On prefabrication implementation for different project types and procurement methods in Hong Kong

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Abstract

The use of prefabrication has been considered as one of the most effective waste minimization methods in the construction context; however, the industry has found difficulties to implement it. Contractors lack experience in using prefabrication and they do not know how to implement prefabrication to their projects effectively. This paper examines possible project types and procurement methods to maximally gain benefits of using prefabricated building components. A questionnaire survey and structured interviews have been conducted. From the results, it should be noted that residential projects and design and build procurement methods are the most effective project types and procurement methods respectively in using prefabrication. Recommendations in effectively implementing prefabrication are also made for each project type and procurement method. This brings early considerations and suggestions to project parties to improve prefabrication implementation. The effects of prefabrication implementation are also considered.

Keywords: Prefabrication, project type, procurement method, waste, construction, Hong Kong

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1 Introduction

The Hong Kong construction industry is characterized by labour-intensive wet-trade activities (Poon *et al.*, 2001). This practice has been criticized by the industry and the public for poor safety records, lengthy construction time and low quality (Chan and Ma, 1998, Construction Industry Research and Information Association, 1993, Construction Industry Research and Information Association, 1995). The use of prefabrication has been strongly advocated recently in the industry as it can help improving site safety by providing cleaner and tidier site environment, enhancing quality under factory production and eliminating site malpractices. Further, factory production can reduce waste generation and encourage recycling construction waste, leading to environmental protection and sustainability of the industry (Hendriks and Pietersen, 2000).

Prefabrication is defined as the transferring stage of construction activities from the field to an off-site production facility (Tatum, 1986). The Hong Kong Housing Authority has adopted small scale prefabrication since 1988 (Cheung *et al.*, 2002). The prefabricated elements used include precast facade units, staircases, drywall and semi-precast floor planking while structural elements still remain cast-in-situ activities. Although the construction industry has been implementing prefabrication, it was continuously encountered difficulties. This paper examines possible project types and procurement methods to maximally gain benefits of using prefabricated building components for construction projects. Questionnaire survey and structured interviews are conducted for analysis. Recommendations on effectively implementing prefabrication are also suggested for each project type and procurement method.

2 The existing prefabrication practice

Prefabrication is one of the best solutions to minimize construction waste. Although prefabrication has long been promoted in Hong Kong (Ho, 2001, Ting, 1997), its adoption is mainly confined to public housing projects. The main reason is because of high initial construction cost, time consuming in initial design development, limited site space in placing prefabricated building components, lack of experience, lack of demand in prefabricated components, water leakage problems and non-standardized design. These reasons form major obstacles to private housing projects in implementing prefabrication (Poon, et al., 2001, Poon *et al.*, 2001). Therefore, the Hong Kong industry still heavily relies on the conventional building technologies including cast-in-situ, bamboo scaffolding, timber formwork, plastering and painting. This renders labour intensive construction processes, along with poor workmanship quality and overwhelming use of multi-layered subcontractors, hampers management control and results in excessive waste generated from construction activities (Shen *et al.*, 2002).

Applications of prefabrication are prescribed by two major considerations in Hong Kong (Poon, 1997, Poon, et al., 2001, Poon, et al., 2001, Tam *et al.*, 2002, Tam *et al.*, 2006): i) high-rise building construction coupled with wind load design and typhoons situation provide risk in using structural prefabrication elements; and ii) expected monsoons and typhoons make water leakage from external envelopes as one of the critical design concerns.

Various types of prefabricated building components are usually used in the industry in which there are three major categories: i) *Semi-prefabrication* covers mainly non-structural prefabrication applications including facades, curtain walls, lost-form systems and dry-wall systems; ii) *Comprehensive prefabrication* covers structural prefabrication applications including staircases, slabs, columns and beams. Most comprehensive prefabrication is pre-finished in a fabrication yard before installation; and iii) *Modular building* is fully finished offsite as a 'one-stop' system. A 40-storey conceptual design in Integer (Integer, 2003), a newly concept applied to a prefabricated tower project, is a typical example of modular building.

Prefabrication in Hong Kong can be broadly divided into non-structural elements, structural elements and volumetric elements. The non-structural elements can be categorized under three main areas (Poon, et al., 2001, Poon, et al., 2001): i) *Facades units* are the most common prefabricated items used in the Hong Kong construction industry which is prefinished before installation. It would be more economical to utilize the facade as a structural component of building structures if technical issues on structural supporting can be resolved; ii) *Dry walls* are mainly concerning on partition walling where subsequent skim coat with painting is required; and iii) *Cooking benches*.

The structural elements include: i) *Stairs* have been used in both public housing and private projects; ii) *Semi-precast slabs* are considered as lean construction technologies and have been used in public housing and private projects; iii) *Curtain walls* are very common prefabrication items for prestige developments but it is rather luxury compared with facades; therefore there may not be suitable for low to medium-price residential developments; and iv) *Fins* for decorative purposes.

The volumetric elements normally include water tanks and bathroom units. However, both units require applications of changes and approval from relevant authorities as alternative designs / proposals.

The Hong Kong Housing Authority is a leading organization in using prefabrication for construction projects. Received feedback is positive in terms of quality, time and safety. Some satisfactory responses are listed as follows (Cheung, et al., 2002): i) Site tidiness is obviously improved, resulting in reduction in site accidents; ii) Construction speed can be improved by moving some critical site casting activities to precasting works; iii) External outlook of building structures can be varied by changing combinations of modular units; iv) In-situ grouted joints can minimize occurrence of water leakage; and v) Quality is much improved by prefabrication.

3 Research methodology

Prefabrication is considered as an effective and efficient procedure in waste minimization (Ting, 1997). However, limited research has been conducted on the effectiveness in implementing prefabrication to various construction project types and procurement methods. To examine the effective methods in using prefabrication, a questionnaire survey had been conducted between May 2002 and October 2005. Two hundred questionnaires were sent out to different project parties including governmental departments, developers, consultants, main contractors and sub-contractors. Thirty-five questionnaires were completed and returned with a response rate of about eighteen percent. Four of the questionnaires were not properly completed and only thirty one questionnaires were valid for analysis. Interviews with all questionnaire respondents were also conducted to further investigate advantages gained and disadvantages encountered in various project types and procurement methods implementing prefabrication. Details of the interviewed construction projects are shown in Table 1.

<Table 1>

In the survey, fourteen conventional construction projects were under investigation including twelve private housing projects and two public housing projects. Table 2 shows the conventional construction methods mainly used by private housing projects, while public housing projects rarely use the traditional in-situ methods which are only applicable for industrial and school projects.

<Table 2>

In addition, seventeen out of thirty-one construction projects are using semi-prefabrication for site construction activities (see Table 2). Six construction projects are private housing projects, while eleven construction projects are public housing projects. Projects using semi-prefabrication are mostly residential projects, constituting to about seventy-five percent of the semi-prefabrication projects. Other semi-prefabrication projects are commercial and office projects; however, industrial, hotel and school projects rarely use prefabricated building components.

To determine relative ranking of factors, questionnaire responses were transformed to important indices using Eq. (1) by Microsoft Excel 2003 (Tam, 2000):

Relative important index (*RII*) = $\sum \frac{w}{AN}$ ---------------------------Eq. (1)

where *w* is the weighting given to each factor by the respondent, ranging from 1 to 5 in which '1' is the least important and '5' the most important; *A* the highest weight, in this study *A*=5; *N* the total number of samples; and *RII* the relative important index, $0 \le RII \le 1$.

Three important levels in reducing construction waste by prefabrication: high (*H*) ($0.8 \le RII \le 1$), medium (*M*) ($0.5 \le RII \le 0.8$) and low (*L*) ($0 \le RII \le 0.5$), are then transformed from the RII values.

4 Characteristics of prefabrication

Applications of manufacturing technologies have been suggested for many years in the construction industry. Industrialization is a manufacturing-process aspect which uses mass production techniques to increase productivity, efficiency and product quality (Tatum, 1986). However, industrialized building techniques and methods, as solutions to waste minimization, have not been widely used.

To successfully implement prefabrication, six prerequisites are categorized (Warszawski, 1999): i) centralization of production; ii) mass production; iii) standardization; iv) specialization; v) effective organization; and vi) integration. Based on the previous findings (Ho, 2001, McDonald, 1998, Poon, 1997, Poon, 2000, Poon, et al., 2001, Poon, et al., 2001, Tam, et al., 2002, Ting, 1997, Warszawski, 1999), twenty-four characteristics on prefabrication and comments on the important level from the respondents in the survey are highlighted. Results of the survey are tabulated in Table 3.

<Table 3>

Ranking of survey results based on the characteristics of prefabrication is shown below:

1st Standardization
2nd Adopt at the design stage
3rd Repetition
4th Contractor experience
5th Dimension coordination
6th Client's requirements
7th Mass production
8th Economics of scale
9th Construction costs
10th Production continuity
11th Environmental friendly
12th Logistics
13th Contract arrangement
14th Steady supply of elements
15th Preassembly
16th Fast tracking
17th Safety
18th Tolerances
19th Less risky
20th Government policy
21st Interchangeability
22nd Predictability
23rd Regulations
24th Aesthetics

From the results, “Standardization” is found as the major characteristic of prefabrication, ranked as the first priority with a RII value of about 0.87 and highlighted as “High” important level in reducing construction waste. One of the interviewed contractors explained that production resources can be mostly efficiently utilized only if the output is standardized. Then the production process, machinery, and workers’ training can best be adapted to particular product characteristics.

“Economics of scale” ranked as 8th in the survey with a RII value of about 0.73 and highlighted as “Medium” important level in reducing construction waste. In the interview discussion, a construction organization noted that prefabrication is more economical in public housing projects than private housing projects. It should be noted that the use of prefabrication in different project types can greatly affect material prices, which are closely related to design standardization. It should also be used to explain why “Mass production” is ranked as 7th in the survey. Standard pubic housing designs can provide mass production at a lower unit-rate price, while unique-design-private-housing projects normally have a higher unit-rate price on prefabricated building components.

“Regulations” is ranked as one of the least important characteristics of prefabrication as 23rd in the survey. In the existing Hong Kong context, there is no regulation controlling the use of prefabrication in construction projects. One of the interviewed developers suggested that the government should impose regulations on controlling the use of prefabrication such as every construction project with more than $300m^2$ in floor area must use at least 60 percent of prefabricated building components. It should be noted that mandatory regulations can highly "encourage" the use of prefabrication in construction projects, particularly at the initial implementation stage.

From the results in Table 3, it is clearly shown that all characteristics of prefabrication are important for its implementation. All characteristics are highlighted in "High" or "Medium" important levels in reducing construction waste. In the interview discussion, the interviewees highlighted that to effectively implement prefabrication on site; there are many variable factors to be considered. One of the major factors is communications among project parties; an interviewed consultant suggested that partnering is one of the best approaches to help developing effective communications, which can also help developing a win-win project goal; thus more effectively implement prefabrication to reduce waste, resulting in greener environment.

5 Prefabrication on various project types

Since the Hong Kong construction industry is relying heavily on the traditional technology, especially in the private sector, management control measures were insufficient to reduce material waste on site where wet-trade activities like plastering, screening, tiling and concreting are commonly found.

In examining the effectiveness of using prefabrication to reduce waste on various construction project types, six types of construction projects were used in the questionnaire survey: residential, hotel, industrial, office, hospital and shopping mall. For each project type, the respondents were asked to comment on a significant level in reducing construction waste by selecting one of five grades, namely, least significant, fairly significant, significant, very significant and extremely significant during the prefabrication implementation. The results of the questionnaire survey are tabulated in Table 4.

<Table 4>

According to Table 4, it should be highlighted that residential buildings are the most suitable construction project types in using prefabrication to reduce waste, with a RII value of about 0.81 and highlighted as “High” important level in reducing waste. In the interview discussion, one of the governmental employees highlighted that about 65 percent of projects are residential projects. The high supply of residential housing suits fast population growth in Hong Kong. The interviewee also explained that shortening construction period is one of the main goals in their projects. Therefore, the use of standardized designs and prefabricated building components are highly encouraged.

Many respondents considered that hotel is one of the most suitable construction project types in using prefabrication with a RII value of about 0.80 and highlighted as “High” important level in reducing waste. In the discussion with one of the main contractors, they argued that every hotel project has a typical size in guestrooms, but guestroom design is very different from different rooms to suit guests. Therefore, prefabricated building components are suitable for hotel projects to reduce construction cost and to shorten construction period.

Although residential, hotel, industrial and commercial projects are suitable for prefabrication implementation, hospital and shopping malls projects are not recommended. From the results of the questionnaire survey, hospital and shopping mall projects are only ranked as the second least and the least with RII values of about 0.63 and 0.59 respectively; both are highlighted as “Medium” important levels in reducing construction waste using prefabrication. An interviewed consultant highlighted that the Hong Kong construction industry does not have enough hospital and shopping mall projects to support the supply of prefabricated building components at a competitive price. Thus, these projects are still commonly using the conventional construction methods with mostly wet-trade activities.

Based on the interview discussion, some suggestions on each project type in effectively implementing prefabrication are highlighted in Table 5. This helps the industry to provide an early implication and insight in using prefabrication.

<Table 5>

6 Prefabrication on various procurement methods

Similar to the previous sections, five significant levels in reducing construction waste are responded from least significant to extremely significant for each procurement method. Five major procurement methods are used for analysis: the traditional procurement method, design and build, management contracting, management contracting with nominated prefabricator, and strategic partnering. Table 6 summarizes results from the questionnaire survey.

<Table 6>

The traditional procurement methods are the most typical methods in the construction industry; however, an interviewed contractor explained that one of the main burdens in using this method in construction projects is the lack of contractor involvement in the design stage. It should be noted that separation of designers and contractors in handling design and construction activities largely affects project constructability. In the interview discussion, an interviewed subcontractor explained that the traditional procurement method lacks co-ordination between design and construction phases of the project, in which individual parties mainly concern on their own interests. Therefore, one of the interviewed environmental consultants explained that design and build procurement methods are highly encouraged for construction projects which help developing common interests in projects to reduce construction waste.

Design and build procurement method has a RII value of about 0.85 from the survey, which is highlighted as “High” important level in reducing construction waste. An interviewed main contractor highlighted that the involvement of contractors at the early design stage in a project can bring advantages in considering construction methods before project commencement on site and to improve project constructability. An interviewed subcontractor also explained that the involvement of construction organizations in the design stage can effectively improve the use of prefabrication in major activities including concreting, plastering and formworking, rather than wet-trade construction activities. However, a governmental department staff argued that the industry is only available to a limited number of main contractors with skills on design and construction processes, in which experienced main contractors normally charge a higher contract price with limited competition. This burdens the applications of design and build procurement methods in using prefabrication.

With the existing situation of economic downturn, construction organizations consider shortening construction time and reducing construction cost as their first priority, rather than improving their quality, environment and safety performance. One of the interviewed developers suggested using contractual requirements to mandatorily require main contractors to implement quality, environmental and safety management for their projects. This interviewee also highlighted that his company is requiring a nominated prefabricator in projects' specifications, which ensures the implementation of prefabrication in projects. From the survey results, management contracting with nominated prefabricators received a RII value of about 0.78, ranked as the second in the survey and highlighted as "Medium" important level in reducing construction waste. An interviewed governmental employee also highlighted that putting environmental requirements as part of the contractual requirements is necessary to force main contractors for the implementation as the first step. The main contractors normally lack of experience in the implementation. Initial implementation needs to be pushed from the contractual requirements; however, after the main contractor gained experience, the implementation will be an easily task.

Based on the interview discussion, some suggestions on each procurement method in effectively implementing prefabrication are highlighted in Table 7. This helps the industry to provide an early implication and insight in using prefabrication.

<Table 7>

7 Conclusion

Prefabrication has been encouraged for many years; however, the implementation of prefabricated building components is not very positive. This paper conducted a survey in examining characteristics of prefabrication and possible project types and procurement methods to maximally gain benefits of using prefabrication. Among various types of construction projects and procurement methods, residential projects and design and build procurement methods are conducted as the best practice in the implementation. Recommendations in effectively implementing prefabrication have been made on each project type and procurement method. This can promote developments of prefabrication more effectively and to fulfill future environmental requirements.

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Table 1: Details of the interviewed construction projects

Respondent	Private / public	Type of project	Method of construction
1	Private	Residential	Conventional
2	Private	Residential	Conventional
3	Private	Residential	Conventional
4	Private	Residential	Conventional
5	Private	Commercial	Conventional
6	Private	Commercial	Conventional
7	Private	Industrial	Conventional
8	Private	Industrial	Conventional
9	Public	Industrial	Conventional
10	Private	Office	Conventional
11	Private	Hotel	Conventional
12	Private	Hotel	Conventional
13	Private	School	Conventional
14	Public	School	Conventional
15	Private	Residential	Semi-prefabrication
16	Private	Residential	Semi-prefabrication
17	Private	Residential	Semi-prefabrication
18	Private	Residential	Semi-prefabrication
19	Private	Residential	Semi-prefabrication
20	Public	Residential	Semi-prefabrication
21	Public	Residential	Semi-prefabrication
22	Public	Residential	Semi-prefabrication
23	Public	Residential	Semi-prefabrication
24	Public	Residential	Semi-prefabrication
25	Public	Residential	Semi-prefabrication
26	Public	Residential	Semi-prefabrication
27	Private	Commercial	Semi-prefabrication
28	Public	Commercial	Semi-prefabrication
29	Public	Office	Semi-prefabrication
30	Public	Office	Semi-prefabrication
31	Public	Office	Semi-prefabrication

Table 2: Measured conventional and semi-prefabrication construction projects in Hong Kong

	Conventional		Semi-prefabrication	
	Private housing	Private housing	Public housing	Public housing
Residential	4 (28.7%)	4 (28.7%)	5 (31%)	7 (44.5%)
Commercial	2 (14.3%)	2 (14.3%)	1 (6%)	1 (6%)
Industrial	2 (14.3%)	2 (14.3%)	-	-
Office	1 (7.1%)	1 (7.1%)	0 (0%)	2 (12.5%)
Hotel	2 (14.3%)	2 (14.3%)	-	-
School	1 (7.1%)	1 (7.1%)	-	-

Table 3: Prefabrication characteristics

Ranking	Characteristics	Least significant	Fairly significant	Significant	Very significant	Extremely significant	Total	Standard deviation	RII	Important Level
1	Standardization	0	1	2	13	15	31	1.98	0.87	H
2	Adopt at the design stage	0	2	7	9	13	31	1.73	0.81	H
3	Repetition	0	2	7	11	11	31	1.68	0.80	H
4	Contractor experience	0	1	8	15	7	31	1.47	0.78	M
5	Dimension coordination	0	3	7	13	8	31	1.71	0.77	M
6	Client's requirements	3	3	1	15	9	31	1.56	0.75	M
7	Mass production	1	3	5	15	7	31	1.49	0.75	M
8	Economics of scale	1	6	4	12	8	31	1.44	0.73	M
9	Construction costs	1	4	7	13	6	31	1.56	0.72	M
10	Production continuity	1	3	9	12	6	31	1.57	0.72	M
11	Environmental friendly	0	5	12	8	6	31	1.46	0.70	M
12	Logistics	0	5	9	14	3	31	1.55	0.70	M
13	Contract arrangement	2	4	8	12	5	31	1.67	0.69	M
14	Steady supply of elements	0	4	10	16	1	31	1.62	0.69	M
15	Preassembly	3	3	8	14	3	31	1.65	0.67	M
16	Fast tracking	1	5	11	11	3	31	1.43	0.66	M
17	Safety	3	8	5	9	6	31	1.69	0.65	M
18	Tolerances	4	6	7	8	6	31	1.47	0.64	M
19	Less risky	7	5	7	6	6	31	1.40	0.59	M
20	Government policy	4	7	11	5	4	31	1.56	0.59	M
21	Interchangeability	3	9	6	12	1	31	1.51	0.59	M
22	Predictability	3	6	15	6	1	31	1.65	0.57	M
23	Regulations	4	6	12	9	0	31	1.46	0.57	M
24	Aesthetics	8	3	11	6	3	31	1.69	0.55	M

Table 4: Prefabrication on various project types

Project type	Least significant	Fairly significant	Significant	Very significant	Extremely significant	Total	Standard deviation	RII	Important Level
Residential	0	2	0	24	5	31	1.49	0.81	H
Hotel	0	0	8	16	8	31	1.51	0.80	H
Industrial	2	3	5	15	7	31	1.50	0.74	M
Commercial	0	5	8	12	7	31	1.61	0.73	M
Hospital	3	4	10	15	0	31	1.3	0.63	M
Shopping mall	3	8	8	13	0	31	1.44	0.59	M

Table 5: Suggestions on the use of prefabrication in various project types

Project type	Suggestions
Residential	High supply of residential buildings for fast population growth. Thus, shortening construction time is important. Standardized designs using prefabrication are highly encouraged.
Hotel	A typical guestroom size can easily implement prefabrication. To attract guests, guestroom designs need to be different in different rooms.
Industrial	As industrial buildings are not necessary to provide special designs, typical external designs and factory sizes are commonly used in Hong Kong. This shows the benefits of using prefabrication.
Commercial	Commercial buildings require special designs externally and internally. As it is normally unique in the design, use of prefabrication is not common. The most typical prefabricated element used in commercial buildings is the partition wall, which is used to separate rooms and to provide an individual room area for each staff member.
Hospital	Hong Kong does not have enough hospital and shopping mall projects to support prefabrication at a competitive price. The interviewees suggested using partition walls, similar as other projects, to separate rooms.
Shopping mall	

Table 6: Prefabrication on various procurement methods

Procurement method	Least significant	Fairly significant	Significant	Very significant	Extremely significant	Total	Standard deviation	RII	Important Level
Traditional	4	1	15	11	0	31	1.56	0.62	M
Design and build	0	1	1	17	12	31	1.51	0.85	H
Management contracting	0	5	17	7	2	31	1.54	0.64	M
Management contracting with nominated prefabricator	0	1	4	24	2	31	1.41	0.78	M
Strategic partnering	3	1	7	17	2	31	1.41	0.70	M

Table 7: Suggestions on the use of prefabrication for various procurement methods

Procurement method	Suggestions
Traditional	Lack of contractor involvement in the design stage largely affects project constructability and the use of prefabrication. Suggestions to use prefabrication are early involvements of contractors in the design stage or educate designers with necessary construction skills.
Design and build	Involvement of a contractor at the early design stage in a project can bring advantages by considering construction methods before project commencement on site and to improve project constructability. This shows the effectiveness of prefabricated building components at the early stage of projects.
Management contracting	
Management contracting with nominated prefabricator	Putting environmental requirements as part of contractual requirements is necessary to force main contractors to implement prefabrication at the first step. The main contractors normally lack experience in the implementation. Initial implementation needs to be pushed from the contractual requirements; however, after the main contractor gained experience, the implementation will be an easily task.
Strategic partnering	Strategic partnering is one of the best approaches to encourage the use of prefabrication in projects. As strategic partnering encourages various project parties to achieve a common goal in a “win-win” situation. Different project parties can raise their ideas and suggestions for the projects to achieve better performance. Use of prefabrication can reduce construction waste, shorten construction period and reduce construction cost, which are commonly suggested for projects using strategic partnering.