Off-site sorting of construction waste: what can we learn from Hong Kong?

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Abstract:

To tackle the large amount of solid waste generated from construction activities, Hong Kong has issued a series of construction waste management policies in the last twenty years. One of the most significant policies is the launch of an off-site construction waste sorting (CWS) program. Since its implementation in 2006, the off-site CWS program has contributed greatly to construction waste minimization by hitherto separating 5.11 million tons of construction waste in total. This paper aims at carrying out a thorough investigation into the off-site CWS program in Hong Kong. Both successful experience and existent shortcomings in relation to the CWS program are discussed in detail. Data on which the analysis and discussions are based are mainly obtained from two channels. One is from literature review and examination on government regulations and statistics, while the other is from two empirical case studies carried out at the Tuen Mun construction waste sorting facility. The findings reveal that the success of the off-site CWS program is mainly attributed to 'sustaining policy support from the Hong Kong government', 'good policy execution', 'encouraging off-site CWS through higher disposal charges' and 'implementation of the trip-ticket system'. Suggestions for further enhancing the effectiveness of the off-site CWS program are also proposed. The study is not only useful for decision makers to further improve the overall effectiveness of this practice, but also provides valuable references for other countries or regions in minimizing construction waste through off-site waste sorting program.

Keywords:

Construction waste; waste sorting; regulation; Hong Kong.

1. Introduction

How to minimize construction waste effectively and efficiently has long been a challenging issue that has received worldwide attention (Skoyles, 1976; Bossink and Brouwers, 1996; Craighill and Powell, 1999; Poon et al., 2001a; Tam, 2008; Lu et al., 2011; Yuan et al., 2011). It is commonly found that people have widely embraced four major clusters of construction waste countermeasures ranging from reduction, reuse, recycling, which are known as '3R', to disposal (Yuan and Shen, 2011). Reduction is perceived as the most environmentally friendly, as it can prevent construction waste from generation in the first place. Typical waste reduction approaches include design out waste and optimal construction material management. After construction waste is inevitably generated, the other three measures (i.e. reuse, recycling and disposal) can be successively applied.

Amongst the various construction waste minimization measures, sorting construction waste into its constituent parts before being dumped in landfills or public fill reception facilities is often introduced as a good practice. In many cases, the construction waste is a mixture of inert and non-inert construction materials (Poon et al., 2001b). In Hong Kong, for example, the inert materials, which comprise mainly sand, bricks and concrete, is deposited at public fill reception facilities for land reclamation, while the non-inert portion, consisting of materials such as bamboo, plastics, glass, wood, paper, vegetation and other organic materials, is dumped at landfills as solid waste. They should be properly sorted instead of being buried as a whole. Sorting can thus increase the efficiency of construction waste reuse and recycling, and in turn extend the lifespan of landfills (Poon et al. 2001b; Hao et al., 2008).

On-site and off-site construction waste sorting (CWS) are the two favorable options. Poon et al. (2001b) investigated the feasibility of carrying out on-site CWS by taking into consideration the character of building related construction waste generated in Hong Kong. The investigation found that building construction participants are mostly reluctant to conduct on-site sorting although it has various advantages as compared with CWS centrally carried out at a designated off-site area. As a matter of fact, on-site CWS had not been popular in Hong Kong, and the prevailing practice was still that contractors sent the construction waste directly to landfills or public fill reception facilities for disposal.

Things have changed when the Hong Kong government implemented a Waste Charging Scheme (WCS) in 2006 based on the “polluter pays principle”. In line with the WCS (Ref. Cap. 354N), a construction contractor will be imposed a levy of HK$125 (1US$ = 7.76HK$) for every ton of construction waste it disposes of at *landfills*; it will be levied HK$100 per ton if the construction waste was accepted by *off-site sorting facilities* while it will be charged only HK$27 per ton if the waste consists entirely of inert materials accepted by *public fill reception facilities*. The price discriminations reflect the different environmental impacts caused by different forms of construction waste. It is also anticipated that the charge will be channeled back to construction contractors to encourage more active construction waste management activities, such as reduction, reuse, and recycling. An off-site CWS program was introduced and two off-site waste sorting facilities were set up against this backdrop.

According to the statistics provided by the Hong Kong Civil Engineering and Development Department (CEDD), the two off-site CWS facilities have successfully handled a total amount of 5.11 million tons of construction waste by February 2012 since its operation in 2006. It comes to an opportune time to examine the off-site CWS program with a view to assimilating the successful experiences or improving its potential weaknesses in the future. Therefore, this paper mainly aims at examining the off-site CWS practices in Hong Kong by drawing upon practical experiences of implementing the off-site CWS program.

This remainder of this paper is organized as follows. Firstly, the research methodology adopted is introduced. Secondly, the off-site CWS program in Hong Kong is reviewed. Thirdly, a blow-by-blow account of major experiences and shortcomings regarding implementation of the off-site CWS program in Hong Kong is presented. Particularly, major regulative, economical, and managerial factors contributing to the effectiveness of the practice are abstracted and analyzed in detail. Finally, the paper concludes by summarizing the lessons learned from the off-site CWS practices in Hong Kong. It is expected that the findings derived from this study could not only identify the strengths and weaknesses residing in the Hong Kong off-site CWS program for further improvements, but also shed light on its successful experience on which other similar economies can base to better develop their own programs of such kind.

2. Research methodology

A hybrid research methodology is adopted in this study, involving literature review, a site survey, and several rounds of interviews. The review of literature helps in constructing a solid understanding about construction waste management in Hong Kong, in particular its off-site CWS program. Also, related government regulations and statistic reports are reviewed to filter information that is highly related to CWS. A site survey was conducted in February 2012 on one of the two off-site CWS facilities, which is located at the Tuen Mun Area 38 in Hong Kong. Six researchers from the research team participated in the site survey, encompassing two senior researchers and four graduate students. The site survey was led by two government staff members: one is from the CEDD head office and the other is a full-time inspector working at the Tuen Mun CWS facility. The two staff members are also responsible for answering questions raised in the interviews in parallel with the site survey. The results of the interviews afford useful supporting materials for the authors to carry out in-depth analyses of the off-site CWS practices.

3. Off-site CWS in Hong Kong

3.1 Introduction of the off-site CWS program

Figure 1 shows the amount of solid waste (including construction waste) which has been disposed of at Hong Kong landfills over the time span of 1991 and 2010. It is obvious that the amount of solid waste dumped at landfills is grave, although a general trend of decreasing is observed, particularly after 2002. The large volume of waste disposal has cost the capacity of the three strategic landfills in Hong Kong in a relatively quick speed. In contrast, there is grievous scarceness of land space for planning and constructing new landfills or extension of existing landfills, if the current waste disposal scale henceforth cannot be diminished. To maximize the efficacy of exiting landfills and prolong their serving span, an optimal strategy under the government's consideration is to enhance the effectiveness of solid waste minimization at source.

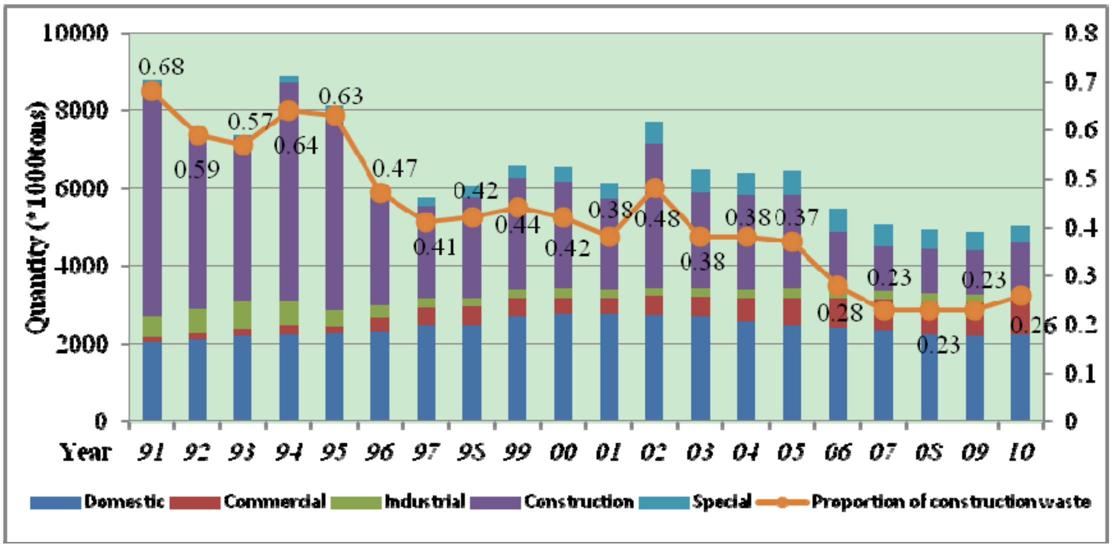

Figure 1: Solid waste disposed of at landfills from 1991 to 2010

(Source: HKEPD, 2011)

Also, it is notable from Figure 1 that the construction waste in Hong Kong makes up a prodigious portion of the total solid waste processed by landfills, touching as high as 68% in 1991 and even the lowest reaching 23% in 2007-2009. In a sense, the effectiveness of solid waste minimization at source relies highly on how the construction waste was reduced at the first place. Corresponding to the increased desire to reduce construction waste, the Hong Kong Legislative Council (LegCo) launched an amendment to the Waste Disposal Ordinance in 2004, a key intention of which is to charge construction waste dumped at designated construction waste disposal facilities on the one hand and to enhance control on illegal construction waste dumping behavior on the other (HKEPD, 2012).

According to the Waste Disposal Ordinance (HKEPD, 2012), project stakeholders, mainly referring to construction contractors here, will have to pay HK$100 per ton for their construction waste containing more than 50% by weight of inert materials if it is sorted by off-site CWS facilities. If sorting is conducted before the construction waste is transported to the off-site sorting facilities, the inert materials can be dumped in designated public fill reception facilities directly at a much lower charge of HK$27 per ton. Construction waste containing less than 50% by weight of inert materials can be disposed of directly at landfills at a higher charge of HK$125 per ton. In accordance to the Ordinance, two CWS facilities were successively built and operated in 2006 (see Figure 2). The design capacities of the two waste sorting facilities (i.e. Tseung Kwan O Area 137 and Tuen Mun Area 38 CWS facilities) are 2800 tons per day and 700 tons per day, respectively.

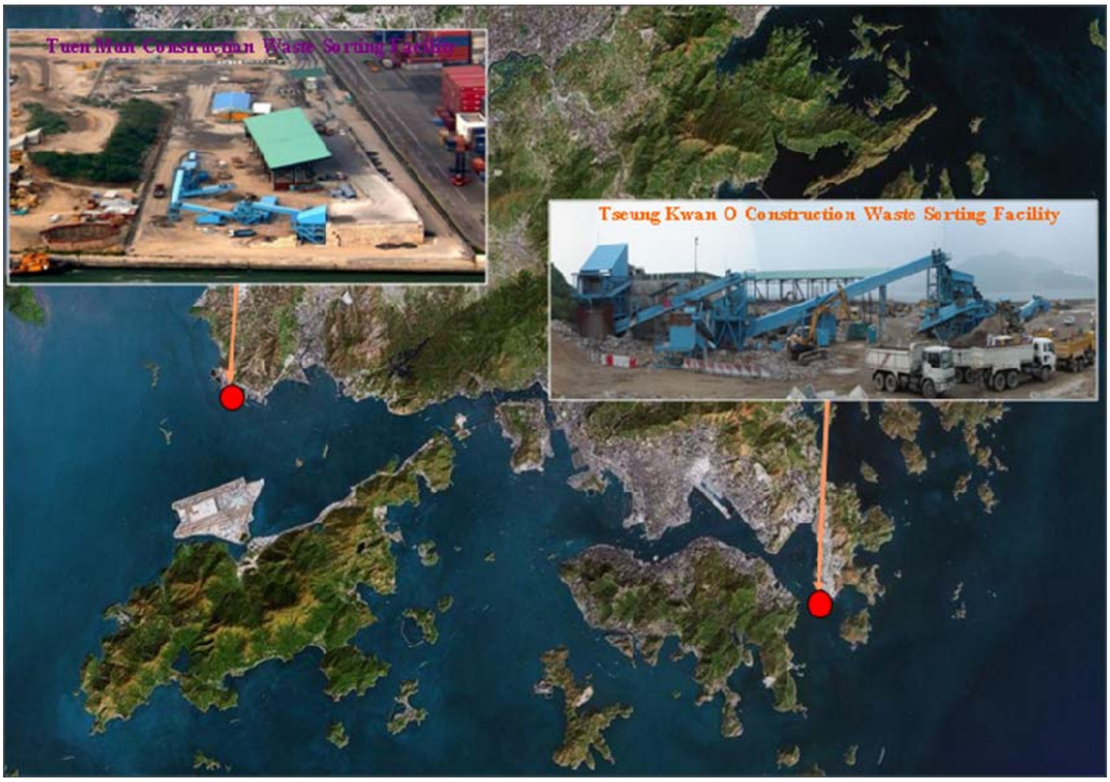

Figure 2: The two construction waste sorting facilities in Hong Kong

(Note: This figure is provided by the Hong Kong CEDD)

3.2 The Off-site CWS practices in Hong Kong

Based on the information provided by the staff members from the CEDD, together with the analyses of our site survey and interviews, a flowchart is developed to describe the circumstantial account of the entire off-site CWS process in Hong Kong (Figure 3). It is clear from the flowchart that central purpose of the practice is to sort the mixed construction waste received at the off-site CWS facilities into inert and non-inert waste, which would otherwise be dumped directly in mixture at landfills and consequently place a heavy burden on existing landfill capacity. The detailed operational procedures are described as follows.

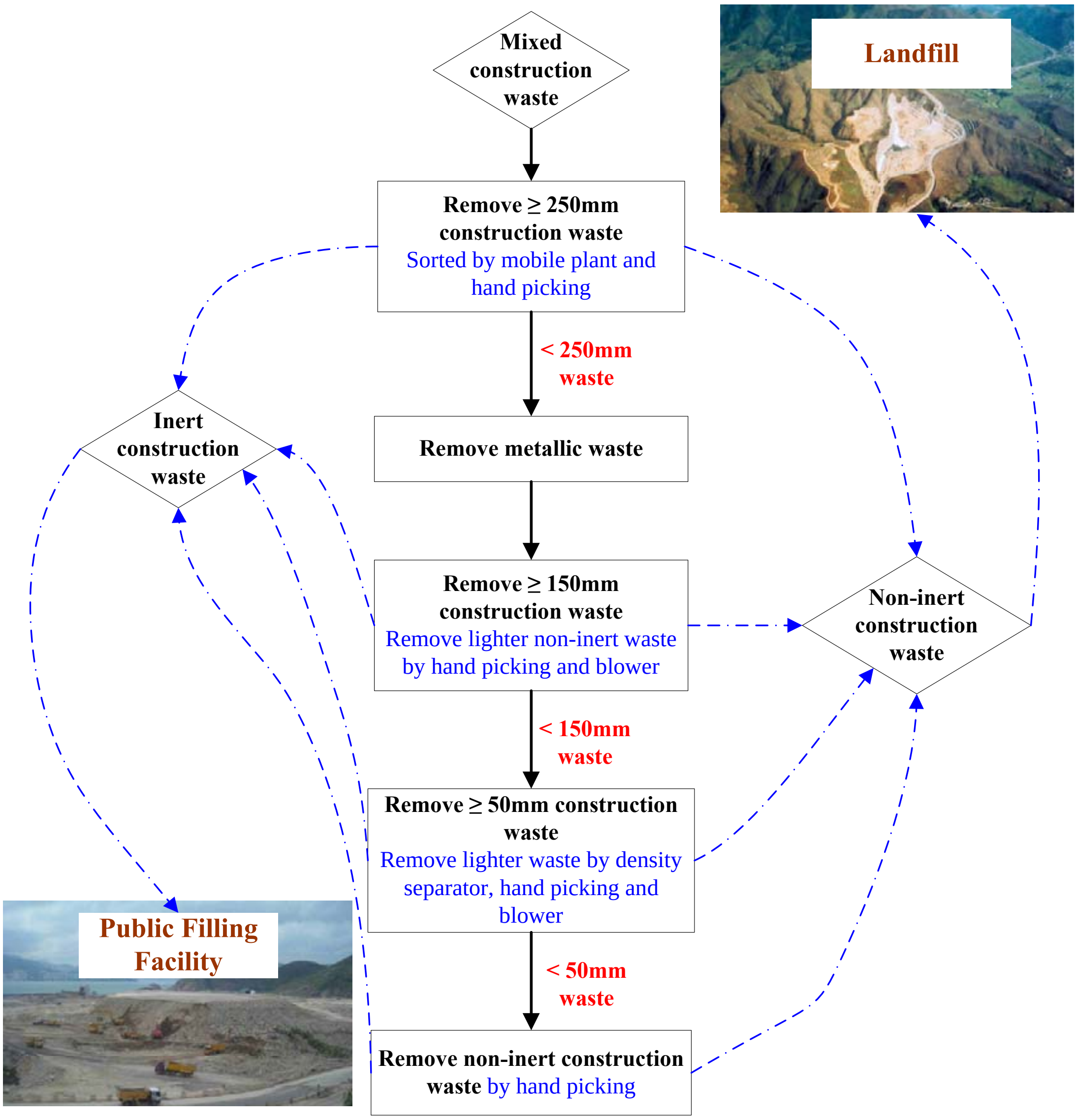

Figure 3: Flowchart of off-site construction waste sorting in Hong Kong

(Note: This figure is depicted by the authors based on information obtained in the sorting facility visit)

Owing to the price difference, contractors certainly tend to send all the waste to these off-site CWS facilities (charging HK$ 100 per ton) if not the public fill reception facilities (charging

HK$ 27 per ton). The first challenge is thus to make sure that the mixed construction waste received at the off-site CWS facilities is acceptable for sorting. There are generally applied criteria drawing from rule-of-thumb for determining whether the construction waste received is acceptable. The off-site sorting facilities only accept construction waste containing more than 50% by weight of inert materials in order to maximize its service efficiency (HKEPD, 2008a). In its current practice, two specific indicators, namely, *weight ratio* and *depth of waste*, are used. They are calculated based on the following formulas: 1) *Weight ratio* equals to results of dividing 'net weight of construction waste' by 'permitted gross vehicular weight'; and 2) *Depth of waste* equals to 'height of waste' minus 'height of loading platform'. The acceptance criteria and main indicators for justifying whether the construction waste received contains more than 50% by weight of inert materials are tabulated in Table 1 (HKEPD, 2008b). Once the waste meets the criteria, it can be accepted for further processing. It is worth mentioning that besides the quantitative measurements, a preliminary visual inspection of the construction waste by experienced management staff will also be conducted. The main purpose is to ensure that the construction waste received does not contain an evident proportion of non-inert materials, which should go to landfills. The construction waste containing obviously perceptible non-inert components will be rejected outright by the management staff, though it may meet the quantitative criteria as afore-mentioned.

Table 1: The criteria for construction waste to be accepted at the sorting facility

Indicators	Demountable trucks	Non-demountable trucks
Weight ratio	> 0.25	> 0.20
Depth of waste	< 1 meter	< 1.5 meter

The qualified construction waste will then enter the first process of sorting (named Process 1), which is performed by using a Vibratory Grizzly Feeder (VGF). In this process, the waste which has a radius greater than 250mm will be segregated. Two means are adopted: one is by mobile plant to separate inert materials and the other is by handpicking mainly for non-inert materials separation. After that, the residual construction waste of Process 1 will be handled to remove the metallic waste with the aid of a Magnetic Separator, which is called Process 2.

In the next process (Process 3), the construction waste has to pass through a Heavy Duty Scalping Screen. The screen is full of holes with the radius of 150mm. With this screening process, the construction waste with radii ranging from 150mm to 250mm can be separated. The 150-250mm separated waste will further be processed through handpicking and air blower to remove non-inert materials.

The construction waste with radii less than 150mm will enter Process 4, in which the waste is filtered by a Rotary Trommel Screen. Similarly, the screen is bestrewn with hollows of radii from 50mm to 150mm. The 50-150mm separated waste will further be handled by a density separator, handpicking and air blower to sort non-inert materials. Finally the residual construction waste from Process 4 will pass through a conveyor belt so that non-inert materials can be sorted out by handpicking.

It should be highlighted that after going through all the sorting processes, the mixed construction waste can be eventually sorted into two piles, namely, inert materials and non-inert materials. As indicated in the flowchart (Figure 3), the inert materials will be sent to the public fill reception facilities while the non-inert ones landfilled.

3.3 Contribution of off-site CWS to construction waste reduction

As discussed previously, the off-site CWS program is implemented by Hong Kong with a primary purpose of minimizing construction waste both on-site and off-site. Figure 4 illustrates the quantities of construction waste received at the public fill reception facilities and landfills respectively during the period of 1991-2010. Generally, the total amount of construction waste processed by the two kinds of facilities has increased quickly by the end of 2005. In the period of 2006-2008, the amount of construction waste has a dramatic decrease. Although later, in 2009, the quantity began to increase again, the average annual amount of construction waste over the period of 2006-2010 is much less compared with that in 2005.

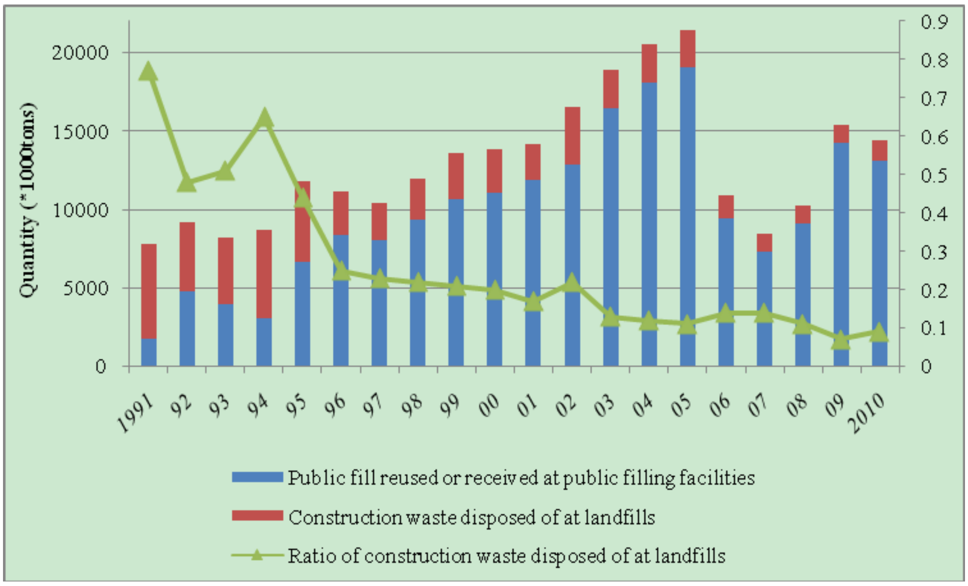

Figure 4: Quantities of construction waste in 1991-2010

(Source: HKEPD, 2011)

If we examine the ratio of construction waste disposed of at landfills to the total waste dumped, it is clear from Figure 4 that the ratio has decreased sharply from 0.77 in 1991 to 0.09 in 2010. Particularly, the ratio has decreased from 0.14 in 2006 to 0.09 in 2010. This demonstrates evidently that increasing proportion of inert materials has been separated from the mixed construction waste and sent to public fill reception facilities, which in turn is helpful in relieving the burden on the existing landfill capacities. These are partly contributed by the off-site CWS program implemented.

To further investigate the effectiveness of the off-site CWS program in Hong Kong, data regarding amounts of construction waste sorted by the CWS facilities are plotted and shown in Figure 5. It is seen that every year a significant amount of construction waste has been handled by the CWS facilities. Meanwhile, both the absolute amount of construction waste sorted by the CWS facilities and the proportion of sorted construction waste to the total construction waste disposed exhibit a general trend of decline. This may imply that after implementing the off-site CWS program for a few years, construction contractors may have been convinced to carry out waste sorting on-site proactively instead of sending the waste directly to the CWS facilities. Nonetheless, this needs to be substantiated by further research on on-site CWS.

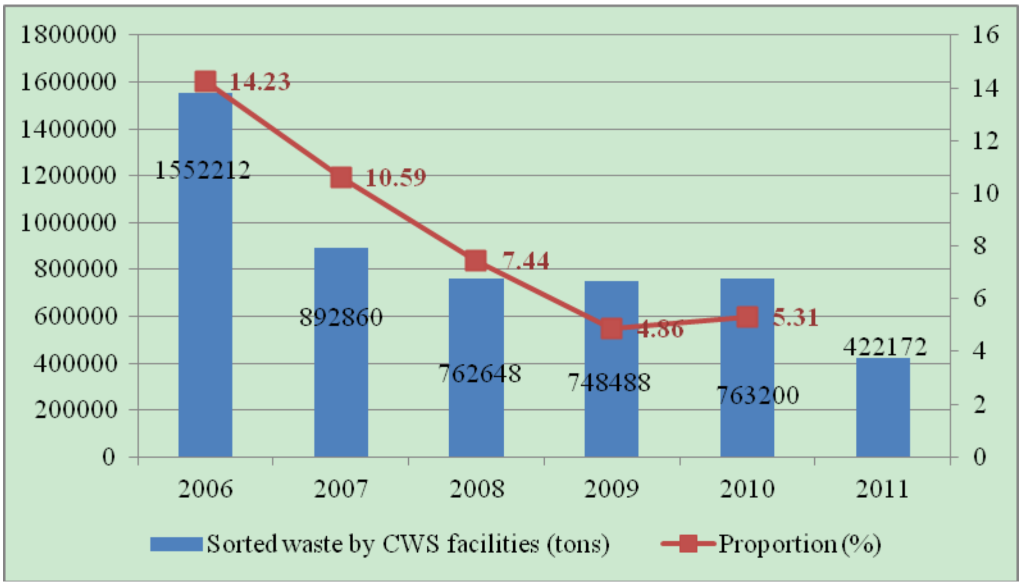

Figure 5: Construction waste sorted by the off-site CWS facilities

(Data source: CEDD, 2012)

4. Potential areas for improving the off-site CWS program

4.1 Properly siting the off-site CWS facilities

As shown in Figure 2, the current two off-site CWS facilities in Hong Kong are located in Tuen Mun (in west Hong Kong) and Tsung Kwan O (in south Hong Kong), respectively. By comparing them with Figure 6, it can be seen that the off-site CWS facilities have been deliberately located next to the landfills. Their locations are largely different from the three strategic construction waste landfills, which are situated in west, south and north east New Territories, respectively. The three landfills are distributed like a triangle and thereby can largely cover all areas around Hong Kong with reasonable radii. Therefore, it is somehow costly if construction waste is transported to the two CWS facilities from either east or north Hong Kong. According to the site survey, it is unclear whether the two locations were investigated thoroughly prior to being selected for building the waste sorting facilities. Given that construction waste can be sent from construction sites in anyplace around Hong Kong, it will be better to investigate and plan locations of CWS facilities in advance so that transportation routes could be optimized and transportation costs reduced.

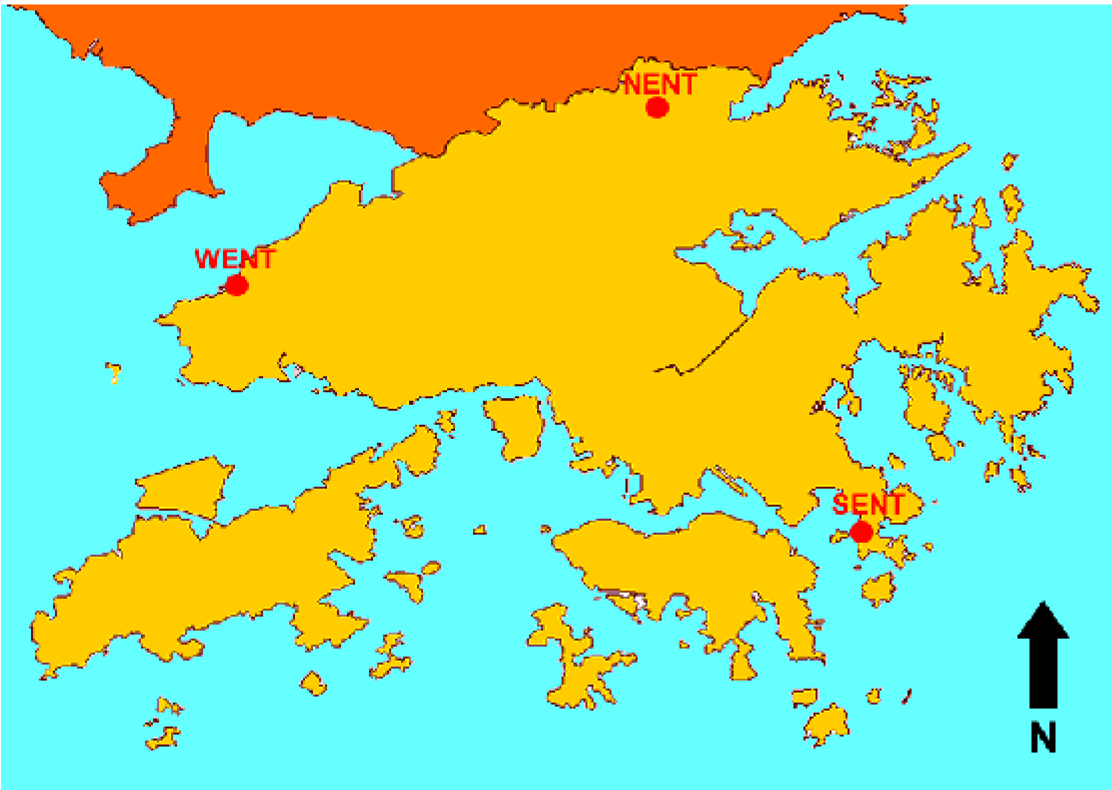

Figure 6: Location of existing strategic landfills in Hong Kong

(Source: HK EPD, 2012)

NENT : North East New Territories Landfill

SENT : South East New Territories Landfill

WENT : West New Territories Landfill

4.2 Effective measurements of the proportion of inert materials

It has been introduced in Table 2 that there is only a 'weight ratio' indicator applied for measuring the proportion of inert materials in each load of construction waste received when the off-site CWS program was originally implemented. After December 2010, a 'depth of waste' indicator was added to the measurement criteria for enhancing the accuracy of the measurement. According to the survey, it is found that there are two issues needing to be addressed. The first issue is that how the two existing indicators (i.e. weight ratio and depth of waste) are calculated and determined. None of the regulations but the rule of thumb explains the rationale behind using the two indicators for quantitatively determining whether the construction waste received contains more than 50% by weight of inert materials. The second is that in its current practice, non-inert materials will be very difficult to be spotted if they are concealed at the bottom of the vehicle. At present the inspector only visually glances at the top of the vehicles to confirm whether it contains significant non-inert materials. In this regard, the inspector has to follow the entire tracks of the vehicles to make sure the construction waste accepted meets related mandatory requirements. Thus, if the program was adapted by other economics, a method to determine components of the construction waste received in the first place is needed.

4.3 Prevention of noise and dust at the CWS sites

The current off-site CWS program affects environment in a paradoxical way. Firstly, it positively contributes to construction waste reduction and thereby saving natural resources. This has been clearly proved by the factual data as exhibited in Figure 5. Unauthorized construction waste dumping occurred at inappropriate areas has also been largely prevented, although concrete data demonstrating its effectiveness is hard to obtain. Nevertheless, paradoxically, a major adverse effect of the off-site CWS program lies in its impacts on the surroundings where the facilities were sited. During the site survey, each of the participants must wear a safety helmet and a mask. It is observed that when the mechanical waste sorting process starts, there will be a lot of noise and dust which are very harmful to the surroundings as well as people on-site. This is probably a primary reason resulting in the two waste sorting facilities to be located at the suburban areas in the New Territory of Hong Kong, as it can be seen from Figure 2.

There are two groups of on-site workers involved in CWS activities, including the inspectors responsible for site observing and visual scanning at the construction waste transportation vehicles, and the workers undertaking the handpicking work in different CWS processes. It is found in the study that when waste sorting starts, there will be a lot of noise and dust which are very harmful to the health of on-site workers irrespective of being equipped with masks and safety helmet throughout the processes. The noise and dust caused by CWS activities can also affect the surroundings. Currently, the CWS is carried out on outdoor sites without little noise or dust prevention measures. In a sense, the original intention of implementing off-site CWS is to reduce construction waste being landfilled so as to contribute to sustainable development. However, the off-site CWS activities themselves can cause a lot of adverse effects on environment and society. Therefore, to maximize the overall effectiveness of the off-site CWS program, adverse effects resulted from the off-site CWS processes should be investigated and corresponding mitigation measures ought to be taken in the future.

4.4 Recycling recyclable materials rather than disposal

In its current practices, construction waste is divided into two groups (i.e. inert and non-inert) in each of the sorting processes. At the end, inert and non-inert materials will be collected to two piles. Prior to the final disposal, both the inert and non-inert materials have to be smashed to pieces by hammers so that they could be well handled at landfills or public fill reception facilities. In the survey, it is observed that some separated waste materials are suitable for recycling or reuse, such as timber. However, the staff told us that all sorted materials entering the waste sorting facilities will be smashed to pieces directly and dumped at landfills or public fill reception facilities. Thus, it is suggested that in future the recyclable material can be preserved to maximize its residual value instead of being smashed or dumped. To some extent, recycling such materials provides a new stream of incentive for the CWS contractors. It has been noticed that in some other economies (e.g. USA, Australia and Taiwan), the facilities were called waste recycling plants. This is apparently a new philosophy although the prosperity of the practice is largely dependent on how well a material recycling market is developed.

5. Lessons learnt from the off-site CWS program in Hong Kong

Whilst there are areas for potential improvement, the off-site CWS program in Hong Kong is largely effective and efficient. Various lessons can be analyzed and summarized from its practices with a view to providing valuable references to other economies trying to stimulate construction waste minimization through CWS.

5.1 Developing a set of supporting and interlocking policies

Government policies always play a key role in promoting the off-site CWS practice, which will ultimately impact the environment as a public good. In December 2005, the Hong Kong government introduced the Waste Disposal Charging Scheme to ensure that final disposal of construction waste is properly differentiated and priced. The waste charging scheme is promulgated not only to serve as an economic tool for construction waste reduction at source but also to promote construction waste reuse and recycling thereby sustaining the landfills and public fill reception facilities (Hao et al., 2008). The off-site CWS program is subsequently launched as a key supporting policy of the waste charging scheme. Under the program, mixed construction waste that contains more than 50% by weight of inert materials can be further processed to separate the non-inert portions prior to its final dumping. In so doing, the inert materials will be transported to public fill reception facilities rather than handled by landfills.

In January 2006, the construction waste sorting facilities and their supportive infrastructure were completed in Tseung Kwan O and Tuen Mun respectively. Table 2 tabulates the detailed criteria for accepting construction waste received at the designated CWS facilities. It can be easily observed that there is a distinct difference in the major criterion for determining whether the construction waste received at the sorting facilities meets the mandatory requirements -- 'waste should contain more than 50% by weight of inert materials'. Before December 29, 2010, it is determined through measuring the *weight ratio* indicator, whereas from that time onward, the criterion has been extended to include a *depth* indicator as explained in Table 2. The interviewees in the study reflected that the new criterion has resulted in increased percentage of inert materials among the construction waste accepted at the sorting facilities. This in a sense proves that stricter waste acceptance criteria do channel contractors and developers to carry out some basic processing on construction sites before the construction waste is sent to the off-site sorting facilities.

Another interlocking policy that supports the implementation of the off-site CWS program is a trip-ticket system (TTS), which was implemented by the Hong Kong government in 1999 and enhanced subsequently in 2004 (HKDB, 2010). It has been anticipated that unauthorized construction waste dumping will increase given the waste charge. Nonetheless, under the TTS, construction contractors must fill in a standard trip-ticket form containing particulars of the transportation vehicle, type and approximate volume of construction waste, and the designated disposal facilities which have been approved by the Public Fill Committee or the Director of EPD. Once the construction waste is accepted by the designated facilities, a receipt will be issued to the vehicle operator for returning to the project engineer for verification of the contractors' compliance with related policies. The contractors are also charged based on their receipts. The system is used to ensure that all construction waste generated by public construction works is properly disposed of through tracking the waste destination.

Also, the TTS is applied throughout the off-site CWS program to prevent unauthorized construction waste dumping. Upon receiving the construction waste, a receipt with essential project particulars, which is issued by the EPD, will be passed by the construction waste transporter to the sorting facility staff responsible for visual inspection and recording. Whenever the construction waste received is accepted or rejected by the sorting facility, the information will be recorded on the receipt and returned to the transporter. Eventually, the transporter will hand in the returned receipt to the contractor who is in authority. The receipts are essential documents for final acceptance of construction works in Hong Kong. In this way, the TTS contributes to recording and tracking construction waste in a real-time way and prevents the waste being dumped improperly.

Implementation of the TTS is a strong enhancement resulting in an improved effectiveness of the off-site CWS program. According to conversations with the staff from the CEDD and the on-site inspector, if the off-site CWS program is solely adopted to encourage secondary separation and sorting of the construction waste before it is dumped, some project stakeholders would dump the generated construction waste directly at some unauthorized areas rather than sending it to designated landfills or public fill reception facilities. This would reduce the effectiveness of the off-site CWS program a lot, as well as diminish the overall effect of guiding construction waste dumping choices by the Waste Disposal Charging Scheme. With the TTS, any construction waste sent out from construction sites could be well tracked and recorded. As a result, major project stakeholders concerned will have to dispose of their construction waste properly. Otherwise, they would have to be subject to a high penalty for their inappropriate waste dumping behavior as regulated by related regulations. In summary, the implementation of the TTS has positive effects on the off-site CWS program.

5.2 Aiming at good policy execution

Without good policy execution, the off-site CWS program cannot be well implemented irrespective that all details of the CWS program have been well regulated and documented. Due to the limited land space and constantly active construction activities throughout the region, the Hong Kong government has been making a strong and continuous commitment to improving its construction waste management situation for more than two decades. With such a commitment, all construction waste management regulations issued have been strictly followed and well executed.

5.3 Improving environment attitudes amongst project stakeholders

Many studies have found that human related factors are important in affecting the overall effectiveness of construction waste management (Teo and Loosermore, 2001). It is also found that many project stakeholders will be involved in the entire construction waste management process. Their attitudes are at the core of the success or failure of a construction waste management process (Yuan and Shen, 2011; Teo and Loosermore, 2001). This is also applicable to the off-site CWS practice in Hong Kong. Here the stakeholders can be sketchily divided into three groups: (a) staff from the CEDD, (b) inspectors and recording staff at the CWS facilities, and (c) workers involved in the mechanical sorting processes.

Staff members from the CEDD are in charge of promulgating regulations for the off-site CWS program. They have two roles to play in the whole program. First, they have to specify and really enforce the related regulations that have been passed by the Hong Kong LegCo or the EPD in practice. Second, as the principal governor of the off-site CWS program, they will supervise and monitor the implementation of the program, and enhance its effectiveness when necessary.

The inspectors and recording staff working at the waste sorting facility are also critical to the success of the off-site CWS program. Normally the inspectors are responsible for inspection and supervision of in- and out-vehicles and the construction waste accepted to ensure that they are in line with the criteria as shown in Table 1. Also, they can audit recording staff's work if it is necessary. For example, a typical work of the inspectors is to visually observe whether the construction waste received at the checking point contains more than 50% by weight of inert materials. If they spot a significant proportion of non-inert materials, the construction waste will be rejected for further processing by the waste sorting facilities, although it might meet requirements of the *weight ratio* and *depth* indicators. This enhances the effectiveness of the off-site CWS program, because under strict check, contractors and developers are expected to carry out a careful pre-sorting of waste on construction sites so as to avoid increased transportation and labor costs. Similarly, the recording staff members are also responsible for scanning the waste at the checking point to make sure components and quality of the construction waste accepted are consonant with the waste acceptance criteria. The only difference is that the recording staff's judgments rely much more on the quantitative measurement results of the construction waste, including its *weight ratio* and *depth* indicators.

The third group of stakeholders concerns workers carrying out the handpicking job throughout the mechanical waste sorting processes. It is evident from Figure 3 that handpicking is conducted in each of the mechanical waste sorting processes. The handpicking is especially useful for sorting lighter non-inert materials that cannot be effectively and fully done by the mechanical sorting plants. As shown in Figure 7, workers equipped with essential safeguards are standing along either side of the conveyor belt to pick out non-inert construction materials before they were conveyed to the next sorting process. Since these workers undertake the handpicking work, their attitudes and behavior toward CWS will be much important to the overall efficiency of waste sorting.

Figure 7: A snapshot of construction waste handpicking

(Note: This figure is provided by the CEDD)

5.4 Economic feasibility is also essential

Despite the increasing environment awareness, the construction waste disposal charges as regulated in the Waste Disposal Charging Scheme is an effective vehicle in stimulating on-site and off-site CWS. As afore-introduced, the disposal charges for construction waste either entering landfills or being accepted by off-site waste sorting facilities will be higher than that received by public fill reception facilities. Through this way, significant amounts of construction materials could be saved for reuse or recycling. Therefore, the discriminative price system for construction waste accepted by the off-site CWS facilities is helpful in bettering the off-site CWS program.

From its commencement in January 2006 to February 2012 when the survey was conducted, the two off-site CWS facilities have successfully accepted and dealt with a total volume of 5.11 million tons of construction waste. The latest daily average intake of Tseung Kwan O and Tuen Mun waste sorting facilities is 780 tons and 380 tons, respectively. In line with its current practices, the government outsourced the two waste sorting facilities to qualified contractors following a public competitive tendering procedure. Now it is within the second contract (contract number: CV/2010/05) ranging from the period between December 22, 2010 and December 26, 2013. The total winning price of the bid was HK$128 million for operating the two waste sorting facilities during the period. Because of ‘commercial secrete’, in this site survey, the authors could not obtain the economic feasibility data, such as operation costs of various mechanical plants, labor costs, and costs of transporting the sorted waste to landfills or public fill reception facilities. However, given that the off-site CWS program in Hong Kong has sustained for a relatively long period from its implementation in 2006 and at present entered its second contract, it is reasonable to assume that the program is economically feasible, both for the CEDD and the contractors.

5.5 Promoting environment awareness amongst the whole society as a long-term strategy

Societal factors also contribute to the implementation of the off-site CWS program. The Hong Kong government has launched a series of regulations for promoting its construction waste management since 1980s. By executing those regulations, the society’s awareness toward construction waste management have been significantly promoted and enhanced. This forms a favorable institutional framework for cultivating better construction waste management culture. For example, the waste charge scheme as well as the off-site CWS program is not introduced overnight without confrontations. Rather, it has gone through a relatively long period before these regulations are accepted by the stakeholders concerned. Elimination of loopholes in these regulations is one contributor, while the increasingly improved societal environment, in particular the environment awareness, is another factor that cannot be ignored.

6. Conclusions

The Hong Kong government launched the off-site CWS program and built two CWS facilities in Tuen Mun area and Tuseng Kwan O area respectively in 2006 for separating and sorting construction waste before its final disposal. Since its implementation, significant amount of construction waste has been handled by the two waste sorting facilities, thereby alleviating the depreciation of existing landfills for receiving and processing construction waste to a large extent. Based on implementation practices of the off-site CWS program in the past years, this paper carried out a detailed analysis of the off-site CWS program for understanding its successful experience and potential shortcomings. Besides data collected from literature review, government regulations and statistic reports, a case study on the Tuen Mun CWS facility was conducted for acquiring data to support the analysis and discussions.

It is found from this study that a total amount of 5.11 million tons of construction waste has been separated and sorted since implementation of the off-site CWS program. This contributes significantly to reducing the amount of construction waste handled by landfills. The success of the off-site CWS program is mainly attributable to four aspects, including ‘sustaining policy support from the Hong Kong government’, ‘good policy execution’, ‘encouraging off-site CWS through higher disposal charges’, and ‘implementation of the TTS’. While acknowledging the off-site CWS program’s success, there are some suggestions that can be used to further improve the program in the future, which are ‘proper location of the off-site CWS facilities’, ‘effective measurements of the proportion of inert materials’, ‘prevention of noise and dust at the CWS sites’, and ‘recycling recyclable materials rather than disposal’.

Drawing upon Hong Kong’s off-site CWS practices, the successful experience identified in the present study can be valuable references for other territories aiming at better managing construction waste through implementation of off-site CWS. On the other hand, the suggestions provided can be used by the Hong Kong government when they consider improving the effectiveness of its current off-site CWS program. Also, it is worth highlighting that the findings are presented in the particular context of Hong Kong, they should be adjusted accordingly if applied to other regions.

Acknowledgement

The work is jointly supported by the Hong Kong Research Grants Council (RGC) Public Policy Research (PPR) Scheme project (RGC Ref. HKU7016-PPR-11) and the National Science Foundation of China (NSFC) project (No.: 71273219). Appreciations go to Ms. Ruth TSO and the Inspector from CEDD Hong Kong for organizing the case study. Special thanks are given to Dr. Sarah Liao, who was the former Secretary for the Environment, Transport and Works of Hong Kong, for her insightful suggestions to this research project.

References

Bossink, A.G., Brouwers, H.J.H. (1996). Construction waste: quantification and source evaluation. *Journal of Construction Engineering and Management*, 122 (1), 55-60.

Craighill, A., Powell, J.C. (1999). A lifecycle assessment and evaluation of construction and demolition waste. CSERGE Working Paper WM 99-03.

Hao, J.L., Hills, M.J., Tam, V.W.Y. (2008). The effectiveness of Hong Kong’s construction waste disposal charging scheme. *Waste Management and Research*, 26(6), 553-558.

HKDB (Hong Kong Development Bureau). (2010). *Trip Ticket System for Disposal of Construction and Demolition Materials*. Available at: http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/308/1/C-2010-06-01.pdf. Accessed on April 8, 2012.

HKEPD (Hong Kong Environmental Protection Department). (2008a). *Government Waste Disposal Facilities for Construction Waste and Charge Level*. Available at: http://www.epd.gov.hk/epd/misc/cdm/scheme.htm#j. Accessed on April 6, 2012.

HKEPD. (2008b). *Waste Disposal (Designated Waste Disposal Facility) Regulation*. Available at: http://www.gld.gov.hk/cgi-bin/gld/egazette/. Accessed on April 6, 2012.

HKEPD. (2011). *Hong Kong Waste Treatment and Disposal Statistics*. Available at: http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/stat_treat.html. Accessed on March 21, 2012.

HKEPD. (2012). *Legislation for the Management of Wastes* http://www.epd.gov.hk/epd/english/laws_regulations/envir_legislation/leg_waste.html. Accessed on April 8, 2012.

Lu, W.S., Yuan, H.P., Li, J.R., Hao, J.L., Mi, X.M., Ding, Z.K. (2011). An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China. *Waste Management*, 31, 680-687.

Peng, C.L., Scorpio, D.E., Kibert, C.J. (1997). Strategies for successful construction and demolition waste recycling operations. *Construction Management and Economics*, 15 (1), 49-58.

Poon, C.S., Yu, T.W., Ng, L.H. (2001a). *A Guide for Managing and Minimizing Building and Demolition Waste*. The Hong Kong Polytechnic University, Hong Kong.

Poon, C.S., Yu, A.T.W., Ng, L.H. (2001b). On-site sorting of construction and demolition waste in Hong Kong. *Resources, Conservation and Recycling*, 32(2), 157-172.

Skoyles, E.R. (1976). Materials wastage - a misuse of resources. Building Research and Practice, 1, 232-243 (July/August 1976).

Tam, V.W.Y. (2008). On the effectiveness of implementing a waste-management-plan method in construction. *Waste Management*, 28(6), 1072-1080.

Teo, M.M.M., Loosemore, M. (2001). A theory of waste behavior in the construction industry. *Construction Management and Economics*, 19(7), 741-751.

Yuan, H.P., Shen, L.Y. (2011). Trend of the research on construction and demolition waste management. *Waste Management*, 31, 670-679.

Yuan, H.P., Shen, L.Y. and Wang, J.Y. (2011). Major difficulties in improving the performance of waste management in China’s construction industry. *Facilities*, 29(5/6), 224-242.