Prefabricated Building Construction Systems Adopted in Hong Kong

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Abstract:

Prefabricated building construction systems have been widely adopted not only in public houses but also in private building projects. Prefabrication together with the increasing use of standardisation and mechanisation has brought a substantial change in the development of the construction industry worldwide over last few decades. Though the development and use of prefabrication in building construction comes a bit late for Hong Kong, the drastic increase in the application of this technology in building projects in the recent years does regain certain momentum in this leaving-behind area. Besides the accompanying of the related advancements to the local construction industry with the adoption of more mechanisation, computer aided manufacturing, and intelligent management systems, the extensive use of prefabrication also contributes to sustainable development by using cleaner and more resources saving production process.

The main aim of this paper is to provide an overview of the development and application of prefabrication techniques in the construction of large-scale and high-rise buildings in Hong Kong. After a brief introduction of the Hong Kong experience, the advantages and constraints are outlined. The measures and solutions, then, are analysed based on Hong Kong's built environment. Also the structural forms and the main fabrication elements applied in Hong Kong are presented by integrating with real cases to demonstrate how prefabrication has been adopted in the design and construction processes.

Keywords: Hong Kong's experience, Building, Construction, Prefabrication.

Introduction

Prefabrication has been used extensively and widely for many years around world. Pre-assembly, prefabrication, modularisation, system building and industrialised buildings are the terms which have been frequently used to describe that the manufacture of building components are constructed either on-site or off-site in a factory covering manufactured, modular and pre-cut or pre-engineered systems. Although the terms, are often interchangeably used, their precise definitions depend heavily on the users' experience and understanding, which vary from countries to countries. In this paper, prefabrication is preferred with special emphasis on the building components are made off-site in a factory. Off-site fabrication is a topic of international interest and provides an effective construction technique in terms of quality, time, cost, function, productivity and safety. It is adopted worldwide as the ideal means of producing an immense array of elements from structural members, cladding units, and bathrooms to fully-finished modular buildings.

As many prefabrication technologies deliver a better product because building is done in a quality controlled, sheltered environment, the move to more prefabrication in construction industry is inevitable. It is seen as one of the tenets of improving construction in the 21st century (Egan, 1998; Yeung, Chan and Chan, 2002). This is also echoed by Raysford (2000), "a much greater emphasis on off-site assembly was one of the key ingredients to changing the construction culture to retain and recruit talent and at the same time deliver improvements in performance required by increasingly demanding clients." This paper is cantered on how prefabricated building systems have been adopted in Hong Kong.

A General Review of Prefabrication Adopted in Hong Kong

Whether the building materials are concrete, steel or timber based system, the advantages of prefabricated building systems are clear. It is an industrialized way of construction, with the inherent advantages of:

- High capacity - enabling the realization of important projects
- Factory made products
- Shorter construction time - less than half of conventional cast in-situ construction
- Independent of adverse weather conditions during construction
- Continuing erection in Winter time until -20 °C
- Quality surveillance system

At the same time, prefabrication offers clients better performance to fulfil all requirements, such as:

- Opportunities for good architecture
- Fire resistant material
- Healthy buildings
- Reduced energy consumption through the ability to store heat in the concrete mass
- Environmentally friendly way of building with optimum use of materials, recycling of waste products, less noise and dust etc.
- Cost effective solutions

All above mentioned advantages comparing with traditional on-site building erection method, can be summarised in the following table

Table 1: A number of significant benefits provided by prefabricated elements comparing with on-site building erection process

Factor	Prefabrication	On-site
Quality	In a climate-controlled environment using efficient equipment operated by well-trained people.	Uncertain weather can result in less-than expected construction.
Speed	Speedy process (up to 70% less)	Time consuming. The process can be delayed by weather or scheduling conflicts.
Cost	Greater control over manufacturing results dramatically reduces the chance of cost overruns.	Uncontrollable variables such as weather and scheduling can increase the construction cost
Versatility	Less	More
Site space	Panels arrive on a flat-bed trailer and are installed with sufficient listing plants.	Bigger space is needed. In addition costly scaffolding is often necessary for installation.
Site refuse	Less waste is generated at the site.	A significant amount of waste produced and removed from the site, which often adds to cost.

Development of Prefabricated Building Construction in Hong Kong

It is recommended that prefabrication together with the extensive use of standardisation and modularization should become essential principles in the design and construction of high-rise residential buildings in Hong Kong in this century (Yeung and et al, 2002). The need to provide affordable, sustainable and functionally competent housing is fundamental to the living standards and well being of individuals and families throughout the World (Howes, 2002). The Hong Kong Special Administrative Region (SAR) government is no exception (Hong Kong Housing Authority (HKHA), 2000; Construction Industry Review Committee (CIRC, 2001). Hong Kong is a small island with scare flat land for building development. There has been a long history of housing shortage. Most of the buildings are dominated by high-rise design.

In the race to meet the extremely tight construction schedule in the Hong Kong construction industry, a trend toward prefabricated construction has set the tone for design. Besides, there is an urgent need for increasing the number of low cost apartments for public housing blocks to help the lower income population. According to the HKHA report (2000), more than 30 percent of population (about 2 millions) in Hong Kong is living in public housing (HKHA, 2000).

With reference to the study of Yeung, Chan & Chan (2002), precast concrete facades and stair flights, coupled with semi-precast concrete floor slabs, have been adopted for the construction of standard public housing blocks in Hong Kong throughout the 1990s (Figure 1 & 2).

Figure 1 – Use of precast façade in HKHA's project under Harmony Design

Figure 2 – Semi-precast slab system used in Harmony project

Figure 3 – Setting up of typical precast factory

Mass production prefabricated building components (precast façade, precast stair flight, drywall and semi-precast floor planking) reduce cost and save time, with added advantage of taking some of the most dirty and awesome work out of the process. Faster erection capabilities and fewer manpower requirements make prefabrication the most viable option for public housing construction in Hong Kong. In addition, the construction cost-saving function served by prefabrication construction is directly linked to the lowest-bid tendering practice. The free market economy will drive capitalists to move the place of production from the costly regions to places with a lower cost of manufacturing (Lipsey, Steiner and Purvis, 1987). Now most of the prefabricated building components are produced in factories situated in China (Figure 3).

The labour cost in Mainland China is just about one-tenth when compares to Hong Kong. According to the study carried out by Tam (2002), there could be a 43 percent reduction in site labour consumption if there is a shift from the in-situ site casting to prefabrication design. Furthermore, factory-manufactured components tend to be superior in quality as they are produced by sophisticated machines under a better controlled and structured environment. Besides, prefabrication opens the door to a much wider variety of architectural finishes, compared to conventional site-cast concrete components. A wide range of colours, textures, and profiles can be created. In fact, the technology is available to produce precast facades with complicated shape, or elements that look like granite, marble or natural stones but with a much lower cost.

Application of Prefabrication Technology in Hong Kong

It is well-recognized that HKHA is the pioneer in the introduction of prefabricated technology to mass-productive housing in Hong Kong. Being the major developer and landlord, the HKHA has made significant influence on the design and construction of buildings, leading the local construction industry from building traditionally towards the era of rationalization (Wong and Yau, 1999).

Despite a few trial projects being executed in the early 1970s', the first project making use of significant amount of prefabrication by the HKHA could be dated back to the late 1980's, in which the façade, stair flight, floor slab (semi-slab) or minor beam were precast in the design. The first generation of precast elements (Figure 4) showed quite a number of problems, especially for the fix-in type façade, where water leakage was very common coming from the window frame which is installed in-situ onto the openings, and the joints between the façade and the structural walls (Figure 5). The second generation of façade was very much improved. This was done by the casting of the window frame together with the façade unit during the concreting process (Figure 6), as well as the façades are cast at the same time with the surrounding in-situ structural walls (Figure 7).

Figure 4 – Fit-in façade for the first generation of housing projects

Figure 5 – In-situ grouting to joints between façade and external walls

Figure 6 – In-situ method to fix window frame into façade panel

The practices that the HKHA adopted for the construction of public housing exhibit significant success in the control of cost, quality and construction time. However, the overall quantity of work using prefabrication is still regarded as immaterial when compare to the total work volume. Besides, at least until these recent 3 to 4 years, there is no sign that similar technique is being applied in a wider scale in other residential building projects in the private sectors.

However, having experienced the rapid developing stages in the entire 1990s', there is a natural tendency that the construction industry is seeking alternatives to build that aim to the reduction of cost, improvement of building quality as well as to minimize construction time from a forward-looking prospective, needless to mention other uprising factors such as the urge from the government, competitiveness through innovative technology, or safety and environment concerns. In Hong Kong, some contractors did employed the concept of prefabrication in construction since the mid 1990s' as an alternative to construct and with projects completed with remarkable result. Table 2 is the summary of some milestone projects other than from the HKHA's where prefabrication technique was employed.

Name of Project	Year	Construction Features
Headquarter and Member Facilities of the Hong Kong Jockey Club	1994	Secondary beams and slab of the 3-storey 4000 m^2 podium structure constructed using precast arrangement (Figure 8)
School package in the Tseung Kwan O New Town	1998	Majority of the beams, slabs and external wall panels are precast
KCR Hung Hom Station Podium Extension/Hung Hom, Kowloon	1999	22,000 m^2 podium extension for freight cargo handling and residential/commercial development (Figure 9)
Hotel Development at Causeway Bay, Hong Kong.	2001	33-storey hotel building on a 620 m^2 site and constructed using modulated precast slab and façade
ASD's Government Quarters at West Kowloon.	2002	2 residential blocks each of 38-storey with large amount of façades, lintel beams and some internal partitioning using precast units (Figure 10)
KMB's Depot Building at Lai Chi Kok, Kowloon.	2002	3-storey depot structure with columns, main and secondary beams, slab constructed using precast (Figure 11)
Office building at Quarry Bay, Hong Kong	2002	40-storey office building with in-situ RC core wall linking to the external frame using precast beams (Figure 12)
Residential development at Cyber Port, Hong Kong	2003	6 residential blocks each of 25-storey with large amount of façades, lintel beams & balcony using precast (Figure 13)
Residential Development at Ma Tau Wai, Kowloon	2003	6 residential blocks each of 52-storey high with large amount of façades, lintel beams balcony and slab constructed using precast units (Figure 14)
Residential Development at Tai Koo Villege, Quarry Valley, Hong Kong.	2003	2 residential blocks each of 48-storey high with façades and balcony constructed using precast units (Figure 15)
Residential Developments in the Tung Chung New Town	2004	More than 10 residential blocks are to be constructed typical to other recent projects of similar nature.

Figure 7 – Casting the façade together with the structural wall

Figure 8 – Hong Kong Jockey Club Headquarters Building

Figure 9 – Podium deck of the KCR Kowloon Station Extension

Figure 10 – Government Quarters at West Kowloon

Figure 11 – Depot building of the Kowloon Motor Bus Ltd.

Figure 12 – Cambridge Tower at Quarry Bay, Hong Kong

Figure 13 – Residential development at Cyberport, Hong Kong

Figure 14 – Residential development at Ma Tau Wai, Kowloon

Figure 15 – Residential development at Tai Koo Valley, Quarry Bay

Having reviewed the projects being done during the past few years, the following development trends in technology can thus be observed.

- Majority of the latent defects such as poor joining and water leakage problems found in previous projects have been eliminated using in-situ fixed approach.
- Application has been diversified to other form of building construction.
- Capable to apply to the construction of rather complicate-shaped buildings.
- More precast elements are involved in the construction process.
- Other techniques like the using of mechanical formwork system (Figure 16), lost-form (Figure 17) or tensioning techniques, are incorporated in the construction process.
- More frequently applied in local construction projects, especially for buildings of residential nature.

Though with relatively limited precedent project cases, Hong Kong is still one of the leading areas in constructing high-rise buildings using significant amount of prefabricated elements. The past decade which serves as an important learning process, in particular the rapid development in the last 3 to 4 years, has trained the building professionals to be very competent in the design, procurement and construction of buildings using prefabricated techniques. As a means to further advancement, the following direction is identified pinpointing to the specific built-environment of Hong Kong:

- More structural elements should be used such as precast columns and shear walls.
- Use more modulated elements such as precast or plug-in modules for apartment cells (Figure 18) or services cubicles (Figure 19).
- Use more architectural precast elements in construction such as for external cladding, projected features or decorative paneling.
- Incorporate more other composite elements together in the prefabrication, such as using structural steel at the same time in the main structure (Figure 20).
- Apply the technique more widely for low to medium-rise buildings such as by the use of fully precast beam and column frames.

- Enhance supply chain management concept to identify specialist suppliers and contractors for technologically more demanding projects in order to shorten the procurement period and to improve interfacing management between specialization (Downing, 2002).

Figure 16 – HKHA Concord project using Jump-form for core wall and precast façade for external walls

Figure 17 – Lost-form is used for external wall (for walls without window opening)

Figure 18 – Modulated precast unit for an experimental project developed by Gammon Construction Ltd.

Lessons Learnt from Hong Kong's Experience

The experiences of using prefabrication in the Hong Kong construction industry in terms of cost, quality, time, and safety are positive. According to Wong (2000), Tam (2002) and Yueng, Chan and Chan (2002), some positive experiences of using prefabrication construction system are listed as follows:

- Site management is obviously improved resulting in reduction in site accidents
- Speed of construction improved by converting some critical site casting activities into off-site precast.
- The external look of building structures can be varied by changing the combination of modular units.
- The in-situ grouted joints can minimize the occurrence of water leakage.
- Quality of prefabrication units is much improved. The former defects like the delimitation of external tiles and water leakage along external window frames have seldom been recorded.
- Faster return on investment for the client.
- Reduced programme durations for fixing and erection operations.
- Lower manpower requirement on-site owing to simplified work content at working floor.
- Saving in space allocated to material storage.
- Less material wastage because of few defective products.
- Less abortive work.
- Re-engineered project delivery and supply chain system based on wide scope of prefabrication and preassembly.
- Elements can be conveniently pre-stressed, or even post-tensioned to form continuous structure afterward, to produce structures of higher performance (Figure 21).
- Productivity is higher than cast in-situ works especially when standardized design is adopted.
- The assembly and installation process carried out on site can save up a significant amount of formwork and falsework especially when the structure is of very high headroom.

Figure 19 – Precast toilet cubicle for a public housing project

Figure 20 – A hybrid construction system using precast panels for the core and floor supported with steel beams

Figure 21 – Deck using precast beams and semi-slabs strengthened by post-tensioning arrangement

From the practical sides, prefabricated construction also inherits some drawbacks or constraints (Wong, 2000), in particular under the unique environment of Hong Kong, which call for special managerial concerns, such as:

- Tighter and longer period of coordination are required to allow for structural design, construction planning, procurements and approval procedures.
- More time to be allocated in advance for the production of the precast elements until they can be accumulated to sufficient numbers for delivery to site to start installation.
- More demanding planning and management inputs are required.
- Huge working space is required for the carrying out of the fabrication works. Though most of the fabrication works are carried out in casting yards scattered around the Pearl River Delta, this will unavoidably increase the transportation cost when delivery is to be arranged by sea or on land.
- Storage and pre-installation handling, again, requires extra working space.
- Installation of precast elements on site requires careful planning and extra cranage provisions.
- The handling and assembly of heavy precast members, sometimes above 15 tons per unit, poses certain safety problems and increase the likelihood of risk both to human operatives and to the semi-completed structure itself.
- The structure under assembly in its semi-completed state may cause difficulties in making access into the work spot (Figure 22).
- Installation is often very complicated especially working with large amount of on-site prefabrication work (Figure 23), fixing to be made under difficult dimensional requirements (Figure 24), working under very congested floor layout, or installation to be carried out at high altitude.
- Defective connections or deformation appear in the precast elements may result to cracks and water leakage which will create further maintenance problems in a long run.

Figure 22 – Access problem may be created during installation of the precast units

Figure 23 – well coordinated construction planning is required for large amount of on-site installation

Figure 24 – Several pieces of precast elements joining together requires accurate dimensional coordination

Conclusion Remarks

In general, the use of prefabricated building construction system can be described as a success experience in Hong Kong. This system has been widely adopted and commonly used in public housing development projects, which are characterised by its great degree of repetitiveness and mass production. After more than 10 years application and accumulated experienced, practitioners in the construction industry hold the general view that prefabricated construction represents reliable, quality and cost-saving means to construct. However, successful implementation of the system still depends on the industry's ability to drift effectively toward a more professional and rationalized structure, as well as the seeking of more opportunity to apply the technique broadly and to a wider range of projects such that the construction system can be perfected. The further enhancement on procurement and supply-chain relationships for prefabrication appears to be an inevitable trend. The construction of housing can be considered as a largely repetitive process, involving a range of components and materials, which can be constructed in a variety of ways to produce an infinite range of designs (Howes, 2002). Traditional construction method relies heavily on the effective integration of various trades in a sequential process to achieve production on site is to a certain extent reaching a dead corner. Research indicates that 80 percent of building and repair works are of a repetitive nature (Environment Committee Report, 1996). Under such circumstances there is plenty of room to rationalize and advance the quality of buildings by the use of prefabricated construction system based on standardised components capable to support factory-based assembly. The prefabricated construction method has already been applied with success in the production of public housing blocks and projects. Indications are that cost has been cut, quality improved and construction time dramatically reduced. Further development needs to take place to improve designs and to provide more flexibility and choices for clients.

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