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USE OF PREFABRICATION TO MINIMIZE CONSTRUCTION WASTE - A CASE STUDY APPROACH

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Abstract
The increasing awareness of environmental impacts from construction waste has aroused much public concern. Some construction organizations have included waste management as one of the major functions of construction project management. As a result, some approaches and methods for managing construction waste have been developed. Replacing wet-trade activities with prefabrication is advocated as one of the waste minimization techniques on site. However, the adoption of prefabrication is mainly confined to public housing developments in Hong Kong. This paper uses four private building projects as case studies to demonstrate the effectiveness in the use of prefabrication to minimize construction waste in Hong Kong. The wastage levels of the four projects are compared with conventional cast in-situ methods under similar project natures and conditions. The hindrances and the future trend of adopting prefabrication in Hong Kong are also examined.

Keywords
Prefabrication, environmental management, waste management, construction.

INTRODUCTION

In November 1998, the Hong Kong government launched a ten-year waste reduction framework plan (WRFP, 1998), aiming at reversing the rising trend of wastes in order to conserve scarce landfill areas. The WRFP sets out the target of dumping construction and demolition (C&D) materials to landfills limited to 16% (currently 20% of C&D wastes are sent to landfills) by: i) introducing a landfill charging scheme; ii) presenting on-site/off-site sorting of C&D materials; iii) implementing reuse and recycling C&D materials; and iv) avoiding and minimizing C&D materials through better design and construction management. In order to meet the targets, the public needs to transfer emphasis from transport of waste to landfills for disposal to waste prevention and reuse of waste materials. The Environmental Protection Department (EPD, 2003) of Hong Kong SAR suggested taking a five-step action (Figure 1): waste avoidance; waste minimization; waste recovery, recycling and reuse; waste bulk reduction; and waste disposal.

McDonald and Smithers (1998) suggested that the main advantage of engaging waste management was cost saving as 50% of material handling costs was saved in their case studies. However, cost reduction by recycling is difficult to achieve in the short term. Shen and Tam (2002) found that one of the greatest barriers to Hong Kong constructors in implementing waste management is the increase in costs due to additional investment on staffing, technology and facilities. It is necessary to recognize that the materials thrown away are a potential hazard to the environment. The waste created from construction sites can be reduced if the material wastage is managed at the beginning of the design and construction process, and a clean and lean technology is adopted. Poon *et al* (2001) found that there were two fundamental techniques on waste minimization: source reduction and recycling (Table 1). As the most effective waste minimization technique would be by source reduction, prefabrication, being a source reduction technique, can be effective in waste minimization (Poon *et al*, 2001).

Reduction of wet-trade activities was also advocated by Ho (2001) and Ting (1997), in which prefabrication is the typical method in reducing in-situ construction activities. This paper uses four construction projects for demonstrating the benefits of prefabrication. Different levels of prefabrication were adopted by the projects, in which the wastage levels are compared and analysed.

WASTE SOURCES

Construction waste is in the form of building debris, rubble, earth, concrete, steel, timber and mixed site clearance materials, arising from various construction activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork and building renovation. Whilst some of these wastes are recyclable and reusable, they are still usually dumped at landfills (Poon et al, 2001). Wastes are often mixtures of inert and organic materials. The inert waste is normally used in public filling areas and site formation works and the remaining waste is often mixed and contaminated, not suitable for reuse or recycling but disposed of at landfills. According to the report by Hong Kong Construction Industry Review Committee (HKHA, 2003), about 79% of construction waste was used for public filling areas and the remaining 21% was disposed of at landfills in 1999.

Construction waste originates from various sources in the whole process of implementing a construction project. Gavilan and Bernold (1994) classified construction waste sources into design errors, procurement or shipping errors, materials handling errors, machine operation errors and residual or leftover scraps. Bossink and Brouwers (1996) considered construction waste from the applications of various building materials and classified the waste sources according to the nature of materials and the technology used into stone tablets, piles, concrete, sand-lime bricks and elements, roof-tiles, mortar, packing, and other small fractions of metal and wood. Faniran and Caban (1998) conducted a survey examining the construction waste sources, and formulated five typical waste sources, namely, design changes, leftover material scraps, wastes from packaging and non-reclaimable consumables, design errors, and poor weather. Rounce (1998) pointed out that the major construction waste sources were at the design stage, such as design changes, the variability in drawings and the variability in the level of design details. These waste classifications indicate that examination on construction wastes must be conducted over the whole construction process of a project.

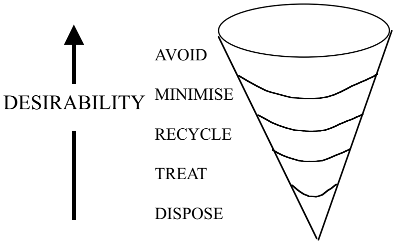

Figure 1 Waste Management Hierarchy (EPD, 2003)

Table 1 Waste Minimization Techniques in Construction (Poon *et al.*, 2001)

Waste minimization techniques					
Source reduction				Recycling	
Old building	**New buildings**			**Use and reuse**	**Reclamation**
Preservation • Renovation of building • Alternation and additional works of building	Design issues • Dimensional co-ordination • Design for long life • Design for flexibility • Design to minimize variations • Design for reuse • Design for recycling	Technology changes • Process changes ***(Prefabrication)*** • Plant or equipment changes • Site layout changes	Good operating practices • Site procedural measures • Loss prevention • Management practices • Waste segregation • Material handling improvement • Material and production scheduling	• Return to origin process • Raw material substitute for another process	• Processed for resource recovery • Processed as a by-product

∇

It is estimated that about 10% of building materials will end up as construction waste on building sites (Guthrie *et al*, 1999), which may be affected by the following human and mechanical factors:

a) Poor site management and practices: lack of management systems aimed at waste minimization; untidy construction sites; poor handling, such as breakage, damage and losses; over-sized foundations and other elements; inadequate protection to finished work; and limited visibility on site resulting in damages;
b) Lack of environmental awareness on clients and designers: non-standardized designs resulting in excessive cut-offs; ignoring buildability; unsuitable material dimensions; change of mind between clients, designers and consultants; specifications failing to match the required quality of building; and resistance to adopt alternative materials;
c) Damage during delivery of products: over-ordering; method of packaging; method of transport; inadequate data regarding time and method of delivery; and inadequate details concerning performance, quality and site facilities; and
d) Rework due to poor workmanship.

PREFABRICATION

In order to minimize the above waste sources, prefabrication can be one of the solutions. Although prefabrication has been promoted in Hong Kong for years (Ho, 2001; Ting, 1997), its adoption is still mainly confined to public housing projects. The industry in Hong Kong still heavily relies on the conventional building technology: cast-in-situ, bamboo scaffolding, timber formwork, plastering and painting. This renders the construction process very labour intensive. This, coupled with the poor quality of workmanship and the overwhelming use of multi-layered subcontractors, hampers management control and results in excessive waste generated from construction activities (Shen *et al,* 2002). Site management practices are considered as a passive defence since it depends on the workmanship and attitude of the workers, while the low waste building technologies such as prefabrication are rather proactive in nature but unfortunately not widely used in the industry. The benefits gained from prefabrication include wastage reduction, shortening construction duration, improving the quality from the off-site fabricated products, reduction of the overall construction cost, improve site safety by providing a cleaner and tidier site environment and eliminate site malpractices (Ho, 2001; Ting, 1997). Further, factory production can reduce wastage and encourage re-cycling of construction waste, leading to environmental protection and sustainability of the industry. Despite these, adoption of prefabrication is mainly confined to public housing developments since the high initial construction cost, time consuming in the initial design development, limited site space for placing prefabricated building components, lack of experiences from contractors, lack of demand for prefabricated components, leakage problems and the non-standardized design form the major obstacles for private housing projects (Poon *et al,* 2001).

In Hong Kong, applications of prefabrication are prescribed by two major considerations: i) high-rise building construction coupled with due wind load design to cater for typhoons putting the adoption of structural prefabrication elements at risk; and ii) rainy seasons always coming with typhoons that makes water leakage from the external envelope one of the critical design concerns. Prefabrication in Hong Kong can be broadly divided into: non-structural elements, structural elements and volumetric elements. Non-structural elements can be categorized under three main areas (Poon *et al,* 2001):

i) Facades: Facade units are the most common prefabricated item used in the construction industry of Hong Kong, which is pre-finished before installation. It would be more economical to utilize the facade as a structural component of the building structure if the technical issues can be resolved;
ii) Dry wall: The application of dry wall is concentrated on partition walling, where subsequent skim coat with painting is required, an effective application of prefabrication; and
iii) Cooking benches.

Structural elements include:
i) Stair: It has been used in both public housing and private projects;
ii) Semi-pre-cast slab: It is considered as a kind of lean construction technology and has been used in public housing and private projects although less common as stairs;
iii) Curtain wall: Curtain wall is considered as a very common prefabrication item for prestige developments but it is rather luxury in comparison with facades; therefore it may not be suitable for low to medium-price residential development; and
iv) Fins: For decorative purposes.

For volumetric elements, they include water tanks and bathroom units. However, both require applications for change and approvals from the relevant authorities as an alternative design/proposal.

The Hong Kong Housing Authority has adopted small-scale prefabrication since 1988 (Cheung *et al*, 2002). The prefabricated elements include pre-cast facade units, staircases, drywall and semi-pre-cast floor planking while the structural elements still remain cast-in-situ. Their experience in using prefabrication is positive in terms of quality, time, safety; some good responses are listed as follows:

- Site tidiness is obviously improved, resulting in reduction in site accidents;
- The speed of construction can be improved by moving some critical site casting activities to pre-casting works;
- The external outlook of building structures can be varied by changing the combinations of modular units;
- The in-situ grouted joints can minimize the occurrence of water leakage; and
- The quality is much improved by prefabrication. The former quality breakdowns like the de-lamination of external mosaic tiles and water leakage along external window frames have been seldom recorded in prefabricated construction.

CASE STUDIES

Adoption of prefabrication technology is mainly confined to public housing developments in Hong Kong, which have the resources and expertise to risk introducing new technology while the technology has not been widely accepted by the private sector. In order to examine the advantages of prefabrication to private developments, four private building projects in the forms of hotel, residential tower and two commercial buildings are selected for this study, which have applied, to a certain extent, some prefabrication techniques. Details of the four projects are tabulated in Table 2.

Table 2 Details of Projects with High Level of Prefabrication

Project title	**Project 1: Hotel redevelopment**	**Project 2: Residential**	**Project 3: Commercial-A**	**Project 4: Commercial-B**
Gross floor area	9,514 m^2	56,756 m^2	181,310 m^2	31,140 m^2
Scope of the project	One 31-storey hotel comprising 3-level podium and 28-storey guestroom tower.	Two blocks of residential buildings of 48-storey high and one level podium.	One 88-storey high office and 5-storey for car parking areas.	36-storey high grade A office building including 2-storey of podium and 1-storey of mechanical and electrical (M/E) floor
Construction methods	Conventional method is adopted for the guestroom tower, while prefabrication is used for the podium.	For the podium, it adopts the conventional method, while prefabrication is applied to the residential towers.	Car park construction adopts the conventional method, while the 88-storey office tower uses prefabrication.	Semi-precast elements at typical floors, in which it splits into two portions, one by in-situ construction and the other by prefabrication
Prefabricated building components	Δ prefabricated slab Δ staircase Δ precast facade Δ system formwork	Δ precast facade Δ lost form Δ precast balcony Δ staircase Δ dry wall system	Δ structural steel frame Δ unitized curtain wall system Δ system formwork for corewall and mega column Δ superdeck material platform Δ precast staircase Δ dry wall system	Δ precast staircases Δ precast plank Δ semi-precast beam jump lifts Δ off-site prefabricated building services components
Cycling time	7 days cycle	4 days cycle	7 days cycle	4 days cycle
Location of prefabrication yard	Yuen Long	Dong Guan	Mainland China	Mainland China

Level of Prefabrication

By interviewing project managers of the four projects, the levels of prefabrication are identified. Table 2 shows the various prefabrication elements for the projects. The most common prefabricated elements are facade and staircase units. During construction of the pre-cast facades, aluminium window units were cast monolithically so that any water leakage through joints can be minimized. "Lost" form (permanent form) for the entire external load-bearing wall and pre-cast balcony were adopted for Project 2. Plastering, tiling and scaffolding work were minimized, thus enhancing site productivity. Pre-cast balconies that were pre-finished with tiling in the prefabrication yard adopted a semi-pre-cast technique in which the final structural portion of the unit was cast in-situ with the supporting beams. Projects 2, 3 and 4 adopted a dry wall system for internal partitions onto which a thin layer of skin coat of 1-2 mm thick was applied before final painting, thus reducing site construction wastes arising from the traditional wet trades.

Another prefabrication technique used was off-site building services fabrication for Project 4. About 95% of building services were fabricated off-site, including integrated lighting and air-conditioning outlets, low-glare fluorescent lights with electronic ballasts, direct digital control variable air volume system, heat absorbing and solar reflective double-glazed curtain walls, semi-pre-cast sprinkler heads, fully recessed lighting unit, suspended acoustic ceiling panel, etc. The project manager suggested that significant cost savings could be achieved by this.

Examination of Wastage Reduction

In order to examine wastage levels, the four projects with some level of prefabrication were compared with similar projects but adopting a conventional cast-in-situ approach, which were identified with the help of the four project managers. Data were collected through a series of structured interviews with the project managers, our site observations and recording. Four major site operations including plastering, timber formwork, concrete and reinforcement were investigated in this study, that exclude the off-site trades at the prefabrication yards and other auxiliary services such as additional transport and hoisting facilities.

Wastage levels of building materials can be defined as the remains of the materials delivered on site after being used in the built work. This can be described in *Equation (1)* and *Equation (2)* for projects with prefabrication and projects using conventional cast-in-situ approach:

$$W_p = \frac{M_{Dp} - M_{Up}}{M_{Dp}} \cdot 100\% \qquad \textit{Equation (1)}$$

$$W_c = \frac{M_{Dc} - M_{Uc}}{M_{Dc}} \cdot 100\% \qquad \textit{Equation (2)}$$

Where W_p and W_c denote the percentages of material wastage for projects of prefabrication and projects of conventional cast-in-situ; M_{Dp} and M_{Dc} for material delivered on site; and M_{Up} and M_{Uc} for material used for built works. Improvements in wastage levels are measured by a relative index, denoted by 'W' in *Equation (3)*:

$$W = \frac{W_c - W_p}{W_c} \cdot 100\% \qquad \textit{Equation (3)}$$

The relative indices of the various trades for these projects are summarized in Table 3.

Wastage resulted from hacking off concrete from grout leakage and dislocation of formwork; excessive plastering to hide surface unevenness and excessive site mixed mortar was completely removed for Project Types 1, 3 and 4. For the hotel project with prefabrication, only 1-2 mm skim coat instead of 15-20 mm plastering was used. Furthermore, timber formwork was reduced by 73.91% to 86.67%, causing significant reduction in timber scraps. Compared with the conventional construction method, steel formwork is used in prefabrication yards; the increase in times of reuse results in significant reduction in material wastage. Wastage resulted from concrete is also significantly reduced by 51.47% to 60% as the prefabricated products are cast off-site. Although wastage of steel bars can be reduced by 35% to 55.52%, the saving is not significant as steel bars from construction sites can be recycled.

Hindrances on the Adoption of Prefabrication

Although significant reduction in wastage levels was recorded in adopting prefabrication for the four types of projects, there were several hindrances in the development of prefabrication as described by the interviewees, which are summarized in Table 4.

First, the congested roadwork in Hong Kong affects timely delivery of prefabricated components, which would impinge on the progress of the tight construction schedule. Moreover, the lack of experience of the labour and the frontline supervisory staff in handling prefabrication will take a longer learning curve/time before arriving at planned cycling times. On the other hand, designers and consultants are very cautious and thus very demanding in managing prefabrication works. Proper training and education in this area are strongly needed. Furthermore, high land costs also form one of the major difficulties in locating prefabrication yards in Hong Kong.

Table 3 Relative Indices on Improvement in Wastage for Various Trades

	Conventional cast in-situ			Prefabrication			W
	MDc	**MUc**	**Wc**	**MDp**	**MUp**	**Wp**	
Project 1: Hotel							
Plastering (m^2)	7,200	6,800	5.56%	600	600	0.00%	100.00%
Timber formwork (m^2)	16,500	14,000	15.15%	2,350	2,300	2.13%	85.96%
Concrete (m^3)	7,700	7,000	9.09%	1,360	1,300	4.41%	51.47%
Reinforcement (ton)	1,370	930	32.12%	350	300	14.29%	55.52%
Project 2: Residential							
Plastering (m^2)	250,000	180,000	28.00%	600	580	3.33%	88.10%
Timber formwork (m^2)	400,000	285,000	28.75%	2,000	1,850	7.50%	73.91%
Concrete (m^3)	50,000	45,000	10.00%	500	480	4.00%	60.00%
Reinforcement (ton)	6,500	6,000	7.69%	400	380	5.00%	35.00%
Project 3: Commercial-A							
Plastering (m^2)	5,000	3,000	40.00%	400	380	5.00%	87.50%
Timber formwork (m^2)	6,000	4,000	33.33%	1,500	1,400	6.67%	80.00%
Concrete (m^3)	2,200	2,000	9.09%	500	480	4.00%	56.00%
Reinforcement (ton)	1,250	1,000	20.00%	200	180	10.00%	50.00%
Project 4: Commercial-B							
Plastering (m^2)	9,500	8,000	15.79%	700	700	0.00%	100.00%
Timber formwork (m^2)	16,000	10,000	37.50%	2,000	1,900	5.00%	86.67%
Concrete (m^3)	13,500	12,000	11.11%	1,000	950	5.00%	55.00%
Reinforcement (ton)	4,500	4,200	6.67%	500	480	4.00%	40.00%

Table 4 Hindrances in Adopting Prefabrication

Projects	**Hotel redevelopment**	**Residential**	**Commercial - Type A**	**Commercial - Type B**
Site conditions	Congested site conditions.	Untidy site environment makes it difficult in managing prefabrication works.	Difficulties in managing and controlling progress and schedule.	Nil
Labour skills	Lack of experience of labour and frontline supervisory staff prolongs the learning curve/time in adopting prefabrication.		Frontline supervisory staff takes time to be acquainted with the concept of prefabrication.	The lack of environmental awareness of the frontline staff: training and education required.
Land costs	High land costs create difficulties for locating prefabrication plants.	Setting up prefabricated yard in Mainland China can help reduce the costs.	Large capital investment in setting up the prefabrication yard forms the major hurdle in this project.	Client's support for adopting prefabrication can help reduce the barriers of high land costs and encourage environmental management.

Future Trends of Prefabrication

Prefabrication will only be successful when contractors and developers can enjoy cost savings. Interviewees suggested that cost was the key factor at this critical moment of economic downturn. Prefabrication will only bring about cost saving when the following issues are addressed: i) fully mechanizing the construction process using heavy plants; ii) turning construction into an assembling industry rather than site production; and iii) use of recycle materials for the prefabricated components. In addition, three main stimulators are needed in adopting prefabrication (Ho, 2001; Poon, 2000; Ting, 1997):

i) Environmental issues: when more stringent environmental control and regulations are forthcoming, prefabrication is one of the ways out in order to facilitate long-term waste minimization and reduction;
ii) Construction costs: introducing more productive and lean construction methods can reduce the construction cost effectively and reduce the burden encountered by the high initial investment (Shen and Tam, 2002);
iii) Government incentives: granting relaxation to the gross floor area for projects employing prefabrication elements (for example, discounting the area occupied by facade units proposed by the Hong Kong government recently) (EPD, 2003) will encourage the use of prefabrication. Moreover, tighter control on workmanship, allowable tolerances, homogeneity, and allowable rework will favour the adoption of prefabrication.

CONCLUSION

Sustainability in construction is becoming more important as it is heavily valued by both developers and the government. Waste reduction in order to prolong the service lives of the landfill areas is pressing hard. Adopting prefabrication can be one of the ways to reduce material wastage. However, the adoption of prefabrication is mainly confined to public housing developments in Hong Kong. Its acceptance by the private sector is not common. Four private building projects with high levels of prefabrication are used as the case study to illustrate the effectiveness of prefabrication in waste minimization. Although there are still many difficulties in using prefabrication, including high land costs and lack of experience of site staff and workers, cutting construction wastes have been, in general, realized. Significant reduction in wastage (sometimes, the savings can be up to 100 percent) for the major construction activities including plastering, timber formwork, concrete and reinforcement was recorded. After all, the prospects of using more prefabrication techniques are very promising in Hong Kong, because prefabrication will ultimately help Hong Kong to lower the high construction cost through mechanization, standardization and industrialization. Although there are various hindrances encountered in the adoption of prefabrication such as the long haulage of prefabricated components, the lack of experiences of the industry, the reluctance of designers and consultants in adopting prefabrication which constrains design flexibility, proper training and education are needed to change the attitude of the construction industry. Further, three stimulators are proposed to facilitate and encourage the adoption of prefabrication, including implementing more stringent environmental control and regulations, highlighting the savings resulted from the more productive lean construction methods, and granting relaxation to the gross floor area for projects employing prefabrication.

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