Mapping Approach for Examining Waste Management on Construction Sites

L. Y. Shen[1]; Vivian W. Y. Tam[2]; C. M. Tam[3]; and D. Drew[4]

Abstract: The increasing awareness of environmental impacts from construction wastes has led to the development of waste management as an important function of construction project management. Various approaches for managing construction wastes have been developed in the existing research works and practices, and these works can be grouped largely into three areas: waste classification, waste management strategies (avoiding waste, reducing waste, reusing waste, and recycling waste), and waste disposal technologies. Nevertheless, these approaches give less attention to the management of the waste handling process on construction sites. In fact, construction wastes pass through a number of processes from generation to final disposal, and proper flow of these processes can improve waste management effectiveness. This paper examines the waste handling process during construction through mapping six cases selected in Hong Kong construction, with the assistance of the free-flow mapping presentation technique. The examination leads to developing a waste management mapping model (WMMM), which incorporates the good operations embodied in the existing practices. The WMMM provides an alterative tool assisting in planning waste management procedures on construction sites. It can serve as a vehicle for comparing the waste management practices between construction sites, thus both good practices and weak areas can be identified.

DOI: 10.1061/(ASCE)0733-9364(2004)130:4(472)

CE Database subject headings: Construction industry; Construction sites; Waste management; Hong Kong; Mapping.

Introduction

Waste management in construction activities has been promoted for the aim of protecting the environment in line with the recognition that the wastes from construction works contributes significantly to the polluted environment. Craven et al. (1994) reported that construction activity generates approximately 20–30% of all wastes deposited in Australian landfills. Ferguson et al. (1995) found that more than 50% of the waste deposited in a typical landfill in the U.K. comes from construction wastes. According to Rogoff and Williams (1994), 29% of the solid-waste stream in the USA is construction waste. Cotton et al. (1999) pointed out that uncollected construction solid wastes have become a major health hazard, yet municipal wastes are still the dominant wastes affecting health hazards. Poon (1997) noted that construction wastes represent a large share among all types of solid wastes. His study shows that construction debris resulting from demolition works constitute a particularly large proportion of all the solid wastes in Hong Kong where demolition works are among the major construction activities.

All these studies demonstrate that the construction business is a large contributor to waste generation. In order to improve controlling construction wastes, existing research works have developed various management methods. Spivey (1974) suggested sorting out wastes into specific categories, such as demolition materials, packaging materials, wood, concrete, asphalt, garbage and sanitary waste, scrap metal products, rubber, plastic and glass, and pesticides and pesticide containers. The classification allows the adoption of specific techniques in dealing with different types of wastes effectively. Petts (1995) suggested building a consensus among the public regarding the impact of waste on the environment, and promoted proactive community involvement in implementing waste management. In recent years, waste reuse and recycle have been widely promoted for reducing the volume of wastes, but the effectiveness of their application is limited largely because the conditions for applying these approaches were not provided (Chun et al. 1997). These conditions include proper site location and equipment for waste sorting, experience of recycling waste, providing trained supervisors and employees, and knowledge of environmental and safety regulations. Faniran and Caban (1998) classified waste management methodologies in a hierarchy in descending order: reducing waste; reusing waste; recycling waste; and disposing waste where the first three options are not possible. Recently, using environmentally friendly construction methods has been encouraged, such as using a large panel system, applying prefabrication components, and reducing the application of wet trade (Ho 2001). A recent study by Shen and Tam (2002) suggests applying waste management methods as part of project management functions and involving all employees' participation. It is suggested to design specific training and education programs for different groups of staff. Of course, employees' participation can only be effective with genuine support

[1]Professor, Dept. of Building and Real Estate, The Hong Kong Polytechnic Univ., Kowloon, Hong Kong.

[2]PhD Research Student, Dept. of Building and Construction, City Univ. of Hong Kong, Tat Chee Ave., Kowloon, Hong Kong.

[3]Associate Professor, Dept. of Building and Construction, City Univ. of Hong Kong, Tat Chee Ave., Kowloon, Hong Kong.

[4]Associate Professor, Dept. of Building and Real Estate, The Hong Kong Polytechnic Univ., Kowloon, Hong Kong.

Note. Discussion open until January 1, 2005. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on August 16, 2002; approved on April 2, 2003. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 130, No. 4, August 1, 2004. ©ASCE, ISSN 0733-9364/2004/4-472–481/$18.00.

J. Constr. Eng. Manage., 2004, 130(4): 472-481

from management. In fact, their study indicates that waste management has been receiving less attention from senior management within organizations. The reason suggested is that the cost for implementing waste management is given more concern than the possible benefits that the organization can gain from the implementation (Shen and Tam 2002).

Nevertheless, it appears that existing waste management methods give less attention to the management of waste handling processes on a construction site. In fact, construction wastes pass through a number of handling processes from their generation to final disposal. These processes can induce various factors affecting waste management effectiveness, thus proper flow of these processes is important. McDonald and Smithers (1998) conducted a survey suggesting that a proper waste management plan can contribute significantly to eliminate waste source, and can result in up to 50% cost savings for waste handling charges, 15% volume reduction of waste generation prior to recycling on site, and 43% waste reduction for landfill. However, there is lack of methodology in providing guidelines on how to produce a proper waste management plan. McGrath (2001) realized that one of the major hindrances to waste minimization on construction sites is the difficulty in establishing a methodology and using this methodology to benchmark future construction projects. He developed a waste minimization system called Site Methodology to Audit Reduce and Target Waste (SMARTWaste) for identifying and auditing waste arisen on a construction site. The principle of this system is to improve materials recovery for reuse and reduce waste generation on future sites by using the audited wastes arising as a benchmark for waste control. This paper extends the existing studies to examining the flow processes of construction wastes on site by using a free-flow mapping presentation technique. The examination is supported with six practical cases selected in Hong Kong construction practice. The case studies lead to developing a waste management mapping model (WMMM), which incorporates the good operations embodied in the existing practices. The model is expected to provide an alternative tool assisting in planning waste management procedures on site and serve as a vehicle to compare the waste management practices between construction sites, thus both good practices and weak areas can be identified.

What are Construction Wastes?

Construction wastes are in the form of building debris, rubble, earth, concrete, steel, timber, and mixed site clearance materials, arising from various construction activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork, and building renovation. While some of these wastes are recyclable and reusable, most of them are usually dumped in a landfill. Wastes are often the mixtures of inert and organic materials. The inert wastes are normally used in public filling areas and site formation works and the remaining wastes are often mixed and contaminated, not suitable for reuse or recycling but disposed of at landfills. In Hong Kong construction practice, for example, construction wastes are broadly classified into Type I and Type II according to the level of the inclusion of inert wastes (EPD 2002). In the classification, inert waste materials are described as soil or mud, concrete, reinforced concrete, asphalt, brick or sand, cement plaster or mortar, aggregate, and rock or rubble. Type I construction waste is defined as containing no more than 20% by volume, or 30% by weight, of inert materials. Type II waste consists of more than 20% by volume, or 30% by weight, of inert material. Therefore Type II waste is normally used for site formation or public filling areas. According to the report by the Hong Kong Construction Industry Review Committee (HKHA 2002), about 79% of construction waste was reused in public filling areas and the remaining 21% was disposed of at landfills in 1999.

Table 1. Terminologies Used in Mapping Waste Handling Process

Term	Definition
Waste source	Waste generation
Waste processing	Collecting debris, collecting reusable, loading waste, review and improving, W(waste)-deliver by hoist, W-deliver by refuse chute, W-sorting-out, W-transport by hand
Waste destination	Dumping, reclamation, reuse, recycle
Waste facilitator	Labor, mechanical tool, bag, rubbish bin, handcart, waste container, lorry

Construction activities also generate chemical and other special wastes, which are normally regulated strictly for special treatment as they can easily cause pollution to the environment or become risks to health. For example, the Waste Disposal Ordinance (WDO 2001) in Hong Kong provides the statutory framework for contractors to comply for dealing with chemical and other special wastes generated from construction activities. In the Ordinance, special wastes are described including abattoir waste, animal carcasses, asbestos, clinical waste, condemned goods, livestock waste, sludge rising from excavation, sewage treatment and waterworks treatment sludge, sewage works screenings, and stabilized residues from the Chemical Waste Treatment Center. The separation of the chemical and special wastes from other types of construction wastes helps the adoption of specific methods for dealing with different types of wastes effectively.

Construction wastes originate from various sources in the whole process of implementing a construction project. Existing studies provide various classifications on construction waste sources. Gavilan and Bernold (1994) grouped construction waste sources into design error, procurement or shipping error, materials handling, machine operation error, and residual or leftover scraps. Bossink and Brouwers (1996) investigated construction wastes from the application of various building materials and classified the waste sources according to the nature and the technology of using the materials into stone tablets, piles, concrete, sand-lime bricks and elements, rooftiles, mortar, packing, and other small fractions of metal and wood. In conducting a survey examining the construction waste sources, Faniran and Caban (1998) formulated five typical waste sources, namely, design changes, leftover material scraps, wastes from packaging and nonreclaimable consumables, design errors, and poor weather. Rounce (1998) pointed out that the major construction waste sources are at design stage, such as design changes, the variability in numbers of drawings and, the variability in the level of design details. These waste classifications indicate that examination on construction wastes must be conducted along the whole construction process of a project.

Research Method

The free-flow mapping presentation technique is adopted in this study for investigating the waste flow practice on construction

J. Constr. Eng. Manage., 2004, 130(4): 472-481

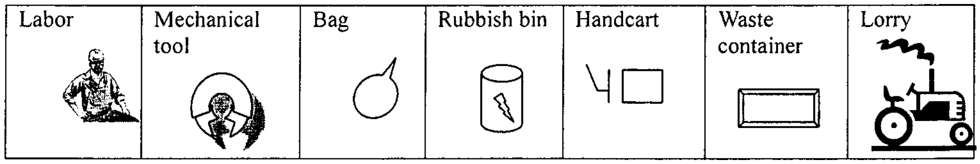

Fig. 1. Symbols used for representing various waste facilitators

sites. The technique has been considered advantageous in presenting flows of processes logically, clearly, and in the simplest way (Fisher and Shen 1992). By using the technique, this research team has examined the waste handling processes of six building construction projects in Hong Kong during the period from August to November 2001. The examination results for each case are presented by mapping the waste handling processes adopted in the concerned case. All six projects selected were under construction when the survey was conducted.

The key information presented in mapping the six cases includes four elements, namely, waste source, waste facilitator, waste processing, and waste destination. In order to conduct comparative analysis between the six cases, consistent terminologies and symbols are used for presenting mappings and representing the four elements, as shown in Table 1 and Figs. 1 and 2(a–d). Waste source denotes the generation of wastes and the locations where wastes originate. Waste processing denotes various processes where waste-handling activities are undertaken, for example, loading waste, sorting out wastes, and so on. Waste facilitator denotes the assistance or tools used to facilitate the waste-handling activities, including labor, tools, mechanical plants, and so on. Waste destination denotes the final status of the wastes, such as reuse or recycle, or the final places where wastes are delivered to, such as dumping or reclamation areas. By using these four elemental symbols, a simple waste flow mapping can be presented as shown in Fig. 2(e). By using the terminologies and symbols listed in Table 1 and Figs. 1 and 2, mappings for the six cases are developed according to the research team's observations and the discussions with the managerial staff involved in the surveyed construction sites. The process of developing these mappings allows the research team to understand the weaknesses and advantages of each practice, which forms the basis for developing an effective waste management mapping model (WMMM). It is necessary to note that this study seeks to present an alternative method for examining waste management practice on site, and the data used are not from a comprehensive survey but they provide a level of indication about the current practice of waste management on construction sites.

Mapping Waste Flow Practice on Construction Sites

The six waste management practices are mapped and presented in Figs. 3–8 separately. As mentioned before, these mappings are constructed based on this research team's on-site observations and the discussions with the site management staff who were undertaking the referenced projects. The observations and discussions on these practices lead to the formulation of a list of weaknesses and advantages in the applications of waste management on construction sites:

Weaknesses:

W_1 = too many waste handling processes;
W_2 = lack of waste sorting-out process;
W_3 = no consideration for recycling wastes;
W_4 = no consideration for reusing wastes;
W_5 = severe air pollution due to collecting and delivering waste;
W_6 = severe noise pollution due to delivering waste;
W_7 = intensive labor work involved in handling wastes;
W_8 = double-handling in collecting wastes;
W_9 = inefficient use of waste delivering mechanical facilities;
W_{10} = time consumed for collecting waste from scattered collection locations;
W_{11} = unsafe practice by allowing more laborers to collect wastes on site;
W_{12} = poor coordination and supervision of waste-handling staff;
W_{13} = insufficient waste handling due to less application of mechanical facilities;
W_{14} = extensive use of plastic bags in collecting waste;
W_{15} = unsafe operation in handling waste; and
W_{16} = undeveloped culture of waste reduction among site staff.

Advantages:

A_1 = fewer waste handling processes;
A_2 = proper waste sorting out;
A_3 = recycling waste;

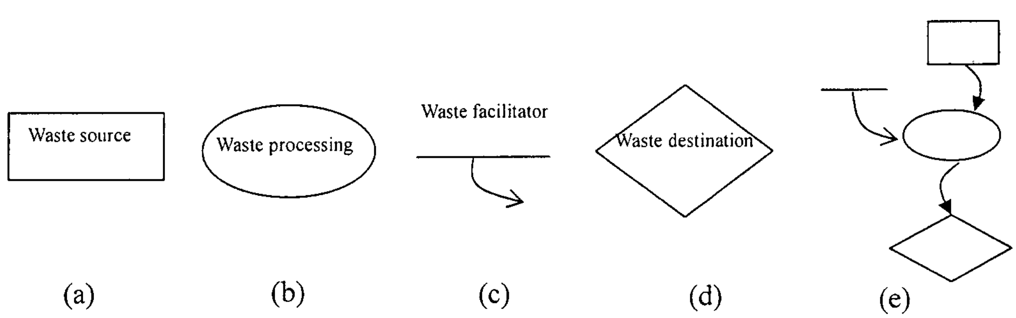

Fig. 2. Waste flow symbols

J. Constr. Eng. Manage., 2004, 130(4): 472-481

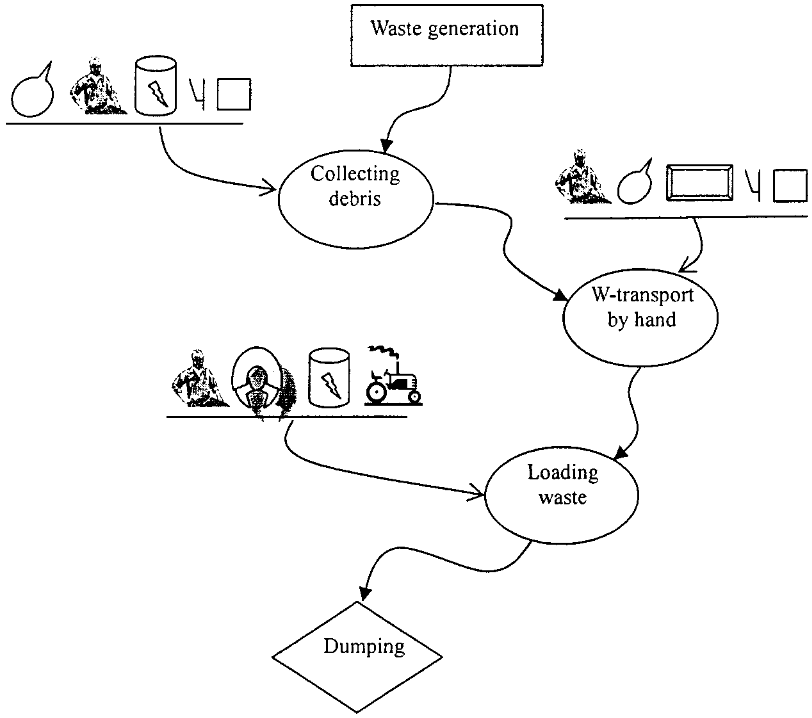

Fig. 3. Mapping of waste management practice for a building project: Project I

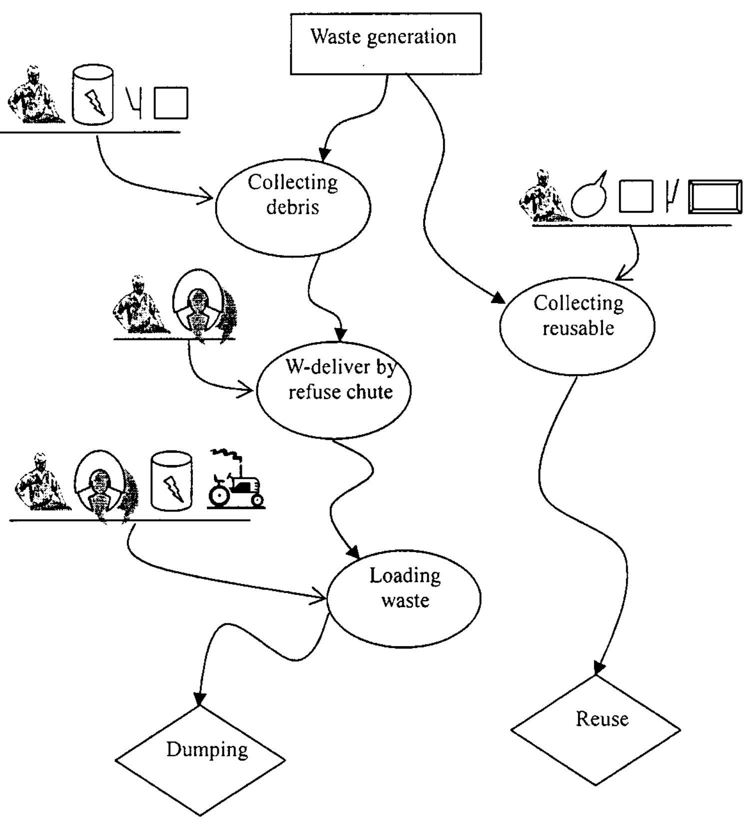

Fig. 4. Mapping of waste management practice for a high-rising office-building: Project II

J. Constr. Eng. Manage., 2004, 130(4): 472-481

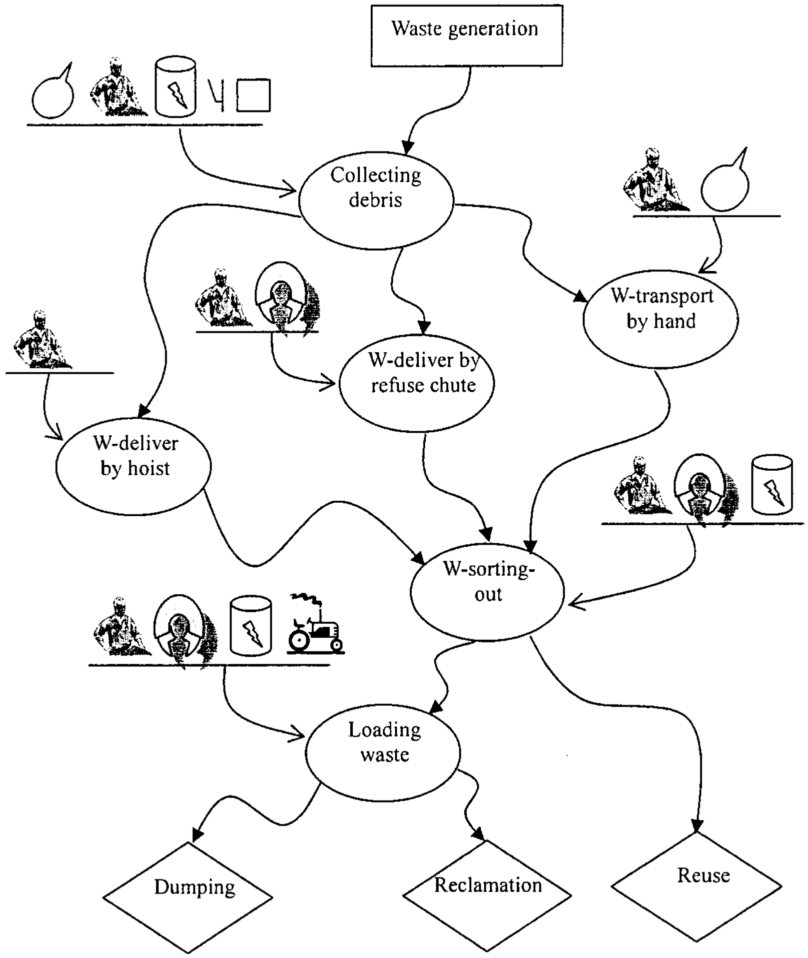

Fig. 5. Mapping of waste management practice for a high rising residential-building project: Project III

A_4 = reusing waste;
A_5 = clean waste handling operation;
A_6 = less labor work involved in handling waste;
A_7 = avoiding double-handling waste;
A_8 = efficient use of mechanical facilities in delivering waste;
A_9 = fewer waste collection locations with seeable distance;
A_{10} = well-coordinated procedures for handling waste;
A_{11} = generating income from selling reusable wastes;
A_{12} = less investment on setting up waste delivering facilities; and
A_{13} = safe waste handling operation.

The analysis on the weaknesses and advantages of the surveyed practices is comparatively conducted between the six cases, and the results are given in Tables 2 and 3. The results are generated from the research team's on-site observations and the discussions with the site managerial staff involved in the six cases.

The typical weaknesses existing in most of the surveyed cases include: W_2 "lack of waste sorting-out process," W_3 "no consideration for recycling wastes," W_7 "intensive labor work involved in handling wastes," W_8 "double-handling in collecting wastes," and W_{10} "time consumed for collecting waste from scattered collection locations." It can be seen in Table 2 that there was no proper sorting-out procedure in four of the six projects. Recycling has received no attention in all the surveyed projects. Most of the surveyed projects involved intensive labor works in handling wastes on site. Projects II, III, IV, and V involved double-handling in collecting wastes. Projects I, III, IV, and VI presented very poor coordination and supervision of waste handling staff. In Projects I, II, IV, and VI, a number of waste collection locations were widely scattered, resulting in serious time consumption in collecting wastes. Furthermore, Projects I and IV presented a higher chance of safety accident as more people were allowed to travel and collect waste materials on the site. In Project II, the delivery of large-sized waste materials through a refuse chute presented many chances for blockage and caused noise pollution as well. In Project III, waste bags were delivered by hand through a long distance to a location where the delivering lorry was located, no waste container was placed on site, thus double-handling in collecting wastes was severe. In Project IV, delivering waste bags through passenger hoist also engaged in double-handling operation as wastes had to be transported in and out of the hoist. In Project V, waste collection operation involved free throwing of waste bags from a 8th floor podium down to the ground floor. This was considered very unsafe and dangerous, and the operation also produced serious air pollution due to the dusts generated from throwing waste materials. Broken waste bags were often found due to throwing from a high position, thus double-handling operation of wastes happened. In Project VI, the practice presented serious air pollution due to the dusts from uncovered wastes in the processes of delivering.

The reasons for these problems identified above are multiple. Typically, there is no organization policy or specific training pro-

J. Constr. Eng. Manage., 2004, 130(4): 472-481

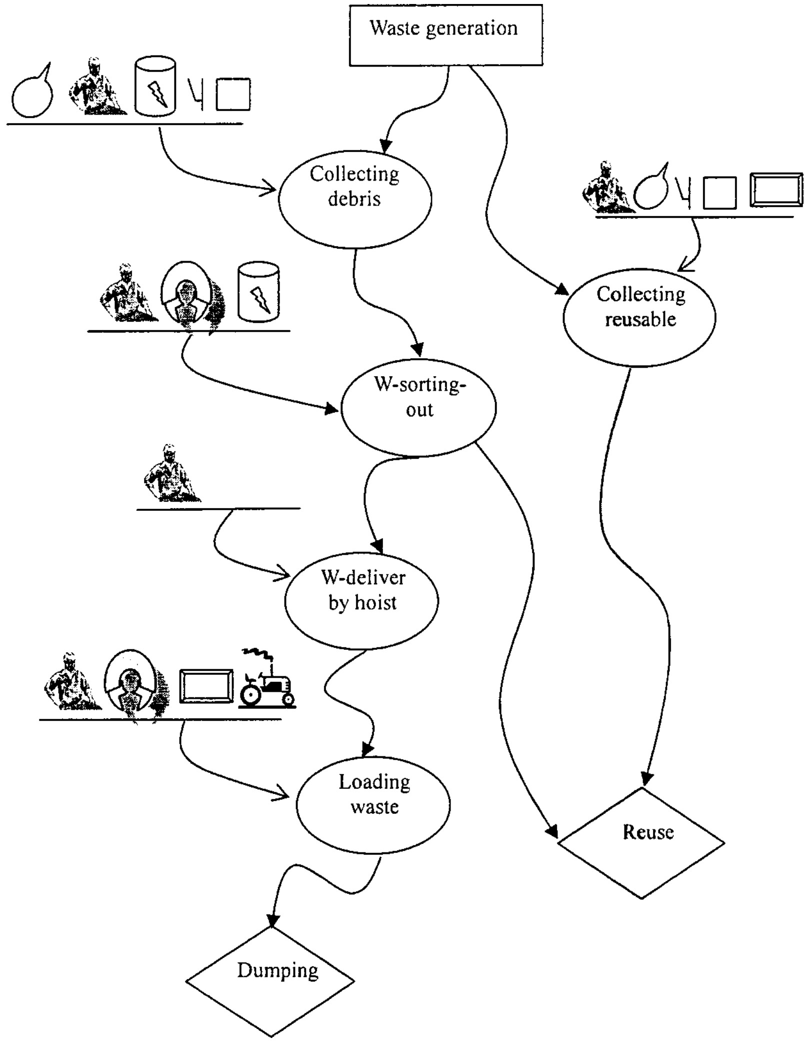

Fig. 6. Mapping of waste management practice for a high rising office-building project: Project IV

gram for the working staff who handled wastes. Less consideration is given among managerial staff to the environmental impacts of the wastes. There is lack of standard waste handling procedures; and there is no review exercise on the effectiveness of waste handling practice.

Developing an Effective Waste Management Mapping Model

The investigation on the six cases in the previous section demonstrates that different site management practices engage different waste handling procedures. However, all the practices involve three basic elements, namely waste generation, waste assembly, and waste destination. First, various types of wastes are generated, and bottom-layer subcontractors and laborers collect and sort out wastes at various locations. In a proper practice, reusable and recyclable waste materials should be identified and sorted out when wastes are generated, such as marble, kitchen cabinet, timber flooring, false ceiling, and waterproofing materials. In fact, it was pointed out in the interview discussion when examining the six cases that the waste marble and wall tiles are particularly useful for defect rectification. The separate purchase of marble and wall-tiles are often found with color deviation and texture incompatible from the first batch of purchase, thus reuse of these waste materials can avoid such a deviation problem. On the other hand, waste reduction for dumping can be gained if proper sorting-out is taken at the waste generation stage.

Second, for assembling wastes, it is the main contractor's responsibility to coordinate and assemble waste handling processes. The investigation on the six practical cases suggests that the main contractor can improve waste handling effectiveness through properly coordinating and supervising subcontractors or specialist trades for adopting more effective waste handling measures. These measures, for example, include: (1) using an open-top lorry container in assembling wastes to avoid double waste handling; (2) assembling waste materials to a central or few collection points within the construction site, thus reducing supervisory efforts; (3) utilizing a rubbish chute in delivering wastes to increase delivering efficiency; (4) sorting-out wastes after normal work hours in order to minimize the interference to other operations; (5) reusing usable wastes or recycling valuable materials in order to reduce waste volume for final dumping (in fact, the experience in three surveyed cases suggests that the sale of recyclable wastes such as timber and steel bar can offset the recycle overheads); and (6) delivering the residual wastes to specific destinations, such as a dumping area or reclamation area designated by the government. These destinations are specified in relevant governmental policies. Further waste sorting-out is suggested to be conducted at

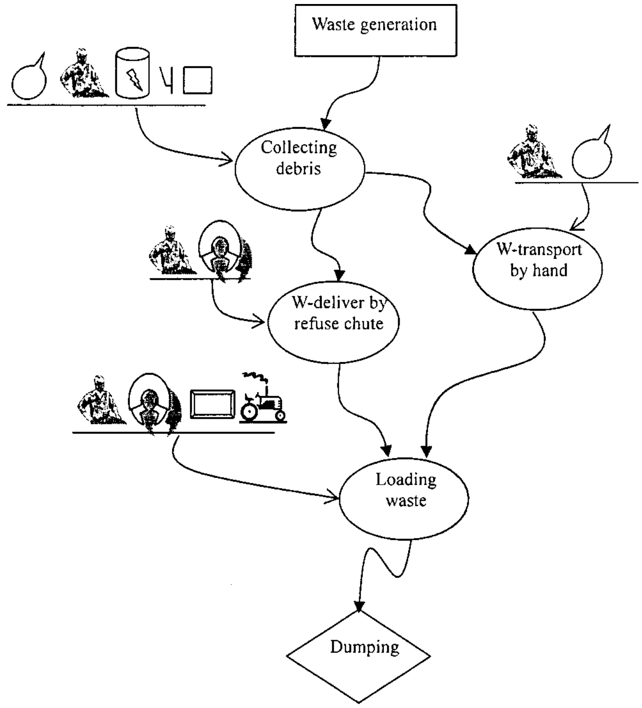

Fig. 7. Mapping of waste management practice for a redevelopment-building project: Project V

these destinations, so that specific disposal measures can be used for dealing with different types of residual wastes.

The examinations on the weaknesses and advantages of handling construction wastes in the six surveyed practices provide valuable references for proposing a more effective and sample waste management mapping model. By incorporating the advantages embodied in these practices and the results of discussions with the site managerial staff who participated in the mapping of these six cases, the major guidelines for constructing such a WMMM are proposed as follows:

- To minimize the cost used for implementing waste management by (1) minimizing the number of processes for handling wastes; (2) involving less labor hours/efforts for handling wastes; (3) using more mechanical means in handling wastes; (4) choosing low energy consumption tools/plants for handling wastes; (5) avoiding double handling operations; and (6) engaging proper supervision of waste-handling activities.
- To protect the environment in the process of handling wastes by (1) controlling to its minimum level waste pollution including air pollution, water pollution, and noise pollution; (2) maximizing waste recycle and reuse; (3) promoting environmentally friendly operation to all production activities among working staff; (4) adopting clean construction practices by keeping tidy and hygienic on construction sites; (5) maximizing the use of environmentally friendly building materials and construction methods; (6) adequately purchasing the quantity of building materials for reducing waste generation; and (7) using the construction plants that have less environmental impacts.
- To minimize the time consumption for handling waste by (1) reducing the number of waste handling processes; (2) simplifying the operation of each handling process; (3) avoiding

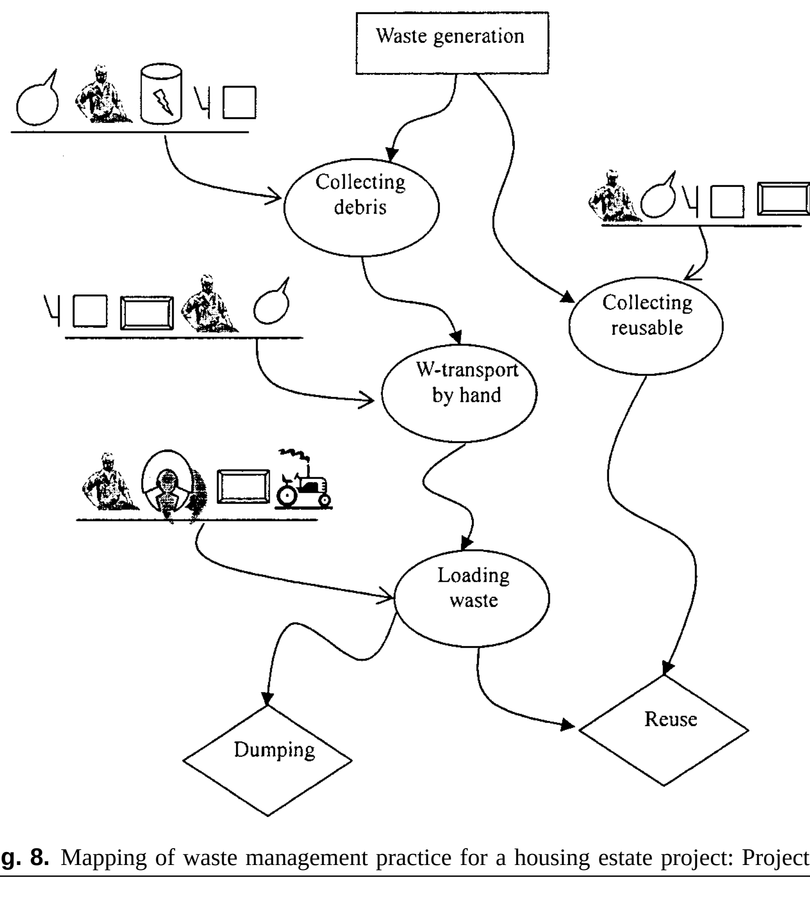

Fig. 8. Mapping of waste management practice for a housing estate project: Project VI

J. Constr. Eng. Manage., 2004, 130(4): 472-481

Table 2. Comparative Evaluations on Weaknesses in Practicing Waste Management between Six Cases

Weaknesses	I	II	III	IV	V	VI
W_1=too many waste handling processes		○		●	○	■
W_2=lack of waste sorting-out process	●	●	○		●	■
W_3=no consideration for recycling wastes	●	●	●	●	●	●
W_4=no consideration for reusing wastes	●				●	
W_5=severe air pollution due to collecting and delivering waste	○	■	●	○	●	●
W_6=severe noise pollution due to delivering waste	○	●	■	■	○	○
W_7=intensive labor work involved in handling wastes	■		■	●		●
W_8=double-handling in collecting wastes		●	●	●	■	
W_9=inefficient use of waste delivering mechanical facilities		■	■	○	○	
W_{10}=time consumed for collecting waste from scattered collection locations	●	■		●		●
W_{11}=unsafe practice by allowing more laborers to collect wastes on site	●		○	■		■
W_{12}=poor coordination and supervision of waste-handling staff	■		■	■		■
W_{13}=inefficient waste handling due to less application of mechanical facilities	●	○	○	●		●
W_{14}=extensive use of plastic bags in collecting wastes	■		■	■	■	○
W_{15}=unsafe operation in handling wastes	■			■	●	●
W_{16}=undeveloped culture of waste reduction among site staff	●	○		○	●	○

Note: ○: insignificant, ■: significant, and ●: strong.

double-handling operation of wastes; and (4) increasing waste handling efficiency by using more mechanical devices and less labor operations.

By incorporating the above guidelines with the six practical cases examined in this study, an alternative WMMM is proposed as shown in Fig. 9. This model introduced a waste management plan before the commencement of construction activities. The plan will specify the resources for handling wastes and waste mitigation measures, and it should be implemented from the start of construction activities. According to the model WMMM, those reusable waste materials should be sorted out as soon as they are generated and delivered to specific locations. The sorting-out at the point of waste generation is easier to do than that at later stages. Such practice can also avoid the increase of waste volume when the project proceeds and provide clean working conditions. Furthermore, earlier waste sorting-out can avoid the possibility that the usable and recyclable waste materials are spoiled in the mixture with other debris. In the current practice in Hong Kong, waste sorting-out is uncommon and often only major reusable wastes are collected at a project's late stages (Ho 2001). This

Table 3. Comparative Evaluations on Advantages in Practicing Waste Management between Six Cases

Advantages	I	II	III	IV	V	VI
A_1=fewer waste handling processes			●	○	●	
A_2=proper waste sorting-out		○	■	○		○
A_3=recycling wastes						
A_4=reusing wastes		■	●	●		●
A_5=clean waste handling operations	●	○		●		●
A_6=less labor work involved in handling waste		●	■		●	
A_7=avoiding double-handing waste	●					●
A_8=efficient use of mechanical facilities in delivering waste		●	●	○	○	
A_9=fewer waste collection locations with seeable distance		○	■	○	○	
A_{10}=well-coordinated procedures for handling waste		■	●	●		■
A_{11}=generating income from selling reusable wastes		○	●	■		○
A_{12}=less investments on setting up waste delivering facilities	●	○			■	■
A_{13}=safe waste handling operation	●	●	○		○	○

Note: ○: insignificant, ■: significant, and ●: strong.

J. Constr. Eng. Manage., 2004, 130(4): 472-481

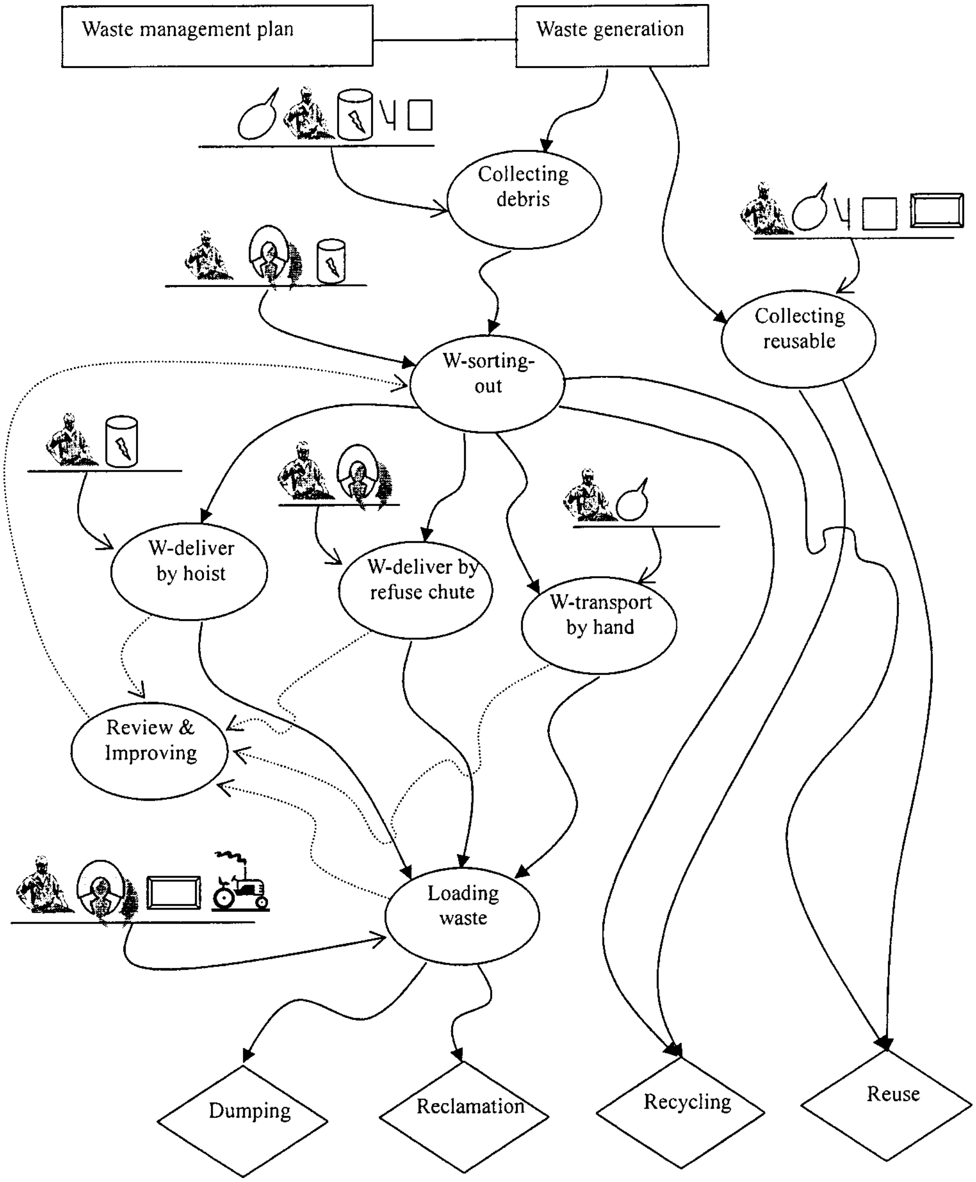

Fig. 9. Waste management-mapping models

practice is considered as one of the major reasons of having massive production of construction wastes in the local construction industry.

Having collected reusable and recyclable wastes, the wastes left are construction debris. The debris will be further sorted out into different types of wastes, for example, inert and noninert materials. The sorting-out of the debris also leads to further identification of reusable and recyclable wastes. Following the sorting-out of construction debris, the residual debris will be delivered to waste collection locations through various methods such as a refuse chute, hoist, or by hand. While the application of different delivery methods depends on the type of debris and conditions of different sites, the practice of waste delivery should aim for involving simple procedures, high efficiency, and less labor work. For protecting the environment, the workers who handle wastes should be encouraged to use less plastic bags or use repeatedly. The model WMMM also recommends placing boxes for collecting recyclable wastes at proper locations for increasing the efficiency of collecting and delivering wastes. The allocation of these boxes can also promote environmental awareness among all working staff on site.

In the final procedure of WMMM, the residual construction debris are classified and transported to waste destinations such as dumping or reclamation. The choice of waste destination needs to be in line with governmental policies. Taking Hong Kong as an example, as mentioned before, the wastes with less than 20% of inert material should be delivered for dumping at landfills, while the wastes with more than 20% of inert material are transported to site formation or public filling areas (EPD 2002). The study by Mills et al. (1999) suggests that for decades, landfills have provided a convenient and cost-effective solution to the wasteful practices of the industry. However, landfills consume land, and this consumption has become increasingly a serious problem in Hong Kong where land is very limited. Thus it is important to reduce the volume of waste materials sent to landfill areas.

To improve waste management practice, the proposed model

J. Constr. Eng. Manage., 2004, 130(4): 472-481

WMMM further suggests applying a review for assessing the effectiveness of the waste management process on site. This review is to identify those weak procedures, examine the reasons behind the weakness, and take necessary actions to improve the weak procedures. The review should involve the participation of all working staff on site, thus the results of the review can be effectively responded to on site.

Conclusion

The benefits of implementing waste management in construction activities are multiple. Although previous researchers suggested that one of the main advantages of engaging proper waste management is cost saving, such cost reduction has received little recognition among professionals. Rather, it seems a shared view that waste management will increase cost in the short term due to additional investment on staffing, technologies, and facilities. Nevertheless, in the long term, for the benefit of all, emphasis should be placed on controlling wastes to preserve the environment and extend the life of existing landfills. In the local practice in Hong Kong, it is the governmental enforcement to push contractors to implement waste management, which of course results in limited effectiveness as there is a lack of contractors' initiatives for engaging proper waste management procedures. This study identifies that one of the essential reasons for the absence of such initiatives is the lack of standard guidance for setting up proper waste management procedures on site.

The investigation of six cases in this paper demonstrates that different site management practices engage different waste management procedures, while they have common weaknesses and share some good practices. Nevertheless, the differences and experiences between different practices have received little attention among professionals. The six mapping presentations by using the free-flow modeling technique in this paper demonstrate an effective approach for examining these differences in practicing waste management on site. The examination on these cases leads to the development of a waste management mapping model as a sample practice for guiding the waste controlling procedures on construction sites. WMMM incorporates the advantages embodied in the current practice, and thus provides a tool for comparing the waste management practice among different projects. When a comparison is conducted, weak areas can be identified and improvement measures can be implemented accordingly.

References

Bossink, B. A. G., and Brouwers, H. J. H. (1996). ''Construction waste: Quantification and source evaluation.'' *J. Constr. Eng. Manage.*, 122(1), 55–60.

Chun, L. P., Domenic, E. S., and Charles, J. K. (1997). ''Strategies for successful construction and demolition waste recycling operations.'' *J. Constr. Manage. Econ.*, 15(1), 49–58.

Cotton, A., Snel, M., and Ali, M. (1999). ''The challenges ahead—solid waste management in the next millennium.'' *Waterlines*, 17(3), 2–5.

Craven, E. J., Okraglik, H. M., and Eilenberg, I. M. (1994). ''Construction waste and a new design methodology.'' *Sustainable Construction: Proc., 1st Conf. of CIB TG 16*, C. J. Kilbert, ed., 89–98.

Environmental Protection Department (EPD). Hong Kong Government. (2002). ⟨http://www.info.gov.hk/epd⟩

Faniran, O. O., and Caban, G. (1998). ''Minimizing waste on construction project sites.'' *Eng., Constr., Archit. Manage.*, 5(2), 182–188.

Ferguson, J., Kermode, N., Nash, C. L., Sketch, W. A. J., and Huxford, R. P. (1995). *Managing and minimizing construction waste—A practical guide*, Institution of Civil Engineers, London.

Fisher, N., and Shen, L. Y. (1992). *Information management within a contractor—A model for the flow of data*, Thomas Telford, London.

Gavilan, R. M., and Bernold, L. E. (1994). ''Source evaluation of solid waste in building construction.'' *J. Constr. Eng. Manage.*, 120(3), 536–555.

Ho, O. S. T. (2001). ''Construction waste management—a contractor's perspective.'' *Hong Kong Inst. Builders*, July, 8–11.

Hong Kong Housing Authority (HKHA). (2002). ⟨http://www.info.gov.hk/hd/eng/ha/publications.htm⟩

McDonald, B., and Smithers, M. (1998). ''Implementing a waste management plan during the construction phase of a project.'' *J. Constr. Manage. Econ.*, 16(1), 71–78.

McGrath, C. (2001). ''Waste minimization in practice.'' *Resour., Conservation Recycling*, 32, 227–238.

Mills, T. M., Showalter, E., and Jarman, D. (1999). ''A cost-effective waste management plan.'' *Cost Eng.*, 41(3), 35–43.

Petts, J. (1995). ''Waste management strategy development: a case study of community involvement and consensus-building in Hampshire.'' *J. Environ. Plan. Manage.*, 38(4), 519–536.

Poon, C. S. (1997). ''Management and recycling of demolition waste in Hong Kong.'' *Waste Manage. Res.*, 15(6), 561–572.

Rogoff, M. J., and Williams, J. F. (1994). *Approaches to implementing solid waste recycling facilities*, Noyes, Park Ridge, N.J.

Rounce, G. (1998). ''Quality, waste and cost considerations in architectural building design management.'' *Int. J. Proj. Manage.*, 16(2), 123–127.

Shen, L. Y., and Tam, W. Y. Vivian (2002). ''Implementation of environmental management in the Hong Kong construction industry.'' *Int. J. Proj. Manage.*, 20(7), 535–543.

Spivey, D. A. (1974). ''Construction solid waste.'' *J. Constr. Div., Am. Soc. Civ. Eng.*, 100(4), 501–506.

Waste Disposal Ordinance (WDO). Hong Kong. (2001). ⟨http://www.info.gov.hk/tid/support/pollution/waste.pdf⟩

J. Constr. Eng. Manage., 2004, 130(4): 472-481