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# Advantages and Limitations of Precast Concrete Construction in High-rise Buildings: Hong Kong Case Studies

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**ABSTRACT**

The Hong Kong construction industry heavily relies on conventional cast in-situ construction involving extensive use of wet trades and on-site construction processes. The construction activities have been described as “labour intensive, dangerous and polluting”. Recently, the use of prefabrication has increased in the building industry. This paper presents the preliminary findings of an ongoing research study on the evolution of the use of prefabrication techniques in Hong Kong. Buildings adopting precast elements were selected as case studies and interviews were conducted with professionals involved. The impact of the use of prefabrication on important issues such as cost, time, quality, on-site safety, labour requirement and environmental issues were investigated. The findings revealed that the construction cost was slightly higher than conventional construction when using precasting. However, this was balanced by improved quality, construction time reduction, and improved on-site environmental performances.

**Keywords**: **Construction Method, High-Rise Building, Hong Kong, Precast Concrete, Prefabrication**.

## 1.1 INTRODUCTION

### 1.1.1 Hong Kong Construction Industry

The construction industry is a major industry in Hong Kong economy, accounting for about 3.2% of the GDP (in 2004), and employing about 8% of the workforce in 2005 (Census and Statistics Department, 2006).

In 2001, the construction activities in Hong Kong were described in the Construction Industry Review Committee report as “labour intensive, dangerous and polluting” (CIRC, 2001).

For most building projects in Hong Kong, the construction process heavily rely on labour intensive in-situ construction methods. The output quality is highly dependent on the workmanship of construction workers. Also, the construction industry is regarded as a dangerous industry, and has the highest level of accident injuries and fatalities (Labour Department, 2006a, 2006b). The construction activities are inherently disturbing to the environment, creating environmental nuisance such as noise, dust, muddy runoffs, and huge amount of waste. These environmental issues are significant in a dense urban environment such as Hong Kong in which construction sites are frequently located in congested areas and adjacent to high-rise buildings.

In Hong Kong, the management and disposal of construction waste is in particular a major environmental issue, as the availability of suitable disposal area is scare. In 2005, the construction industry generated about 21.5 millions tonnes of construction waste, of which 11% was disposed of at landfills and 89% at public filling areas. Recently, the government has implemented various construction waste reduction measures, such as the requirement for public work contractors to prepare waste management plans and to comply with the trip ticket system. Recycling of hard inert materials as recycled aggregates and rock fills are also being promoted. Since the beginning of 2006, the government has introduced a construction waste disposal charging scheme. The charges are HK$125/tonne of waste disposed at landfills, HK$100/tonne at sorting facilities, and HK$27/tonne at public fill reception facilities. In recent years, the use of prefabrication in building projects are also being promoted to alleviate some of the waste generation burdens associated with the use of conventional construction and timber formworks.

### 1.1.2 The CIRC report and prefabrication

In 2001, the Construction Industry Review Committee (CIRC) published a report describing current construction activities in Hong Kong and providing 109 recommendations to improve the performance of the construction industry (CIRC, 2001). Among other recommendations, the report recommended the industry to extend the use of modern construction methods and information technology. It also recommended a wider adoption of prefabrication in buildings to overcome environmental issues associated with conventional construction methods such as dust nuisance from on-site concrete mixing, excessive noise and waste from the use of timber formwork and muddy site run-off.

### 1.1.3 The Joint Practices Notes 1 and 2

Since 2001 and 2002, the government started to implement incentives schemes, with Gross Floor Area (GFA) exemption granted for the use of green and innovative building technologies and prefabrication (Buildings Department, 2001, 2002). The objectives were to encourage the adoption of a holistic life cycle approach to planning, design, construction and maintenance; to maximise the use of natural renewable resources and recycled/green building materials; to minimise the consumption of energy; and to reduce construction and demolition waste. The Joint Practice Note 1 (JPN 1) was introduced in February 2001. It included incentives for installation of green features such as balconies, wider common corridors and lift lobbies, communal sky gardens and communal podium gardens. In February 2002, a second package of incentives was issued for green features such as communal sky gardens for non-residential buildings, noise barriers, mail delivery rooms with mailboxes, utility platforms, and non-structural prefabricated external walls. The use of these features may be exempted from GFA and/or Site Coverage calculations under the Building Ordinance.

### 1.1.4 Prefabrication in Hong Kong

Prefabrication has been defined as a manufacturing process, generally taking place at a specialised facility, in which various materials are joined to form a component part of the final installation (Tatum *et al.*, 1986; CIRIA, 1999). Sarja (1998) differentiated the full prefabrication and the composite construction where the components or assemblies are manufactured fully or partly. Testa (1972) pointed out that building components could be produced in a factory environment (factory prefabrication) or under the open sky at the site (site-prefabrication). The term off-site fabrication was used when both prefabrication and pre-assembly are incorporated (Gibb, 1999). Gibb (1999) defined three types of off-site fabrication such as, non-volumetric, volumetric and modular building, arguing that the line dividing each type is flexible. Warszawski (1999) classified precast concrete systems according to the geometrical configuration and their framing components in three major categories, namely, linear or skeleton systems, planar or panel system, and three-dimensional or box system.

Precast concrete construction was made feasible with the advancement of adapted equipment for transportation and erection. The demand was at its peak, after the World War II, in the 1950s, 1960s and the early 1970s in Eastern and Western Europe for the construction of new cities and suburbs, and large public housing projects (Warszawski, 1999).

In Hong Kong, the use of prefabrication was first developed along with the public housing program. In the mid 1980s, prefabrication combined with standard modular design, were introduced in public housing projects (Mak, 1998). Since then, the Hong Kong Housing Authority (HKHA) has recommended the adoption of precast elements, reusable formwork and other environmentally friendly building techniques in all public housing contracts. In 2002, prefabricated elements accounted for about 17% of the concrete volume used in public housing projects (Chiang *et al.*, 2006). The major precast elements used are precast facades, staircases, parapets, partition walls (dry wall), and semi-precast slabs. Pilot projects currently under construction, extend the use of precasting to 65% with bathroom and kitchen volumetric prefabrication and structural walls (HKHA, 2005).

With over two decades of experience in prefabrication techniques, the HKHA housing projects provided extensive opportunities for research. Therefore, the majority of previous studies were focused on studying innovations and performances in public housing projects which normally are constructed with standard design blocks (Mak, 1998; Chan and Lee, 1998; Chiang *et al.*, 2006; Chan and Chan, 2002; Lam, 2002; Wong and Yau, 1999).

In contrast, the private building sector in Hong Kong still predominantly adopts traditional construction methods involving in-situ concreting and timber formwork, considerable amount of wet trades and bamboo
scaffolding. Only a limited number of research studies have studied and quantified the benefits of adopting prefabrication techniques in private building projects, especially in recently completed private residential buildings (Fong et al. 2003). Chu and Sparrow (2001), and Chu and Wong (2005) examined the advantages and limitations of using the prefabrication technique in private high-rise residential buildings. But these studies were confined to a limited number of case studies without quantitative data. This provides rooms for further investigation in the quantification of benefits and limitations of the use of prefabrication techniques in private high-rise residential buildings involving non-standard design.

## 1.2 OBJECTIVES AND METHODOLOGY

The aims of this study are to examine advantages and limitations of the use of prefabrication and precast construction in high-rise residential buildings; and to assess the performances of prefabrication when compared with conventional construction.

The methodology consisted of a questionnaire survey, interviews with professionals in the industry, and detailed case study analysis. The questionnaire survey was developed and administered to 354 professionals in the building industry. The survey was conducted in a period of four months in 2005. The response rate was 24%. Interviews were also conducted in order to reinforce the data collected. Then, a comparison between two residential building projects that had used respectively prefabrication and conventional construction methods was carried out. The data collection process for these two projects involved literature review, interviews with the project clients, architects, contractors, engineers and

precast manufacturers. Site observations were carried out at the two construction sites in 2001 and 2006.

## 1.3 RESULTS AND DISCUSSION

The detailed case study analysis examined the adoption of construction methods and building performances in two high-rise residential buildings (Table 1.1). Project A, adopted conventional cast in-situ construction and timber formworks, whereas project B, adopted 60% (by volume) of prefabrication and aluminium formworks. The type of precast elements employed included precast façades, lost form panels (permanent formwork), semi-precast balconies, precast staircases and other elements. This project was the first private residential development in Hong Kong adopting prefabrication techniques for the construction of lost form panels and semi-precast balconies. It was considered as a demonstration project for the industry and was developed taking the incentives provided by the JPNs. This project was the first urban residential development to be awarded with an "Excellent" rating from HK BEAM (Hong Kong Building Environmental Assessment Method). Project A also received a Quality Building Award in 2006. Both projects were completed at about the similar time in 2003 and 2004.

**Table 1.1** Comparison between two high-rise residential projects adopting conventional and prefabrication construction methods

| | Conventional Construction Project A | Precast Construction Project B |
|---|---|---|
| Year of construction | 2002-2004 | 2001-2003 |
| No. of blocks | 8 | 2 |
| Max no. of /F | 35 | 48 |
| No. of units | 1,404 | 442 |
| GFA (m2) | 109,700 | 56,756 |
| CFA(m2) | 119,900 | 56,000 |
| Precast % (by volume) | 0% | 60% |
| Construction cycle | 5 days/floor | 4 days/floor |
| Construction duration | 28 months | 20 months |
| GFA exempted under JPNs/CFA | - | 10% |

### 1.3.1 Reasons for selecting construction methods

According to the project team, in project A, the conventional construction method was used due to the lower cost when compared with other methods. The ease in construction progress control was another reason for using the conventional construction. The contractor also mentioned the increased flexibility was a major advantage of using the conventional construction method as the design could be frequently modified even during the construction phase. This enabled the design to vary suiting customers' preferences and market demand even during the construction stage.

In project B, prefabrication was adopted primarily for the enhancement of building quality, the reduction of labour cost (decrease in labour requirement on-site), and for controlling environmental (especially noise) nuisance. Above all, the client was an environmentally conscious company and intended to demonstrate green building development in Hong Kong. The use of green design and construction also enhanced the cooperate image of the developer.

However, according to the survey results, cost and time remained the principal governing factors when selecting a construction method, followed by the familiarity with the construction technology. The least important factors were the reduction of waste and the delivery logistics.

### 1.3.2 Benefits of prefabrication

In Project B, the project manager mentioned that prefabrication contributed to improved quality. The precast elements were manufactured in a factory environment with better quality control. In addition, with prefabrication, the external wall tiles were applied monolithically during concrete casting. With this method, the tiles have better durability as the maintenance problem associated with de-bonding tiles is avoided. Window frames were also installed when concrete was cast and thus could reduce water leakage risks. The architect expressed that with the use of both precast façades and lost form panels, uniform quality was achieved in the building elevations, and hence promoting continuity in visual quality and aesthetics.

The adoption of prefabrication techniques also contributed to a reduction of construction time by about 20%, when compared with conventional construction (Table 1.2). A 4-day cycle per typical floor was achieved in project B, compared with a 5-day cycle for project A. Prefabrication permitted the early enclosure of the building and the early commencement of indoor works and building finishes.

In Project B, prefabrication also enhanced environmental benefits on-site. According to the contractor, prefabrication contributed to both considerable waste reduction and material conservation. The lost form panels were used as the permanent formwork reducing the need of timber formwork on one side of the panel. No bamboo scaffolding was required as most of the external finishing work of the precast elements had been completed off-site at the manufacturing plant. When compared with project A, a reduction of construction waste by 28% was achieved. Although waste was generated at the manufacturing plant, it was easier to be reused and recycled. Prefabrication also eliminated the use of plastering and tiling wet trades on-site, thus reducing water consumption and contributing to a cleaner and safer working environment on-site.

Another advantage of adopting prefabrication in project B was the reduction of labour requirement on-site by 9.5%, when compared with conventional construction.

In terms of design, the architect believed that prefabrication permitted the design and construction of complex and curved shapes for prefabricated façade elements, such as the sunshade and balcony elements. These elements, inspired from aeronautical forms, would have been extremely difficult to build on-site, especially when working at height. The architect also expressed that flexibility in space arrangement and adaptability for future changes was achieved with the avoidance of cast in-situ shear walls connecting precast facades.

Finally, the GFA exemption provided by the incentive schemes of the JPNs permitted the developer to gain one additional floor in the development. This represented about 10% of the total GFA, of which 19% were non-structural prefabricated external walls including precast façades and lost form panels.

The results of the case study in Project B were consistent with those gathered from the questionnaire survey. From the survey results, it was revealed that the major benefits when using precast construction were (in order of importance): improved quality control, reduction of construction waste, improved health and safety, reduction of labour demand and construction time.

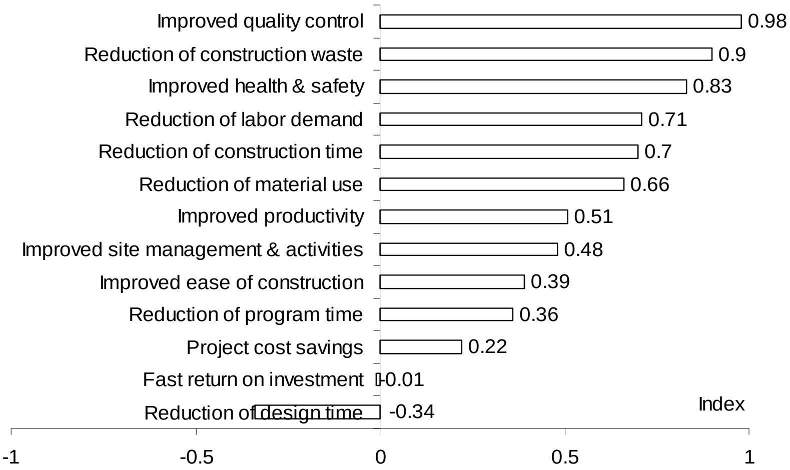


**Figure 1.1** Major benefits of adopting precast construction in buildings, 2005

**Table 1.2** Summary of comparison between Project B and conventional construction (Adapted from Fong *et al*., 2003)

| | |
|---|---|
| Precast percentage by volume | 60% |
| GFA exempted under JPNs/CFA | 10% |
| Cost/m2 | +0.25% |
| Time | -20% |
| Labour requirement/m2 | -9.5% |
| Energy/m2 | +12% |
| Water/m2 | -41% |
| Waste/m2 | -56% |

### 1.3.3 Limitations of prefabrication

There were a number of limitations when adopting prefabrication techniques. In Project B, early decisions on design were required in the building process, as precast elements were manufactured before delivered to the site for assembly. The architect also expressed that the possibility of late change in the design was limited, as modifications in precast elements once produced and installed on-site was difficult. In Project A, the contractor pointed out that the client instructed modifications to the design even during the construction stage.

Project scheduling and logistics were also important factors. The contractor of Project A expressed that time management for fabrication, transportation and installation was less flexible if prefabricated elements had been used. He also believed that site progress would have been constrained by the production progress of the precast elements. The transportation of the precast elements and access to site were also considered as common limitations in a dense urban environment such as in Hong Kong.

However, these issues were not considered as the limiting factors in Project B. The project manager expressed than although small sites, especially when adjacent to high-rise buildings on three faces, posed problems for tower crane manipulation and storage of prefabricated elements, in project B, the adoption of just-in-time delivery principle, storage location on site could be kept to a minimum (Chu and Wong 2005).

According to the project client, the overall construction cost of Project B, with the use of prefabrication was slightly higher than for conventional construction by about 1%. The higher cost would be off-set by a reduction in

the overall building programme and savings in labour, material and waste handling and disposal costs, and reduction of in-built defects. But an increased of energy consumption by 12% due to the transportation of prefabricated elements was noted.

In Project A, the contractor expressed that although the tender price for a bid based on timber formwork was similar to a bid based on the use of prefabrication, the use of timber formwork allowed the use of a variety of

façade designs and the flexibility for late modifications which were the prevalent factors for the use of the conventional construction.

In the survey, the respondents opined that the major limitations when adopting precast construction were (in order of importance): higher initial costs, site dimensions (small sites), resistance to change, and higher overall cost.

## 1.4 CONCLUSION

The construction industry in Hong Kong had been described as labour intensive, dangerous and polluting. Most of the buildings are still built with conventional construction methods involving cast in-situ concrete, timber formworks and wet trades with high labour requirement.

From the case studies, it was revealed that the benefits of adopting prefabrication in building construction were considerable, when compared with conventional construction methods. Improved quality was achieved as the precast elements were manufactured in a factory environment with stringent quality control. In addition, building components with curve and specific shapes could be easily produced and fabricated with the prefabrication technique, as the elements were produced off-site, avoiding working at height on-site. Furthermore, the lost form panel system and the precast façade connection provided flexibility in space arrangement and adaptability for future changes.

Significant environmental benefits on-site were demonstrated by the use of prefabricated elements. This contributed to a cleaner and safer working environment on-site. The construction cost for using prefabrication was slightly higher than for conventional construction. However, this additional cost would be off-set by a reduction in construction time, improved quality and environmental benefits at the site. Important issues when adopting prefabrication were the requirement of early decisions, the scheduling and logistics, and site access and storage of prefabricated elements in dense urban areas.

The requirement for early decisions when using prefabrication was perceived as a major limitation factor. The aspiration toward a more environmentally responsible construction industry and the implementation of further incentives could help to promote a wider use of prefabrication in the construction in Hong Kong.

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