work with the President and were given the opportunity to interact with other leading engineering professionals.

- On 15 July 2020, President Ir Prof P L Yuen together with other Hong Kong's construction and engineering counterparts and architectural sector attended a briefing session organised by the Development Bureau, the HKSAR Government about the range of new measures brought about under the "Interim Guidelines for the Management of Hong Kong Engineering Construction Consultant Enterprises and Professionals Starting Business and Practising in the Guangdong-Hong Kong-Macao Greater Bay Area Cities".

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September

- To mark the launch of the meaningful programmes for Session 2020/2021, the "Championing Innovation" Kick-off Ceremony was held on 28 September 2020 at the Eaton Club in Central. The "Innovation Roadmap for Engineers" prepared by the President and a number of engineers with extensive experience in their innovation journeys were introduced at the Ceremony, and can be viewed via the QR code below.

October

- President Ir Prof P L Yuen delivered his Presidential Address online, and the video is available via the QR code below.

- Mrs Monica Yuen, the then Chief Executive and Secretary retired after serving the Institution for 23 years. The Institution welcomed Ir Hon Chi-keung, the current Chief Executive and Secretary and Ir Eva Kong, the newly appointed Director on board.

- A hybrid briefing session for the School Ambassadors of the HKIE School Ambassadors Programme was held on 27 October 2020.

December

- Awardees of The HKIE Outstanding Paper Award for Young Engineers/Researchers 2020 presented their awarded papers and accomplishments at a Public Lecture online on 11 December 2020.

During 2020, the Institution received 62 invitations from government departments and other organisations for nominations of HKIE representatives to serve on their boards/committees. A total of 129 members were nominated. The HKIE also responded to seven consultation documents issued by government departments, the Legislative Council and external organisations.

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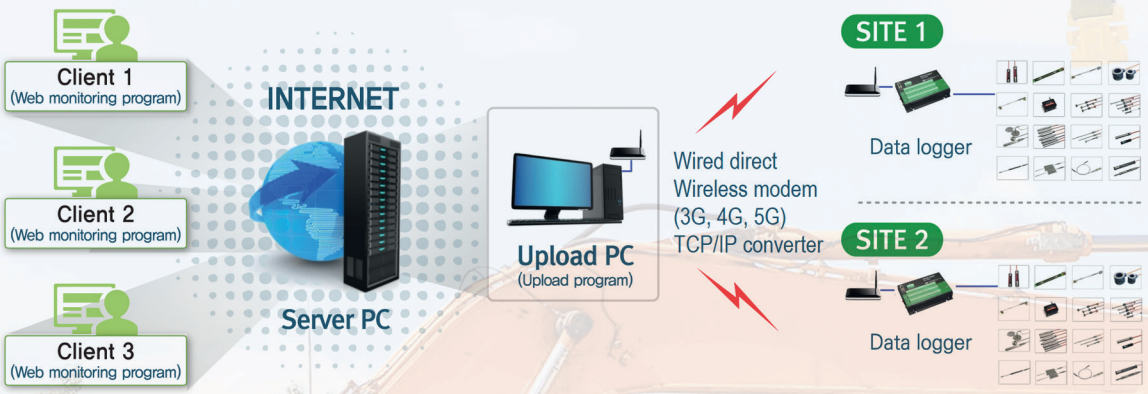


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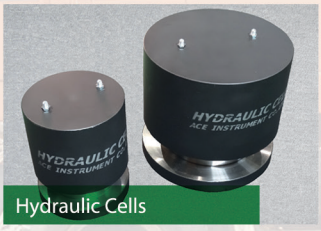
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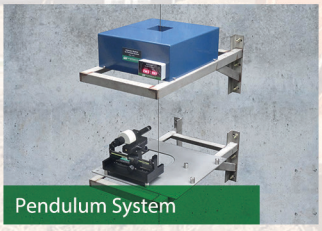
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Letter to the Editor

Dear Editor

The cover of Volume 48 (May 2020 issue) of your journal features a photo of an anchored man-made slope covered with an extensive system of grid beams and concrete surface, without any hint of slope greening. This photo is not representative of the conditions of upgraded man-made slopes in Hong Kong and may give a false impression that slope upgrading works turn man-made slopes into eyesores and cause adverse visual impact.

One of the HKSAR Government's priorities in upgrading man-made slopes, as mentioned in the Cover Story of that issue, is to make the upgraded slopes look as natural as possible by state-of-the-art landscape treatment. According to the Technical Guidelines promulgated by the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department, native flora should be planted on upgraded slopes to create a more visually pleasing and sustainable slope environment. Depending on the slope gradient, different types of native flora including trees, shrubs, grass and climbers should be planted as far as practicable to enhance the slope aesthetics, ecology and biodiversity. As highlighted in the Cover Story of that issue, government slopes upgraded under the GEO's Landslip Prevention and Mitigation Programme are in compliance with this guideline. There are plenty of successful cases of greening of upgraded slopes around Hong Kong. Notable examples include the greening and upgrading of an unsightly bare slope along Bowen Road overlooking urban Hong Kong, and the enhancement of a series of substandard slopes along South Lantau Road, both of which received positive media coverage.

Please refer to the links below showing the successful greening cases for the slopes in Hong Kong.

- https://www.cedd.gov.hk/eng/publications/geo/greener-slopes-better-cityscape/index.html
- https://www.cedd.gov.hk/eng/publications/geo/south-lantau/index.html

The cover photo of the concerned issue, which features an unsightly upgraded man-made slope covered with concrete without any greening, is not representative of the actual condition in Hong Kong. Where was this photo taken? We are interested to know. We suspect that the cover photo might have been selected from a professional creative perspective with a view to offering a better artistic expression and stimulating the interest of readers. However, this photo can also mislead readers to associate upgraded man-made slopes in Hong Kong with massive concrete structures without greening measures, which is far from the truth. While we would like to express our concern with respect to the above, as it is a Cover Story, we expect that the communication would be improved in the future.

Yours faithfully

Ir Maureen NG
Chairlady
The HKIE Geotechnical Division for Session 2020/2021

Response to Ir Maureen Ng

Thank you for sharing with us and readers the latest development on slope upgrading works in Hong Kong.

In response to your enquiry on the slope featured in the cover of the May 2020 issue, it is in fact a generic visual used to capture "landslip prevention" in a purely communication perspective as suggested by the cover design house, who also advised that no information regarding the location of where the stock photo was taken was available. The technical perspective will be taken into consideration in future designs to better deliver the essence of the Cover Story.

We value your feedback and look forward to the future article contribution from the GE Division to *Hong Kong Engineer*.

The Editorial Office

Modular integrated construction for high-rise buildings: Measured benefits

By the Development Bureau and the Architectural Services Department of the HKSAR Government, the Hong Kong Science and Technology Parks Corporation, and the Centre for Innovation in Construction and Infrastructure Development of The University of Hong Kong

This article provides an overview of the benefits of modular integrated construction (MiC) in comparison with the conventional construction method for projects. It also illustrates how MiC can contribute in tackling the challenges, such as ageing workforce, declining productivity, high construction costs, etc, being faced by the construction industry in Hong Kong.

From the analysis of the two high-rise pilot projects, it is demonstrated that the adoption of MiC in future building projects can achieve at least 10% cost saving, 30% to 50% shortening in on-site superstructure construction to occupation[1], on-site labour productivity improved by 100% to over 400%, higher construction quality, better site safety performance and enhanced environmental sustainability etc. As reiterated in the 2020 Policy Address, the HKSAR Government will continue to promote the use of MiC proactively for a wider adoption in order to uplift the performance of the construction industry.

Challenges faced by the construction industry

We have been facing severe challenges including ageing workforce, declining productivity, high construction costs, etc. These challenges are evidenced by the statistics, such as more than half of skilled construction workers are aged 50 or above, the declining construction output per worker, and building construction costs ranked among the top three worldwide (DEVB, 2018; Pan et al, 2019). To tackle these challenges and to uplift the performance of the construction industry, the Chief Executive announced in the 2017 Policy Address the adoption of MiC with a view to enhancing productivity and cost-effectiveness. Since then, the HKSAR Government promotes wider adoption of MiC through pilot projects. Commissioned by the Development Bureau (DEVB) of the HKSAR Government, the Centre for Innovation in Construction and Infrastructure Development (CICID) of The University of Hong Kong (HKU) conducted a study on the performances of two high-rise MiC pilot projects, to assess the benefits of this innovative construction method in Hong Kong.

MiC

Modular construction is the most advanced off-site construction technology with three-dimensional units that enclose usable space and are often prefinished. The modular construction approach has been widely adopted globally, albeit various terminologies have been used in different countries or regions as explained and illustrated in the Glossary published by the HKU (Pan et al, 2020a). Examples of that include "prefabricated prefinished volumetric construction (PPVC)" in Singapore (BCA, 2017), "modular building" in the UK (Gibb and Pendlebury, 2006), "permanent modular construction" in the US (MBI, 2013). The worldwide adoption of the modular approach has demonstrated its wide-ranging benefits such as accelerated project delivery, enhanced construction quality and productivity (for details please refer to the strategy paper published by the HKU - Pan et al, 2019).

In Hong Kong, the modular approach has been adopted under the term of MiC, which builds on the modular construction approach but emphasises the integration of advanced manufacturing technologies into the re-engineered building and construction processes. The concept of MiC was defined by Pan and Hon (2018) as:

"a game-changing disruptively-innovative approach to transforming fragmented site-based construction of buildings and facilities into integrated value-driven production and assembly of pre-finished modules with the opportunity to realise enhanced quality, productivity, safety and sustainability."

In addition, the DEVB Technical Circular (Works) No 2/2020 defines MiC as:

"a construction method whereby freestanding volumetric modules with finishes, fixtures, fittings, furniture and building services installation, etc manufactured off-site and then transported to site for assembly."

As MiC changes the project delivery process relative to conventional construction practices, it is important to systematically understand its performances.

High-rise MiC projects measured

The Disciplined Services Quarters for the Fire Services Department (FSD), the HKSAR Government at Pak Shing Kok project (PSKDQ) by the Architectural Services Department (ArchSD), the HKSAR Government (Figure 1 left) is a staff quarters development in Tseung Kwan O comprising four 16-storey blocks and one 17-storey block. The typical floor of each block was constructed using 46 concrete modules to form eight dwelling units, with size of about 50 sq m each. In total, the project provides 648 dwelling units, and comprising 3,726 modules that were prefabricated in Huizhou, Mainland China, and then transported by land to the construction site. The performance of this project was measured and benchmarked against a similar ArchSD's departmental quarters project in Kwun Tong that adopted cast-in-situ concrete method with typical precast building elements.

The InnoCell, a residential apartment developed by the Hong Kong Science and Technology Parks Corporation (HKSTP) (Figure 1 right) of the Hong Kong Science Park, provides co-living and co-working residence space within the park. This 17-storey building provides 393 ensuite units with 418 steel-framed modules that were prefabricated in Jiangmen, Mainland China and then transported by sea and land to the construction site. The performance of this project was measured and compared with a conventional scenario.

Systematic framework of KPIs

Key performance indicator (KPI) is a factor for measuring the success of a project and specifies whether or not the desired result was achieved. Following the MiC Performance Measurement Guidebook (Pan et al 2020b) published by the HKU, a systematic framework of KPIs was established and adopted for measuring the performance of the two selected projects.

The framework of KPIs is based on the triple-bottom-line concept of sustainable development integrating the economic, social, and environmental aspects of performance. This framework includes 32 KPIs as detailed in Figure 2:

- There are 15 economic-aspect KPIs, which reflect the direct and indirect costs of a project. The economic efficiency of a project is defined as issues dealing with the amount of money invested. For construction projects, the integration of various inputs such as materials and labour determines the economic value of completed buildings.
- There are ten social-aspect KPIs, which are concerned with the impact on the needs of people and communities.

Figure 1: The PSKDQ (left) and InnoCell (right) MiC projects

Social harmony in construction refers to the engagement of employees, local communities, and stakeholders along the supply chain to meet the needs of people and communities.

- There are seven environmental-aspect KPIs, which evaluate the environmental impact over the construction life cycle. Environmental sustainability is one of the most significant aspects of construction performance, which consists of not only direct impact of the construction and assembly process, but also the indirect impact from the manufacturing of building materials and components.

The systematic framework of KPIs should be adaptable for applications in other building sectors than staff quarters and apartment buildings such as hostels, hotels, and office buildings.

Measured benefits of MiC

The adoption of MiC in these two projects has demonstrated substantial improvements in the economic efficiency with ensured cost competitiveness, increased labour productivity, enhanced construction quality, and accelerated construction speed. It has also significantly fortified environmental sustainability with reduced construction waste, pollution, and energy consumption. Furthermore, impressive enhancements in social harmony were observed resulting from the shortened construction programme and enhanced safety performance. The major benefits of MiC compared with the conventional practices as demonstrated by the KPIs are summarised in Table 1 and elaborated in the sections thereafter.

Ensured cost competitiveness

From project client's point of view, the cost competitiveness of MiC has been established by estimating the construction cost savings as well as by establishing the overall economics of the pilot projects.

The assessment using the two pilot cases showed significant savings in construction costs. The estimated unit cost of building works adopting MiC indicates a possible cost reduction of around 6%[2] for high-rise staff quarters development constructed with concrete modules; and around 7%[2] for high-rise apartment development constructed with steel modules, both compared with similar projects using conventional practices.

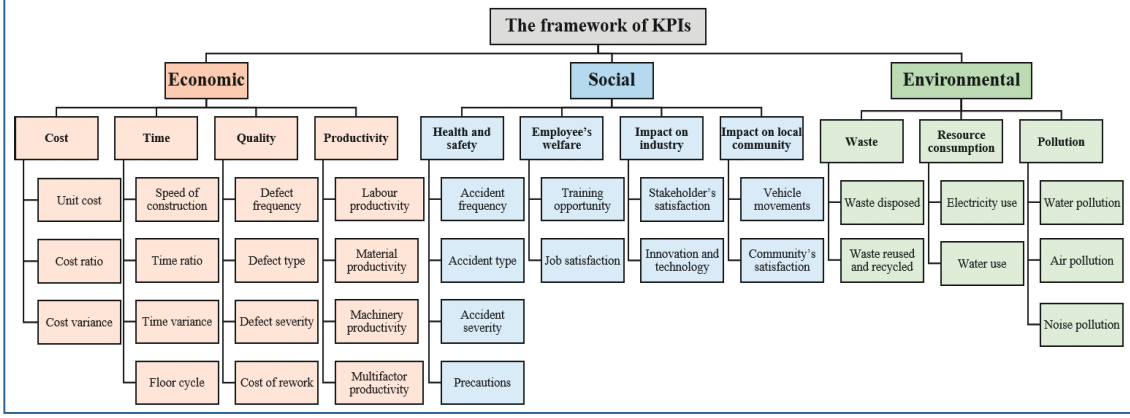

Figure 2: A systematic framework of KPIs for MiC performance measurement

Measured performance of MiC pilot projects		Concrete MiC	Steel MiC
Economic performance	Superstructure construction to occupation	shortened by ~30%	shortened by ~50%
	Unit cost of building	~6% lower	~7% lower
	Overall labour costs	~45% lower	~70% lower
	Defect frequency	largely reduced	largely reduced
	On-site labour productivity	~100% improved	over 400% improved
	Overall labour productivity	~35% improved	~45% improved
Environmental performance	On-site waste disposal	~45% reduced	~80% reduced
	Air pollution	~25% reduced	~50% reduced
	Noise pollution	~7% reduced	~10% reduced
	Water for treatment	~75% reduced	~70% reduced
	On-site electricity consumption	~70% reduced	~60% reduced
	On-site water consumption	~70% reduced	~70% reduced
Social performance	Labourers working at height	~50% reduced	~80% reduced
	Training opportunities	largely increased	largely increased
	Stakeholder's satisfaction	largely increased	largely increased
	Innovation and technology	BIM, IoT, Blockchain	BIM, VR
	Young professions involvement	largely increased	largely increased
	Vehicle trips to site	~25% reduced	~60% reduced
	Community's satisfaction	largely increased	largely increased

Table 1: Benefits of MiC compared with conventional practices

The possible cost savings are mainly attributed to the following areas:

- Reduction in number of on-site labour;
- Reduction in preliminaries resulting from the shortened programme;
- Reduction in temporary works required such as formwork;
- Reduction in the number of material delivery trips;
- Reduction in on-site electricity and water consumption; and
- Enhanced construction quality with no rework or fewer defects.

Projects adopting both concrete and steel MiC have indicated advantages in cost competitiveness over their conventional counterparts. First, this cost competitiveness is evidenced in the cost neutrality that both projects have been delivered without the need for the client to get any extra budget approved originally for a conventional construction. This achievement is remarkable as overseas experiences showed a premium cost of adopting modular approaches in the initial stage of implementation.

It is estimated that cost saving of at least 10% can be achieved in future MiC projects, with the following considerations:

- There should be about additional two-month time and cost savings without the interruption of the COVID-19 pandemic.
- The two pilot MiC projects that changed from conventional to modular design incurred additional costs, which can be avoided in future MiC projects.
- The project teams have also gone through a learning curve and engaged considerable research and development investment.
- The design and construction costs will be further reduced as professionals are increasingly skillful in MiC design and the supply chain becomes better established.

In addition to the construction cost, a project client is also very much concerned about the overall financial benefit that MiC can provide. One of the major benefits to the overall project economics can be established by how much earlier the projects have been ready for occupation in comparison with conventional methods. For the PSKDQ project, with nine months advance in anticipated occupation[3], it is equivalent to a financial benefit to FSD's staff of more than HK$58 million (being estimated saving in rental cost of at least HK$10,000 per month for each of these 648 households). For the InnoCell project, with 14 months advance in occupation[4], it is estimated that the rental income generated for HKSTP will be more than HK$44 million (being estimated rental cost of at least HK$8,000 per month for each of these 393 units).

Increased labour productivity

It was observed that only a few on-site workers were needed for constructing a typical floor with the installation of modules (Figure 3) leading to a significant increase in labour productivity with the adoption of MiC.

- In PSKDQ, the on-site labour productivity for constructing a typical floor improved by 100% as compared with the cast-in-situ baseline.
- In InnoCell, on-site labour productivity was observed to be over 400% as compared with the conventional scenario.

Figure 3: Fast installation of modules

The significant increase in labour productivity in adopting MiC shed light on addressing the challenge of ageing workforce which has been facing by the Hong Kong construction industry.

Accelerated construction speed

The adoption of MiC could accelerate the project delivery process, largely as a result of the concurrent module production in the factory (Figure 4) and foundation works on site. In conventional construction, the floor cycle refers to structural works only; while for MiC projects, the floor cycle includes both structural and architectural works.

- In PSKDQ, a five-day cycle was achieved for constructing a typical floor which included over 90% structural and architectural works. As shown in the construction programme, around nine months were saved for the overall project development.
- In InnoCell, a two- to three-day cycle was achieved for constructing a typical floor which included over 95% structural works and architectural works. This is much faster than the six-day floor cycle in conventional construction which only covers structural works. As shown in the construction programme, around 14 months were saved by using MiC compared with the conventional scenario.

In addition to the significantly faster construction speed, the adoption of MiC substantially reduces project delivery risks like time variance caused by uncertainties such as inclement weather. In the future, the time performance using MiC should be further improved, as more time savings are expected without the impact of COVID-19 and with the valuable experience gained from the pilot projects.

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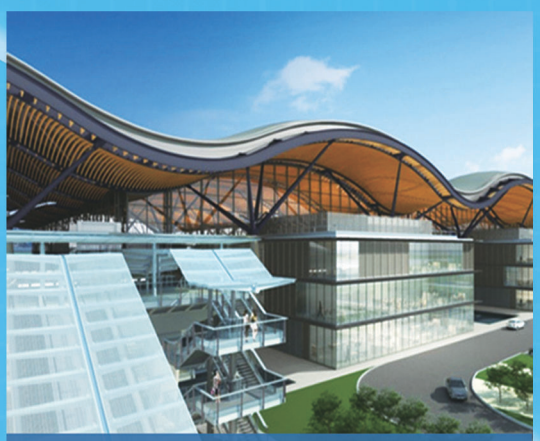

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Enhanced construction quality

The adoption of MiC contributed to the achievement of higher construction quality with fewer defects, less rectification, and minimised rework. The obtained results include:

- No rework was reported both in the factory and on site for both MiC projects.
- In PSKDQ, the defects in both architectural and structural works were greatly reduced due to the well-controlled finishing works, concrete casting and curing in the factory.
- In InnoCell, the defects were greatly reduced due to the adoption of steel-framed modules that were precisely manufactured and assembled.

Reduced construction waste

With well-controlled factory production (Figure 4) and the reduction of fragmented site-based works, the use of MiC led to a significant reduction in construction waste in both concrete and steel MiC projects:

- In PSKDQ, concrete and rebar wastage was measured and turned out to be much lower than that of the conventional practice, and the amount of construction debris was reduced by over 40%.
- In InnoCell, over 80% of on-site construction debris was reduced, and over 50% of the on-site material wastage was recycled and reused.

Figure 4: Module production in the factory

Reduced construction pollution

Due to the greatly reduced wet concrete works on site, the use of MiC helped achieving a more tidy and cleaner site environment as well as the production line in the factory (Figure 4). The levels of construction pollution in terms of water, air, and noise were also therefore much reduced as evidenced below:

- In PSKDQ, wet concrete works were reduced by 75% on site, leading to reduced water pollution generated from washing concrete trucks and curing concrete structures. On-site noise was measured to be around 7% lower than that in a conventional project.
- In InnoCell, the air quality level was much improved due to the 50% reduction in the levels of particulate matter (PM). The noise performance was approximately 10% lower than that monitored for a typical conventional high-rise project.

Reduced water and electricity consumption

With the adoption of MiC, most of the fragmented construction works were transferred from the sites to the factories for module production. As a result, on-site water and electricity consumption in the MiC projects was much lower than that in conventional construction practices. The measured evidence is shown below:

- In PSKDQ, on-site water and electricity consumption was around 70% lower than that in conventional construction practices.
- In InnoCell, on-site water and electricity consumption was estimated to be over 60% lower than that in conventional construction practices. This was due to the reduced cast-in-situ and on-site finishing works and the shortened construction programme; and 418,000 L of water was saved as most of the water tightness tests were conducted in the factory.

By ensuring well-controlled production in the factory and reduced fragmentation in the site-based works, the use of MiC can substantially reduce construction debris and material wastage, resources such as water and electricity, and pollution in both concrete and steel MiC projects. Thus, MiC is creating a new image of modern construction as being resource-saving and environmental-sustainable.

Enhanced health and safety

The adoption of MiC also effectively reduced health risks and improved work safety. It can minimise or even eliminate the possibility of accidents on site, by minimising workers working at height (Figure 5). Besides, well-organised factory and tidier site environment can allow a quick response to site incidents and provide a much better, safer and healthier working environment for the workers. In the InnoCell and PSKDQ projects, the number of labours working at height was reduced by over 50%, and no accident at all was reported for MiC-related works during the overall construction.

Enhanced employees' welfare

The adoption of MiC was found to have reduced health and safety risks with a much cleaner and safer working environment, thereby enhanced project employees' job satisfaction. Besides, the projects with MiC helped to

Figure 5: Minimised working at height

increase training and education opportunities. The "training opportunity" is evidenced in the projects:

- In PSKDQ, weekly safety training was conducted for the workers to properly use the working platform for module installation.
- In InnoCell, each worker received four times training opportunities per month.

Reduced disturbance to the community

A reduced number of material delivery trips to the construction site minimised the impact on the local transportation systems and thus caused much less disturbance to the nearby community. With the adoption of MiC, a significant reduction in vehicular trips to site was achieved in both pilot projects, mainly due to the fact that most of the MiC materials were already integrated into the prefinished and pre-furnished modules in the factory (Figure 6). The "vehicle movements" are evidenced in the projects:

- In PSKDQ, less than 40 deliveries of module transportation were required for all living areas of a typical floor, which covered around 90% of structural and architectural works, and 90% installation of concealed conduits and domestic electrical services.
- In InnoCell, only 30 deliveries of module transportation were required for constructing all living areas of a typical floor, which covered over 95% of structural, architectural and building services works in the domestic areas.

Increased community's satisfaction by addressing the urgent social needs

The use of MiC accelerated project delivery and thus should benefit the early delivery of projects to address social needs. The "community's satisfaction" of addressing urgent social needs is evidenced in the projects:

- The PSKDQ was completed within just 30 months, while it might take 39 months for the development of a similar project if conventional methods were used.
- The InnoCell was completed with the time saving of over 14 months for the overall development.

Improved industry image

The MiC adoption provided evidence that the traditional 4D (ie dirty, dangerous, demanding, and disorganised) perception of the industry could be transformed to 5S (ie shine, safe, speed, sustainable and smart). As a result, the industry should be able to attract more youth and professionals to join. Wider adoption of MiC could trigger more innovation as well as provide more opportunity for application of new technologies in construction industry such as building information modelling (BIM), virtual reality (VR), internet of things (IoT), Blockchain, which could greatly facilitate the design, production, transportation and installation processes. The "innovation and technology" is evidenced in the projects:

- In PSKDQ, module production and installation were integrated with BIM, IoT, and Blockchain technologies for quality and efficient project delivery.

Figure 6: Prefinished and pre-furnished modules from the factory

- In InnoCell, a digital QA/QC platform and VR technologies were implemented for module production inspection and module installation training, respectively.

Socially, MiC enables safe project delivery and thus benefits the employees, and the enhanced collaboration and innovation training ensure that the workers gain a sense of achievement from their jobs. In addition, MiC contributes an improved and modernised image of the construction industry as being cleaner, safer and smarter, which will attract more young talents and thus trigger more construction innovation.

In addition, the adoption of MiC can dramatically reduce the disturbance to the local community caused by multiple material delivery trips. More importantly, MiC provides a more effective and efficient approach to shortening the project realisation time.

Uplifting MiC to new heights

It was found that MiC outperforms the conventional construction in both concrete and steel cases. First, economic efficiency was substantially improved with ensured cost competitiveness, increased labour productivity, accelerated construction speed and better quality. Cost neutrality was guaranteed, and cost savings were estimated around 7% for steel MiC and around 6% for concrete MiC. With more projects embracing MiC after the learnings from these two pilot projects, the cost saving can be further enhanced to more than 10%. Second, environmental sustainability was significantly fortified with reduced construction waste and energy consumption. More tidy and cleaner construction sites were observed for both concrete and steel MiC. Third, social harmony was greatly enhanced with reduced disturbance to community, enhanced safety performance and ensured employees' welfare.

It is worth noting that the two high-rise MiC projects cover both concrete and steel MiC building methods and both residential and apartment building types. Albeit the evidence is being based on only two cases, the findings are powerful in revealing that MiC outperforms conventional construction in all economic, social and environmental aspects. The proven performance of MiC for high-rise building projects in particular has made a significant contribution to the industry in addressing multi-faceted challenges such as the ensured cost competitiveness to reduce high construction costs, increased labour productivity by addressing the ageing workforce, and the accelerated project delivery by shortening the overall project realisation time.

To enable the long-term development of Hong Kong and ensure the sustainability of the construction industry, the HKSAR Government has developed Construction 2.0 to reform and upgrade the industry through the three pillars: innovation, professionalisation and revitalisation. Adoption of MiC in building projects is one of the key measures in addressing the multi-faceted challenges. In early 2020, the HKSAR Government has taken the lead in promoting the wider use of MiC in certain types of new government building works as well as building projects funded by the HKSAR Government, and it is envisaged more private MiC building projects will follow.

The wide adoption of MiC is beneficial for the development of not only Hong Kong but also other economies in the Greater Bay Area and overseas. On the one hand, the increased demand will stimulate investment in establishing MiC factories in the Greater Bay Area or in Hong Kong. On the other hand, as Hong Kong is a well-developed economy with international building standards for high-rise buildings and world-leading expertise in design and construction, the knowledge and experiences developed in adopting MiC for high-rise buildings will provide invaluable learning or even set international standards for adopting MiC in other cities.

With the whole construction industry including clients, consultants, contractors and supply chains in public and private sectors joining hands marching for a wider adoption of MiC in Hong Kong, we can bring MiC to a new height, contributing an international brand and reinforcing the global status of Hong Kong.

Notes

1. Counting from on-site superstructure commencement to anticipated occupation.
2. The estimated cost only involved construction cost for building works (ie structural, architectural and building services works and foundation works). The estimation was based on the combination of relevant figures in the public domain, academic publications and interviews with MiC professionals. Due to commercial reasons and other constraints, no actual construction cost data of the project is disclosed.
3. Compare with the construction programme in the submission to the Finance Committee FCR(2018-19)27, which construction was planned to commence in Q1 2018 for completion by Q2 2021.
4. Compare with the three-year construction period as stated in the submission to the Finance Committee FCR(2017-18)54.

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