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AN EXAMINATION ON THE PRACTICE OF ADOPTING PREFABRICATION FOR CONSTRUCTION PROJECTS

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Abstract
Generation of construction and demolition waste has becoming a pressing issue around the world. Waste minimization has been on the agenda of various organizations including clients, designers, contractors and suppliers. However, one of its major problems is the lack of environmental support from project parties. To implement waste minimization effectively, adoption of prefabricated building components should be implemented. This paper investigates an efficient approach in adopting prefabricated components in various building elements for various project types including general projects, public housing, private residential and commercial projects. Detailed surveys are conducted based on six major building elements: substructure, drainage and underground services, structural frame, external works, internal works and building services. From that, the effectiveness of using prefabrication in the practice can be examined. This examination also leads to the introduction of an efficient approach. Various project parties can clearly understand how to efficiently adopt prefabrication which brings direct benefit to environmental construction organizations.

Keywords
Prefabrication, waste management, environmental management, construction.

INTRODUCTION

Significant generation of construction and demolition waste is considered as major impacts to the environment [1]. Waste is defined as by-products generated and removed from construction, renovation and demolition workplaces or sites of building and civil engineering structures [1]. With the demands in implementing major infrastructure projects, together with many commercial building and housing redevelopment programmes, a large amount of construction waste has been produced. Furthermore, excessive wastage of raw materials, improper waste management and low awareness of the need for waste reduction are major difficulties in implementing waste minimization.

Existing works have proposed various waste management approaches. Petts [2] proposed proactive community involvement in implementing waste management, and suggested a consensus in public building to control waste generation and mitigate waste impacts for the environment. Coffey [3] pointed out that construction solid waste management is generally seen as a low priority when financial constraints are present and suggested that considerable waste reduction can be achieved if waste management is implemented as part of project management functions. He further suggested that whilst the choice of the optimum waste handling methods should be determined by considering the cost implications, any practices, which induce waste reduction, should be encouraged. The provision for training and educating staff are considered as effective approaches in implementing waste management [4, 5]. However, employee participation can only be effective with genuine support from top management [4]. In fact, a previous survey reported that waste management has received less attention from senior business management compared with construction cost and time [5]. The cost for implementing waste management is often given higher priority than possible benefits that the organization can gain from the implementation.

Poon *et al.* [6] indicated that about 5 to 10 percent of building materials ended up as waste on building sites. There are many contributory factors to these figures; Table 1 highlights some of these.

Table 1 Causes and Examples of Building Waste on Site [12, 18, 6, 19]

Building waste	Causes of building waste on site	Examples
Site management and practices	Lack of a quality management system aimed at waste minimization	Lack of waste management plan
	Untidy construction sites	Waste materials are not segregated from useful materials
	Poor handling	Breakage, damage, losses
	Over-sized foundations and other elements	Over design leads to excess excavation and cut-offs
	Inadequate protection to finished work	Finished concrete staircases are not protected by boarding
	Limited visibility on site resulting in damage	Inadequate lighting in covered storage area
	Poor storage	Pallet is not used to protect cement bags from contamination by ground water
	Poor workmanship	Poor workmanship of formwork
	Waste generation inherited with traditional construction method	Timber formwork, wet trade
Delivery of products	Over-ordering	Over ordering of concrete becomes waste
	Method of packaging	Inadequate protection to the materials
	Method of transport	Materials drop from forklift
	Inadequate data regarding time and method of delivery	Lack of records concerning materials delivery

Although waste generation is serious in the construction industry, there are many possibilities in disposing construction and demolition waste, from recycling to incineration and landfilling. Five waste management actions had been recommended by the Waste Reduction Framework Plan [7]: (1) Waste avoidance: waste should not be produced in the first place, for example, packaging should not be used unless essential; (2) Waste minimization: if waste production is unavoidable, the quantities should be minimized. Essential packaging, for example, should be designed to minimize the materials used; (3) Waste recovery, recycling and reuse: the recovery, recycling and reuse of suitable waste materials should be maximized; for example, using a producer responsibility scheme to recover waste packaging for reusing; (4) Waste bulk reduction: if it is not possible to recover, recycle or reuse the waste materials, the volume of residual wastes should be reduced before final disposal, this might involves incineration or composting; and (5) Waste disposal: wherever possible the residue left after bulk reduction will be used for construction purposes or reclamation in preference to being dumped in the landfills.

The best way to deal with material waste is not to create it in the first place [8, 9]. Table 2 summarizes the problems of current practices and the recommended measures for controlling construction pollutions at the management and operational levels. Four management measures are highlighted including: i) policy; ii) training; iii) audit; and iv)feedback and two operational measures on design and construction stages are also be considered.

Table 2 Problems and Recommended Measures for Controlling Construction Waste by Previous Researchers [20-22, 3, 8, 23, 24, 4, 25-31, 12, 6, 19, 5, 32, 9, 33-36]

	Management Level				Operational Level	
	Policy	**Training**	**Audit**	**Feedback**	**Design**	**Construction**
Aim	Enhance environmental awareness and company culture	Provide benchmarking measures in understanding the weaknesses		Achieve continuous improvement	Have an early planning for the environmental issues	Ensure all construction wastage had been minimized by all means
Problems	Waste management as a low priority in a project	Insufficient training provided and lack of knowledge on waste minimization technology	Normally no benchmarking tool provided in an organization	No encouragement to provide feedback	Lack of consideration of environmental issues in the design stage	Waste generation is increasing
Measures	•Set up environmental policy •Demonstrate greater commitment to waste management •Implement waste management plan •Consider reduction of construction waste and awareness of environmental protection as basic requirements in building management	•Provide training programme to all levels of employees	•Provide benchmarking measures for understanding the problems of the current measure and provide some improvements •Incentive reward scheme	•Provide feedback loop from the public and in-house employees •Improve building construction technology by research or adoption	•Use long-life construction materials, such as steel •Consider dimensional coordination construction •Minimize variations •Flexible design •Purchasing quantity of materials just required •Consider site selection •Provision of adequate information on maintenance •Clear specification •Use environmental- friendly construction method and modular design, such as prefabrication •Avoid buying poor quality materials •Coordinate with designer and specification writer to use recyclable materials	•Reuse, recycle and reduction •Good site planning •Separation of construction materials •Well-organized site and proper storage facilities •Use of secondary materials •Avoid complex and labour intensive works •Labeling of construction materials •Effective logistics •Agreements with subcontractors •Avoid overloading limited storage space on site •Avoid unnecessary handling •Less packaging or reusable packaging •Adopt just-in-time ordering •Avoid damage while unpacking on site •Order appropriate material sizes to minimize cutting, and order appropriate quantities to avoid excess •Designate central areas for cutting and storage so reusable pieces can easily be located •Review waste management periodically to identify additional waste reduction alternatives •Employ competent subcontractors and skill labourers

In recent years, waste reusing and recycling have been promoted to reduce waste generation and protect the environment. However, the effectiveness of the applications has been largely limited because of insufficient support is applying in these approaches [10]. These include proper site location and equipment for sorting waste, good experience in waste recycling operations, trained supervisors and employees, knowledge of secondary materials markets and knowledge of environmental and safety regulations.

In recent years, prefabricating building components has been promoted for waste minimization in construction. This paper explores major efficient approaches in adopting prefabrication. The objectives of the paper are: i) examining waste management strategies in construction organizations; ii) investigating existing prefabrication practices; and iii) developing an efficient approach in adopting prefabrication for various types of projects including general projects, public housing, and private residential and commercial projects.

WASTE MANAGEMENT STRATEGY

Uncollected construction solid waste has becoming a major health hazard [11]. Construction waste contributed almost 40% to all types of solid waste in landfill areas [12]. Three main landfills areas are now being used in Hong Kong, namely, South East New Territories (SENT), North East New Territories (NENT) and West New Territories (WENT) (see Figure 1). However, it is expected that these landfill sites will be full in capacity within 10 to 15 years [7] (see Table 3 and Table 4).

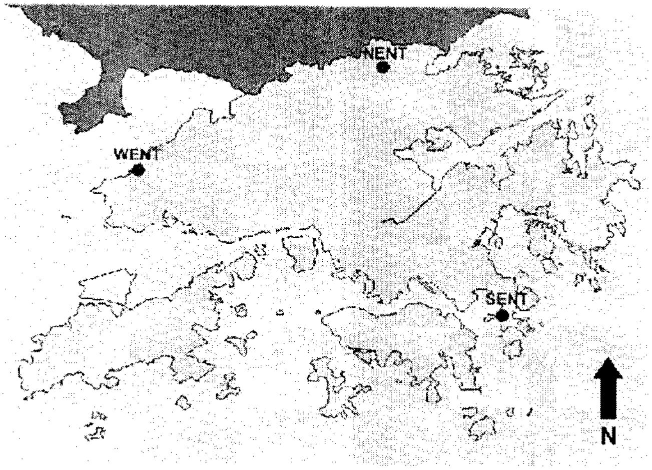


Figure 1 Location of existing strategic landfilles [16]

Table 3 Landfill void space consumption [13]

Landfills	Void space consumption (end 2000) Design capacity	Percentage consumption	Remaining capacity
SENT	43.1 Mm^3	34%	28.6 Mm^3
NENT	35.0 Mm^3	20%	28.1 Mm^3
WENT	61.9 Mm^3	15%	52.8 Mm^3

Notes:
South East New Territories – SENT;
North East New Territories – NENT; and
West New Territories – WENT

Table 4 Landfill life expectancy [13]

	Landfill life expectancy		
	Optimistic scenario	**Pessimistic scenario**	**Worst scenario**
Waste growth	Low	High	High
Achieve waste reduction targets	✓	×	×
Sufficient public fill outlets	✓	✓	×
SENT	2012	2010	2005
NENT	2016	2013	2007
WENT	2018	2013	2008

Notes:
South East New Territories – SENT;
North East New Territories – NENT; and
West New Territories – WENT

Conventional construction methods consisting of extensive cast-in-situ activities are now being widely adopted. Although conventional methods still offer immediate available solutions to the given problems, large quantities of unwanted but useful surplus materials are running out of disposal areas [5]. For sustainable development and to conserve landfill capacity, there is an urgent need for the industry to adopt certain new construction methods or technologies which can be effectively used to reduce wastage generation [13]. As a result, prefabrication is currently adopted in European countries, Japan and Singapore to resolve these problems.

Recently environmental-friendly construction methods have been proposed such as using large panel systems, applying prefabrication components, and reducing applications of wet trade [14]. However, applications of these methodologies should be considered as part of project management functions and should involve employees' participation [5]. It is suggested designing specific training and education programs for different levels of employee to achieve effective employee participation with genuine support from management. In fact, a previous survey indicated that waste management has received less attention from senior management in the business than company profit [5]. The main reason for this is that the cost in implementing waste management is given higher priority than the possible benefits that the organization can gain from the implementation [5].

RESEARCH SURVEY

To examine an efficient methodology in adopting prefabrication for various project types in Hong Kong construction, a structured survey was undertaken. Four major types of building projects are investigated: i) general project; ii) public housing; iii) private residential; and iv) commercial projects. Six major types of building activities are examined: i) substructure; ii) drainage and underground services; iii) structural frame; iv) external works; v) internal works; and vi) building services.

Two hundred questionnaires were sent out to various project parties which included governmental departments, developers, consultants, main contractors and sub-contractors. Seventy responses had been completed and returned, corresponding to a response rate of around 35 percent. However, six of the questionnaires were not properly completed and only sixty-four questionnaires were valid for the analysis.

Six interview discussions were also conducted to clarify and provide in-depth explanation of the questionnaire survey results. The interviewees were from one governmental department, one developer, two consultants, one main contractor and one sub-contractor.

THE EXISTING PREFABRICATION PRACTICES

Manufacturing technologies to the construction industry have been applied for many years so that organizations remain competitive in the emerging global economy which is a basic requirement. Industrialization, such as prefabrication of building components, is critical to achieve the competitiveness [15]. Many prefabrication technologies deliver a better product because of the quality control of prefabrication components.

Four major systems of construction methods, namely, conventional, semi-prefabrication, comprehensive prefabrication and volumetric off-site fabrication were summarized and are given below [16]:

i) *Conventional construction* is the most traditional construction method where all the construction activities are in-situ practices on site;

ii) *Semi-prefabrication* divides as two sub-categories: system formwork and non-structural semi-prefabrication, involving a part of in-situ construction activities and a part of prefabrication. Normally, the non-structural semi-prefabrication is applied on facade, curtain walls, lost form systems and dry wall systems;

iii) *Comprehensive prefabrication* involves a structural part and pre-finished construction. Examples of applications of structural comprehensive prefabrication include staircases, slabs, columns and beams; and

iv) *Volumetric off-site fabrication* encloses usable space but does not constitute the whole building. Volumetric off-site fabrication is mainly used for 'facilities' and includes solutions on office washrooms, plant rooms, building services risers and lifts.

AN EFFICIENT APPROACH IN ADOPTING PREFABRICATION

In this section, an efficient approach in adopting prefabrication for various types of projects is discussed. Surveys on six building elements, including substructure, drainage and underground services, structural frames, external works, internal works and building services to suggest the most suitable construction methods out of methods of conventional, semi-prefabrication, comprehensive prefabrication or volumetric off-site fabrication. Various project types, including general projects, public housing, private resident and commercial projects, are used for comparison.

For the general projects, it was found that about 100% and 96.3% of the respondents suggested using conventional methods for construction in foundation and basement respectively (see Table 5). One of the main contractors interviewed explained that foundation and basement were non-standardized designs and may be subject to change according to the underground conditions. This is difficult if adopting prefabrication or predicted it beforehand. Therefore, the conventional construction method is still encouraged for substructure.

Although some respondents suggested the prefabrication method for drainage and underground services, about 76%, 69.2% and 48.1% of the respondents suggested adopting conventional method for plant and equipment, piling and manholes respectively. In the interview discussions, a specialized subcontractor argued that both drainage and underground services are different for different projects. Adopting standard ranges of prefabrication is unsuitable for most of the projects. It should be more convenient and suitable in adopting cast in-situ installation rather than prefabrication.

Table 5 Respondents on the effectiveness in adopting prefabrication for the general projects

Building elements	Sub-elements	Conventional	Semi-prefabrication		Comprehensive prefabrication		Volumetric
			System formwork	Non-structural	Structural	Pre-finished	Modular building
Substructure	Foundation	100%	0%	0%	0%	0%	0%
	Basement	96.3%	3.7%	0%	0%	0%	0%
Drainage and underground services	Manhole	48.1%	7.4%	11.1%	29.6%	3.7%	0.0%
	Piling	69.2%	0.0%	11.5%	11.5%	7.7%	0.0%
	Plant and equipment	76.0%	0.0%	4.0%	8.0%	8.0%	4.0%
	Column	48.1%	37.0%	0.0%	11.1%	3.7%	0.0%
Structural frame	Beam	48.1%	37.0%	3.7%	7.4%	3.7%	0.0%
	Bearing wall	42.3%	26.9%	3.8%	19.2%	3.8%	3.8%
	Lift shaft	46.4%	28.6%	7.1%	7.1%	7.1%	3.6%
	Stairs	20.0%	30.0%	0.0%	30.0%	13.3%	6.7%
	Slab	20.0%	30.0%	0.0%	30.0%	13.3%	6.7%
External works	External wall	20.7%	17.2%	10.3%	20.7%	20.7%	10.3%
	Roof	66.7%	11.1%	3.7%	11.1%	7.4%	0.0%
Internal works	Partition wall	16.7%	10.0%	20.0%	16.7%	23.3%	13.3%
	Plastering	48.3%	3.4%	6.9%	6.9%	24.1%	10.3%
	Tiling	48.4%	3.2%	3.2%	9.7%	22.6%	12.9%
	Washroom	43.3%	0.0%	10.0%	10.0%	20.0%	16.7%
	Kitchen	40.7%	0.0%	14.8%	7.4%	22.2%	14.8%
Building services	Distribution ductwork	59.3%	0.0%	22.2%	7.4%	11.1%	0.0%
	Plant room	76.9%	0.0%	11.5%	3.8%	0.0%	7.7%
	Lift	67.9%	3.6%	7.1%	7.1%	10.7%	3.6%
	Escalator	63.0%	3.7%	7.4%	11.1%	7.4%	7.4%

On the structural frame, the majority of the respondents recommended using conventional construction methods of about 48.1%, 42.3%, 46.4% and 20% on columns and beams, bearing walls, lift shafts, and stairs and slabs respectively. System formwork was ranked as the second recommended construction method for structural frames with 37%, 26.9%, 28.6% and 30% on columns and beams, bearing walls, lift shafts, and stairs and slabs respectively. One of the interviewed governmental departments encouraged adopting system formwork for structural frames to enhance the performance, productivity and waste reduction. He also suggested compulsory control in the adoption of system formwork for structural framework as one of the specification requirements. However this implementation is dependent on the project nature.

For the elements of external works, about 51.4% of the respondents argued that adopting comprehensive prefabrication on external walls can achieve waste minimization in construction. One interviewed consultant highlighted that adopting external facades currently is the most popular prefabrication method for external wall practices. It can also improve the appearance of the building outlook and reduces waste generation by generating wet-trade activities.

The survey results recommended adopting conventional construction method for applications in internal works such as plastering, tiling, washroom and kitchen, with about 48.3%, 48.4%, 43.3% and 40.7% of respondents respectively. In the interview discussions, one developer strongly encouraged the fundamental perception of applying internal works with prefabrication which can be economical in the long term.

In the current construction practice, escalators, lifts and distribution ductworks are prefabricated offsite for site installation. However, the majority of the respondents suggested the conventional construction method with about 76.9%, 67.9%, 63% and 59.3% on plant rooms, lifts, escalators and distribution ductworks construction respectively. One of the interviewed main contractors argued that prefabrication is becoming a norm of distribution ductwork, plant rooms, escalators and lifts, conventional constructions shall only refer to site installation of the prefabricated product.

After discussing the general project, the following compares the efficiency in adopting prefabrication in public housing, private residential and commercial projects. Many construction projects are carried out by public housing to solve the problems of current housing issues. However, private residential developments have become the new trends in the changing economies of Hong Kong. Waste generation on construction and demolition activities, public housing, private residential and commercial projects contribute to large amount of the total generated waste. The efficiency in adopting prefabrication for these three types of projects are surveyed and summarized in Tables 6, 7 and 8.

In comparing the recommended construction methods for public housing, private residential and commercial projects, it was found that the conventional construction method is nearly 100% recommended for the foundation and basement construction in substructures for all project types. During discussions, interviewees highlighted that for unexpected circumstances in the underground environment, it would be more suitable to adopt conventional construction methods.

Comprehensive prefabricated construction methods were suggested for the development of pubic housing projects on structural frames with responses of about 33.3%, 50%, 33.3%, 50% and 66.6% in columns, beams, bearing walls, lift shafts and stairs, and slabs respectively and responses of about 100% and 33.3% in external walls and roofs respectively (see Table 6). On

Table 6 Respondents on the effectiveness in adopting prefabrication for public housing

Trade	Elements	Conventional	Semi-prefabrication		Comprehensive prefabrication		Volumetric
			System formwork	Non-structural	Structural	Pre-finished	Modular building
Substructure	Foundation	100%	0%	0%	0%	0%	0%
	Basement	100%	0%	0%	0%	0%	0%
Drainage and underground services	Manhole	66.7%	0.0%	0.0%	33.3%	0.0%	66.7%
	Piling	66.7%	0.0%	0.0%	33.3%	0.0%	66.7%
	Plant and equipment	66.7%	0.0%	0.0%	0.0%	33.3%	66.7%
Structural frame	Column	33.3%	33.3%	0.0%	0.0%	33.3%	33.3%
	Beam	50.0%	0.0%	0.0%	25.0%	25.0%	50.0%
	Bearing wall	33.3%	33.3%	0.0%	0.0%	33.3%	33.3%
	Lift shaft	50.0%	0.0%	0.0%	0.0%	50.0%	50.0%
	Stairs	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%
	Slab	0.0%	0.0%	0.0%	33.3%	33.3%	0.0%
External works	External wall	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%
	Roof	66.7%	0.0%	0.0%	0.0%	33.3%	66.7%
Internal works	Partition wall	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%
	Plastering	25.0%	0.0%	0.0%	25.0%	50.0%	25.0%
	Tiling	25.0%	0.0%	0.0%	25.0%	25.0%	25.0%
	Washroom	25.0%	0.0%	0.0%	25.0%	25.0%	25.0%
	Kitchen	25.0%	0.0%	0.0%	25.0%	25.0%	25.0%
Building services	Distribution ductwork	66.7%	0.0%	0.0%	0.0%	33.3%	66.7%
	Plant room	66.7%	0.0%	0.0%	0.0%	0.0%	66.7%
	Lift	66.7%	0.0%	0.0%	0.0%	33.3%	66.7%
	Escalator	66.7%	0.0%	0.0%	0.0%	0.0%	66.7%

Table 7 Respondents on the effectiveness in adopting prefabrication for private residential

Trade	Elements	Conventional	Semi-prefabrication		Comprehensive prefabrication		Volumetric
			System formwork	Non-structural	Structural	Pre-finished	Modular building
Substructure	Foundation	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Basement	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Drainage and underground services	Manhole	42.9%	0.0%	28.6%	28.6%	0.0%	42.9%
	Piling	71.4%	0.0%	28.6%	0.0%	0.0%	71.4%
	Plant and equipment	71.4%	0.0%	14.3%	14.3%	0.0%	71.4%
Structural frame	Column	71.4%	14.3%	0.0%	14.3%	0.0%	71.4%
	Beam	57.1%	28.6%	0.0%	14.3%	0.0%	57.1%
	Bearing wall	57.1%	14.3%	0.0%	28.6%	0.0%	57.1%
	Lift shaft	71.4%	14.3%	0.0%	14.3%	0.0%	71.4%
	Stairs	12.5%	12.5%	0.0%	62.5%	12.5%	12.5%
	Slab	12.5%	12.5%	0.0%	62.5%	12.5%	12.5%
External works	External wall	11.1%	0.0%	11.1%	33.3%	44.4%	11.1%
	Roof	57.1%	0.0%	14.3%	28.6%	0.0%	57.1%
Internal works	Partition wall	0.0%	11.1%	22.2%	22.2%	44.4%	0.0%
	Plastering	25.0%	12.5%	12.5%	12.5%	37.5%	25.0%
	Tiling	40.0%	10.0%	0.0%	20.0%	30.0%	40.0%
	Washroom	22.2%	0.0%	22.2%	22.2%	33.3%	22.2%
	Kitchen	33.3%	0.0%	22.2%	11.1%	33.3%	33.3%
Building services	Distribution ductwork	42.9%	0.0%	42.9%	14.3%	0.0%	42.9%
	Plant room	71.4%	0.0%	28.6%	0.0%	0.0%	71.4%
	Lift	71.4%	0.0%	28.6%	0.0%	0.0%	71.4%
	Escalator	71.4%	0.0%	28.6%	0.0%	0.0%	71.4%

Table 8 Respondents on the effectiveness in adopting prefabrication for commercial projects

Trade	Elements	Conventional	Semi-prefabrication		Comprehensive prefabrication		Volumetric
			System formwork	Non-structural	Structural	Pre-finished	Modular building
Substructure	Foundation	90.9%	9.1%	0.0%	0.0%	0.0%	90.9%
	Basement	76.9%	23.1%	0.0%	0.0%	0.0%	76.9%
Drainage and underground services	Manhole	25.0%	0.0%	0.0%	75.0%	0.0%	25.0%
	Piling	25.0%	0.0%	25.0%	25.0%	25.0%	25.0%
	Plant and equipment	50.0%	0.0%	0.0%	0.0%	25.0%	50.0%
Structural frame	Column	0.0%	75.0%	0.0%	25.0%	0.0%	0.0%
	Beam	0.0%	75.0%	0.0%	25.0%	0.0%	0.0%
	Bearing wall	25.0%	50.0%	0.0%	25.0%	0.0%	25.0%
	Lift shaft	25.0%	50.0%	0.0%	25.0%	0.0%	25.0%
	Stairs	0.0%	60.0%	0.0%	20.0%	20.0%	0.0%
	Slab	0.0%	60.0%	0.0%	20.0%	20.0%	0.0%
External works	External wall	25.0%	25.0%	50.0%	0.0%	0.0%	25.0%
	Roof	40.0%	20.0%	0.0%	20.0%	20.0%	40.0%
Internal works	Partition wall	50.0%	0.0%	25.0%	0.0%	0.0%	50.0%
	Plastering	50.0%	0.0%	0.0%	0.0%	25.0%	50.0%
	Tiling	50.0%	0.0%	0.0%	0.0%	25.0%	50.0%
	Washroom	50.0%	0.0%	0.0%	0.0%	0.0%	50.0%
	Kitchen	0.0%	0.0%	50.0%	0.0%	0.0%	0.0%
Building services	Distribution ductwork	20.0%	0.0%	40.0%	20.0%	20.0%	20.0%
	Plant room	25.0%	0.0%	25.0%	25.0%	0.0%	25.0%
	Lift	16.7%	16.7%	0.0%	33.3%	33.3%	16.7%
	Escalator	16.7%	16.7%	0.0%	33.3%	33.3%	16.7%

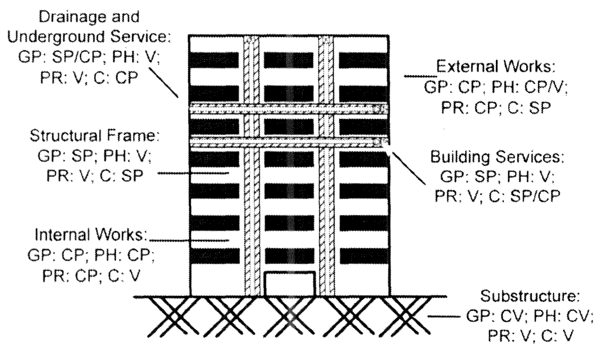
the other hand, conventional construction methods for un-standardized design layouts were recommended for adoption in private residential and commercial projects.

Although conventional construction methods are adopted in the construction of housing and commercial developments, according to the survey, building services on commercial projects were recommended adopting semi-prefabrication and comprehensive prefabrication of 40% and 40%, 25% and 25%, and 16.7% and 66.6% for distribution ductwork, plant rooms, and lifts and escalator constructions respectively. One of the interviewed developers pointed out that these results may come from practices in adopting similar-sized building services for commercial and office designs.

Survey results indicate there is tendency to adopt modular prefabrication for washrooms in public housing and private residential, since it satisfies the key characteristics of prefabrication standardization, repetition, and mass production [17].

Based on the survey results and discussions with interviewees, five major building elements meeting the basic prerequisite requirements in adopting prefabricated building components are: i) steel structural frame; ii) prefabricated external cladding; iii) prefabricated concrete slab; iv) comprehensive prefabricated washroom; and v) dry wall system. Since most of the prefabrication products are load bearing, the development of lightweight prefabrication should also be introduced to reduce the cost on materials and transportation in construction.

A summary of the efficient approach in adopting prefabrication for various types of projects and building activities is shown in Figure 2.



Note:
GP: General Project; PH: Public Housing; PR: Private Residential; C: Commercial Project; CV: Conventional; SP: Semi-Prefabrication: CP: Comprehensive Prefabication: V: Volumetric

Figure 2 Summary of Effective Approaches in Adopting Prefabrication for Various Project Types

CONCLUSION

This paper has shown that waste management is an important issue in construction and prefabrication can be effectively used to solve waste generation on site activities. The paper explores the efficiency of adopting prefabrication for general projects, public housing, private residential and commercial projects. From that, five major building elements have been shown efficient in adopting prefabricated building components, namely : i) steel structural frame; ii) prefabricated external cladding; iii) prefabricated concrete slab; iv) comprehensive prefabricated washroom; and v) dry wall system. For further work on this study, a case study approach in adopting these five major building elements will be provided in a separate publication.

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