Assessing the Levels of Material Wastage Affected by Subcontracting Relationships and Projects Types with Their Correlations

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Abstract

A significant amount of solid wastes are produced every year from construction and demolition activities, and construction wastes have become the major sources among them; the increasing generation of construction wastes has caused significant pollution to the environment and risen public concern. Therefore, the minimization of construction wastes has become a pressing issue in the Hong Kong construction industry. This paper investigates the generation of construction waste on site and their relations with prevailing subcontracting arrangements and projects types in Hong Kong. This investigation will lead to the identification of the major waste generation areas on construction sites. Nineteen construction projects are under in-depth interviews for collecting the relevant data and information for the analysis to the local construction industry. By using the findings of this research, four methods are proposed to mitigate the generation of wastes by reshaping the current practices of construction projects. These methods are: i) development of cost-effective approach; ii) integrated waste minimization on the tender stage; iii) provision and motivation of waste reduction training; and iv) a waste control system as part of site management functions.

Keywords: Construction, material wastage, waste management, subcontracting, project type, Hong Kong

1. Introduction

In line with the recognition that wastes from construction and demolition (C&D) works significantly contribute to the polluted environment, waste management in construction activities has been increasingly promoted with the aim of protecting the environment [1-3]. Previous works suggested that the construction industry in Hong Kong plays a vital role in meeting the needs of its society and enhancing its quality of life [4-5]. The industry remains as a major economic sector, thus the pollution generated from construction activities continuously presents a major challenge to implement environmental management in practice. Whilst various management methods have been developed, the best way to deal with material wastes is not to create them in the first place [6-8].

The environmental pollution resulted from construction in Hong Kong has become a pressing issue. The construction waste remains at an average of 15% growth rate every year [9]; Figure 1 shows the quantities of C&D wastes disposed of from 1991 to 2001. The Hong Kong government adopts a policy of disposing the waste to either land reclamation or landfills. In fact, landfill has been traditionally considered a convenient and cost-effective solution to the wasteful practices of the industry [10]. Ferguson *et al.* [11] found that more than 50% of the wastes deposited in a typical landfill in the United Kingdom come from construction wastes. According to Rogoff and Williams [12], 29% of solid-wastes in the United States of American are construction wastes. These investigations demonstrated that construction business is a large contributor to waste generation, and that to effectively protect the environment; construction wastes must be properly managed. In particular, it becomes a concern issue to reduce construction waste in Hong Kong as previous studies suggested that the landfills in Hong Kong would be filled up by 2010, even if there were adequate outlets of C&D materials [13].

<Figure 1>

The benefits of managing construction wastes are multiple. The economic and environmental benefits to be gained from waste minimisation and recycling are enormous, since it will benefit both the environment and the construction firms in terms of cost reduction [14]. The economic benefits of waste minimisation and recycling include the possibilities of selling specific waste materials and the removal from site of other wastes at no charge or at a reduced cost, with a subsequent reduction in materials going to landfill at a higher cost [6]. Therefore, waste minimization practice can increase contractors' competitiveness through lower production costs and a better public image. However, previous studies showed that very few contractors spent efforts in considering the environment and in developing new concepts of recycling building materials [15]. Contractors in Hong Kong rank timing as their top priority, thus their effort is always focused on completing the project in the shortest time, rather than environmentally friendly [16]. In fact, it is evidenced in other studies that managing building material waste can achieve higher construction productivity, save time and achieve the safety improvement [7,17-18], while additional wastes take extra time and resources for disposal that may slow down the construction progress.

2. Research Objectives

The aim of this paper is to:

- i) Find out the most wasteful construction materials during construction activities;
- ii) Investigate the wastage levels on the practice of various subcontracting arrangement and types of projects; and
- iii) Formulate the solutions for mitigating waste generation.

3. Classification of On-Site Materials Wastage

Wastages of building materials can be defined as the remains of the materials delivered on site after being used in the built work. The application of building materials can generate various types of wastes. Five major types of building material, including concrete, reinforcement, formwork, brick and block, tile are under examination. The sources where waste may present and the typical reasons why these materials can be wasted are highlighted in Table 1 [19].

<Table 1>

3.1 Concrete (M_1)

Concrete is the most widely used material for buildings structures. Concrete wastage is mainly resulted from excess quantity of ready mix concrete. There are variations and errors in calculating the quantity of needed concrete because of improper planning or poor communication, which results in over-ordering. A certain amount of concrete wastages also occurs during transportation, in which it may settle over a long period and cannot be used for construction activities. Because of the congested traffic in Hong Kong, one of the interviewed project managers explained that their concrete wastage due to the settlement of long transportation time affected around 1.5% of the total mixed concrete materials, which is a quite significant issue; however, it is difficult and nearly impossible to control the transportation system in Hong Kong. Furthermore, significant concrete wastes involve difficult waste handling processes, which request significant labour hours and time. Poor formwork may also cause wastage of concrete.

3.2 Reinforcement (M_2)

Steel reinforcement bars are commonly used materials in building construction. The main

cause of steel wastage is resulted from cutting. Damages and rusting during storage also form a major part of steel wastage.

3.3 Formwork (M_3)

Another major building material used is timber board. The main causes of timber wastage include the natural deterioration resulted from usage and cutting waste, and both are difficult to avoid. Timber wastage can be significant without proper management. According to the survey by Shen *et al.* [2-3], the wastage of timber materials can be as high as 20% of the total materials during foundation works.

3.4 Brick and block (M_4)

Brick and block are the most common walling materials. The main cause of these wastes is by cutting. In the case of unpacked supply, wastage can also be induced due to damages to these fragile materials. On the other hand, unused bricks left on site may end up in the trash skip ultimately, and such wastes can be significant in those projects where materials planning are poor.

3.5 Tile (M_5)

Tiles are normally wasted in a non-consequent process, affected by different stages of construction sequences. The sizes of the materials may not match what specified in the design due to poor coordination and communication. Sometimes, wastes have to occur in the application to these specific sized areas. Furthermore, during transportation, tiles can be easily cracked, thus more attention should be paid in delivering these materials.

4. Research Methodology

To examine the wastage levels of on-site practices of the five major types of construction materials identified above, a focus group investigates them within a large construction organization. All nineteen construction projects started from 2003 to 2005 have been under investigation. Project managers, quantity surveyors, material purchasers or related representatives on the surveyed projects are interviewed to clarify data and information collected about their subcontracting arrangements and project types with related to the levels of wastage generated to explore the difficulties encountered for reducing the wastage.

To accurately realize the actual wastage levels for the surveyed projects, one representative from our research team is nominated to audit the relevant documentations as agreed from that construction organization. The detailed information about the interviewed projects is tabulated in Table 2.

<Table 2>

5. Correlations between Material Wastage Levels and Sub-Contracting Arrangements

It is considered that different sub-contracting arrangements could cause different extents on material wastages. This was echoed by the study of Skoyles and Skoyles [18], which suggested that subcontracting arrangements can bring problems to the construction activities, such as delay on site operations, untidy site conditions and lower overall efficiency. These problems not only curtail profit of sub-contractors, but also disturb the progress of the main project. The client would eventually pay for the wastes and the main contractor also suffers more losses when improper subcontracting arrangement is adopted. [18]. The analysis here is focused on three major sub-contracting arrangements, namely, direct labour (D-L), labour only (L-O) and labour and material (L-M).

The survey in this study aims at studying the material wastage levels in adopting various sub-contracting arrangements. The reasons for the waste generation vary under different subcontracting arrangements. Table 3 summarizes different types of sub-contracting arrangements and their relationships to wastage levels. It is worth noting that no matter which types of sub-contracting arrangements are chosen, the cost of removing material wasted is paid by the main-contractor. Thus proper waste control always brings benefits to main contractors.

<Table 3>

Table 4 summaries the results of various types of subcontracting arrangement with their wastage on percentage levels as formulated in *Equation (1)*. Figure 2 graphically presents the results. For the L-M arrangement, the survey results show that the levels of material wastage in L-M arrangement are less than those in L-O and D-L arrangements with 4.48%, 4.11%, 4.97%, 5.87% and 6.62% for concrete, reinforcement, formwork, brick/block and tile respectively. Sub-contractors were bound into a supply and install contract, the main contractor would lose control on material applications including purchasing, installation and management [17]. Thus sub-contractors would take the responsibilities of all material wastage. With the explanations of a project manager, those L-M subcontractors will be much aware of the generation of wastage levels since they should take care of the material cost which will be finally wasted and directly affected their profit gained from the project. However, this sub-contracting arrangement sometimes would shift the materials related risk to the sub-contractors and increase the sub-contract sum [18].

$$Wastage\ Level\ (in\ \%) = \frac{M_p - M_u}{M_p} \times 100\% \quad Equation\ (1)$$

where M_p is the purchased material; and M_u is the used material (in m^3 for concrete; in ton for reinforcement; in m^2 for formwork; in m^2 for brick/block; and in m^2 for tile).

<Table 4>

<Figure 2>

However, by using the L-O arrangement, the results show the highest material wastage level across most of the building materials, especially concerning formwork (M_3), the wastage level under the L-O arrangement with 20% of the total material is at least four hundred percent higher than by using the L-M arrangement with 4.97%. This is explained in the interviews that L-O subcontractors are less concerned about the material wastage as the materials are not supplied by themselves. For example, the interview discussions revealed that L-M subcontractors re-use formwork for up to fifty times while L-O subcontractors only use ten times for the same material of formwork. Therefore, the wastage of formwork for L-O is much higher than that of other subcontracting arrangements.

The major reason of the wasted brick and block (M_4) can be found from their standard sizes as the standard sizes of brick and block are typically of 125mm in height and 250mm in width in Hong Kong. The design layout of brick and block is usually missing to consider the specific sized of the materials. Furthermore, the pattern of the design usually wastes a lot of useful materials. Therefore, the increased quantities of wasted brick and block will likely occur for all types of subcontracting arrangements.

Although the reinforcement (M_2) is having about 5.00%, 7.70% and 4.11% of the levels of material wastage in the subcontracting arrangements of D-L, L-O and L-M respectively, those construction materials will not be act as wastes and will not be sent to landfill or public filling

areas. The recycling cost of reinforcement generates a profit for the Hong Kong construction industry; therefore, reinforcement recycle will always occur.

6. Correlations between Materials Wastages Levels and Projects Types

To study the material wastage levels of various types of projects, the maximum and minimum levels of material wastage, while the average levels of material wastage varying with different types of projects are shown in Table 5. However, no matter which type of project it is, there is some unavoidable wastage, called as ‘natural wastage’, such as cutting, thus a minimum material wastage level should be set.

<Table 5>

Table 5 shows the lowest level of wastage of 0.00% for all types of construction materials (M_1 to M_5) in private housing, private commercial and composite building projects, which indicated that it can hardly be further reduced and the value can be set as a natural wastage. For items with higher wastage levels than their natural wastages, for examples, 25.09% of formwork wastage in private housing projects, there should be more room to reduce the wastage levels. These items are called as potential wastage, which are given in *Equation (2)*:

$$\text{Potential Wastage Items} = \text{Max.} - \text{Min.} / \text{wastage} \quad \text{Equation (2)}$$

The survey results show that wastage level is significant for various types of construction materials, especially for projects in private housing and private commercial as shown in Table 5. As the private housing and private commercial projects generate the highest wastage levels, it may reflect the non-standardized building structures. One of the methods to effectively reduce the wastage generation is to promote the use of prefabrication. Nevertheless, many methods may also be employed in the Hong Kong private construction industry in yielding

“zero” waste on site, for examples, reuse, recycling and reduce the construction materials and initial on-site planning.

Poon *et al.* [20] addressed different material wastages in the trades of concrete, reinforcement, formwork and masonry for private and public housing projects as shown in Table 6. The table shows that the wastage in formwork for private housing projects is much higher than that for public housing projects, in which it brings the same argument with the above discussion on standardized design of public housing.

<Table 6>

Rather than the methods identified above, implementation of environmental management system, material management, on-site supervision, education and training are also essential and effective methods to enhance the environmental performance on site.

In addition, as one of the major problems of unaltered situations of wastage generation is the lack of incentives for on-site employees, some of the interviewed project managers decided to promote and implement reward schemes for the whole project team members if their wastage levels are lower than that in last year.

However, in promoting the environmental awareness as one of the basic components for the projects, in addition to cost, quality and safety, is the major criteria to enhance and improve the environmental culture in the construction industry.

7. Mitigate the Material Wastage Levels

Since the above discussed problem on the sub-contracting arrangement and project types and

the discussions with the representatives of the construction project, four methods to mitigate the material wastage levels are proposed.

1. A problem that the natural level of material wastage depends on the cost effectiveness of the approaches used to control it [18]. Therefore, the cost of reducing wastage is directly related to the values of material saved; however, this relationship is no longer linear. It shows that higher cost effectiveness can only be achieved at the initial stage, and lower cost effectiveness happens at the later stages. Thus, the optimum level of material saved should be identified before projects start. The optimum level should be the small improvement cost in reducing wastage that brings about a large impact on materials saved, yielding an increase in profit. It seems to be more effective to reduce the wastage for items bearing higher levels of wastage, which have relatively larger room for wastage reduction. This approach is important in determining where attention should be focused on maximising saving in material wastage.
2. Wastage minimization should be integrated into the construction processes and planned at the tender stage. Thus; sub-contractors proposed wastage reduction plans should be included in the assessment criteria.
3. Provision and motivation of waste reduction training to on-site staff is also considered important in raising environmental awareness and helping site staff generating a better working procedure to reduce generation of materials wastage.
4. A waste control system is suggested as part of site management functions, which collects waste generation data, identifies the major areas of waste generation, analyzes the causes for the waste generation, produces solutions for mitigating waste and feedbacks the decision-making to the working staff who work on those key areas. The waste control system can also present dynamic information to the senior management who can coordinate among various subcontractors and departments for implementing

the system effectively.

8. Conclusion

This paper demonstrates that waste generation has a direct link with subcontracting arrangements. The survey results show that labour only (L-O) sub-contracting produces the highest wastage levels compared with the direct labour (D-L) and labour and materials (L-M) sub-contracting arrangements. On the other hand, the paper also demonstrates that different types of construction projects have different levels of waste generation. Private housing and private commercial projects generated the highest wastage levels when compared with other types of projects. The main reason for that is private projects normally are of non-standardized building structures. As a result, different sizes and shapes of building components such as formwork, reinforcement and brickwork are required, which results in higher wastage levels. Based on the problems found from the survey, four methods to mitigate the material wastage levels are proposed: i) development of a cost-effective approach; ii) integrated waste minimization on the tender stage; iii) provision and motivation of waste reduction training; and iv) a waste control system as part of site management functions.

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Table 1: Typical Building Materials and Reasons for Their Wastages [19]

Construction materials	The way of waste generation	Reason of waste generation
Concrete (M_1)	Ordering too much	Required quantity of products unknown due to imperfect planning
	Loss during transportation	Settlement of concrete on long transportation time
	Scraping off	Method to lay the foundations of a building
Reinforcement (M_2)	Cutting	Use of steel bars that size does not fit
Formwork (M_3)	Cutting	Use of timber boards that size does not fit
Brick / Block (M_4)	Cutting	Use of products that size does not fit
	Damaged during transportation	Unpacked supply
Tiles (M_5)	Sawing consequent on the design of the surface	Attention not paid to sizes of the used products in design; designer not familiar with possibilities of different products; information about that will be used late; types and sizes of the different products do not fit
	Cracking during transportation	Negligent handling by the supplier

Table 2: Summary of Surveyed Subcontracts

Number of case	Sub-contracting arrangements	Trades of materials	Project types	Contract sum
1	L-O	C, R	PBH	150 millions (M)
2	L-O	C, R, B, T	PBH	119M
3	L-O	C, R, F	PH	5M
4	L-O(C, R), L-M(F)	C, R, F	PH	470M
5	L-O(C, R, B, T), L-M(F)	C, R, F, B, T	PH	600M
6	L-O	C, R, T	PH	10M
7	L-O	C, R, B, T	PH	418M
8	L-O	C, R, B, T	PH	142M
9	L-M	C, R, T	PH	43M
10	D-L(C, R, T), L-O(B)	C, R, B, T	PH	306M
11	D-L(C, R, B), L-M(T), L-M (F)	C, R, F, B, T	CM	260M
12	L-M	R, T	CM	180M
13	L-M	C, R, F, B, T	CP	213M
14	L-M	C, R, B, T	I	63M
15	L-O	C, R, B	M	95M
16	L-M	C, R, F	S	63M
17	L-O	C, R	PH	5M
18	L-O (C, R, B, T), L-M (F)	C, R, F, B, T	PH	17M
19	L-M	C, R, B, T	CM	90M
<p>Notes:</p> <p>Sub-contracting arrangement: L-O – Labour only; L-M – Labour and material; D-L – Direct labour;</p> <p>Trades of materials: C – Concrete; R – Reinforcement; F – Formwork; B – Brick/block; T – Tiles;</p> <p>Project types: PBH – Public housing; PH – Private housing; CM – Commercial; CP – Composite building; I – Industrial; M – Monastery; S – School.</p>				

Table 3: Types of Sub-Contracting Arrangements and Their Relationships to Waste Generation

Sub-contracting arrangements	Responsibility in material wastage
Direct labour (D-L)	Main contractors provide their in-house staff to purchase materials directly. Hence, main contractors directly control and pay for the wastage.
Labour-only (L-O)	Main contractors purchase materials and sub-contractors provide labour force only. Hence, main contractors directly pay for the wastage.
Labour and material (L-M)	Sub-contractors purchase materials and hire labour. But the main contractor indirectly pays for wastage through higher sub-contract prices.

Table 4: Levels of Material Wastage Among Different Sub-Contracting Arrangements

Trade	Sub-contracting arrangements		
	D-L	L-O	L-M
Concrete (M_1)	4.86%	8.99%	4.48%
Reinforcement (M_2)	5.00%	7.70%	4.11%
Formwork (M_3)	-	20.00%	4.97%
Brick / Block (M_4)	6.02%	8.90%	5.87%
Tile (M_5)	6.67%	15.58%	6.62%

Table 5: Maximum and Minimum Wastage Levels Among Different Types of Projects

Project	Concrete (M ₁) (%)				Reinforcement (M ₂) (%)				Formwork (M ₃) (%)				Brick / block (M ₄) (%)				Tile (M ₅) (%)			
	M _L ¹	M _H ²	M _H -M _L	A ³	M _L	M _H	M _H -M _L	A	M _L	M _H	M _H -M _L	A	M _L	M _H	M _H -M _L	A	M _L	M _H	M _H -M _L	A
Public housing	0.18	5.84	5.66	4.51	2.96	6.25	3.29	3.77	-	-	-	-	-	-	-	-	0.51	0.51	0.00	0.51
Private housing	0.00	13.28	13.28	6.82	0.00	15.22	15.22	7.74	0.00	25.09	25.09	23.08	0.00	12.26	12.26	7.90	0.00	12.21	12.21	9.05
Private Commercial	2.47	8.73	6.26	5.78	2.25	7.52	5.27	4.48	0.00	8.20	8.20	5.17	3.50	10.56	7.06	6.51	0.00	10.4	10.4	7.66
Composite Bldg	0.00	6.13	6.13	4.06	0.00	4.61	4.61	3.81	0.00	4.67	4.67	3.33	4.96	4.96	0.00	4.96	4.21	4.21	0.00	4.21
Industrial	4.00	4.00	0.00	4.00	3.54	3.54	0.00	3.54	-	-	-	-	-	-	-	-	4.24	4.24	0.00	4.24
Monastery	2.09	5.96	3.87	4.53	1.54	5.97	4.43	3.27	-	-	-	-	-	-	-	-	-	-	-	-
School	-	-	-	-	2.78	2.78	0.00	2.78	-	-	-	-	4.52	4.52	0.00	4.52	-	-	-	-

Notes:

¹ M_L is the lowest wastage level;

² M_H is the highest wastage level; and

³ A is the average wastage level.

Table 6: Percentage Wastage of Materials Private and Public Housing Projects [20]

Trade	Material	Percentage wastage in private housing	Percentage wastage in public housing
Concrete	Concrete	4-5%	3-5%
Reinforcement	Steel bars	1-8%	1-8%
Formwork	Timber broad	15%	5%
Masonry	Brick and block	4-8%	6%

Figure 1: C&D Waste for Reclamation Landfills From 1991 to 2001 [8]

Figure 2: Levels of Material Wastage and Sub-Contracting Arrangements