CONSTRUCTION INDUSTRY COUNCIL
建造業議會

Report on Strategy for Management and Reduction of Construction and Demolition Waste in Hong Kong

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Background

Construction and demolition waste contributes a higher portion of total waste to the landfill in Hong Kong. Land resource is a precious asset due to the scarcity of land in Hong Kong. It is essential for construction industry to consider the strategy for management and reduction of construction waste. A Task Force on Strategy for Management and Reduction of Construction and Demolition Waste (TF-C&D) in Hong Kong was thus set up under the Committee on Environment (Com-ENV) of the Construction Industry Council (CIC) to work together with relevant industry stakeholders to discuss and agree on strategy for management and reduction of construction and demolition waste in Hong Kong.

TF-C&D suggested to commission a Consultant to carry out Consultancy Services on Strategy for Management and Reduction of Construction & Demolition Waste in Hong Kong. After careful assessment and screening process, PolyU Technology and Consultancy Co. Limited (PolyU) was commissioned by CIC to conduct the Consultancy Services.

The objectives of the Consultancy are:

1. To conduct literature review on overseas policies and measures for management and reduction of construction waste;
2. To conduct literature review on the current statutory and administrative measures for management and reduction of construction waste in public works and private works projects;
3. To propose strategy and measures for management and reduction of construction waste;
4. To conduct feasibility study of on-site snapshot survey for the non-inert construction waste composition in Hong Kong;
5. To propose an appropriate methodology (upstream or downstream approach) for the non-inert construction waste composition study after the feasibility study;
6. To prepare a service specification for the suggested methodology (upstream or downstream approach) to carry out the snapshot survey for the non-inert construction waste composition.

This final report consists of eight reports that PolyU has made for CIC with a summary report.

REPORT 1

LITERATURE REVIEW ON OVERSEAS C&D WASTE MANAGEMENT POLICIES AND MEASURES

August 2017

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The aim of this report is to give a general overview of overseas construction and demolition (C&D) waste management policies and measures. The overseas policies and measures were identified and summarised from three sources:

1) Academic literature;
2) Official websites of overseas governments;
3) Overseas green building rating systems.

1. Overseas policies and measures from academic publications

This section introduces and discusses the overseas C&D waste management policies and relevant measures identified from academic publications.

1.1. Overseas C&D waste management policies

1.1.1. Legislation

In order to avoid and give appropriate disposal to C&D waste, legislative measures have been implemented in European countries. Sáez et al. (2011) gave an overview of European C&D waste management from four aspects:

- Landfill Regulations. Regulations have been implemented to restrict the disposal at landfills. For example, it is forbidden to dispose waste which can be incinerated at landfills in Denmark. In Germany, the waste that can be recycled is also illegal to be disposed at landfills. In the Netherlands, a high landfill disposal fee of approximately 83 €/t (622 HKD/t) has been required.
- Waste Management Policy. Legal measures have been adopted to regulate C&D waste management. For instance, Spain has implemented the Second National Plan on C&D waste in 2008 and the Royal Decree 105/2008. It is required that the construction industry needs to recover some particular types of C&D waste if their quantities exceed certain amounts. More specifically, it is a must for the Spanish construction companies to segregate the different types of waste if they exceed the following amounts: >80t

concrete; >40t bricks & tiles; >2t metal; >1t wood; >1t glass, >0.5t plastic; >0.5t paper.

- Quality Standards. It is a common measure to promulgate standards on the quality of secondary materials from C&D waste. For example, in Belgium, the nature of recyclable C&D waste and the concentration limits of heavy metals and aromatic hydrocarbons in the secondary materials are specified in a waste framework policy.
- Voluntary Commitment. Germany has tried a national voluntary commitment which aims to reduce 50% of landfilled C&D waste in the construction industry. This measure was implemented since 1996, and is regarded achieving good results.

The ‘Spanish Royal Decree 105/2008’ was particularly introduced by Marrero et al. (2011). This decree was enacted on 1 February 2008, requiring all the construction participants to be involved in the planning, implementation and control of C&D waste. In the decree, specific requirements concerning C&D waste include: ‘(1) an estimation of C&D waste amount; (2) action plans for waste prevention; (3) description of reuse, recovery and/or disposal operations; (4) waste separation actions at the construction site; (5) site plans for storage, handling, separation and other operations in C&D waste management on the construction site; (6) particular technical requirements related to waste storage, handling, and separation, and, where appropriate, other related operations; (7) an estimated management cost that will be part of the project budget in a separate chapter; (8) where appropriate: an inventory of hazardous waste generated on site, a provision for selective disposal in order to avoid mixing different types of waste with each other, and a guarantee of delivery by authorised hazardous waste managers’.

Del Río Merino et al. (2011) suggested that legislative measures should be taken by local authorities to promote C&D waste management from the following aspects:

- Establishing standards to provide technical guarantee for the quality of recycled materials from C&D waste;
- Adjusting economic instruments to promote C&D waste prevention and recycling;

- Promoting the construction of C&D waste treatment plants;
- Planning C&D waste generation through effective policies and instruments;
- Controlling the production and management of C&D waste more effectively;
- Consolidating a uniform framework involving environmental indicators, C&D waste production, reuse and recycling at the level of regional administration;
- Specifying the C&D waste management responsibility of producers;
- Supporting research programmes for improving C&D waste management.

Župová and Kozlovská (2012) further presented the legislative regulations concerning C&D waste management in Slovakia:

- Directive 2001/42/EC of the European Parliament and of the Council on the assessment of the effects of certain plans and programmes on the environment;
- Council Directive 97/11/EC amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment;
- Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment;
- Law No. 17/1992 on environment;
- Law No. 587/2004 on the environmental fund;
- Law No. 24/2006 on the assessment of environmental impact;
- Law No. 469/2002 on environmental labeling of products;
- Law No. 245/2003 on the integrated pollution prevention and control of environmental pollution;
- Law No. 223/2001 on waste;
- Law No. 17/2004 on fees for waste disposal;
- Law No. 359/2007 on the prevention and remedying of environmental damage;
- Notice of the Ministry of Environment No.283/2001 for implementing certain provisions of the waste;
- Notice of the Ministry of Environment No.284/2001 of establishing waste catalogue.

1.1.2. Market-based instruments

It is specified that market-based instruments, such as taxes, subsidies and other incentives, are more effective to promote environmental innovations than laws (Kemp and Pontoglio, 2011). A waste disposal charging scheme has been widely adopted to stimulate project stakeholders' C&D waste minimisation intentions. In China, the present charging fees are mostly determined based on a rule of thumb in many cities, thus the effectiveness of the charging scheme is very limited. In order to provide an effective charging standard, Yuan and Wang (2014) developed a model based on the theory of system dynamics. Two rounds of simulations were carried out using the Shenzhen case: (1) a base run simulation for investigating the status quo of waste generation; and (2) a policy analysis simulation for determining the appropriated charging. The base run simulation showed that a total of 8.81 million tons C&D waste will be generated in 2030 under the current conditions. The policy analysis simulations suggested that the appropriated waste charging standard is around 80 yuan/ton in the region.

1.1.3. Vehicle impoundment policy

The Israeli ministry for environmental protection has implemented a vehicle impoundment policy to avoid illegal waste dumping since 2006. According to this policy, the vehicles will be impounded if illegal dumping is caught. Seror et al. (2014) investigated the effectiveness of this vehicle impoundment policy. By conducting comparisons of historical legal disposal data and interviews with truck drivers, the vehicle impoundment policy was found to be effective for reducing illegal C&D waste disposal in Israel.

1.2. Overseas C&D waste management measures

The existing overseas C&D waste management measures were identified from academic publications. The identified measures are discussed in the following subsections.

1.2.1. Proper design

Proper design is an effective method for reducing C&D waste generation (Baldwin et al., 2009; Baldwin et al., 2008; Poon, 2007; Poon et al., 2004a; Zhang et al., 2012). However, the awareness of architects towards designing out C&D waste is not optimistic. Osmani et al. (2008) investigated the UK architects' perspectives on C&D waste reduction through proper design. The findings revealed that, in the design stage, waste management is not a priority. In addition, though one-third of C&D waste could be reduced through proper design decisions, the UK architects seemed to take the viewpoint that waste is mainly generated during construction process. Li et al. (2015) investigated the designers' attitude and behaviour towards C&D waste minimisation by proper design in Shenzhen. Through the analysis of structural equation modeling, it was found that designers' attitude and perceived behavioural control have positive and significant effects on their C&D waste minimisation behaviour; however, subjective norm plays a limited role. Zoya Kpamma and Adjei-Kumi (2011) investigated the Ghanaian consultants' perspectives on reducing C&D waste during the design process. The results revealed that the awareness of lean design management should be improved in Ghana. Ordoñez and Rahe (2013) interviewed construction professionals from five countries including Sweden, Germany, Chile, India, and Egypt about the collaborative work between C&D waste management and proper design. It was found that the collaboration was not enough to have any effective C&D waste management because of lacking mutual understanding and knowledge.

Wang et al. (2014) conducted a questionnaire survey in Shenzhen and derived six critical factors that can improve waste reduction at design stage, including (1) large-panel metal formworks, (2) prefabricated components, (3) fewer design modifications, (4) modular design, (5) waste reduction investment, and (6) economic incentive. In another paper published by Wang et al. (2015), the best design strategies were suggested through system dynamics modeling. The results showed that the use of prefabricated components has the most significant influence in effective C&D waste reduction, followed by few design changes and waste reduction investment.

The importance of proper design for C&D waste minimisation is also acknowledged by Manrique et al. (2011) and Ajayi et al. (2016).

1.2.2. Use of prefabrication

Prefabrication is defined as 'a manufacturing process, generally taking place at a specialised facility where various materials are joined to form a component part of the final installation' (Tatum et al., 1987). The effectiveness of prefabrication on C&D waste minimisation has been well acknowledged. More than 200 public educational buildings have been assembled in Catalonia, Pons and Wadel (2011) found that the prefabrication technology can reduce around 60% of C&D waste during a building's life cycle. Li et al. (2014) also evaluated the possible C&D waste reduction of using prefabrication, several scenarios were analysed and the results showed that prefabrication is an effective method for C&D waste minimisation.

1.2.3. Waste sorting

Sorting is generally a prerequisite before waste can be successfully reused or recycled (Dupre, 2014; Vegas et al., 2015). The sorting of C&D waste can be conducted on-site or off-site (Brunner and Stampfli, 1993; Lu and Yuan, 2012; Poon et al., 2001). The two sorting strategies can be selected according to different situations.

Wang et al. (2010) explored the critical success factors for on-site sorting in Shenzhen. Six factors were identified including (1) manpower, (2) market for recycled materials, (3) waste sortability, (4) better management, (5) site space, (6) equipment for sorting of construction waste.

Huang et al. (2002) introduced an off-site sorting process of C&D waste in Taiwan. An illustration of the mechanical sorting process is given in Figure 1. From the figure, it can be seen that the sorting process in a sorting plant consists of five operation units, including bar screening, disk screening, magnetic separation, air classification, and final manual separation.

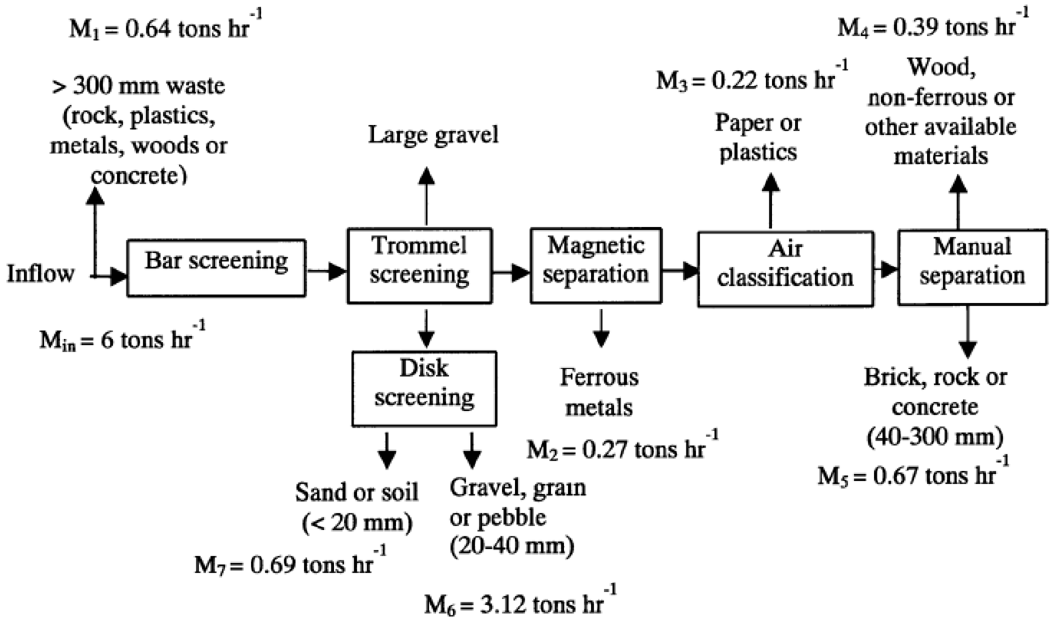

Figure 1 An illustration of the sorting process in a sorting plant (Huang et al., 2002)

1.2.4. Selective demolition

Selective demolition, which is also known as deconstruction, is an application of on-siting sorting at demolition sites. Lauritezen and Hahn (1992) regarded that this strategy is ‘principally carried out in reversal to the construction process, requiring that, before and during the demolition process, a concise sorting of the different material categories should be carried out to prevent any contamination of inert or recyclable parts with wood, paper, cardboard, plastics and metals’. It is an effective strategy for facilitating C&D waste reuse and recycling (Poon, 1997; Poon et al., 2004b).

Though selective demolition is very effective for minimising C&D waste, the cost of this strategy is an important factor that may hinder its implementation in practice. Dantata et al. (2005) conducted an analysis of cost and duration for selective demolition of residential buildings in Massachusetts. The study showed that, under the existing conditions, adopting selective demolition could cost more than traditional demolition about 17% to 25%. They further identified three significant parameters that affect the cost, including labour cost (either productivity or hourly rate), disposal cost (tipping fee and transportation), and resale value of deconstructed materials. Denhart (2009) and Denhart (2010) further reported the implementation of a deconstruction programme in post-disaster New Orleans after the 2005 hurricanes of Katrina and Rita. These two cases supported the use of deconstruction from the economic and psycho-social aspects. Coelho and de Brito (2011b) evaluated the economic viabilities of selective demolition in Portugal. The scenarios which favor selective demolition over the conventional type are provided in the consideration of local conditions (i.e. labour cost, tipping fees, and market prices for recovered materials).

In order to improve the implementation of selective demolition, Couto and Couto (2009) provided some recommendations, such as assessment of the deconstruction potential, establishment of goals for deconstruction, clear and consistent communications at the job site. Akinade et al. (2015) stated that the components of the end-life buildings can have several disposal options (see Figure 2), thus it is essential to develop a Building Information Modelling (BIM) based Deconstructability Assessment Score (BIM-DAS) to determine the feasibility of deconstruction at the design stage.

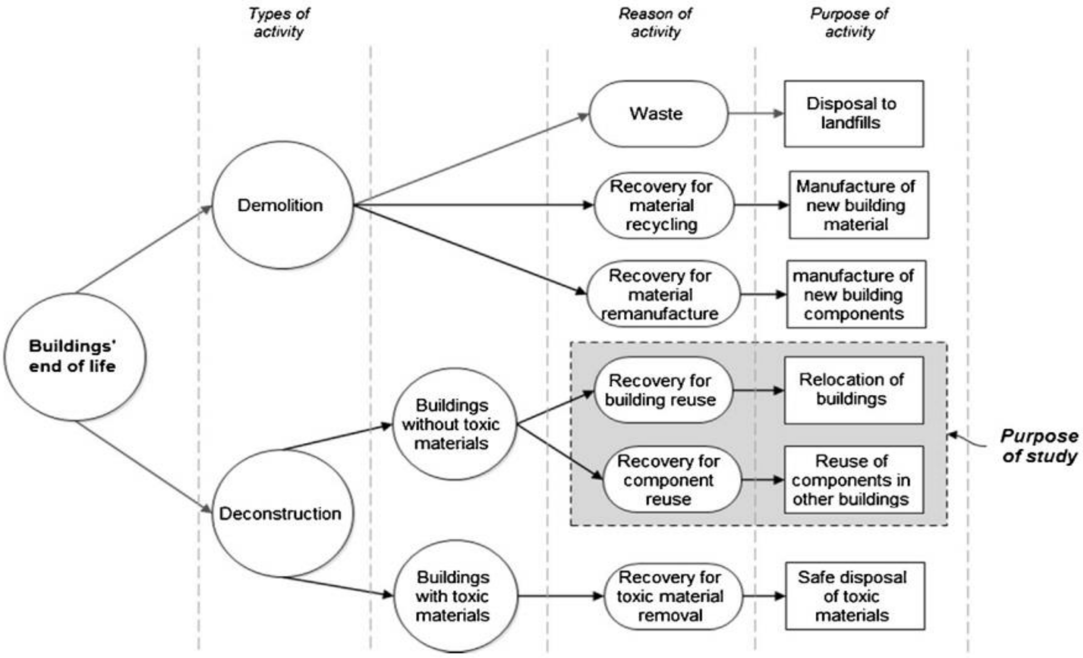

Figure 2 Disposal choices of end-life buildings (Akinade et al., 2015)

1.2.5. Accurate waste quantification

Accurate quantification of C&D waste is regarded as a prerequisite for the successful implementation of waste management (Cheng and Ma, 2013; Li and Zhang, 2013; Lu et al., 2016; Wu et al., 2015; Wu et al., 2014). Since the first paper published by McBean and Fortin (1993), a number of more realistic waste quantification methodologies have been introduced in subsequent academic literature.

In the existing waste quantification methodologies, the most direct and simple one is to obtain C&D waste generation information through site visits. For example, Lu et al. (2011) investigated the C&D waste generation rate in Shenzhen by weighing bucket by bucket and recording the collected data in inventory forms. Lau et al. (2008) estimated the C&D waste amount in Malaysia according to the shapes of on-site piled waste. Kartam et al. (2004) obtained truck load records from landfills in Kuwait. This quantification methodology was also used by Gavilan and Bernold (1994), Bossink and Brouwers (1996), McDonald and Smithers (1998), Formoso et al. (2002), Begum et al. (2006), Kelly and Hanahoe (2008), Kofoworola and Gheewala (2009), Mokhtar et al. (2010), and Nagapan et al. (2013).

Based on the C&D waste generation information collected from site visits, estimation can be made through Generation Rate Calculation (GRC) method. This method the most commonly used C&D waste quantification methodology in academic literature. The principle of this methodology is to obtain C&D waste generation rate for a particular activity unit (such as kg/m^2, m^3/m^2, etc.). For example, McBean and Fortin (1993) assumed the average C&D waste generation amount was 1.09 tons/person/year, so the annual regional C&D waste generation can be estimated through multiplied by the number of population. In recent years, many studies employed GRC methodology based on C&D waste generation rate per construction/renovation/demolition area. For example, Lage et al. (2010) utilised the surface areas of newly constructed buildings, renovations and demolitions in Galicia to estimate the regional C&D waste generation. The GRC methodology has also been used in other papers, such as Yost and Halstead (1996), Fatta et al. (2003), Cochran et al. (2007), Kourmpanis et al. (2008a), Kourmpanis et al. (2008b), Zhao et al. (2010), Banias et al. (2010), Coelho and de Brito (2011c),De Melo et al. (2011), Tamraz et al. (2012),Hoglmeier et al. (2013), Li et al. (2013), and Mália et al. (2013).

In order to obtain more detailed estimation of C&D waste generation, the Classification System Accumulation (CSA) method is an emerging quantification methodology to be used in academic literature. Prior to the implementation of this methodology, a classification system needs to be established. Solis-Guzman et al. (2009) established a classification system based on the European Waste List (EWL). This classification system was hierarchically organised in chapters and sub-chapters. For example, 02TX corresponds to chapter 02 (stands for earth works) and sub-chapter TX (represents earth transportation). Then, the waste amount of this specific item was calculated by applying site visit and generation rate calculation. Once the quantities of all items have been determined, the total amount of waste could be derived by accumulating all items. The CSA methodology has also been used in other studies, such as Wang et al. (2004), Coelho and de Brito (2011a), Llatas (2011), Masudi et al. (2011), de Guzmán Báez et al. (2012), Saez et al. (2012), Mercader-Moyano and Ramírez-de-Arellano-Agudo (2013), and Li et al. (2016).

There are also some other C&D waste quantification methods, such as lifetime analysis method (Bergsdal et al., 2007; Cochran and Townsend, 2010; Hashimoto et al., 2007, 2009; Hsiao et al., 2002; Hu et al., 2010; Shi and Xu, 2006), variables modeling method (Al-Sari et al., 2012; Che Hasan et al., 2013; Hettiaratchi et al., 2010; Katz and Baum, 2011; Wimalasena et al., 2010; Ye et al., 2010), etc.

Combining the advantages of above-mentioned quantification methodologies, Li et al. (2016) developed an integrated model to estimate C&D waste generation in an illustrative project in Hebei Province, China. The overall methodology of this model is shown in Figure 3. An example of the work breakdown structure (WBS) is given in Figure 4.

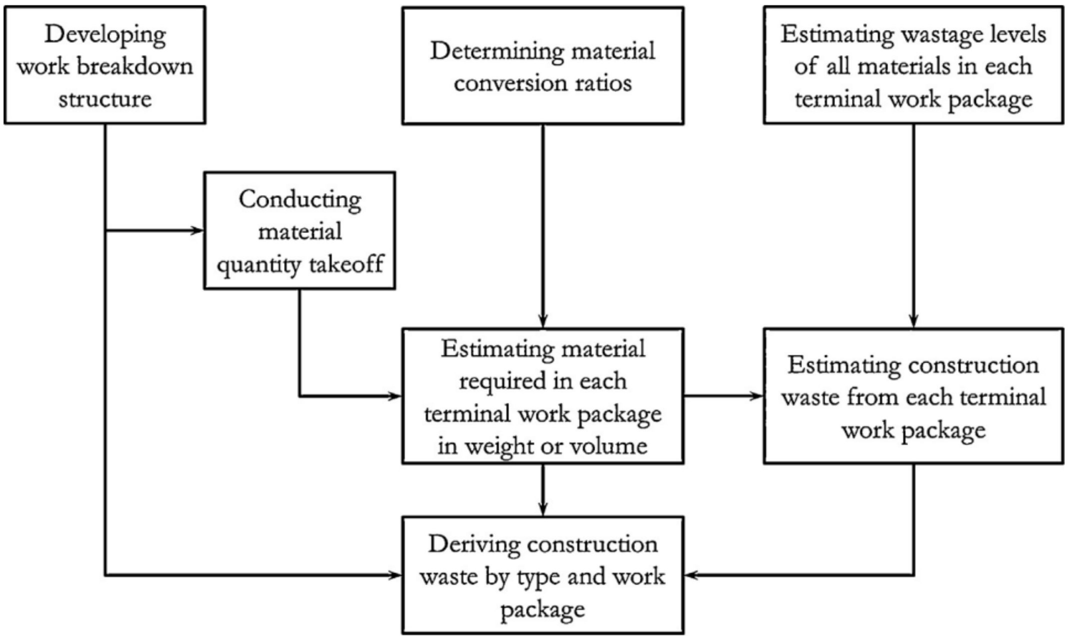

Figure 3 Overall methodology in developing the proposed model (Li et al., 2016)

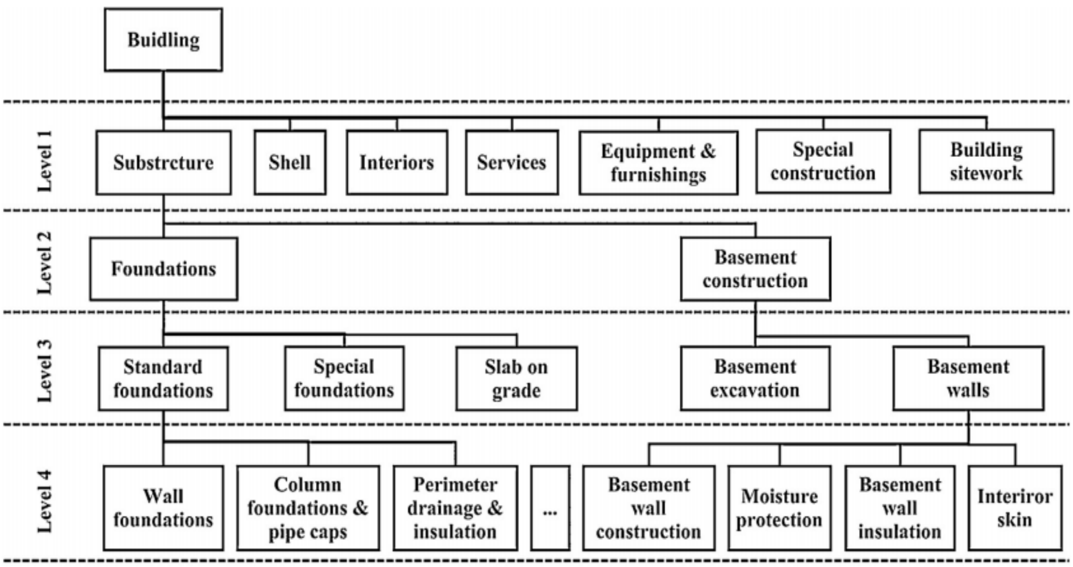

Figure 4 An example of the work breakdown structure (WBS) (Li et al., 2016)

In recent years, new technologies have also been introduced for quantifying C&D waste, such as BIM (Cheng et al., 2015), GIS (Wu et al., 2016), etc.

1.2.6. Incentive reward programme

Incentive reward programmes can be used to encourage the construction workers to minimise C&D waste generation. Rewards can be given to the workers according to the amounts and values of the materials they save. Materials can be saved through several options: reducing operational mistakes, returning unused materials which can be reused or recycled, etc. Kulatunga et al. (2006) claimed that the incentive rewarding programme can help construction workers to improve their waste minimisation intentions. Without the reward system, construction workers may become unawareness when handling the materials.

1.2.7. Online waste exchange

Nasaruddin et al. (2008) presented an online waste exchange model in Malaysia after Chen et al. (2006) have introduced an e-commerce model in Hong Kong. The aim of the online waste exchange system is to create a convenient platform for contractors, developers, recyclers and local authorities to communicate their waste data instantly.

An E-ConWaste Exchange model was established by Nasaruddin et al. (2008), as shown in Figure 5. Before using this system, it is required a user to register as a member. Based on their types of membership, access levels will be assigned to differentiate contractors, developers, recyclers and local authorities. Users can add new list and purchase C&D waste on the platform, and each transaction will be recorded in the database. The online waste exchange can also help the local authorities to monitor the developers' and contractors' performance of C&D waste management.

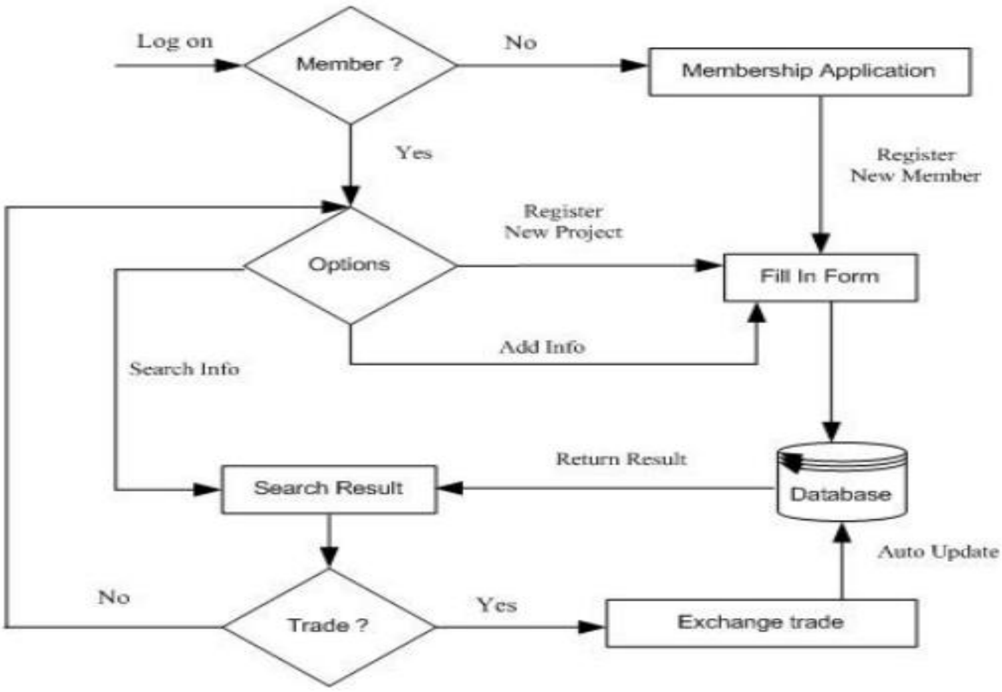

Figure 5 E-ConWaste Exchange process flow model (Nasaruddin et al., 2008)

1.2.8. GIS (Geographic Information System) technology

In academic literature, Li et al. (2005) first introduced the GIS technology in C&D waste management, Long et al. (2009) and Su et al. (2012) further utilised this technology to manage hazardous waste and material layout evaluation in renovation projects. The most recent application of GIS was conducted by Wu et al. (2016) for demolition waste management. In the developed GIS model, five components were involved, i.e. building basic information datasets; weight calculation of demolition waste; demolition time setting; recycling potential of demolition waste; and projection of landfill demands, as shown in Figure 6. An illustrative case study was conducted in Shenzhen, and the results showed that GIS is an appropriate tool for demolition waste management in terms of quantifying waste flows.

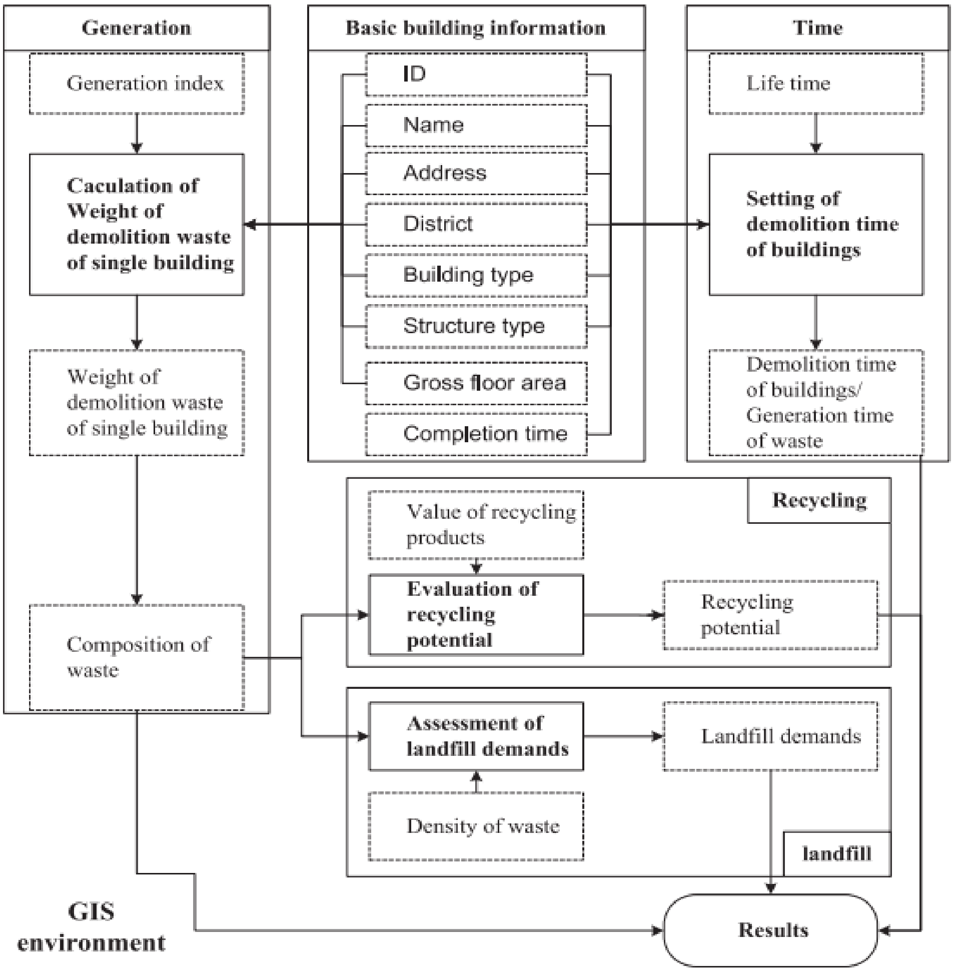

Figure 6 A GIS model designed for the demolition waste management

1.2.9. Building Information Modeling (BIM)

Building Information Modeling (BIM) is getting more and more popular in the construction industry, and the use of BIM in C&D waste minimisation has also been proposed by many researchers, especially in recent years (Cheng and Ma, 2013; Cheng et al., 2015). Liu et al.

(2015) employed a questionnaire survey and follow-up interviews with the top 100 architectural practices in the United Kingdom. An industry-reviewed ‘BIM-aided construction waste minimisation framework’ was proposed by on the collected data. Hamidi et al. (2014) used BIM in a cost-benefit analysis of demolition waste management. Park et al. (2014) analysed the disposal routes of demolition waste considering their characteristics. Akinade et al. (2015) applied BIM in the deconstruction process. Won et al. (2016) estimated the amount of construction waste prevented by a BIM-based design validation process. A case studies has been conducted in Korea, showing that BIM-based design validation could reduce 4.3% - 15.2% of construction waste compared with traditional methods.

1.2.10. System dynamics modeling

C&D waste management is a dynamic process throughout the whole lifecycle of a project. System dynamics (SD) modeling was suggested in order to get a better understanding of the dynamic interactions and interdependencies of the C&D waste management process (Hao et al., 2007). Tam et al. (2014) used SD modeling to examine the complexity of C&D waste management in Shenzhen, China. Different C&D waste management phases were explored including waste generation, transportation, recycling, landfilling and illegal dumping. In recent years, SD modeling approach was also employed in other studies, such as estimation of C&D waste generation (Ye et al., 2010), selection of C&D waste recycling centre (Zhao et al., 2011), cost-benefit analysis (Liu et al., 2014), proper conservation and recycling of aggregates (Mallick et al., 2014), environmental and economic impact assessment of C&D waste disposal (Marzouk and Azab, 2014), assessment of potential impact of policies (Calvo et al., 2014), determination of C&D waste disposal charging fee (Yuan and Wang, 2014), and environmental performance simulation of C&D waste reduction (Ding et al., 2016).

1.2.11. Education and training

The importance of education to general waste management has been acknowledged by Williams (2014). In terms of C&D waste management, many studies have emphasised the importance of construction stakeholders' attitudes towards C&D waste management (Begum et al., 2009; Kulatunga et al., 2006; Ling and Leo, 2000; Yuan and Shen, 2011). It is regarded that education and training can improve construction practitioners' C&D waste management awareness as well as deepen their knowledge of how to adopt appropriate waste minimisation measures.

1.2.12. Others

There are also other C&D waste management measures mentioned in the academic literature, such as goal setting and feedback for increasing C&D waste reduction and reuse (Lingard et al., 2001), developing C&D waste management plans to guide better performance of on-site C&D waste management (Merino et al., 2010), developing an Environmental Management System (EMS) which is based on regulation measures and economic incentives (Calvo et al., 2014), etc.

2. C&D waste management policies and measures from overseas official websites

This section introduces the C&D waste management policies and measures identified from overseas official websites. The investigated countries/regions include the United States, European Union, Japan, Singapore, Korea, Australia, and Taiwan.

2.1. United States

2.1.1. Waste management in United States

In the United States (US), the government unit for supervising C&D waste management is the Environmental Protection Agency (EPA). A specific EPA's website is designed for C&D waste management. According to the official website, C&D waste is 'generated when new building and civil-engineering structures are built and when existing buildings and civil-engineering structures are renovated or demolished (including deconstruction activities)' (EPA, 2016c). Examples of C&D materials are provided by EPA, such as concrete, wood, asphalt, gypsum, metals, bricks, glass, plastics, salvaged building components, trees, stumps, earth, and rocks (EPA, 2016c).

In the United States, C&D materials represent a significant proportion of total waste. The most recent C&D waste generation information is given in the 'Advancing Sustainable Materials Management: Facts and Figures Report' (EPA, 2015a). It was reported that, in 2013, the generated C&D debris were 530 million tons. The composition is shown in Figure 7. From Figure 7, it can be seen that Portland cement concrete accounts for the largest portion of 67%. The second is asphalt concrete, representing 18%. Other products account for 15% combined. As shown in Figure 8, demolition represents over 90% of total C&D waste generation as opposed to construction which represents under 10%.

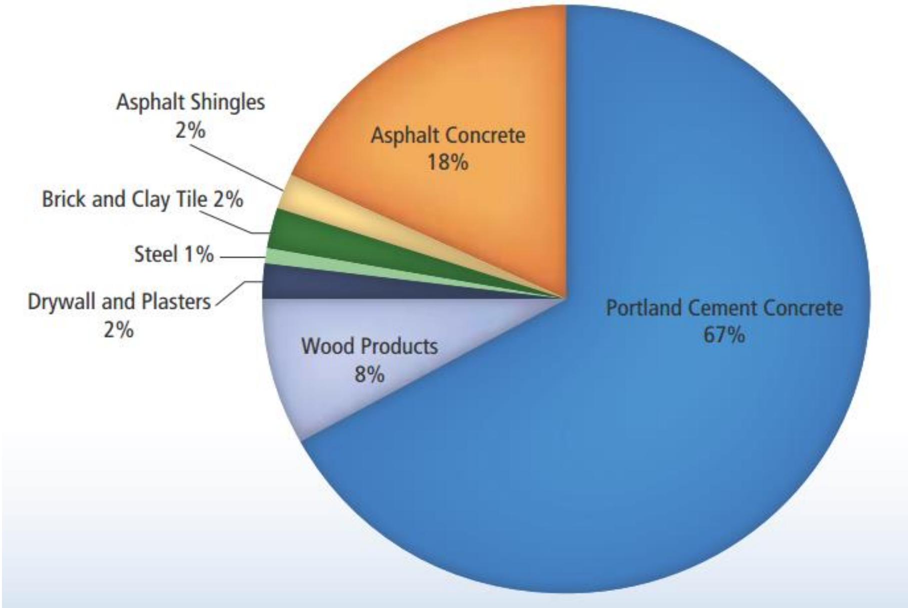

Figure 7 C&D waste composition in the United States, 2013 (EPA, 2015a)

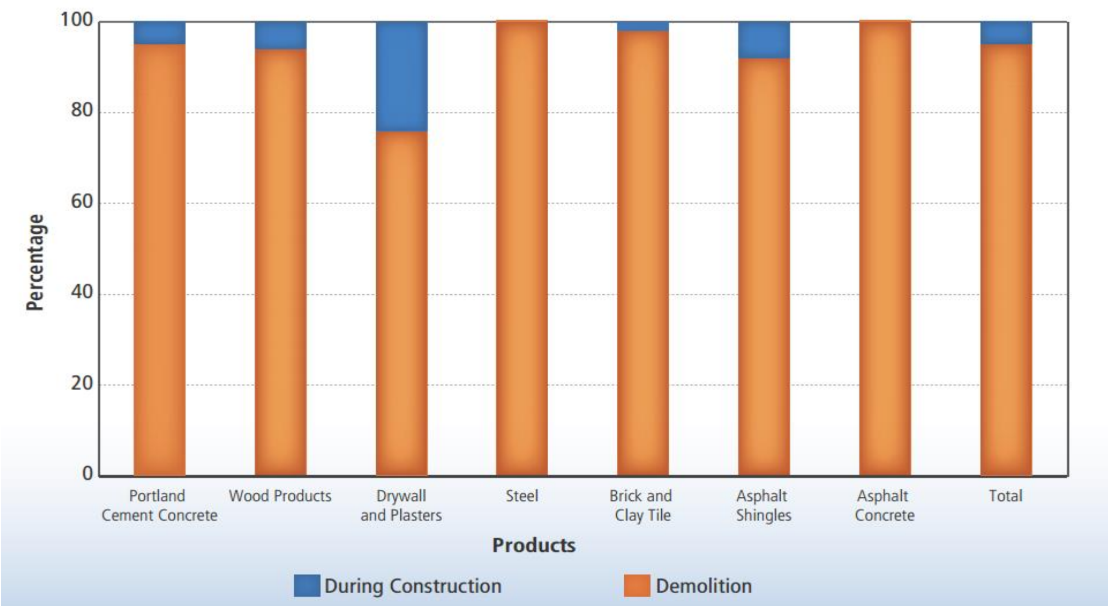

Figure 8 Contributions of construction and demolition phases to C&D waste generation (EPA, 2015a)

In order to diverted C&D materials from disposal into new productive uses, the EPA provided measures of how to recover C&D materials from single-family homes (EPA, 2013). Four strategies have been suggested by the EPA for C&D waste minimisation: Reduce, Reuse, Recycle and Rebuy (EPA, 2016c).

Source reduction is recommended by the EPA because it can prevent waste before it is actually generated. Suggested examples of C&D source reduction measures include 'preserving existing buildings rather than constructing new ones; optimising the size of new buildings; designing new buildings for adaptability to prolong their useful lives; using construction methods that allow disassembly and facilitate reuse of materials; employing alternative framing techniques; and reducing interior finishes'. In order to encourage C&D reduction waste through proper design, the EPA has promoted several innovative pilot projects in the United States (EPA, 2016b).

Considering the large contribution of demolition, deconstruction is also recommended by the EPA to promote C&D waste reuse from demolished buildings. Two manuals have been published for guiding deconstruction: Design for Deconstruction Manual (EPA, 2015b) and Residential Deconstruction Manual (EPA, 2005). In addition, some commonly reused C&D materials and applications are suggested by the EPA (EPA, 2016c):

- Easy-to-remove items (i.e. doors, appliances, and fixtures) can be salvaged for donation or reused in other projects;
- Scrap wood can be reused as mulch or groundcover;
- Crushed gypsum can be used as a soil amendment;
- Brick, concrete and masonry can be recycled on site as fill;
- Extra insulation from exterior walls can be reused as noise deadening material in interior walls;
- Packaging materials can be reused for other purposes.

C&D waste are suggested to be recycled if it cannot be reused directly. The EPA gives examples of C&D waste recycling (EPA, 2016c). For example, asphalt, concrete, and rubble are often recycled into aggregates for producing new asphalt and concrete products. A website has been established for finding a proper C&D recycler (CDRA, 2016).

In the United States, there are different kinds of markets for buying and selling reusable and recyclable materials (EPA, 2016a). Some markets are physical warehouses while others are websites that connecting buyers and sellers. Some are coordinated by local governments while others are organised for private businesses.

2.1.2. Experiences learnt

Based on the investigation of official websites in the United States, insightful experiences are concluded as follows:

(1) Implementation of source reduction. Source reduction is suggested by the EPA because it can be preventing waste before it is actually generated.
(2) Implementation of deconstruction. Demolition contributes large proportion of C&D waste in the United States; reusable materials can be sorted out for direct reuse by using deconstruction.
(3) Illustrative manuals and practical cases. Illustrative manuals, such as Residential Deconstruction Manual, are provided as guidelines for implementation of particular C&D waste management strategies. Practical cases are also presented on the EPA official website.
(4) Development of mature waste trade markets. Mature waste exchange markets formulate the fundamental for stakeholders to gain benefits from waste recycling.

2.2. European Union

2.2.1. Waste management in European Union

According to the European Commission (EC), C&D waste is regarded as ‘one of the heaviest and most voluminous waste streams’ in the European Union (EU) (EC, 2016a). It was reported that C&D waste represents approximately 25-30% of all EU waste (EC, 2016a). Examples of C&D waste are presented on the official website, including ‘concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled’ (EC, 2016a).

EU has published a Waste Framework Directive (2008/98/EC) with the aim of reaching a high level of resource efficiency. In Article 11.2, it is stipulated that 'Member States shall take the necessary measures designed to achieve that by 2020 a minimum of 70% (by weight) of non-hazardous construction and demolition waste, excluding naturally occurring material defined in category 17 05 04 in the List of Wastes, shall be prepared for re-use, recycled or undergo other material recovery' (EU, 2008).

The potential for reusing and recycling C&D waste is very high. For the C&D materials with high resource values, they have been regarded as a priority by EU. For example, there has been a reuse market for trading aggregates derived from C&D waste in roads, drainage and other construction projects. Technologies, which are readily accessible and in general inexpensive, are also well developed for separating and recovering C&D waste. However, the recycling levels of C&D waste vary greatly among different EU countries, as shown in Figure 9.

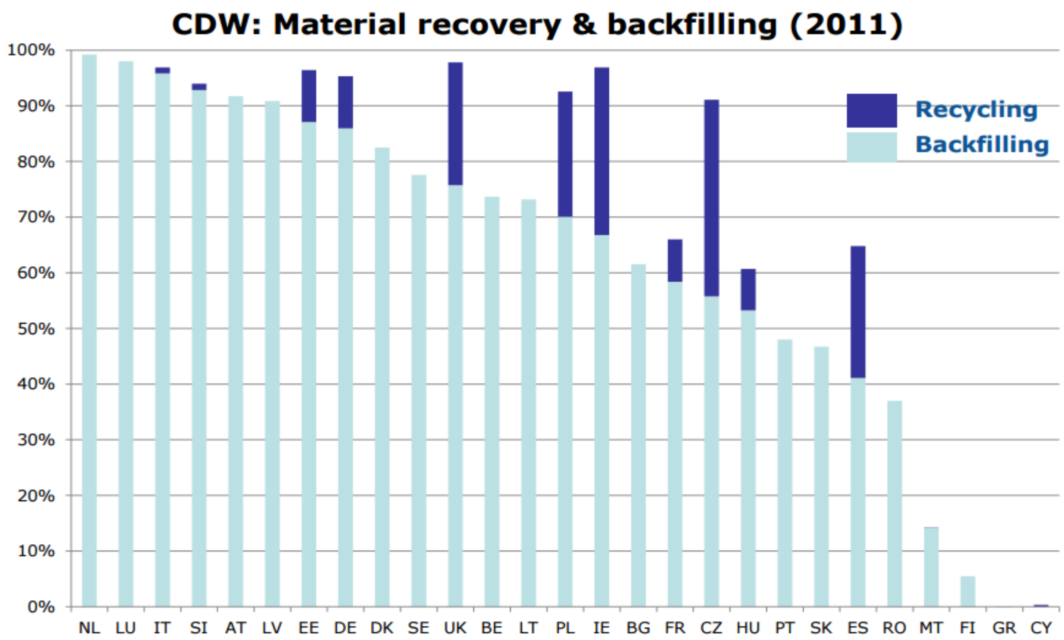

Figure 9 Level of recycling and material recovery of C&D waste in EU (EC, 2016a)

Several research projects have been funded by EU towards C&D waste management. In a completed project, the Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) were introduced for C&D waste management (EC, 2011). LCT is a concept that ‘accounts for the upstream and downstream benefits and trade-offs’. This thinking seeks opportunities for environmental improvement across the whole lifecycle of a project. LCA is ‘a structured and internationally standardised method that transposes LCT principles into a quantitative framework’. The assessment evaluates all consumptions, emissions and environmental impacts throughout the life cycle. Therefore, LCA is an effective and efficient tool to make consumption and production more sustainable.

Another on-going project is being conducted to investigate the current C&D waste management situation in EU Member States (EC, 2016b). The aim of this project is identifying regional obstacles to C&D waste recycling and exploring potential deficiencies that could lead to non-compliance with EU waste legislation. In addition, good experiences and recommendations that can address the identified barriers are also investigated (EC, 2016b).

As the C&D waste management situations in the EU members vary from each other, two countries (i.e. Sweden and the Netherlands), which are regarded as having good practices in C&D waste management, were selected for detailed investigations.

2.2.2. Waste management in Sweden

The C&D waste management experiences in Sweden has been summarised by EC (2015a). In 2012, it was officially reported that the C&D waste generation was 7.7 million tons in Sweden. The amount of C&D waste in 2012 decreased by 18% compared to the generation in 2010 (9.4 million tons) (EC (2015a). The legislative policies and non-legislative instruments for C&D waste management in Sweden are presented as follows.

Since 2002, the Ordinance on Landfilling of Waste has been implemented, prohibiting the disposal of unsorted combustible waste at landfills. In terms of building demolition, waste management is regulated by the Building Code (SFS 2010:900). An inventory of hazardous waste is required before demolishing buildings.

The Swedish Environmental Protection Agency (SEPA) is responsible for setting up the national plans and programmes for waste prevention. The recent Sweden's Waste Plan 2012 - 2017 was published in 2012, superseding the previous waste management plan dating from 2005. The following actions for C&D waste management are listed in the waste management plan for 2012 - 2017:

- ‘Continue the work to compile reliable statistics for C&D waste.
- Prepare guidance concerning the way in which the general rules of consideration in the Environmental Code and the waste hierarchy should be applied in connection with inspections of the management of C&D waste, and how the cooperation between municipal construction boards and environmental boards can be developed.
- Monitor developments and, when necessary, propose additional measures and instruments to achieve the EU's recycling target’.

There are also some non-legislative initiatives for C&D waste management in Sweden, such as landfill tax; green building rating systems that cover C&D waste (e.g. BREEAM); pre-demolition audits; selective demolition in Planning and Building Ordinance; guidelines on sorting of C&D waste; guidance for construction clients, design teams and contractors; etc.

EC (2015a) has concluded three main drivers for C&D waste management in Sweden: ‘(1) improved and better controlled quality of C&D waste opens new possibilities for recycling; (2) implementation of landfill taxes; and (3) ban on landfilling of combustible waste fractions promotes sorting of waste’.

Sweden has done a great job in solid waste management: only 1% of its municipal solid waste was landfilled, approximately 50% was recycled, and 49% was thermally processed for heat and power generation in waste-to-energy (WTE) plants (Gershman, 2013). High landfill charges are the most significant factors for Sweden's reliance on WTE. In 2011, the average landfilling charge was roughly US$ 193 (1496 HKD) per ton, including US$ 126 landfill fee and US$ 67 landfilling tax. Landfill disposal is the most expensive option in Sweden, comparing with the average charge of US$ 84 per ton at WTE plants.

2.2.3. Waste management in the Netherlands

The Netherlands is also one of the leading countries of waste recycling (DWMA, 2016). It is reported that, in 2012, a total of 25.71 million tons of C&D waste were generated in the Netherlands, of which 93% was recovered (EC, 2015b). Similar with Sweden, there are two drivers for the successful C&D waste in the Netherlands: comprehensive regulatory framework and mature recycling market.

Several regulations have been implemented for improving C&D waste management in the Netherlands. In the Environmental Protection Act which was implemented on 12 December 2012, it was required that everyone should take actions to avoid adverse effects from waste. A national waste management plan was further established, specifying what actions can be done to each type of waste. The minimum requirement for C&D waste processing is sorting. The aim of this requirement is to make the mixed waste available for recycling.

From the market perspective, the most important incentive that contributes to C&D waste recycling is landfill and incineration taxes. In the Netherlands, waste is allowed to be landfilled only in the situation that there is no other way for waste processing. From 2015, a tax of €13 per ton has been employed for landfill and incineration. Moreover, the logistics cost is very high, the renting fee of a C&D waste container reaches €329. In this circumstance, waste sorting is cheaper than not separating, thus constructors are willing to separate waste at the source in order to minimise logistics cost.

There are also some other positive market conditions for improving C&D waste management. For example, the contractors in the Netherlands are not negative to use recycled materials because the quality is good compared with their prices. It is suggested that contractors will be more positive to use secondary materials if quality label can be issued. In addition, project clients have been becoming more and more willing to obtain certificates from green building rating schemes.

2.2.4. Experiences learnt

The experiences learnt from EU can be concluded as:

(1) Implementation of Waste Framework Directive. The C&D waste reduction target is proposed as to reuse or recycle a minimum of 70% by weight by 2020.

(2) Mature reuse/recycling market. There is a reuse market for aggregates derived from C&D waste in roads, drainage and other construction projects.

(3) Life-cycle thinking. The fundamental aim of life-cycle thinking is to provide a structured and comprehensive approach in support of the overall reduction of product impacts and to help optimising benefits.

(4) Support for research projects. Project are supported to identify obstacles, good practices, and recommendations.

The experiences learnt from Sweden can be concluded as:

(1) Implementation of legislative initiatives. The legislative initiatives can regulate the waste management behaviour.

(2) Improved and better controlled quality of C&D waste. Good quality of recycled materials can increase the confidence of their implementation.

(3) Implementation of landfill taxes. C&D waste reuse or recycling have more economic

benefits compared with landfilling.

(4) Ban on landfilling of combustible waste fractions. The combustible waste fractions are recycled as fuels.

The experiences learnt from the Netherlands can be concluded as:

(1) Implementation of legislative initiatives. The legislative initiatives can regulate the waste management behaviour.
(2) Implementation of landfill and incineration taxes. C&D waste reuse or recycling have more economic benefits compared with landfilling and incineration.
(3) Development of mature secondary material market. A mature waste exchange market is the fundamental for the stakeholders to gain benefits from waste recycling.

2.3. Japan

2.3.1. Waste management in Japan

The recycling rate of C&D waste in Japan is very high, as shown in Figure 10. The Japan Ministry of the Environment (JME) explained the main reason for the high recycling rate is the implementation of 'Construction Material Recycling Law', which was enacted in May 2000. According to this law, it is required that contractors should sort and recycle the demolition waste. In addition, some specific construction materials, such as concrete, asphalt/concrete and wood building materials are particularly suggested to be reused.

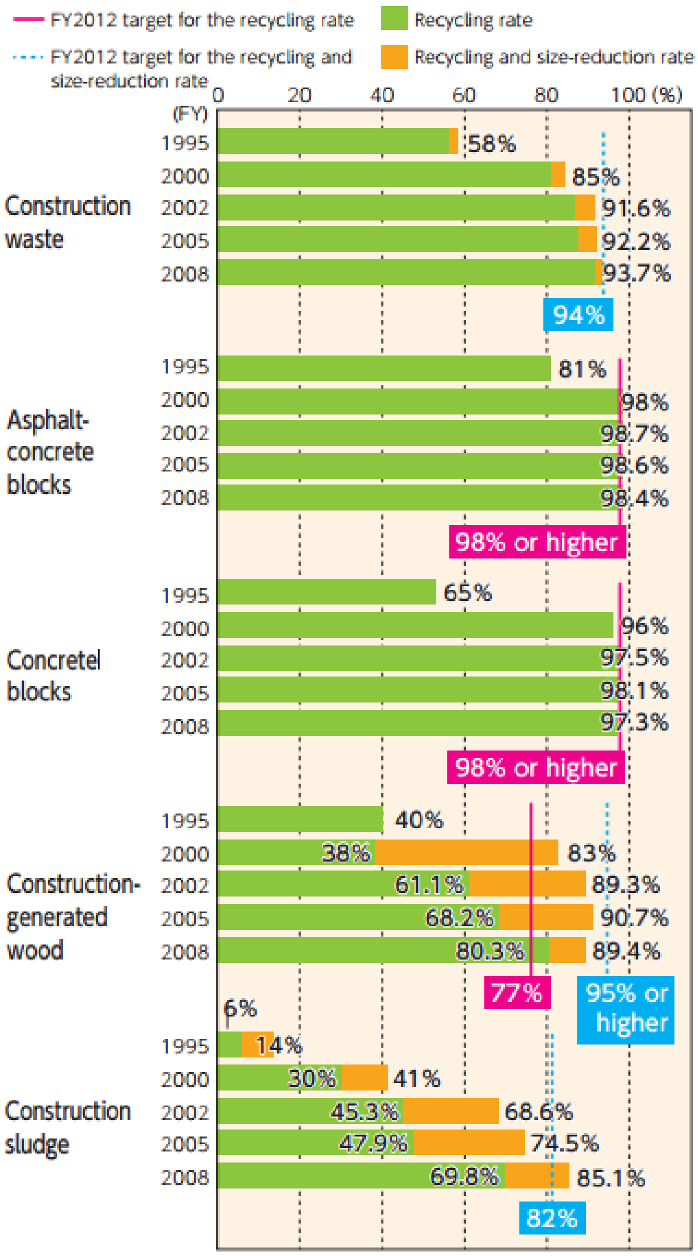

Figure 10 Construction waste recycling rate in Japan (JME, 2014)

This law also stipulates the roles of concerned parties for C&D waste management. The roles of relevant stakeholders are illustrated in Figure 11.

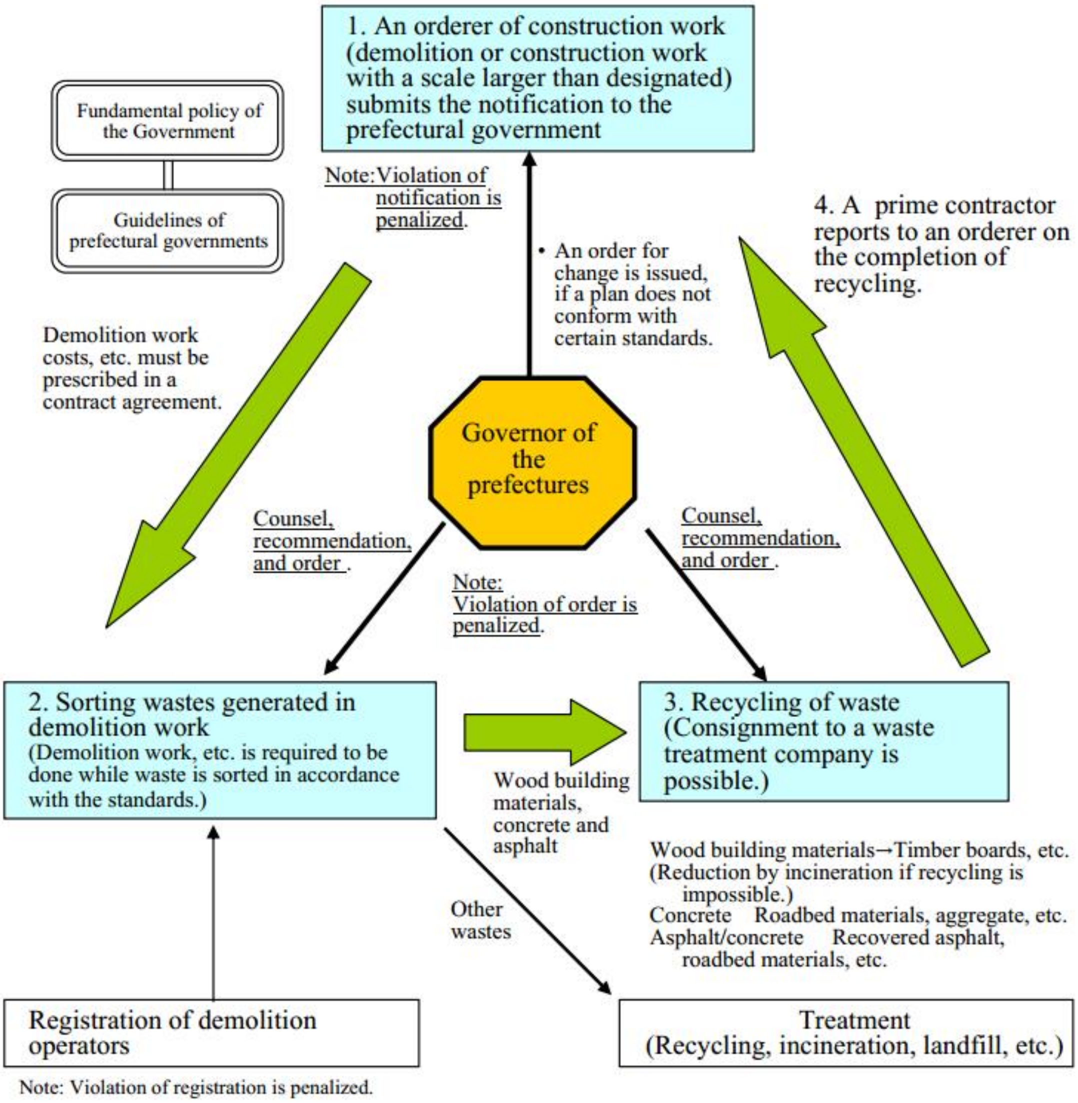

Figure 11 Roles of stakeholders for C&D waste management in Japan (JME, 2016a)

The Construction Recycling Law also gives a guideline for the flow of sorted demolition and recycling (JME, 2014):

(1) ‘Explanation: The main contractor provides the ordering party with a written document to explain plans for sorted demolition and other operations.

(2) Contract: It is necessary to specify the method used for sorted demolition in the contract concluded between the ordering party and the main contractor.

(3) Preliminary reporting: The ordering party prepares plans for sorted demolition and other operations to submit a report to the relevant prefecture in advance.

(4) Notification: When outsourcing work to a subcontractor, the main contractor notifies the subcontractor of what needs to be reported to the prefecture.

(5) Contract: It is necessary to specify the method used for sorted demolition in the contract concluded between the main contractor and the subcontractor.

(6) Sorted demolition, recycling, and other operations.

(7) Reporting: When having completed recycling and other operations, the main contractor provides the ordering party with a written document of completion and also prepares and preserves a record concerning how recycling was performed'.

From the English official websites, it can be seen that the Japanese government pays great effort on C&D waste recycling technologies. The technologies and companies relevant to Japanese waste management and recycling industry are provided with detailed information on the website (JME, 2016b).

2.3.2. Experiences learnt

From the official websites, it can be concluded that the successful experiences from Japan are:

(1) Implementation of Construction Recycling Law. The regulation requires the constrictors to sort C&D waste.

(2) Mature C&D waste recycling technologies and facilities. Appropriate technologies and facilities are recommended by the JME for recycling.

2.4. Singapore

2.4.1. Waste management in Singapore

The Singapore Building & Construction Authority (BCA) has given a definition for C&D waste: "Construction and demolition (C&D) waste is the material resulting from the construction, alteration or demolition of buildings and other structures. It consists of a mixture of hardcore (concrete, masonry, bricks, tiles), reinforcement bars, dry walls, wood, plastic, glass, scrap iron and other metals etc." (BCA, 2008). From the definition, it can be seen that, compared with Hong Kong, the earth excavated during foundation work is not included in "C&D waste" in Singapore.

The National Environmental Agency (NEA) of Singapore reported that the recycling rate of construction debris (mainly refers to concrete and masonry waste) reached 99% in 2015 (NEA, 2016d). The total generation of construction debris was 1,411,800 tons of which 1,402,900 tons was recycled. Though the recycling rate of construction debris is very high, it should be noted that steel re-bars, wood and glass waste is excluded from construction debris; they are accounted under separate item headings called "Ferrous Metals", "Wood" and "Glass" respectively.

Little information of successful C&D waste management experiences can be found from the official website of NEA. Only the recycling process for C&D waste is briefly introduced: 'Various recyclable materials such as metals, plastic, wood and hardcores etc., are recovered from the construction and demolition (C&D) waste for further processing. Recycled concrete aggregates (RCA) derived from crushed concrete can be reused back for a range of structural and non-structural applications' (NEA, 2016a).

Another C&D waste related information is about the category of general waste collectors (GWCs). In Singapore, the GWCs must get licences from the NEA. Three classes of GWCs are licenced to handle certain types of waste: Class A – Inorganic waste; Class B – Organic waste; Class C – Sludge and grease (NEA, 2016c). Construction debris is involved in Class A, which also includes excavated earth, discarded furniture, appliances, etc.

In Singapore, illegal dumping of any kind of waste is a serious offence. Contacting information has been provided on the official website for reporting illegal dumping (NEA, 2016c).

The website of the Building and Construction Authority (BCA) on C&D waste management was also reviewed in order to understand deeper of the successful experiences from Singapore. In the 'Sustainable Construction' category, a sample of site waste segregation plan is provided, as shown in Figure 12. The treatment of C&D waste is also provided by BCA, as shown in Figure 13.

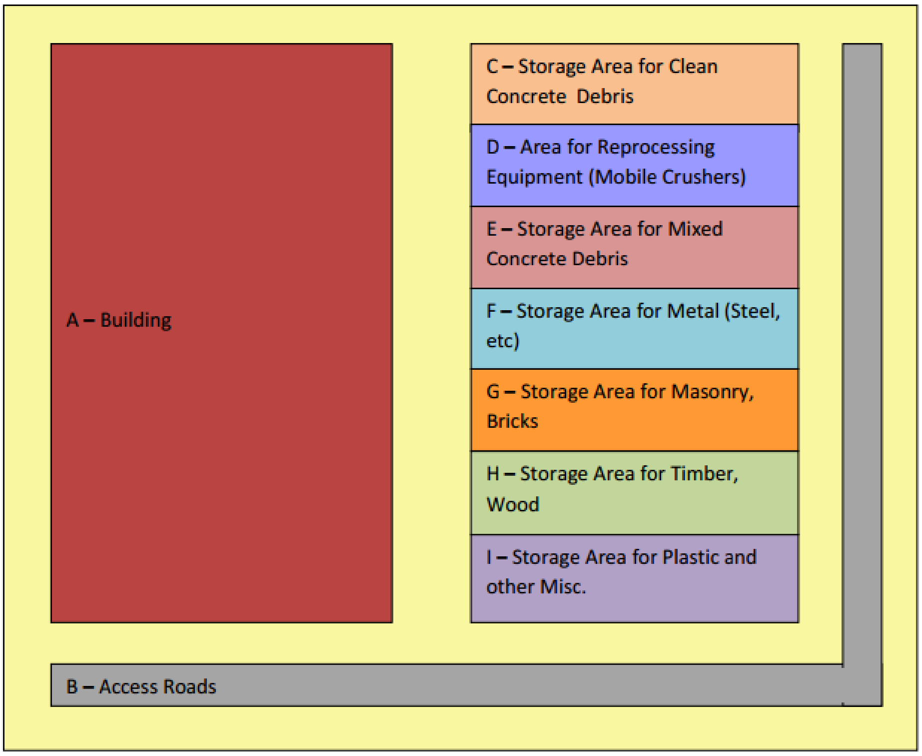

Figure 12 Sample of storage area for waste segregation on-site (BCA, 2016d)

Figure 13 Treatment of C&D Waste (BCA, 2012)

In addition, the BCA has published a series of Green Mark Schemes, encouraging C&D waste minimisation and use of recycled materials (BCA, 2016a). Similarly, Green and Gracious Builders Scheme gives recognition to builders for green practices, e.g. 3R initiatives and adoption of demolition protocol (BCA, 2016c); Construction Productivity Capability Development Fund supports the purchase of demolition equipment that facilitates concrete recovery (BCA, 2016b). In order to increase the recycling rate of construction debris, the NEA has imposed a high solid waste disposal fee of Sig$77/ton (NEA, 2016b).

2.4.2. Experiences learnt

From the above results, it can be concluded that the successful experiences from Singapore are:

(1) Efficient waste sorting. Good sorting can increase the productivity of recycling facilities.

(2) Strict supervision on illegal dumping. The government has no tolerance of illegal dumping.

(3) Mature waste recycling technologies and facilities. Mature waste recycling technologies and facilities can reduce wastage to a large extent.

(4) Effective initiatives. Several schemes have been implemented to improve C&D waste management, such as Green Mark Scheme, Green and Gracious Builder Scheme, Construction Productivity Capability Development Fund, etc.

2.5. Korea

2.5.1. Waste management in Korea

According to the data provided by the Ministry of Environment (ME) of Korea, construction waste makes up more than half of the total amount of business waste. In recent years, it has increased consistently in Korea, from around 53 million tons in 2003 to around 68 million tons in 2012 (ME, 2016). Most of construction waste in Korea is recycled at a low level due to negative perceptions on recycled materials. The recycling rate of high-value-added waste resources (e.g. aggregates and asphalt) remains at 32.3% (ME, 2016).

In order to increase the recycling rate of resources to 45% by 2016, the government has been implementing various policies. The Construction Waste Recycling Promotion Act, which was promulgated by the Ministry of Environment, has been put into effect in January 2005. The aim of this Act is to provide a legal basis for promoting construction waste management in an eco-friendly manner (ME, 2016).

The Act mandatorily requires the use of recycled aggregates for the construction of roads, industrial complexes and environmental infrastructure. Revisions have been made in 2013 in order to enhance the requirements. According to the revisions, the asphalt concrete waste which is used for simple mounding and backfill should be stored away from other construction waste, and the recycling of asphalt concrete waste was restricted to road construction. In order to guarantee the quality of recycled aggregates, in 2007, the government introduced a quality certification system for recycled aggregates (ME, 2016). Moreover, an electronic information treatment programme was proposed for communicating C&D waste information during the discharge, collection, and transportation processes (ME, 2016).

2.5.2. Experiences learnt

Based on the collected information, the successful C&D waste experiences in Korea can be summarised into three aspects:

(1) Implementation of Construction Waste Recycling Promotion Act. The act provides the legal basis to treat construction waste in an eco-friendly manner.

(2) Quality certification system for recycled aggregates. The system can increase the reliability of recycled materials for a broader implementation.

(3) Construction waste information management system for waste exchange. The system can provide the most recent waste information.

2.6. Australia

2.6.1. Waste management in Australia

The Department of the Environment and Energy (DEE) of Australia has published two reports concerning C&D waste management: ‘Construction and demolition waste status report - management of construction and demolition waste in Australia’ (HC, 2011) and ‘Construction and demolition waste guide - recycling and re-use across the supply chain (EEPL, 2011). In HC (2011), it was reported that a total of 8,529,374 tons of C&D waste were disposed while a total of 10,468,186 tons were recycled in 2009, representing a national resource recovery rate of 55%.

There is no specific regulation on C&D waste management at national level. The management of all waste streams is largely regulated by state and territory governments. The regulatory frameworks are different from each other.

EEPL (2011) reported that the majority of stakeholders regard high cost of landfills as a significant factor for C&D waste reuse and recycling. It was stated that the landfill cost in Australia was ranged from A$ 42 per ton to A$ 102 per ton. In addition, the state and territory jurisdictions can levy an additional charge. For example, the landfill levy in New South Wales ranges from A$20.40 per ton to A$70 per ton. It is expected that this would drive additional re-use and recycling from the construction industry.

In order to achieve C&D waste minimisation, EEPL (2011) recommended to use building supply chain. The building supply chain requires each stakeholder in the construction industry to play their own parts in building delivery. It is important to emphasise the early stages of building supply chain to realise the opportunities of integrating new materials and products derived from C&D waste. At the end of the supply chain, it is required to publicise the new materials derived from C&D waste.

2.6.2. Experiences learnt

From the review of the official websites in Australia, the following policies and measures are summarised:

(1) Implementation of legislative initiatives. The legislative initiatives can provide the legal ground to treat construction waste in an eco-friendly manner.

(2) Implementation of landfill tax. The landfill tax is aiming to reduce C&D waste disposal at landfills.

(3) Supply chain management. It is important to focus on the earliest stages of the building supply chain because there are more opportunities for waste reduction.

2.7. Taiwan

2.7.1. Waste management in Taiwan

The C&D waste management information is very limited in the Environmental Protection

Administration in Taiwan. Two regulations concerning C&D waste management are found from the Construction and Planning Agency (CPA): 'Regulation on construction waste recycling' (CPA, 2002) and 'Categories and management methods for construction waste' (CPA, 2013). The 'Regulation on construction waste recycling' specifies general requirement for C&D waste management. For example, before C&D waste can be disposed of, permissions must be obtained in prior. The 'Categories and management methods for construction waste' lists nine C&D waste streams (i.e. wasted timber, wasted glasses, wasted steel, other single wasted metal materials such as copper, wasted plastics, waste rubber, wasted mixed construction waste such as concrete, wasted calcium silicate board, and wasted gypsum board), and the corresponding management methods are regulated as well.

2.7.2. Experiences learnt

Though the information derived from Taiwan governmental official websites is limited, it can be identified that the Taiwan governments focus on two aspects:

(1) Implementation of legislative initiatives. The legislative initiatives can provide the legal basis to treat construction waste in an eco-friendly manner.

(2) Effective sorting. Effective sorting is the fundamental of efficient reuse and recycling.

3. C&D waste management measures from overseas green building rating systems

This section introduces the C&D waste management requirements in the overseas green building rating systems (GBRSs). The investigated GBRSs include LEED used in the United States, BREEAM used in the United Kingdoms, Green Globes used in Canada, Green Mark used in Singapore, and GB/T50378-2014 in Mainland China.

3.1. Leadership in Energy and Environmental Design (LEED)

LEED (i.e. Leadership in Energy and Environmental Design) is developed by the non-profit organisation - U.S. Green Building Council (USGBC). Nowadays, around 1.85 million square feet of buildings are certified by LEED each day (USGBC, 2016a). Four LEED ranking levels are rated based on the achieved points : Certified, Silver, Gold and Platinum (USGBC, 2016a).

There are five divisions in the LEED system, including 'LEED v4 for building design and construction' (LEED BDC), 'LEED v4 for interior design and construction' (LEED IDC), 'LEED v4 for building operations and maintenance' (LEED BOM), 'LEED v4 for neighborhood development' (LEED ND), and 'LEED v4 for homes design and construction' (LEED HDC). The latest version of these five divisions can be downloaded from the internet. C&D waste management requirements in the five schemes are presented as follows.

3.1.1. LEED v4 for building design and construction (LEED BDC)

The latest LEED BDC was updated on 5 April 2016 (USGBC, 2016b). Waste management requirements are located in the Chapter of 'Materials and Resources (MR)'. Credits are generally applied to New Construction, Core & Shell, Schools, Retail, Data Centres, Warehouses & Distribution Centres, Hospitality, and Healthcare. The particular C&D waste management requirements in the MR Chapter are presented in Table 1.

Table 1 C&D waste management requirements in LEED BDC

Code	Requirement	Attainable credits	Intent
P	Storage and Collection of Recyclables	-	To reduce the waste that is generated by building occupants and hauled to and disposed of in landfills.
P	Construction and Demolition Waste Management Planning	-	To reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, and recycling materials
MR	Building Life-Cycle Impact Reduction	2-6	To encourage adaptive reuse and optimise the environmental performance of products and materials.
MR*	Design for Flexibility	1	Conserve resources associated with the construction and management of buildings by designing for flexibility and ease of future adaptation and for the service life of components and assemblies.
MR	Construction and Demolition Waste Management	1-2	To reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, and recycling materials.

Note: ‘P’ stands for ‘Prerequisite’; ‘MR’ refers to ‘Materials and Resources’; the requirement with ‘*’ is only applicable to Healthcare.

In the LEED BDC, there are three prerequisites in the MR Chapter, involving two general prerequisites for all building types (namely ‘Storage and Collection of Recyclables’ and ‘Construction and Demolition Waste Management Planning’) and one particular prerequisite for healthcare (i.e. ‘PBT Source Reduction – Mercury’). It can be seen that the two general prerequisites are both related to C&D waste management.

The requirement of ‘Storage and Collection of Recyclables’ in Retails is different from the other seven building types. In the Retail scheme, it is suggested a waste stream study should be conducted in order to identify the top five recyclable waste streams. It is also recommended to provide dedicated areas for the separation, collection, and storage of recyclable materials. For the other seven building types, it is required that recyclable materials must include mixed paper, corrugated cardboard, glass, plastics, and metals.

A C&D waste management plan is compulsorily required in LEED BDC. Two aspects should be included in the plan: establishment of waste diversion goals and specification of waste diversion strategies. In addition to the waste management plan, a final report is required to give detailed information of all major waste streams, including waste disposal and diversion rates.

In the requirement of 'Building Life-Cycle Impact Reduction', adaptive reuse is advised. The reuse of existing building resources is designed during the initial project decision-making process. Options are provided as well, such as 'Historic Building Reuse', 'Building and Material Reuse', etc.

A maximum of two credits are given to the requirement of 'Construction and Demolition Waste Management'. LEED BDC provides two options for gaining the assigned credits:

'Option 1. Diversion (1-2 points)

> Path 1. Divert 50% and Three Material Streams (1 point)
>
> Divert at least 50% of the total construction and demolition material; diverted materials must include at least three material streams.
>
> OR
>
> Path 2. Divert 75% and Four Material Streams (2 points)
>
> Divert at least 75% of the total construction and demolition material; diverted materials must include at least four material streams.

OR

Option 2. Reduction of Total Waste Material (2 points)

Do not generate more than 2.5 pounds of construction waste per square foot (12.2 kilograms of waste per square meter) of the building's floor area'.

3.1.2. LEED v4 for interior design and construction (LEED IDC)

The latest LEED IDC was updated on 5 April 2016 (USGBC, 2016d). Waste management requirements are located in the Chapter of 'Materials and Resources (MR)'. The credits are generally applied to Commercial Interiors, Retail, and Hospitality. The particular waste management requirements in the MR Chapter are presented in Table 2.

Table 2 C&D waste management requirements in LEED IDC

Code	**Requirement**	**Attainable credits**	**Intent**
P	Storage and Collection of Recyclables	-	To reduce the waste that is generated by building occupants and hauled to and disposed of in landfills.
P	Construction and Demolition Waste Management Planning	-	To reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, and recycling materials.
MR	Long-Term Commitment	1	To encourage choices that will conserve resources and reduce environmental harm from materials manufacturing and transport for tenants' relocation.
MR	Interiors Life-Cycle Impact Reduction	1-5	To encourage adaptive reuse and optimise the environmental performance of products and materials.
MR	Construction and Demolition Waste Management	1-2	To reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, and recycling materials.

Note: 'P' stands for 'Prerequisite'; 'MR' refers to 'Materials and Resources'.

There are two prerequisites in the MR Chapter for the three building types, namely 'Storage and Collection of Recyclables' and 'Construction and Demolition Waste Management Planning'. The detailed specifications of the two prerequisites are similar with the ones in LEED BDC.

In order to encourage long-term commitment, it is required that 'the occupant or tenant must commit to remain in the same location for at least 10 years'. One credit is assigned to this requirement.

In terms of 'Interiors Life-Cycle Impact Reduction', adaptive reuse is recommended. Three options are offered to gain a maximum of five points:

'Option 1. Interior Reuse (2 points)
Reuse or salvage interior nonstructural elements for at least 50% of the surface area. Hazardous materials that are remediated as a part of the project must be excluded from the calculation.

AND/OR

Option 2. Furniture Reuse (1 point)
Reuse, salvage, or refurbish furniture and furnishings for at least 30% of the total furniture and furnishings cost.

AND/OR

Option 3. Design for Flexibility (1 point ID&C, 2 points Retail CI)
Conduct an integrative planning process to increase the useful life of the project space.

Increase project space flexibility, ease of adaptive use, and recycling of building materials while considering differential durability and premature obsolescence over building design life and individual component service lives. Use at least three of the following strategies.

- Install accessible systems (floor or ceiling) for at least 50% of the project floor area to allow for flexible use of space and access to systems (under floor distribution systems) not entangled with other building systems.
- Design at least 50% of interior nonstructural walls, ceilings, and floors to be movable or demountable.
- Ensure that at least 50%, by cost, of nonstructural materials have integral labels (radio frequency identification, engraving, embossing, or other permanent marking) containing information on material origin, properties, date of manufacture, in compliance with Canadian Standards Association CSA Z782-06 Guideline for Design for Disassembly and Adaptability in Buildings.
- Include in at least one major component or systems purchase contract a clause specifying sub-contractor, vendor, or on site take back system.
- Ensure that at least 50% of nonstructural materials, by cost, are reusable or recyclable, as defined by the Federal Trade Commission Guide for Use of Environmental Marketing Claims, 260.12.
- Implement flexible power distribution (i.e., plug-and-play) systems for at least 50% of the project floor area so that lighting, data, voice, and other systems can be easily reconfigured and repurposed.
- Implement a flexible lighting control system with plug and play components such as wall controls, sensors, and dimming ballasts for a minimum of 50% of the lighting load. The system shall allow for reconfiguring and repurposing of luminaires and controls without rewiring such as having the capability to group and assign luminaires into zones and change those zones as needed. Also, the system shall be flexible so that as a space changes functions, the lighting levels can change to suit the needs of the space without rewiring or removing or adding luminaires'.

3.1.3. LEED v4 for building operations and maintenance (LEED BOM)

The latest LEED BOM was updated on 1 July 2016 (USGBC, 2016c). Waste management requirements are located in the Chapter of 'Materials and Resources (MR)'. The credits are generally applied to Existing Buildings, Schools, Retail, Data Centres, Hospitality, Warehouses and Distribution Centres, and Multifamily. The particular waste management requirements in the MR Chapter are presented in Table 3.

Table 3 C&D waste management requirements in LEED BOM

Code	**Requirement**	**Attainable credits**	**Intent**
P	Ongoing Purchasing and Waste Policy	-	To reduce the environmental harm from materials purchased, used, and disposed of in the operations within buildings.
P	Facility Maintenance and Renovation Policy	-	To reduce the environmental harms associated with the materials purchased, installed, and disposed of during maintenance and renovation of buildings.
MR	Solid Waste Management - Facility Maintenance and Renovation	2	To divert construction, renovation, and demolition debris from disposal in landfills and incinerators and recover and recycle reusable materials.

Note: 'P' stands for 'Prerequisite'; 'MR' refers to 'Materials and Resources'.

Solid waste management is particularly specified in the prerequisite of 'Ongoing Purchasing and Waste Policy'. Storage locations are required to be established for recyclable materials (e.g. mixed paper, corrugated cardboard, glass, plastics, and metals).

In the prerequisite of 'Facility Maintenance and Renovation Policy', waste management policy is required to address the following aspects:

- 'Facility maintenance waste. The policy should address safe storage and recycling and diversion of waste associated with maintenance activities.

- Renovation waste. The policy should describe the procedure for creating an individual plan for each renovation project. Each renovation project should establish waste diversion goals, target five materials for diversion, approximate the volume of waste anticipated, and identify waste diversion strategies to be used.
- Furniture waste (Multifamily only). The policy should address storage locations for furniture and reuse or recycling of furniture waste'.

In the 'Solid Waste Management – Facility Maintenance and Renovation', two points will be assigned by satisfying 'Divert at least 70% of the waste (by weight or volume) generated by facility maintenance and renovation activities from disposal in landfills and incinerators. Include base building elements as specified in the Materials and Resources prerequisite: Facility Maintenance and Renovation Policy. Exclude furniture and furnishings that pose human health concerns (e.g. mold) as well as components not considered base building elements; mechanical, electrical, and plumbing components; and specialty items, such as elevators'.

3.1.4. LEED v4 for neighborhood development (LEED ND)

The latest LEED ND was updated on 5 April 2016 (USGBC, 2016e). Waste management requirements are located in the Chapter of 'Green Infrastructure and Buildings (GIB)'. The credits are generally applied to Plan and Built Project. The particular waste management requirements in the GIB Chapter are presented in Table 4.

Table 4 C&D waste management requirements in LEED ND

Code	Requirement	Attainable credits	Intent
P	Construction Activity Pollution Prevention	-	To reduce pollution from construction activities by controlling soil erosion, waterway sedimentation, and airborne dust.
GIB	Building Reuse	1	To extend the life cycle of buildings and conserve resources, reduce waste, and

Code	Requirement	Attainable credits	Intent
			reduce environmental harm from materials manufacturing and transport for new buildings.
GIB	Historic Resource Preservation and Adaptive Reuse	2	To respect local and national landmarks and conserve material and cultural resources by encouraging the preservation and adaptive reuse of historic buildings and cultural landscapes.
GIB	Recycled and Reused Infrastructure	1	To avoid the environmental consequences of extracting and processing virgin materials by using recycled and reclaimed materials.
GIB	Solid Waste Management	1	To reduce the volume of waste deposited in landfills and promote the proper disposal of hazardous waste.

Note: ‘P’ stands for ‘Prerequisite’; ‘GIB’ refers to ‘Green Infrastructure and Buildings’.

In the prerequisites of LEED ND, waste management is not particularly suggested. However, in the prerequisite of ‘Construction Activity Pollution Prevention’, it is mentioned that topsoil should be stockpiled for reuse.

The strategy of building reuse is suggested in LEED ND, it is required that ‘no demolition is allowed to any historic buildings or contributing buildings in a historic district, or portions thereof, or alter any cultural landscapes as part of the project’. In order to obtain one point, the following criteria are provided:

- ‘Case 1. For projects with five or fewer buildings undergoing major renovations, reuse 50% of one such building, based on surface area. Calculations must include structural elements (e.g., floors, roof decking) and enclosure materials (e.g., skin, framing). Exclude from the calculations window assemblies, nonstructural roofing material, and any hazardous materials that are remediated as part of the project.
- Case 2. For projects with more than five buildings undergoing major renovations, reuse

20% of the total surface area of such buildings (including structure and enclosure materials, as defined in Case 1)'.

The historic resource is particularly emphasised in LEED ND. According to the requirement of 'Historic Resource Preservation and Adaptive Reuse', it is required 'not to demolish any historic buildings or contributing buildings in a historic district, or portions thereof, or alter any cultural landscapes as part of the project. An exception is granted only with approval from an appropriate review body'.

In order to avoid the environmental consequences of extracting and processing virgin materials by using recycled and reclaimed materials, it is encouraged to 'use materials for new infrastructure such that the sum of the postconsumer recycled content, on-site reused materials, and one-half of the preconsumer recycled content constitutes at least 50% of the total mass of infrastructure materials'.

One point is assigned to the requirement of 'Solid Waste Management'. It is required to meet at least four of the following five requirements:

(1) 'Include as part of the project at least one recycling or reuse station, available to all project occupants, dedicated to the separation, collection, and storage of materials for recycling; or locate the project in a local government jurisdiction that provides recycling services. The recycling must cover at least paper, corrugated cardboard, glass, plastics, and metals.

(2) Include as part of the project at least one drop-off point, available to all project occupants, for potentially hazardous office or household wastes and establish a plan for postcollection disposal or use; or locate the project in a local government jurisdiction that provides collection services. Examples of potentially hazardous wastes include paints, solvents, oil, mercury-containing lamps, electronic waste, and batteries.

(3) Include as part of the project at least one compost station or location, available to all

project occupants, dedicated to the collection and composting of food and yard wastes, and establish a plan for postcollection use; or locate the project in a local government jurisdiction that provides composting services.

(4) On every mixed-use or nonresidential block or at least every 800 feet (245 meters), whichever is shorter, include recycling containers either adjacent to or integrated into the design of other receptacles.

(5) Recycle, reuse, or salvage at least 50% of nonhazardous construction, demolition, and renovation debris. Calculations can be done by weight or volume but must be consistent throughout. Develop and implement a construction waste management plan that identifies the materials to be diverted from disposal and specifies whether the materials will be stored on site or commingled. Reused or recycled asphalt, brick, and concrete (ABC) can account for no more than 75% of the diverted waste total. Exclude excavated soil, land-clearing debris, and materials contributing toward GIB Credit Building Reuse from calculations. Include materials destined for alternative daily cover in the calculations as waste (not diversion)'.

3.1.5. LEED v4 for homes design and construction (LEED HDC)

The latest LEED HDC was published in 2013 (USGBC, 2013). Waste management requirements are located in the Chapter of 'Materials and Resources (MR)'. The credits are generally applied to Homes & Multifamily Lowrise and Multifamily Midrise. The particular waste management requirements in the MR Chapter are presented in Table 5.

Table 5 C&D waste management requirements in LEED HDC

Code	Requirement	Attainable credits	Intent
P	Durability Management	-	To promote durability and performance of the building enclosure and its components and systems through appropriate design, materials selection, and construction practices.
MR	Durability	1	To promote enhanced durability and

Code	Requirement	Attainable credits	Intent
	Management Verification		high performance of the building enclosure and its components and systems through appropriate design, materials selection, and construction practices.
MR	Environmentally Preferable Products	0.5-5	To increase demand for products or building components that minimise material consumption through recycled and recyclable content, reclamation, or overall reduced life-cycle impacts.
MR	Construction Waste Management	3	To reduce construction waste generation and to reuse and recycle debris.
MR*	Material - Efficient Framing	0.5-2	To conserve resources by reducing the use of unnecessary framing materials.

Note: 'P' stands for 'Prerequisite'; 'MR' refers to 'Materials and Resources'; the requirement with '*' is only applicable to Homes.

In the LEED HDC, there is a prerequisite concerning waste management, namely 'Durability Management'. The aim is to 'promote durability and performance of the building enclosure and its components and systems through appropriate design, materials selection, and construction practices'. A credit is further assigned for 'Durability Management Verification'. In order to increase demand for products or building components that minimise material consumption through recycled and recyclable content, reclamation, or overall reduced life-cycle impacts, a maximum of 5 point is allocated to the requirement of 'Environmentally Preferable Products'.

A requirement is particularly emphasising C&D waste management. The maximum points can be earned from this requirement is 3. The evaluation is based on the percentage of total reduced or diverted construction waste from landfills and incinerators. Corresponding to the waste reduction percentage of 10%, 20%, 30%, 40%, 50%, and 60%, the points assigned are

0.5, 1.0, 1.5, 2.0, 2.5, 3.0.

In terms of Homes, an additional requirement of ‘Material - Efficient Framing’ is proposed. The aim of this requirement is to ‘conserve resources by reducing the use of unnecessary framing materials’. Modular, panelised, or other prefabricated wall or structural systems are suggested to comply with this requirement.

3.2. Building Research Establishment Environmental Assessment Method (BREEAM)

BREEAM (Building Research Establishment Environmental Assessment Method), first published by the Building Research Establishment (BRE) in 1990, is the world’s longest established method of assessing, rating, and certifying the sustainability of buildings (Wikipedia, 2016). Globally, there are more than 548,900 BREEAM certified developments, and almost 2,249,800 buildings registered for assessment since it was first launched in 1990 (BRE, 2016a).

The BREEAM family includes five divisions, namely ‘Communities’, ‘Infrastructure’, ‘New Construction’, ‘In-Use’, and ‘Refurbishment and Fit-Out’. The corresponding technical standards are listed in Table 6. The C&D waste management requirements are presented in the following sub-sections.

Table 6 Technical standards in BREEAM

Division	Technical standard
Communities	BREEAM Communities 2012
Infrastructure	BREEAM New Construction: Infrastructure (Pilot)
New Construction	BREEAM International New Construction 2016
In-Use	BREEAM In-Use International
Refurbishment and Fit-Out	BREEAM International Non-Domestic Refurbishment 2015

3.2.1. BREEAM Communities 2012

The BREEAM Communities 2012 is a framework for ‘considering the issues and opportunities that affect sustainability at the earliest stage of the design process for a development' (BRE, 2012).

In BREEAM Communities, waste management requirements are located in the category of 'Resource and Energy (RE)'. The particular waste management requirements in the RE category are presented in Table 7.

Table 7 C&D waste management requirements in BREEAM Communities 2012

Code	**Requirement**	**Attainable credits**	**Aim**
RE02	Existing Buildings and Infrastructure	2	To take account of the embodied carbon in existing buildings and infrastructure and to promote their re-use where possible.
RE04	Sustainable Buildings	6	To increase the sustainability of all buildings within the development.
RE06	Resource Efficiency	4	To promote resource efficiency by reducing waste during construction and throughout the life cycle of the development.

In the requirement of 'Existing Buildings and Infrastructure', there are two mandatory requirements:

(1) 'An assessment of any existing buildings and infrastructure is carried out to determine what can be refurbished, re-used, recycled or maintained and those of significant value. The assessment considers the following:

- heritage and local identity;
- the location and condition of buildings and infrastructure;
- the embodied carbon in existing materials;
- potential uses of buildings and infrastructure;
- possible use of materials (on or off-site);
- community and local authority knowledge and opinion.

(2) A decision is made and justified with evidence regarding the use and/or demolition of

all existing buildings and infrastructure on site'.

Once the two mandatory requirements are satisfied, one credit will be awarded in the case of 'the developer commits to the reuse or recycling of building and/or infrastructure materials on the development site'. Two credits will be given if 'the developer commits to refurbishing any existing buildings and/or infrastructure that have been identified in the assessment as being of significant value to the local community or for sustainability reasons'.

In terms of the 'Sustainable Buildings', two credits will be awarded if 'the developer and design team have committed to designing new/refurbished buildings on site to comply with recognised industry best practice standards in sustainable design for all of the following key sustainability areas: energy, water, waste, embodied impacts of materials, and occupant health and wellbeing. If the developer and design team have committed to one or more, but not all of the key sustainability areas, only one credit will be awarded. The commitment should be confirmed through a planning condition (or other binding mechanism, such as a planning obligation) by the local authority'.

3.2.2. BREEAM New Construction: Infrastructure (Pilot)

The BREEAM New Construction: Infrastructure (Pilot) describes 'an environmental performance standard against which new, infrastructure assets can be assessed' (BRE, 2015c). In BREEAM New Construction: Infrastructure (Pilot), waste management requirements are located in the categories of 'Materials (Mat)' and 'Waste (Wst). The particular waste management requirements in the two categories are presented in Table 8.

Table 8 C&D waste management requirements in BREEAM New Construction: Infrastructure (Pilot)

Code	Requirement	Strategic credits	Project detail credits	Aim
Mat03	Materials Efficiency	2	4	To recognise and encourage measures to optimise material efficiency and reduce virgin material consumption.
Mat04	Reuse and Recycling	1	3	To recognise and encourage the specification of reused and recycled materials within the asset, reducing demand for virgin material.
Wst01	Construction Waste Management	1	2	To promote resource efficiency via the effective management and reduction of construction waste.

The requirement of ‘Materials Efficiency’ includes two strategic credits and four project detail credits. The two strategic credits are split into two parts: material efficiency (one credit) and design for deconstruction (one credit). In order to satisfy the credit of ‘material efficiency’, three detailed requirements are provided, namely ‘resource management plan’, ‘lean tools and activities’, and ‘material optimisation’. The four project detail credits are awarded to three aspects: implementation of lean tools and activities (one credit), enhanced materials efficiency (one credit), and reuse and recycling of deconstruction materials (up to two credits).

In terms of the requirement of ‘Reuse and Recycling’, one strategic credit will be awarded if reuse and recycling strategy is well established. For the project detail credits, three credits are awarded to: ‘reuse of existing infrastructure on site’ (one credit), ‘reuse and recycling of materials and elements’ (one credit), and ‘recycled aggregates’ (one credit).

There is a specific requirement on C&D waste management in BREEAM New Construction:

Infrastructure (Pilot), namely ‘Wst 01 Construction waste management’. One strategic credit is available for this requirement. To obtain the strategic credit, a strategic evaluation of the amount of waste likely to be generated during the construction of the asset is required to be produced for the project options. The estimated waste arisings are categorised as: excavated waste; demolition waste; construction waste; hazardous waste. In addition, it is required that the project delivery team's or contractor's brief should include the following requirements: (a) Development of a Resource Management Plan (RMP) that promotes resource efficiency throughout the project's lifetime; (b) Development of on-site features to minimise waste.

Two project detail credits are available for the requirement of ‘Wst 01 Construction waste management’. To obtain the assigned credits, a prerequisite must be fulfilled, namely development of a Resource Management Plan (RMP). The RMP should be ‘based on an appropriate risk assessment and must be produced during the concept design stage and reviewed and updated regularly through to handover’. A verification report should be produced to demonstrate the implementation of the RMP and to feedback on lessons learnt. After the prerequisite has been fulfilled, one credit can be awarded if ‘an appropriate target is set for construction waste arising related to on-site construction and dedicated off-site manufacture or fabrication (excluding demolition and excavation waste)’. Actual waste arising should also be recorded and reported in the BREEAM Infrastructure online tool along with the target for the asset. Another credit will be given if non-hazardous waste is diverted from landfill.

3.2.3. BREEAM International New Construction 2016

The BREEAM International New Construction 2016 Scheme describes ‘an environmental performance standard against which new buildings worldwide can be assessed and achieve a BREEAM New Construction rating’ (BRE, 2016b). In BREEAM International New Construction 2016, waste management requirements are located in the categories of ‘Materials (Mat)’ and ‘Waste (Wst). The particular waste management requirements in the two categories are presented in Table 9.

Table 9 C&D waste management requirements in BREEAM International New Construction 2016

Code	Requirement	Attainable credits	Aim
Mat05	Designing for durability and resilience	1	To recognise and encourage adequate protection of exposed elements of the building and landscape, therefore minimising the frequency of replacement and maximising materials optimisation.
Mat06	Material efficiency	1	To recognise and encourage measures to optimise material efficiency in order to minimise the environmental impact of material use and waste without compromising on structural stability, durability or service life of the building.
Wst01	Construction Waste Management	3	To promote resource efficiency via the effective and appropriate management of construction waste.
Wst02	Recycled aggregates	1	To recognise and encourage the use of recycled and secondary aggregates, thereby reducing the demand for virgin material and optimising material efficiency in construction.

In order to improve the durability and resilience, two strategies are suggested: (1) protecting vulnerable parts of the building from damage; (2) Protecting exposed parts of the building from material degradation. In addition, the efficient use of materials should be achieved by ‘identifying opportunities, investigating and implementing appropriate measures in building design, procurement, construction, maintenance and end of life’.

A particular section of ‘Waste’ is presented in BREEAM International New Construction 2016. This category encourages ‘the sustainable management (and reuse where feasible) of construction and operational waste and waste through future maintenance and repairs associated with the building structure’. By encouraging good design and construction practices, issues in this section aim to reduce the waste arising from the construction and operation of the building, encouraging its diversion from landfill.

In the requirement of ‘construction waste management’, two aspects are evaluated: construction waste reduction (2 credits) and diversion of resources from landfill (1 credit). To achieve the construction waste reduction purpose, ‘appropriate targets for the amount of non-hazardous and hazardous waste produced on site should be set in m^3 of waste per $100m^2$ or tons of waste per $100m^2$. The amount of site construction waste created is being monitored and targets regularly reviewed. A pre-demolition audit of any existing buildings, structures or hard surfaces is completed to determine if refurbishment or reuse is feasible and, if not, to maximise the recovery of material from demolition for subsequent use, prioritising high grade or value applications. Using the collated data, the amount of waste generated per $100m^2$ (gross internal floor area) in m^3 (where volume is actual volume of waste, not bulk volume) or tones from the construction process should be reported via the BREEAM scoring and reporting tool. Once the first credit is obtained, another credit can be earned by placing procedures for sorting, reusing and recycling construction waste into at least five defined waste groups either on-site or off-site through a licenced external contractor’.

In order to obtain the credit for ‘recycled aggregates’, at least 25% of the high grade aggregate uses (within the development) should be provided by secondary or recycled aggregate. The recycled or secondary aggregates are either construction, demolition and excavation waste obtained on site or off-site or secondary aggregates.

3.2.4. BREEAM In-Use International

The BREEAM In-Use International describes ‘an environmental performance standard against which existing, non-domestic assets can be assessed and achieve a BREEAM In-Use International rating’ (BRE, 2015a). There are three parts in this scheme, namely ‘asset performance’, ‘building management’, and ‘occupier management’. In BREEAM

In-Use International, waste management requirements are located in the categories of 'Materials (Mat)' and 'Waste (Wst). The particular waste management requirements in the two categories are presented in Table 10.

Table 10 C&D waste management requirements in BREEAM In-Use International

Code	**Requirement**	**Attainable credits**	**Aim**
PART 1 Asset Performance			
Mat06	Future adaptation	4	To recognise and encourage buildings which have been built to allow a degree of flexibility for future usage.
Mat07	Designing for robustness	2	To minimise the frequency of building part replacement, maximising materials optimisation.
Wst01	Storage of operational waste	4	To ensure assets have adequate space for waste stream separation on site, allowing for recycling to take place and thus reduce waste being sent to landfill or for incineration.
PART 2 Building Management			
Mat09	Sustainable procurement policy	2	To recognise and encourage the implementation of formal environmental policies that address, and aim to reduce organisational purchases of materials, products and services with a high environmental impact.
PART 3 Occupier Management			
Wst02	Waste management	8	To encourage alignment of waste management policies with the waste hierarchy.
Wst03	Waste management	4	To encourage ease of recycling and reclamation when waste creation is unavoidable.
Wst04	Waste management arrangements	51	To recognise and encourage management arrangements aimed at improving waste production performance, segregation and awareness.
Wst05	Waste monitoring	4	To promote the practice of monitoring waste arisings within the asset so the

Code	Requirement	Attainable credits	Aim
			organisation can understand what it produces and thus target improvements with well-designed policy.
Wst06	Waste performance	2	To encourage the continual improvement of waste performance.
Wst07	Waste management objectives	4	To encourage and recognise the meeting of waste management objectives, thereby improving waste performance.
Wst08	Waste sent to landfill	2	To identify the impact of waste that is sent to landfill.
Wst09	Waste diverted from landfill	2	To encourage and promote the recycling of resources, avoiding the associated impacts of sending waste to landfill.
Wst10	Waste sent for incineration	2	To encourage and promote the recycling of resources, avoiding the associated impacts of sending waste to landfill.

3.2.5. BREEAM International Non-Domestic Refurbishment 2015

The BREEAM International Non-Domestic Refurbishment 2015 describes 'an environmental performance standard against which non-domestic refurbishment and fit-out projects can be assessed and achieve a BREEAM Refurbishment and Fit-out rating' (BRE, 2015b). In BREEAM International Non-Domestic Refurbishment 2015, waste management requirements are located in the categories of 'Materials (Mat)' and 'Waste (Wst). The particular waste management requirements in the two categories are presented in Table 11.

Table 11 C&D waste management requirements in BREEAM International Non-Domestic Refurbishment 2015

Code	Requirement	Attainable credits	Aim
Mat05	Designing for durability and resilience	1	To recognise and encourage adequate protection of exposed elements of the building and landscape, therefore minimising the frequency of replacement and maximising materials optimisation.
Mat06	Materials Efficiency	1	To recognise and encourage measures to optimise material efficiency in order to minimise the

Code	Requirement	Attainable credits	Aim
			environmental impact of material use and waste without compromising on structural stability, durability or service life of the building.
Wst01	Project waste management	6	To promote resource efficiency via the effective management and reduction of refurbishment and fit-out waste and the reuse and direct recycling of materials.
Wst02	Recycled aggregates	1	To recognise and encourage the use of recycled, secondary aggregates and reuse of aggregates in situ, thereby reducing the demand for virgin material and optimising material efficiency in major refurbishment works.
Wst03	Operational waste	1	To recognise and encourage the provision of dedicated storage facilities for a building's operational-related recyclable waste streams, so that this waste is diverted from landfill or incineration.
Wst04	Speculative finishes	1	To encourage the specification and fitting of finishes selected by the building occupant and therefore avoid unnecessary waste of materials.

3.3. Green Globes

Green Globes (GG) is an online green building rating and certification tool that is used primarily in Canada and the USA. Green Globes was developed by Energy and Environment Canada (EEC) (EEC, 2016). Since 2011, there have been 1,700 certified buildings (EEC, 2016).

Green Globes is a practical, web-based alternative to LEED (GG, 2013).There are three modules in Green Globes, including New Construction/Significant Renovations; Commercial Interiors (i.e. Office Fit-ups); and Existing Buildings (offices, multi-residential, retail, health care, light industrial) (EEC, 2016). As Green Globes is an online based rating system and only the technical manual for new construction can be downloaded from the internet, the Green Globes for New Construction was investigated in this study.

3.3.1. Green Globes for New Construction

Nowadays, both the Canadian and the US federal governments endorse the use of Green Globes. In 2013, the US General Services Administration (GSA) recommended Green Globes and LEED as the two certification options for federal government construction projects.

There are a total of 1000 points in the Green Globes for New Construction. The main categories are: project management (50 pts.); site (120 pts.); energy (395 pts.); water (110 pts.); materials and resources (125 pts.); emissions and other impacts (50 pts.); and indoor environment (150 pts.). The waste management requirements are located in the category of 'Materials and Resources (MR)'. The particular waste management requirements in the MR category are presented in Table 12.

Table 12 C&D waste management requirements in Green Globes for New Construction

Code	Requirement	Attainable points
MR	Reuse of Existing Structures	• Facades (6) • Structural systems (5) • Non-structural elements (13)
MR	Waste	• Construction waste (6) • Operational waste (2)
MR	Resource Conservation	• Minimised use of raw materials (3) • Multi-functional assemblies (1) • Deconstruction and disassembly (2)

In the requirement of 'Reuse of Existing Structures', three main components are specified. A maximum of 6 points are assigned for reusing of facades if the percentage reaches more than 60%. For reusing structural systems, 5 points will be awarded if the recycling percentage reaches 95%. In terms of recycling non-structural elements, 5 points will be awarded if the reusing percentage of the existing interior ceilings, interior partitions, and/or demountable walls reaches more than 95%; 4 points will be awarded if the reusing percentage of existing furnishings (including systems furniture) reaches more than 65%; 4 points will be awarded if the project incorporates reused and off-site salvaged materials.

In order to manage waste properly, five points will be awarded if there is a Construction Waste Management Plan that requires at least 50% (by weight) of construction and demolition waste to be recycled and/or salvaged. Another point will be given if there is a requirement to reuse existing on-site materials for site development or landscaping. Resource conservation is suggested to be achieved by minimised use of raw materials, use of multi-functional assemblies, and deconstruction and disassembly.

3.4. Green Mark

Green Mark schemes are published by the Building and Construction Authority (BCA); it evaluates the environmental impact and performance of a building or a project. It can sever as a comprehensive framework for assessing the overall environmental performance of new and existing buildings (BCA, 2016a).

The assessment criteria cover the following aspects: Energy Efficiency; Water Efficiency; Environmental Protection; Indoor Environmental Quality; and Other Green Features and Innovation. Points are awarded for encouraging the achievement of environment-friendly features. Depending on the overall assessment, four levels of ranking are available: Platinum, Gold^{Plus}, Gold or Certified rating. There are a total of 17 currently effective schemes in use, as shown in Table 13.

Table 13 Current effective Green Mark Schemes

No.	BCA Green Mark Schemes	Effective Date
1	Non-Residential New Buildings (Version 4.1)	15 Jan 2013 onwards
2	Residential New Buildings (Version 4.1)	15 Jan 2013 onwards
3	Existing Non-Residential Buildings (Version 3)	26 Jul 2012 onwards
4	Existing Residential Buildings (Version 1.1)	27 Mar 2015 onwards
5	Existing Schools (Version 2)	1 Jan 2016 onwards

No.	BCA Green Mark Schemes	Effective Date
6	Healthcare Facilities (Version 1)	01 Jul 2014 onwards
7	Office Interior (Version 1.1)	01 Nov 2012 onwards
8	Landed Houses (Version 1)	27 May 2009 onwards
9	Infrastructure (Version 1)	27 May 2009 onwards
10	District (Version 2)	01 Jan 2013 onwards
11	Restaurants (Version 1)	12 Sep 2011 onwards
12	Supermarket (Version 1)	11 Oct 2012 onwards
13	Existing Data Centres (Version 1.1)	11 Oct 2012 onwards
14	New Data Centres (Version 1.1)	14 Mar 2013 onwards
15	Retail (Version 1)	11 Oct 2012 onwards
16	New Parks (Version 1)	26 May 2010 onwards
17	Existing Parks (Version 1)	22 May 2008 onwards

3.4.1. Non-Residential New Buildings

In the Non-Residential New Buildings scheme, the requirements on C&D waste management are not too many. Only three related requirements can be found in this scheme. In the 'Sustainable Construction' requirement, recycled concrete aggregates from approved sources are recommended as secondary materials for producing concrete of main building elements. In the requirement of 'Environmental Management Practice', construction waste reduction target is suggested to be set. In addition, different recyclable materials are suggested to be stored in recycling bins or facilities.

3.4.2. Residential New Buildings

The C&D waste management requirements in Residential New building are same with the ones in the Non-Residential New Buildings expect mentioning indoor waste disposal. It is required to locate refuse chutes or waste disposal areas at open ventilation areas in order to minimise airborne contaminants from waste.

3.4.3. Existing Non-Residential Buildings

There is a particular waste management requirement in the Existing Non-Residential Buildings scheme. Four sub-requirements are provided: '(1) Provision of facilities or recycling bins for collection and storage of different recyclable waste; (2) Promote and encourage waste minimisation and recycling among occupants, tenants and visitors through various avenues; (3) Provide proper storage area for the recyclable waste; and (4) Quantify and monitor the recycling programme for continuous improvement'.

3.4.4. Existing Residential Buildings

In the Existing Residential Buildings scheme, it is required to document and disseminate Green Guides which involving waste management to residents. In addition, a particular 'Waste Management' requirement is proposed. According to this requirement, promotional materials (e.g. posters, circulars and recycling bags) are suggested to be provided. Recycling bins are recommended to be distributed at central locations at each block. Waste amount and recyclable items should be monitored monthly, and a waste management improvement plan is required to be made.

3.4.5. Existing Schools

A particular requirement of 'Waste Management' is given in the Existing Schools scheme. Five sub-requirements are suggested: '(1) Provision of recycling facilities to encourage segregation of waste (such as plastics, metals and paper) at strategic locations (such as canteens, sports hall, school hall and office); (2) Promote and encourage recycling among student, tenants, cleaners and visitors by displaying recycling posters at strategic locations - with information on what not to put into recycling bins (e.g. food/liquid waste); (3) Provision of a waste storage area to promote sorting, collecting, and recycling of a large range of waste generated in house. Examples of types of waste recycled: glass waste, paper waste, metal waste (including drink cans), plastic waste; (4) Create a monitoring system to track the amount of waste and recyclables generated; (5) In-house composting of horticulture waste and use of compost produced within the school or recycling of horticulture waste through landscape contractors or other avenues'.

3.4.6. Healthcare Facilities

In the Healthcare Facilities scheme, use of sustainable and recycled materials is encouraged. Recycled Concrete Aggregates (RCA) from approved sources are suggested for producing concrete. A construction waste reduction target is suggested to be set. It is also encouraged to conserve existing building structures and adopt demolition protocol for maximising resource recovery.

3.4.7. Office Interior

'Sustainable Office Design' and 'Sustainable Material Selection' are the two aspects in Office Interior that differ from above-mentioned schemes. In the requirement of 'Sustainable Office Design', it is required that 'office renovation should conserve at least 50% (by area) of the existing finishing for walls, flooring and ceilings'. In the requirement of 'Sustainable Material Selection', it is required to maintain at least 50% (by volume) of the existing furniture. There is also a 'Waste Management' requirement in the Office Interior scheme. In this requirement, recycling bins are recommended to be distributed at central locations at every floor or strategic locations. Waste monitoring and a waste management improvement plan are also suggested.

3.4.8. Landed Houses

In the Landed Houses scheme, use of Recycled Concrete Aggregates (RCA) from approved sources is encouraged. In addition, products with at least 30% recycled content by weight or volume and products that made of rapidly renewable materials (e.g. bamboo, cork) are encouraged to be used. A particular requirement of 'Construction Waste Management' requires more than 50% waste should be recovered and reused on site or sent to recyclable uses. Recycling facilities or bins should be provided for collecting and storing different kinds of waste.

3.4.9. Infrastructure

Compared with above-mentioned schemes, Infrastructure scheme gives more emphasis to waste management. A particular chapter is designed as 'Waste Management and Environmental Protection'. Three waste management requirements are listed in the Chapter: Buildability; Minimise Cut and Fill, and Use of Recycled Materials. Use of prefabricated components and buildable design features (e.g. standardisation of grids) are recommended for increasing the buildability. In order to encourage the reduction of excavated materials, it is suggested to optimise the use of cut and fill materials in the construction process. Recycled materials with at least 30% recycled content are recommended as well.

3.4.10. District

Waste management is also significantly emphasised in the District scheme. Seven specific requirements are presented in the Chapter of 'Material & Waste Management', as listed in Table 14.

Table 14 Waste management requirements in Green Mark - District

No.	Requirement	Attainable points
1	Minimise Cut and Fill in Earthworks	• Reusing of at least 50% of the topsoil (1 point) • Reusing of at least 50% cut and fill material (2 points)
2	Sustainable Construction for Infrastructure and Public Amenities	• Use of sustainable and recycled materials (2 points) • Recycle or salvage at least 50% of non-hazardous construction waste by weight, or conserve at least 50% of existing structural elements or building envelope by area (3 points)
3	Waste Reduction	• Minimise waste generation in a sustainable manner, covering all kinds of waste including domestic household waste (e.g. food waste), commercial waste (e.g. paper waste), construction waste, etc. (2 points)

No.	Requirement	Attainable points
4	Waste Management and Segregation	• Provision of at least one recycling station at the district level dedicated to the separation, collection and storage of recyclable materials such as paper, glass, plastics and metals (1 point) • Provision of at least one drop-off point for potentially hazardous waste such as paints, solvents, batteries (1 point) • Provision of litter receptacles with integrated recycle containers at public areas (including at public amenities) (1 point) • Develop a community waste strategy and education programme e.g. promotional materials such as posters, circulars and provision of recycling bags to promote waste sorting, collecting and recycling of waste (1 point)
5	Waste Conveyance	• Reduce the negative impact on environment during waste conveyance, such as use of odorless pneumatic conveyance system, specific waste transport design to minimise the disturbance (2 points)
6	Waste Reuse and Processing	• Provision of local composting (kitchen and garden wastes) /chipping facilities within the boundary of the development and / or at strategic locations. Compost should be made available to local users (building occupiers, owners, residents, maintenance firms) (2 points)

3.4.11. Restaurants

The Restaurants scheme encourages the use of consumable materials, such as those materials which are recyclable/recycled/non-disposable. Two points will be awarded if at least 50% (by volume) of the existing furniture or equipment is maintained. A particular

‘Waste Management’ requirement is given. In this requirement, 1 point is assigned to ‘waste collecting and monitoring’ and ‘waste management plan’ respectively.

3.4.12. Supermarket

A particular ‘Waste Management’ requirement is given in the Supermarket scheme. Dedicated storage facilities are suggested for collecting operational related recyclable waste. In addition, an organic waste composting system is encouraged to facilitate the reduction in volume of compostable organic waste.

3.4.13. New Data Centres

In the New Data Centres scheme, there is a sub-requirement particularly for waste management. The assessment criteria are same with the ones in the Existing Data Centres scheme. In addition, Recycled Concrete Aggregates (RCA) and Washed Copper Slag (WCS) from approved sources are encouraged for reproducing concrete of main building elements.

3.4.14. Existing Data Centres

There are only two sub-requirements in the Existing Data Centres scheme. The two sub-requirements are located in the requirement of ‘Sustainable Policy’. One point is assigned to ‘promote and encourage waste minimisation’, another point will be awarded if waste sorting, collecting, quantifying, monitoring and recycling are promoted for a large range of waste generated in-house.

3.4.15. Retail

In the Retail scheme, renovation is required to consist of at least 50% (by area) of the existing finishing for walls, flooring and ceilings. Environmental-friendly products with at least 30% recycled content by weight and consumable materials are also encouraged to use. The retailers are encouraged to promote waste minimisation.

3.4.16. New Parks

Waste management is emphasised in the New Parks scheme; corresponding requirements are located in the Chapters of 'Material Resources (MR)' and 'Parks Development and Construction Management (PDCM)'. The specific requirements are listed in Table 15.

Table 15 C&D waste management requirements in Green Mark - New Parks

No.	Requirement	Detailed assessment criteria
1	Use recycled content material or salvaged material	• Use of materials with more than 30% recycled content (4 points)
2	3R Management Plan	• Provision of management plan on Reuse, Recycle and Reduce (2 points)
3	Waste and Material Resource Management	• On-site recycling and amount re-used through recycling (1 point) • Proper waste disposal measures (1 point) • Topsoil and fill (1 point) • Provision of storage for recycles material (0.5 points) • Treatment of recycled construction materials (0.5 points)

3.4.17. Existing Parks

The Existing Parks scheme also focuses on waste management - the first Chapter of this scheme is entitled 'Waste & Material Minimisation'. The specific requirements are listed in Table 16.

Table 16 C&D waste management requirements in Green Mark - Existing Parks

No.	Requirement	Detailed assessment criteria
1	Waste & Material Monitoring (up to 4 points)	• Amount of segregated waste and total waste collected • Monthly handling cost of waste • Monthly records of waste and material used • Use of material should follow local authority's recommendation/good

No.	Requirement	Detailed assessment criteria
		practices
2	Waste & Material Recycling (up to 8 points)	• Monthly records of waste and material that is being recycled (tons/year) for 2 years • Recycling handing costing • Waste used from any retrofit or renovation • Documentation of recycling details, name of recycling company & address is compulsory • Records of recycled waste used in Parks and its monthly market value in ($) • Provide documentation on estimated market value • Site plan on composting bins and storage space to facilitate onsite composting and recycling of waste • Detail of recycling training and related outreach programme
3	Waste Management Improvement Plans (up to 3 points)	• Options to minimise/reduce waste • Description for each waste minimisation/reduction option • Estimated volume of waste reduction (i.e. kg) for each waste stream • Estimated costs • Estimated payback period and net savings • Implementation schedule of the options (steps or phases and timing for implementation) • Implementation requirements (such as tasks and personnel assignments) • Training of personnel
4	Sustainable Construction (up to 5 points)	• Low impact: Up to 1.5 points can be scored if more than 30% of product and or/product components for development/construction are reusable or recyclable at the end of the product life • Middle impact: Up 3 points can be scored if more than 60% of product and

No.	Requirement	Detailed assessment criteria
		or/product components for development/construction are reusable or recyclable at the end of the product life • High impact: Up to 5 points can be scored if more than 90% of product and or/product components for development/construction are reusable or recyclable at the end of the product life

3.5. Assessment standard for green building (GB/T50378-2014)

The green building rating system in Mainland China is 'Assessment standard for green building (ASGB)' (GB/T50378-2014), which is published by the Ministry of Housing and Urban-Rural Development (MOHURD) in cooperation with the Administration of Quality Supervision, Inspection and Quarantine (AQSIQ). This green building standard was implemented on 1 January 2015. It is now acting as a national standard in China.

The assessment system consists of seven categories of requirements: Land Saving and Outdoor Environment, Land Saving and Outdoor Environment, Water Saving and Water Resource Utilisation, Material Saving and Material Resource Utilisation, Indoor Environment Quality, Construction Management, Operation Management, and Promotion and Innovation. Each category includes prerequisite requirements and assessment requirements. According to the acquired score, green buildings are ranked as 'one star' (50 points), 'two-star' (60 points), and 'three-star' (80 points).

The C&D waste management requirements are located in the Chapter of Material Saving and Material Resource Utilisation. Three prerequisites are given in this Chapter; the prerequisite concerning C&D waste management is about structure design. Ornamental elements are not allowed to be used extensively in a certified green building. The assessment requirements and corresponding points are listed Table 17.

Table 17 C&D waste management requirements in assessment standard for green building (GB/T50378-2014)

No.	Requirement	Attainable points
1	Selection of optimised building architecture. Irregular structure shapes should be avoided to reduce materials.	9
2	Optimised design of foundation, structural systems, and structural components.	5
3	Integrated design of construction and decoration.	10
4	Use of reusable partitions in multi-functional indoor spaces.	5
5	Use of prefabricated components.	5
6	Use of integrative design for kitchens and bathrooms.	6
7	Use of ready-mixed concrete.	10
8	Use of ready-mixed mortar.	5
9	Use of structural materials with high durability.	5
10	Use of reusable and recyclable materials.	10
11	Use of materials produced by wasted components.	5
12	Proper use of decoration materials with high durability.	5

4. Summary of overseas C&D waste management policies and measures

This report presents the overseas C&D waste management policies and measures in academic papers, overseas government official websites, and prevailing green building rating tools worldwide.

From the academic papers, three overseas policies were abstracted from the academic literature, such as ‘legislation’, ‘market-based instruments’, and ‘vehicle impoundment policy’. In addition to the overseas C&D waste management policies, twelve specific C&D waste management measures were summarised, including ‘proper design’, ‘use of prefabrication’, ‘waste sorting’, ‘selective demolition’, ‘accurate waste quantification’, ‘incentive reward programme’, ‘online waste exchange’, ‘GIS (Geographic Information System) technology’, ‘Building Information Modeling (BIM)’, ‘system dynamics modeling’, ‘education and training’, and others. Remarks, including its effectiveness and potential limitations, are provided in Table 18.

Table 18 Summary of the identified overseas policies and measures.

Policy/measure	Remarks
Legislation	Legislation on C&D waste management can provide legal basis for implementing C&D waste minimisation. However, most countries have no legislation particularly focusing on C&D waste. The C&D waste related requirements are usually embedded in the regulation of general waste related regulations or solid waste related regulations.
Market-based instruments	The recycling market is a critical factor that influence the stakeholders’ waste reuse/recycling intentions, because most of them are benefit-earning oriented. Meanwhile, a certification system is suggested to ensure the quality of recycled materials.
Vehicle impoundment policy	The vehicle impoundment policy is efficient to prevent illegal dumping, especially in developing countries. An effective supervision system should be established to oversee the illegal dumping behaviour.

Policy/measure	Remarks
Proper design	Proper design is an effective measure that can avoid waste before it is generated. However, the awareness of C&D waste minimisation is not optimistic among designers. Publicity should be made to let the designers know their roles in waste reduction.
Use of prefabrication	Prefabrication is an effective strategy for not only minimising C&D waste, but also carbon emissions. It is an emerging strategy that has been encouraged by many studies.
Waste sorting	Waste sorting can be conducted on-site or off-site according project conditions; on-site sorting is highly recommended. Potential limitations of employing on-site sorting include space limitation, time limitation, labour limitation, and cost limitation. However, cost limitation is the most important factor concerned by the contractors. A high landfill disposal fee can facilitate the improvement of on-sorting.
Selective demolition	Selective demolition is also named as deconstruction in some literature, it is a reverse process of construction. The separated waste can be reused directly or sold to recyclers. However, selective demolition faces the same limitations as waste sorting; cost is the major consideration factor.
Accurate waste quantification	Accurate waste quantification is essential for good management at both regional and project levels. Regional waste generation can be estimated through forecasting techniques if historical generation data are well collected and stored. At project level, a feasible waste management plan can be made based on the accurate waste estimation. However, the main obstacle is that reliable estimation of C&D waste generation is rare.
Incentive reward programme	The incentive reward programme can promote the waste reduction intentions of construction workers. However, benchmarks should be set up and an efficient system should be established to monitor how many materials saved by the construction workers.
Online waste exchange	Online waste exchange can increase the C&D waste reuse/recycling rate by avoiding disposal at landfills. A reliable platform is needed for efficient exchanging of waste generation information. Meanwhile, the

Policy/measure	Remarks
	government should permit such exchange. Thus, the platform is suggested to be established by the government.
GIS (Geographic Information System) technology	GIS technology can be used at a project to monitor the distribution of materials storage. The advantages include visual representation and quantification of the waste flows. However, this technology need comprehensive GIS data.
Building information modeling (BIM)	BIM can be used to minimise C&D waste from many aspects, such as estimation of waste amount, flexible design change, etc. However, this is a comparatively novel technology, more modules should be developed for C&D waste management.
System dynamics modeling	The system dynamics modeling is an analysis method based on the systematic thinking. The application can be wide, however, many elements are involved in a system dynamics model and the reliable data are limited for utilising this modeling method.
Education and training	The aim of education and training is to increase the construction practitioners' awareness of C&D waste management and enhance their relevant skills. This needs project managers' support and a better C&D waste management culture.

The overseas C&D waste management policies and measures were also investigated from government official websites. A total of nine countries/regions have been investigated, including US, EU, Sweden, the Netherlands, Japan, Singapore, Korea, Australia, and Taiwan. The successful experiences were identified from the investigated websites, as shown in Table 19.

Table 19 Overseas successful experiences on C&D waste management

Country/region	Successful experience
United States	• implementation of source reduction; • implementation of deconstruction; • illustrative manuals and practical cases; • development of mature waste trade market.
European Union	• implementation of Waste Framework Directive;

Country/region	Successful experience
	• mature reuse/recycling market; • life-cycle thinking; • support for research projects.
Sweden	• implementation of legislative initiatives; • improved and better controlled quality of C&D waste; • implementation of landfill taxes; • ban on landfilling of combustible waste fractions.
The Netherlands	• implementation of legislative initiatives; • implementation of landfill and incineration taxes; • development of mature secondary material market.
Japan	• implementation of Construction Recycling Law; • mature C&D waste recycling technologies and facilities.
Singapore	• efficient waste sorting; • strict supervision on illegal dumping; • mature waste recycling technologies and facilities.
Korea	• implementation of Construction Waste Recycling Promotion Act; • quality certification system for recycled aggregates; • construction waste information management system for waste exchange.
Australia	• implementation of legislative initiatives; • implementation of landfill tax; • supply chain management.
Taiwan	• implementation of legislative initiatives; • effective sorting.

Selected green building rating systems were also reviewed in this report, including LEED, BREEAM, Green Globes, Green Mark, and Assessment Standard for Green Building (GB/T50378-2014). The results showed that LEED and BREEAM have very detailed requirements and specifications for C&D waste management. However, Green Globes and Green Mark do not have too much emphasis on C&D waste management. Although GB/T50378-2014 gives emphasis on C&D waste management, the detailed specifications are not adequate.

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REPORT 2

LITERATURE REVIEW ON CURRENT STATUTORY AND ADMINISTRATIVE C&D WASTE MANAGEMENT MEASURES IN HONG KONG

August 2017

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The aim of this report is to give a general overview of the current statutory and administrative measures in Hong Kong. The current statutory and administrative measures were identified and summarised from three sources:

(1) Academic literature;

(2) Official websites of Hong Kong governments and industrial associations;

(3) BEAM Plus.

1. Current statutory and administrative measures from academic publications

This section introduces the statutory and administrative measures of C&D waste management in Hong Kong identified from academic publications.

1.1. Research on C&D waste management policies in Hong Kong

The research concerning C&D waste management policies in Hong Kong has been identified from academic publications. The identified policies are introduced in the following subsections.

1.1.1. Regulations, codes, and initiatives

A series of regulations, codes, and initiatives has been promulgated by the Hong Kong government in order to improve C&D waste management. Wang et al. (2010) identified the C&D waste management policies in Hong Kong:

- In 1980, the Waste Disposal Ordinance was come into effect with the aim of controlling and reducing the illegal waste dumping including illegal C&D waste dumping.
- In 1989, a 10-year plan was announced aiming to encourage the community to reduce waste and conserve resources.
- In January 1994, a Green Manager Scheme was set up, requiring all governmental departments to appoint green managers to oversee green housekeeping measures involving waste minimisation, energy conservation, etc.
- In 1998, a waste reduction framework was launched in order to change the public waste treatment habits.

- In 2005, a landfill charging scheme was implemented. C&D waste producers were encouraged to reduce, sort and recycle waste.

In order to evaluate the effectiveness of existing C&D waste management policies in Hong Kong, Lu and Tam (2013) conducted a longitudinal review by triangulating empirical data collected from relevant governments or associations with the qualitative data derived from interviews and case studies. Existing C&D waste management policies were identified, as shown in Figure 1. The research findings showed that the implementation of C&D waste management policies can increase construction companies' C&D waste minimisation awareness; however, Lu and Tam (2013) argued that 'it seems that there was a pause in governmental initiatives on C&D waste management after the implementation of Construction Waste Disposal Charging Scheme in 2005'.

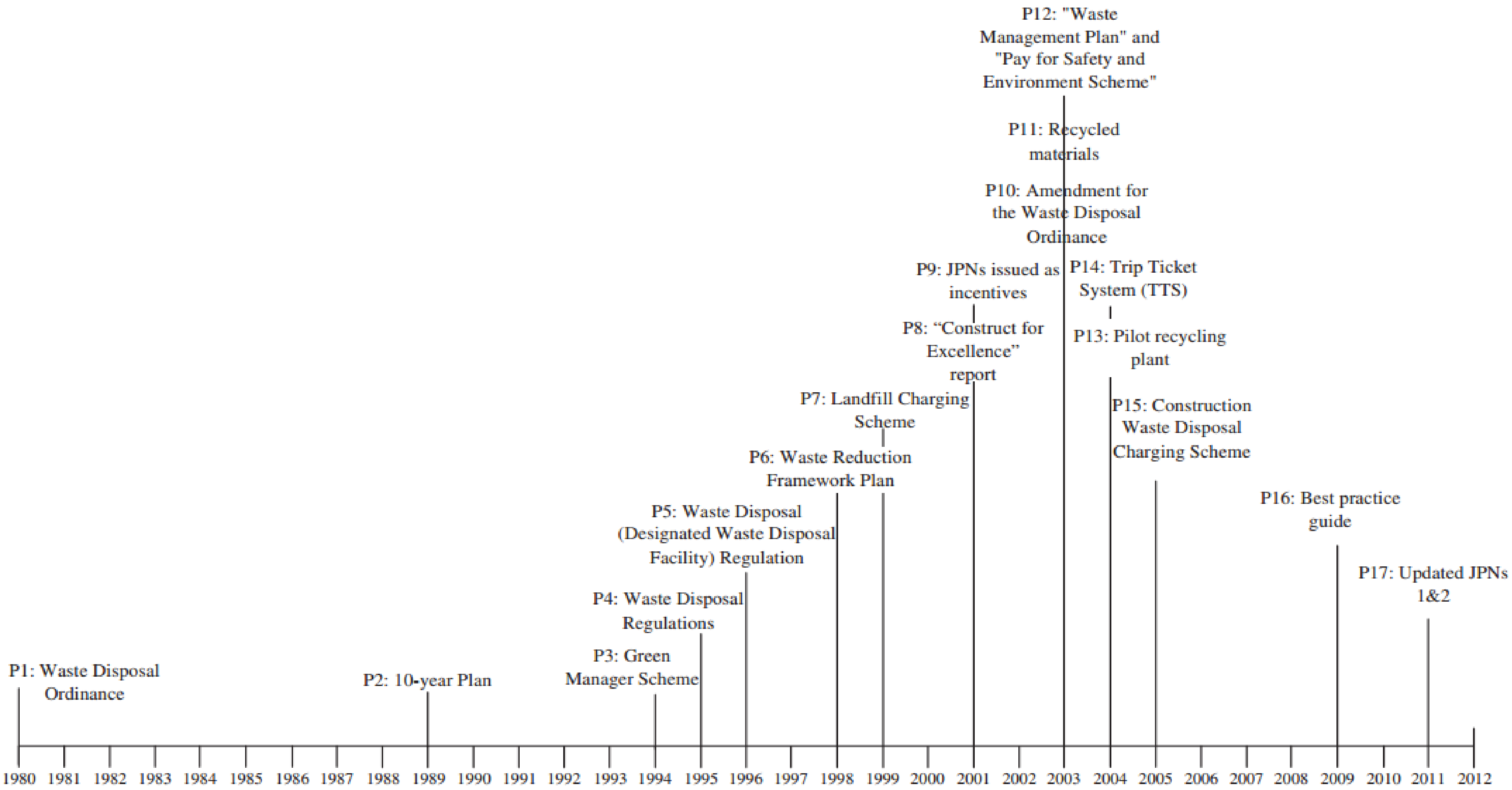

Figure 1 Policy framework of C&D waste management in Hong Kong (Lu and Tam, 2013)

Note: 'JPN' refers to 'Joint Practice Notes on protection and improvement of the built and natural environment'.

1.1.2. Construction waste disposal charging scheme

The policy of Construction Waste Disposal Charging Scheme (CWDCS) was enacted in January 2005 (EPD, 2016a). This policy requires dumping licences should be obtained from the fill management division prior to dumping at landfills or public fill reception facilities; meanwhile, certain charges are required for the disposal (Yeung, 2008). After its implementation, the effect of this policy has been well investigated by several Hong Kong academic researcher.

Hao et al. (2008b) examined the effectiveness of the CWDCS after its implementation of one year. A survey was conducted at Tseung Kwan O Area 137 and Tuen Mun Area 38, the daily C&D waste records were collected from landfills and public filling facilities between January 2006 and December 2006. The results of the survey showed that waste disposal at landfills has been reduced by approximately 60%, while the reduction rate reached approximately 23% at public fills between 2005 and 2006. The results showed that the implementation of CWDCS has significantly reduced the total waste generation. In order to have further improvements, fine-tuning was also suggested, such as introducing incremental charges.

After five years' implementation of the CWDCS, Hao et al. (2011) conducted another research study to re-evaluate its effectiveness. Nevertheless, the effectiveness of the charging scheme was found to be not so promising. It was found that only 49% of construction practitioners performed on-site waste sorting. The potential reason was that the landfill disposal fee is insignificant compared with project sums, thus the existing charging standard is not high enough to encourage contractors to employ effective C&D waste management measures.

Yu et al. (2013) tried to investigate the changes of contractors' behaviour after the implementation of CWDCS via a structured questionnaire survey and case studies. The research findings revealed that 'a significant reduction of construction waste was achieved during the first three years (2006–2008) of CWDCS implementation; however, the reduction could not be sustained'. The implementation of CWDCS has not yet motivated construction practitioners to promote their C&D waste minimisation behaviour.

Poon et al. (2013) conducted a study to explore the construction participants' perceptions towards the CWDCS in Hong Kong. A questionnaire survey with follow-up interviews with experienced professionals were conducted. The findings revealed that about 40% of the respondents believed that C&D waste reduction is less than 5% after the implementation of CWDCS. In addition, 30% of survey respondents agreed that the charging standard of CWDCS was not high enough to raise awareness of waste minimisation at construction sites.

Lu et al. (2015b) investigated construction stakeholders' willingness to pay (WTP) for effective C&D waste management using a questionnaire survey in February 2014. The results showed that 'the average maximum WTP is around HK$ 232/t for landfill disposal of C&D waste, HK$ 186/t for off-site sorting facility (OSF) disposal, and HK$ 120/t for public fill reception facility (PFRF) disposal'. These numbers are higher than the existing CWDCS charges (i.e. HK$ 125/t for land filling, HK$ 100/t for OSF disposal, and HK$ 27/t for PFRF disposal).

Through the above literature review, it can be summarised that the CDWCS in Hong Kong was effective when it was first introduced. However, as (1) the contractors have got used to the charge requirements of the current CWDCS, and (2) the inflation throughout the past years, the current 'relatively low' charging fees are not effective to provide incentives to contractors and other related professionals to improve their C&D waste management behaviour. Moreover, the current charging standards are even lower than the perceived acceptable payments of construction practitioners. Therefore, it is essential for the government to increase the C&D waste charging standards so as to improve the regional C&D waste management level.

1.1.3. Waste management plan

The Hong Kong government has required all government funded construction projects to employ a waste management plan (WMP) before the implementation of construction work. In the academic literature, the study on the effectiveness of WMP was firstly conducted by Poon et al. (2004c). During the implementation of a WMP, the site staff are required to carry out monthly reviews to ensure that on-site C&D waste management follow the WMP. Site inspection are required to be carried out on a regular basis. It is essential to consider reduction of construction waste and awareness of environmental protection as basic requirements in site inspection records.

The effectiveness of the implementation a waste management plan was further investigated by Tam (2008). It was mentioned that during the trial period of WMP implementation, the government received different version of feedback from the industry. A questionnaire survey and structured interviews were conducted. The result showed that ‘Propose methods for on-site reuse of materials’ and ‘Propose methods for reducing waste’ were the main benefits gained from the implementation of the WMP method. However, ‘Low financial incentive’ and ‘Increase in overhead cost’ were considered as the major difficulties in its implementation.

1.1.4. Development of a mature waste recycling market

Establishing a mature recycling market is essential for promoting the C&D waste management intentions of construction stakeholders. Poon et al. (2004b) indicated that, although selective demolition can improve the waste recycling rate, there is a need to develop recycling markets to provide outlets for the collected recyclables. In addition, Wong and Yip (2004) argued that the products using recycled materials must meet higher quality standards before recycling becomes a viable option, because 29% of the respondents worried about the quality of recycled building materials (including 15% expressed concern about the lower quality of recycled products, 4% about the unreliable quality, and 10% about the ability of the recycled materials to meet specifications). However, Poon (2007a) claimed that high quality concrete products could also be produced with recycled aggregates.

A number of European countries, Japan and some states in the United States have already modified their specifications to make provision for the use of recycled aggregates in the construction projects.

In order to promote the utilisation of recycled materials, Poon (2007a) suggested the government to adopt policy measures, particularly in government funded projects. It was also suggested that opportunities should be considered in the precast industry about the use of recycled aggregates as it is easier to ensure quality in the end products due to the presence of an existing quality assurance system. Such a scheme can be implemented first for the production of non-structural products such as partition walls, road dividers, bridge fencing, noise barriers, and paving blocks etc. Ling et al. (2013) also agreed that there is a need to develop a reliable market to utilise recycled glass.

1.2. Research on C&D waste management measures in Hong Kong

The identified measures are described and discussed in the following subsections.

1.2.1. Proper design

There are six levels for C&D waste management: reduce, reuse, recycle, compost, incinerate, and landfill (Peng et al., 1997). In these six levels, ‘reduce’, namely avoid waste before it is actually generated, is the most recommended strategy. Proper design can reduce waste generation to a large extent (Li et al., 2015; Wang et al., 2014).

Poon et al. (2004a) indicated that there have always been cases that the design specifications do not agree with the practical material dimensions causing large amounts of off-cuts during construction. If detailed technical information about the construction materials or construction process can be taken into account by the designers, a significant amount of waste can be avoided.

Poon (2007b) further presented several design measures for avoiding C&D waste generation, such as dimensional coordination and standardisation, minimising the use of temporary works, avoiding late design modifications, and providing more detailed designs. Baldwin et al. (2008) and Baldwin et al. (2009) further described how modeling information flows in the design process may be used to evaluate design solutions when seeking to reduce construction waste in high rise residential buildings in Hong Kong. Zhang et al. (2012) summarised the low-waste technologies during design stage, such as design for thinner internal walls and floor slabs, design for smaller foundation size, design for reusing excavated spoils as back-fill material to balance cut and fill, modular building designs and prefabricated components, design for recycled materials such as recycled aggregates and asphalt, design for hanging cradles. However, the importance of proper design for C&D waste reduction has not been widely acknowledged by the designers.

1.2.2. Use of prefabrication

Prefabrication is a manufacturing process, generally taking place at a specialised facility where various materials are joined to form a component part of the final installation (Tatum et al., 1987). Various forms of prefabricated construction modules have been applied in the construction industry. For example, in Hong Kong, they can be generally classified into three categories: (1) semi-prefabricated non-structural elements, such as windows, ceiling, facades, and partition walls; (2) comprehensive prefabricated units containing structural prefabricated elements, such as columns, beams, floor or roof sheathing, slabs, load-bearing walls, and staircases, most of which are completed in the factory prior to assembly; (3) and modular buildings that are wholly completed offsite as a one-stop system (Tam et al., 2007b; Tam et al., 2007c). Prefabrication reduces the amount of on-site wet-trade work, thereby contributing to construction waste minimisation (Li et al., 2014).

The implementation of prefabrication can improve buildability, increase quality and efficiency as well as construction waste reduction (Chiang et al., 2006). Tam et al. (2005) investigated four private building projects to demonstrate the effectiveness of prefabrication to minimise construction waste in Hong Kong. Tam et al. (2007c) conducted a feasibility analysis in adopting prefabrication in construction activities, the wastage levels between conventional and prefabrication constructions were compared. It was found that the wastage generation can be reduced up to 100% after adopting prefabrication, in which up to 84.7% can be saved on wastage reduction while others can be reused or recycled. Jaillon and Poon (2008) further examined the adoption of prefabrication in high-rise buildings from the economic, environmental and social aspects using a questionnaire survey. Seven residential and non-residential buildings in Hong Kong were selected for case studies. The findings revealed that environmental, economic and social benefits of using prefabrication were significant when compared to conventional construction methods. In another research conducted by Jaillon et al. (2009), it was estimated that the average wastage reduction level was about 52%. The evolution of prefabricated residential building systems in the public and the private sectors in Hong Kong was also reviewed (Jaillon and Poon, 2009).

By considering the upstream processes, which include the manufacturing and transportation of components, of prefabrication, Lu and Yuan (2013) investigated the waste reduction potential in the upstream processes of off-site prefabrication construction. It was claimed that the issues are even more complicated in Hong Kong because components are manufactured in the Pearl River Delta Region (PRDR) of Mainland China and transported across the border to construction sites in Hong Kong. Three in-depth case studies with selected PRDR prefabrication factories were conducted. It was found out that the waste generation rate in the upstream processes of off-site prefabrication is around 2% or lower by weight. The results proved that prefabrication in a factory environment is more conducive to waste reduction than the traditional cast in-situ construction method.

Although the research findings suggested that prefabrication could bring significant benefits to the Hong Kong construction industry, concerns were also proposed about its application in dense urban environments. The limitations of prefabrication were discussed by Jaillon and Poon (2008) from the economic, environmental, and social aspects. From the economic aspect, the higher initial cost is a major limitation in adopting prefabrication when compared with conventional construction methods. The higher initial cost is mainly due to the preliminary investment in a set of fabrication molds (steel molds). It was also mentioned that the transportation cost of prefabricated elements is higher when compared to conventional construction, because the most prefabrication factories are located in the Guangdong Province, which increases the overall transportation distance. From the environmental aspect, some respondents felt that the transportation of prefabricated elements and its associated pollution are environmental limitations when compared with conventional construction. One respondent also argued that a wider use of prefabrication could pose serious social problems in Hong Kong. The reduction of labour requirement on-site as a result of using prefabrication techniques might increase the unemployment rate in the building industry.

In order to promote the implementation prefabrication in Hong Kong, Tam and Hao (2014) argued that prefabrication will only be successful when contractors and developers can enjoy cost savings. Prefabrication will bring effective cost saving only when the following processes or methods are implemented:
(1) Fully mechanised construction process using heavy plants;
(2) Turning construction into an assembly line industry rather than on-site production;
(3) Use of recycle materials for the prefabricated components.

In addition, the following three main stimulators were suggested to encourage the use of prefabrication (Hsieh, 1997; Shen and Tam, 2002; Tam and Hao, 2014):
(1) Environmental issues: When more stringent environmental control and regulations are forth coming, prefabrication is one of the ways to facilitate long-term waste minimisation and reduction;
(2) Construction costs: Introducing more productive and lean construction methods can reduce the construction cost effectively and reduce the burden incurred due to high initial investment;
(3) Government incentives: Granting relaxation to the gross floor areas for projects employing prefabrication elements (e.g. discounting the area occupied by facade units), will encourage the use of prefabrication. Moreover, tighter control on workmanship, allowable tolerances, homogeneity and allowable rework will favor the adoption of prefabrication.

1.2.3. On-site sorting

On-site sorting is a popular strategy that has been recommended in many green building rating systems (Wu et al., 2016). Poon et al. (2001) investigated the on-site sorting of C&D waste in Hong Kong. Three alternative waste sorting methods at building construction sites were presented:

Alternative 1

1) Two refuse chutes for each block of building: one for inert waste and the other for non-inert waste.
2) Separate collection of inert waste and non-inert waste from the refuse chutes.
3) Inert waste and non-inert waste are cleared by different trucks and disposed of at public filling area and landfills separately.

Alternative 2

1) One refuse chute for each block of building.
2) Only one type of waste, either inert or non-inert waste, will be collected separately and removed within a period of time (e.g. every one or two days).

Alternative 3

1) One refuse chute for each block.
2) A sizable pit for waste storage on the ground level.
3) Manual sorting of waste at the pit.
4) Separate removal of sorted wastes.

It was summarised that alternative 1 performs better than the others, especially in large building projects where site space is available for setting up two refuse chutes. For small projects in which the use of multiple debris chutes is restricted, alternative 2 should be opted. Under any circumstances, alternative 3 should be the last resort unless minimum interference with the site activities becomes predominant. It was further found that the building construction participants are reluctant to carry out on-site waste sorting. Even when a high tipping fee is imposed, they have little incentive to perform on-site waste sorting which is considered to be time and labour demanding. Only through contractual requirements or legislation can on-site waste sorting be fully implemented and becomes a long-term solution to the landfill shortage problem in Hong Kong.

1.2.4. Off-site sorting

Besides the on-site sorting of C&D waste, Lu and Yuan (2012) investigated the effectiveness of off-site sorting strategy in Hong Kong. The data were collected from two channels: (1) literature review and examination on government regulations and statistics, and (2) two empirical case studies carried out at the Tuen Mun construction waste sorting facility. The flowchart of off-site construction waste sorting in Hong Kong is presented in Figure 2. As shown in the figure, after going through all the sorting processes, the mixed construction waste can be eventually sorted into inert materials and non-inert materials. The inert materials will be sent to the public fill reception facilities while the non-inert ones landfilled.

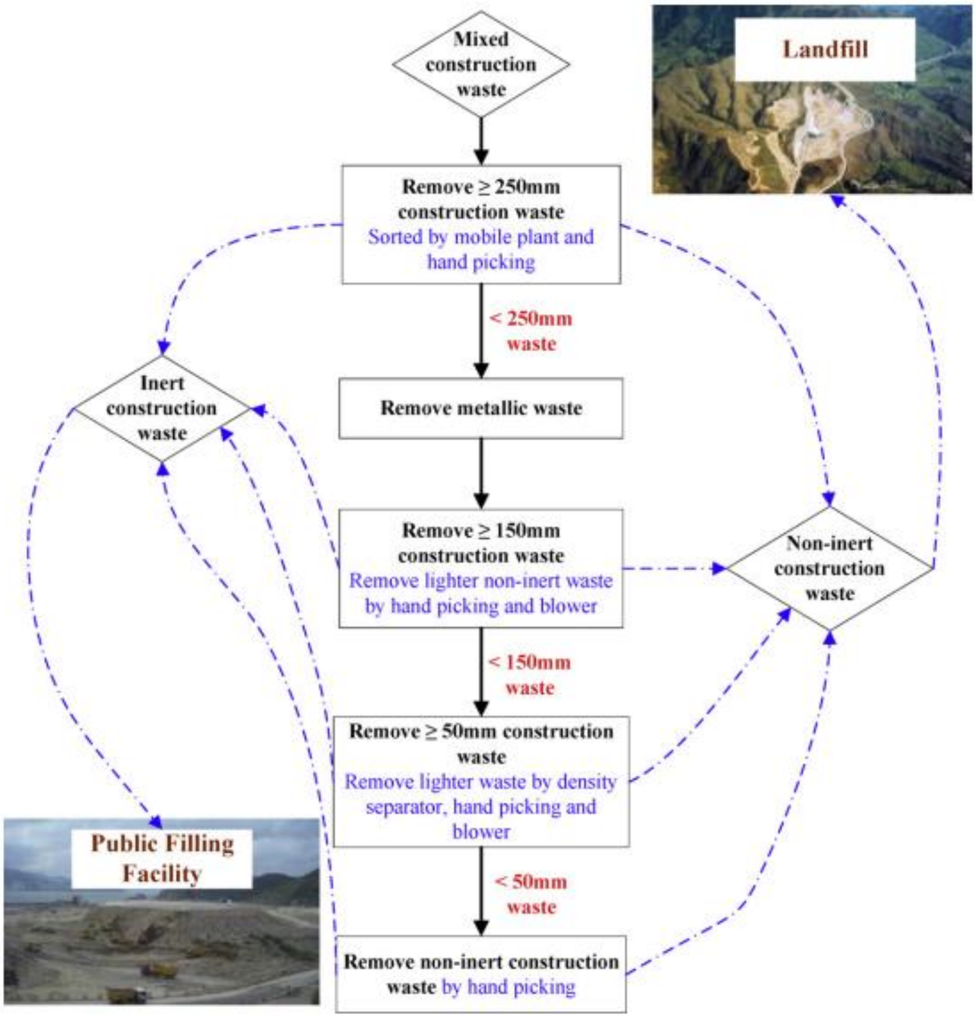

Figure 2 Flowchart of off-site construction waste sorting in Hong Kong (Lu and Yuan, 2012)

It was found by Lu and Yuan (2012) that, from its commencement in January 2006 to February 2012 when the survey was conducted, the off-site construction waste sorting facilities have successfully accepted and dealt with a total volume of 5.11 million tons of construction waste. The off-site sorting strategy when it was first introduced contributed significantly to reducing the amount of construction waste handled by landfills*. The findings revealed that the success of the off-site construction waste sorting programme is mainly attributed to 'sustaining policy support from the Hong Kong government', 'good policy execution', 'encouraging off-site construction waste sorting through higher disposal charges' and 'implementation of the trip-ticket system'. Future suggestions for improving the effectiveness of off-site sorting are 'proper location of the off-site construction waste sorting facilities', 'effective measurements of the proportion of inert materials', 'prevention of noise and dust at the construction waste sorting sites', and 'recycling recyclable materials rather than disposal'.

**recent observations at the sorting facilities improvement in administrative arrangements are needed to sustain the effectiveness of the sorting plants*

1.2.5. Selective demolition

Selective demolition is an extension of on-siting sorting; it is an effective strategy for reusing and recycling demolition waste. This measure is principally carried out in reversal to the construction process, requiring that, before and during the demolition process, a concise sorting of the different material categories should be carried out to prevent any contamination of inert or recyclable parts with wood, paper, cardboard, plastics and metals (Lauritezen and Hahn, 1992).

Poon (1997) indicated that selective demolition is usually carried out in the following procedures: (1) removal of remains and non-fixtures; (2) stripping, comprising internal clearing, removal of doors, windows, roof components, installation, water, air conditioning, electrical wiring and equipment, leaving only the building shell structure; and (3) demolition of the building shell. A picture was further given by Poon et al. (2004b) to illustrate the sequence of selective demolition process, as shown in Figure 3.

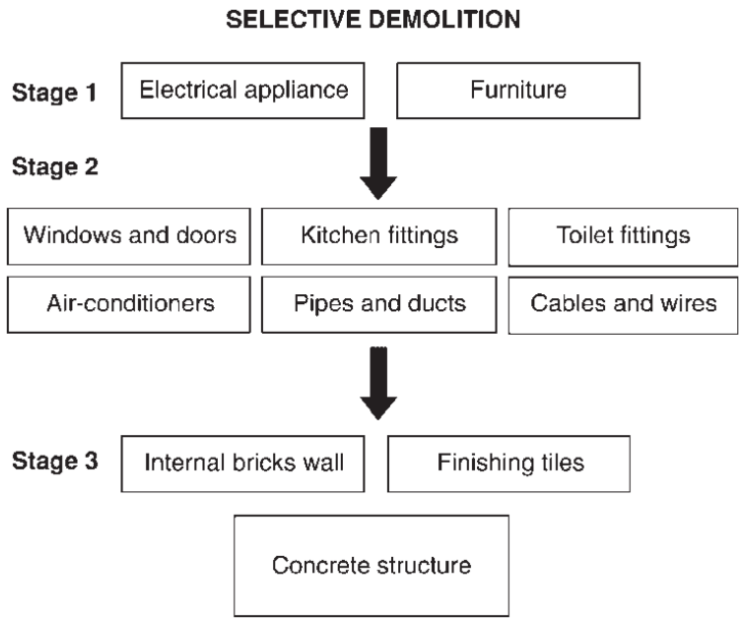

Figure 3 Sequence of selective demolition process (Poon et al., 2004b)

Selective demolition is considered labour intensive and time consuming because the work involved for the removal of non-fixtures and other internal services/remains is primarily carried out by hand. Lauritezen and Hahn (1992) estimated that the overall cost for the demolition work will be increased by 10~20% if selective demolition is implemented. In Hong Kong, demolition of old buildings is traditionally regarded as a low technology. Contractors usually aim at a fast demolition rate and rapid clearance of site for the new development. In addition, special measures to separate the different types of materials may be not possible due to time constraint and other site related factors (e.g. space limitations). Therefore, a major part of the reusable demolition materials could not be reclaimed (Poon, 1997).

The importance of selective demolition has been realised by the Hong Kong government. In the demolition contract of the Kowloon Walled City, it was specified that ‘the general demolition debris resulting from the project shall be sorted and processed to remove all timber, steel, rubbish and other decomposable materials’ (Poon, 1997). However, in order to make the contractors more willing to conduct selective demotion, there is a need to develop recycling markets to provide outlets for the collected recyclables (Poon et al., 2004b).

1.2.6. Accurate waste quantification

Accurate waste quantification is regarded as a prerequisite for the successful implementation of C&D waste management (Llatas, 2011; Yost and Halstead, 1996). Wu et al. (2014) conducted a systematic review of the existing C&D waste quantification methods. Six categories of existing C&D waste quantification methodologies were identified, including site visit (SV) method, waste generation rate (WGR) method, lifetime analysis (LA) method, classification system accumulation (CSA) method, variables modeling (VM) method and other particular methods. The comparison of the retrieved methods is presented in Table 1. A decision tree was further proposed for aiding the selection of the most appropriate quantification method in different scenarios, as shown in Figure 4. Through the investigation of the existing quantification methods, it was concluded that no independent quantification method can fulfill all of the potential scenarios; appropriate methodology should be selected according to actual quantification objectives and realistic conditions. The classified information of C&D waste can be recorded with the aid of computer technologies for benchmarking and better waste management.

Table 1 Comparison of the current C&D waste quantification methodologies (Wu et al., 2014)

Methodology		Typical Paper	Waste generation activity	Estimation level	Comments
SV	Direct measurement	Lau et al. (2008), Lu et al. (2011)	CNB, DOB, CIW	PL	Direct measurement of C&D waste can provide the most practical waste generation rates, which is the most basic information for C&D waste quantification. Besides, the waste generation rates enable the comparison and benchmark of C&D waste management in different economies. However, the direct measurement should first successfully seek the support from the contractors, and the consumption of time, money and labour is immense.
	Indirect measurement	Poon et al. (2004b)	CNB, DOB, CIW	PL	Indirect measurement can quickly supply general information of waste generation situation. However, the waste generation amounts derived from this method can only approximately reflect the fact.
GRC	Per-capita multiplier	McBean and Fortin (1993)	CNB, DOB, CIW	RL	Per-capita multiplier is a method developed from MSW quantification. The population statistics, which is very basic information for a region, is utilised. However, as C&D waste generation is more construction related, this method is not suggested if construction related statistics can be derived.
	Financial value extrapolation	Yost and Halstead (1996)	CNB, DOB, CIW	RL	Financial value extrapolation utilises financial value presented in construction/demolition permits as a converting factor to estimate the area of construction/demolition activities, making the estimation construction activities related. However, this method is not suggested when the area of construction/demolition

Methodology		Typical Paper	Waste generation activity	Estimation level	Comments
					activities can be directly derived.
	Area-based calculation	Fatta et al. (2003), Lage et al. (2010)	CNB, DOB, CIW	PL, RL	Area-based calculation is the most popular method in literature. It can be employed to estimate all kinds of C&D waste at both project and regional levels. However, the demolition areas statistic may not available at regional level.
LA	Building lifetime analysis	Poon (1997)	DOB	RL	Building lifetime analysis is a method that estimates demolition areas, making it possible for quantifying DW without governmental demolition statistics. However, appropriate assumptions of building lifetime are required when conducting this method and the detailed wasted amount at material level cannot be derived.
	Material lifetime analysis	Cochran and Townsend (2010)	DOB	RL	Material lifetime analysis is a method that can estimate DW generation at material level. The lifetime of the material is considered. However, similar with building lifetime analysis, appropriate assumptions of material lifetime are required.
CSA		Solis-Guzman et al. (2009), Llatas (2011)	CNB, DOB, CIW	PL, RL	CSA is a methodology developed based on GCC. This methodology can give more detailed information at material level, which makes the project managers and regional policy-makers more feasible to formulate effective and efficient waste management plans. However, a classification system is suggested to be established in advance.
VM		Wimalasena et al. (2010)	CNB, DOB, CIW	PL, RL	VM is a methodology that can simulate the potential inter-relationships between waste generation affecting

Methodology	Typical Paper	Waste generation activity	Estimation level	Comments
				variables. This method has a great perspective in modeling future C&D waste generation. However, as the realistic data for C&D waste estimation is rare at this stage, this method has not got a wide application.
Others	Shi and Xu (2006)	CNB, DOB, CIW	PL, RL	Other methodologies are essential supplement for C&D waste quantification. However, due to various limitations, they cannot be generalised.

CNB – Construction of new buildings; DOB – Demolition of old buildings; CIW – Civil and infrastructural works; PL – Project level; RL – Regional level; SV – Site visit; GRC – Generation rate caculation; LA – Lifetime analysis; CSA – Classification system accumulation; VM – Variables modeling.

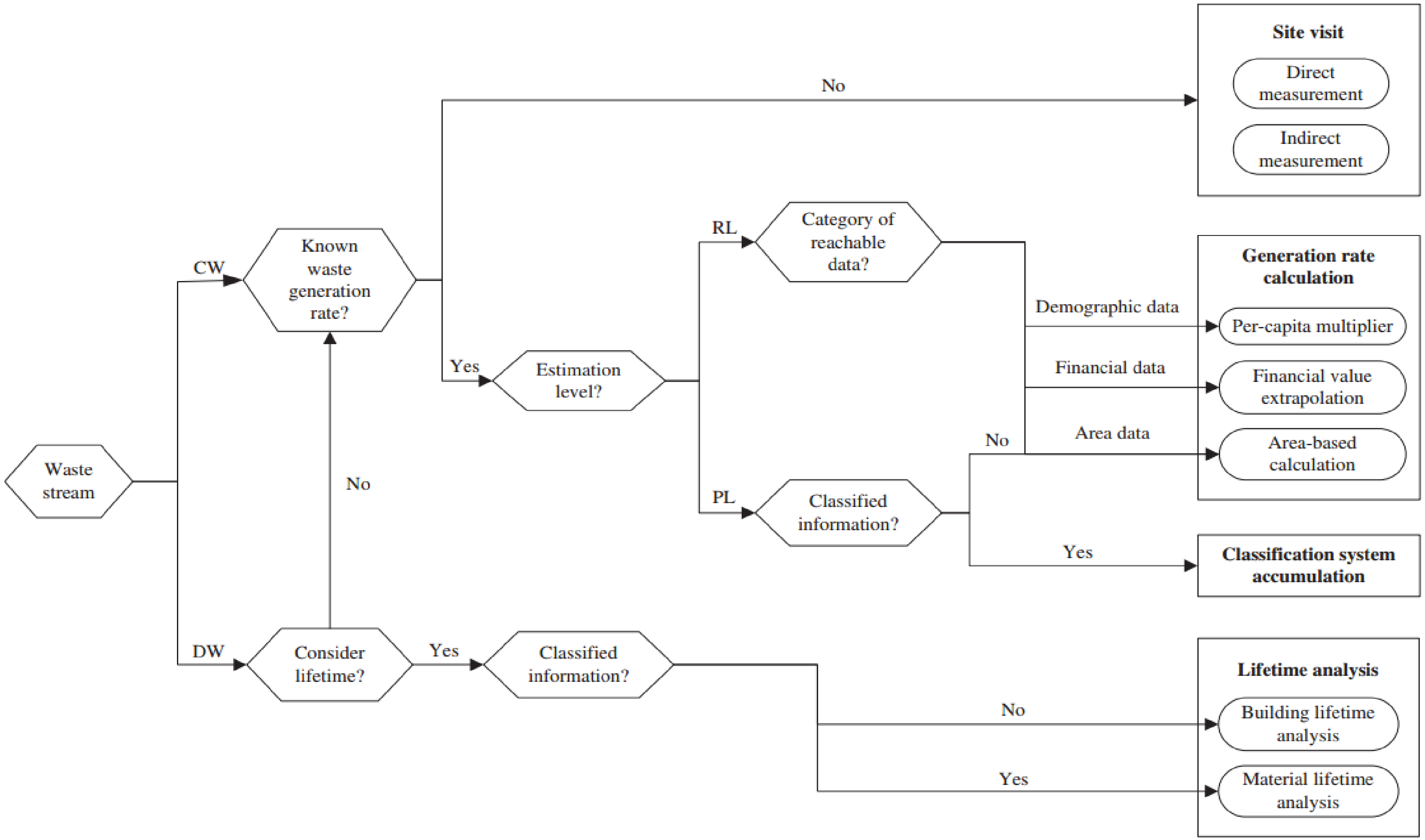

Figure 4 Relevance tree for methodology selection (Wu et al., 2014)

In order to dynamically estimate different kinds of waste generated in the construction process at the project level, Li and Zhang (2013) proposed a web-based construction waste estimation system (WCWES) for building construction projects, incorporating the concepts of work breakdown structure, material quantity takeoff, material classification, material conversion ratios, material wastage levels, and the mass balance principle. The WCWES integrates online data input modules and online analytical modules, the structure of the web-based construction waste estimation system is shown in Figure 5. The proposed web-based system can facilitate accessibility, interfacing, connectivity and information sharing of users in carrying out a wide range of construction waste estimation tasks.

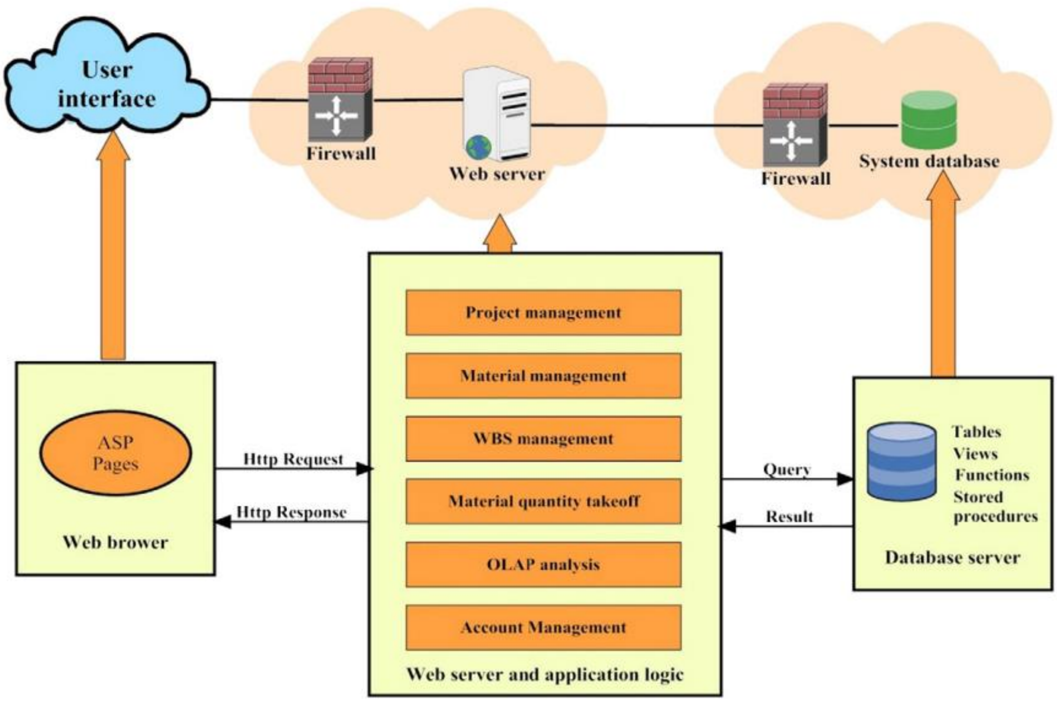

Figure 5 Structure of the web-based construction waste estimation system (Li and Zhang, 2013)

In recent years, some other studies have been conducted for C&D waste estimation and forecasting based on the existing data. For example, Wu et al. (2015) forecasted the C&D waste generation in Hong Kong using a gene expression programming method. As the EPD and CEDD have collected a marvelous amount of C&D waste disposal records in recent years, Lu et al. (2015a) used data mining technique to evaluate the C&D waste management performance. By mining 2,212,026 waste disposal records generated from 5,764 projects in two consecutive years of 2011 and 2012, the waste generation rates were revisited and refined. This study revealed that demolition is the most wasteful works. New building, and maintenance and renovation works individually produce the least waste amount but by accumulating all maintenance and renovation works, their contribution to the total amount of construction waste could be phenomenal. Based on the more reliable performance benchmarks for different categories of projects, a contractor can benchmark its waste management performance against its counterparts or its past performance as 'Good', 'Average', and 'Not-so-good', and thus identify better waste management practices. Based on the benchmarks, the government may consider setting up a toll system to encourage those 'Not-so-good' contractors to perform well in the future, and initiate incentives to the companies conducting 'Good' projects to spur better performance. It was regarded that the 'big data' and the robust analyses can provide a very powerful and handy tool for better C&D waste management.

Lu et al. (2016) further utilised the data mining technique to compare the C&D waste management performance of public and private sectors in Hong Kong. By analysing two million waste disposal records generated from around 5.7 thousand projects, the results showed that there is a notable C&D waste management performance disparity between the public and private sectors, with contractors performing better in managing both inert and non-inert waste in public projects than they do in private projects. The reason for this might be the public projects receive higher social scrutiny in C&D waste management and they should show leadership in environmental management.

1.2.7. Incentive reward programme

According to Maslow's motivation theory, beyond their safety and health needs, construction workers require both emotional and financial rewards for exercising self-discipline in handling construction materials (Warren, 1989). Some rewarding or punishing methods have been used on construction sites. For example, the use of special motivational programme and financial incentive programmes have been reported (Carberry, 1996; Liska and Snell, 1992). The financial incentive programme is an important method for motivating workers, and it has been proven to be effective in improving quality and reducing project time and cost (Laufer and Jenkins, 1982). Thus there is a need to improve the way of managing waste by encouraging workers to reduce avoidable waste, and to reward the good practices of workers in cutting down the amount of waste. In order to meet the demand of on-site construction material management, a group-based incentive reward programme (IRP) was introduced by Chen et al. (2002), cooperating with an application of bar-code system.

In the group-based IRP proposed by Chen et al. (2002), members of the group will be rewarded or punished equally according to the reduction and increase amount of material waste. Each working group has a group leader who is responsible for withdrawing all the materials needed by his group from the storage keeper. The storage keeper records the amount of materials taken by each group. When a group finishes its work, the group leader is also responsible for arranging any unused materials to be returned back to the storage keeper for updating the records. Once a construction operation is completed, the project manager can measure the amount of material waste reduced or increased by comparing the actual amount of material used by the group with the estimated amount. The actual amount of material used is recorded by the storage keeper, while the estimated amount of material is prepared by the contractor’s quantity surveyors. The estimated amount includes a percentage that is considered as a normal amount of waste on site. The percentage is determined based on the contractor’s experience from the levels of waste in past projects. The contracting company has to share with workers of the benefits incurred from the reduction of material waste.

To facilitate the implementation of the IRP, a bar-code system was introduced by Chen et al. (2002) as well. The bar-code applications have been introduced to construction industry for material management, plant and tool control since 1987 (Bell and McCullouch, 1988; Bernold, 1990; McCullouch and Lueprasert, 1994). The primary function of the bar-code system is to provide instant and up-to-date information of quantities of materials exchanged between the storage keeper and the group leaders. Specifically, the bar-code system can provide the following functions (Chen et al., 2002):

- Automatically tracking real-time data of construction materials on the site;
- Automatically recording historical data of construction materials consumed in the project;
- Automatically monitoring materials consumption of working groups; and
- Automatically transferring real-time data of materials to head office via intranet and/or internet.

The architecture of the bar-code system used in this implementation is illustrated in Figure 6. From Figure 6, it can be seen that when the group leader goes to the storage to withdraw new materials or return surplus materials, the storage keeper scans the bar-code labels for the materials as well as the ID card of the group (samples are shown in Figure 7 and Figure 8), so that the amounts of materials taken or returned by the group are registered in the database. Based on the amounts of materials initially ordered according to the estimated requirements and the materials used by working groups, the computer system can calculate the amount of material reduction/wastage for each group. Bar-codes are given to each item (if it is big, e.g. door, window, etc.), or each pack (if the items are small, e.g. pack of nails, bolts and nuts). For each working group, an identification card is issued to the group leader who is responsible for withdrawing and returning construction materials. By scanning the bar-codes for the materials and the group, the computer system keeps records of materials used or returned by the group. These records are then used to calculate the reduction and increase of material waste generated by the group.

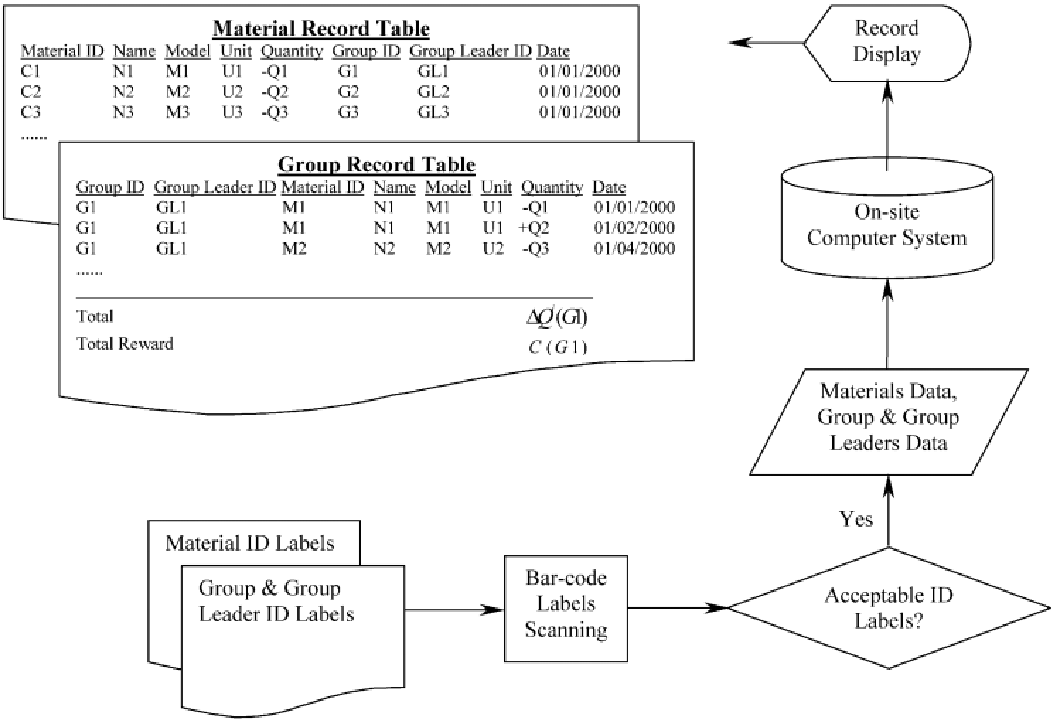

Figure 6 Data flowchart of the bar-code system for group-based incentive reward system

(Chen et al., 2002)

Figure 7 Sample bar-codes for construction materials (Chen et al., 2002)

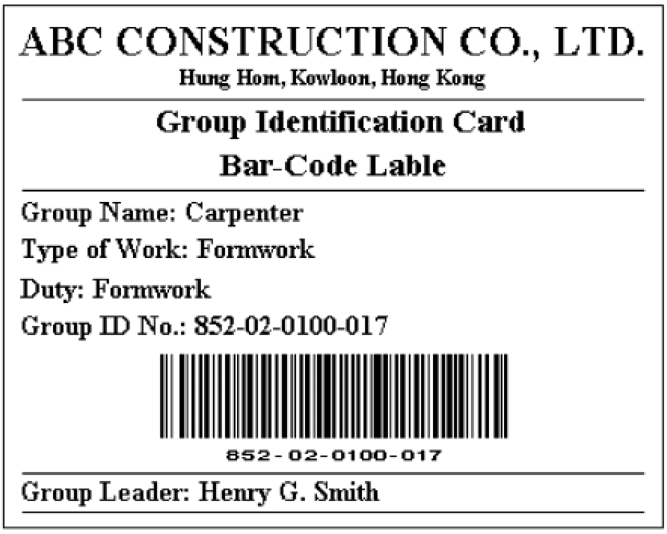
ABC CONSTRUCTION CO., LTD.
Hung Hom, Kowloon, Hong Kong
Group Identification Card
Bar-Code Lable
Group Name: Carpenter
Type of Work: Formwork
Duty: Formwork
Group ID No.: 852-02-0100-017
852-02-0100-017
Group Leader: Henry G. Smith

Figure 8 ID Card for the Carpenter group (Chen et al., 2002)

Tam and Tam (2008) also addressed the important of incentives. A Stepwise Incentive System was used to measure the cost saving on purchasing materials and controlling waste generation so as to improve 'Lack of motivation' and 'Lack of experience' factors. The procedures of the incentive system are shown in Figure 9. A case study was conducted, the results showed that the developed stepwise incentive scheme which can reduce construction waste by up to 23%.

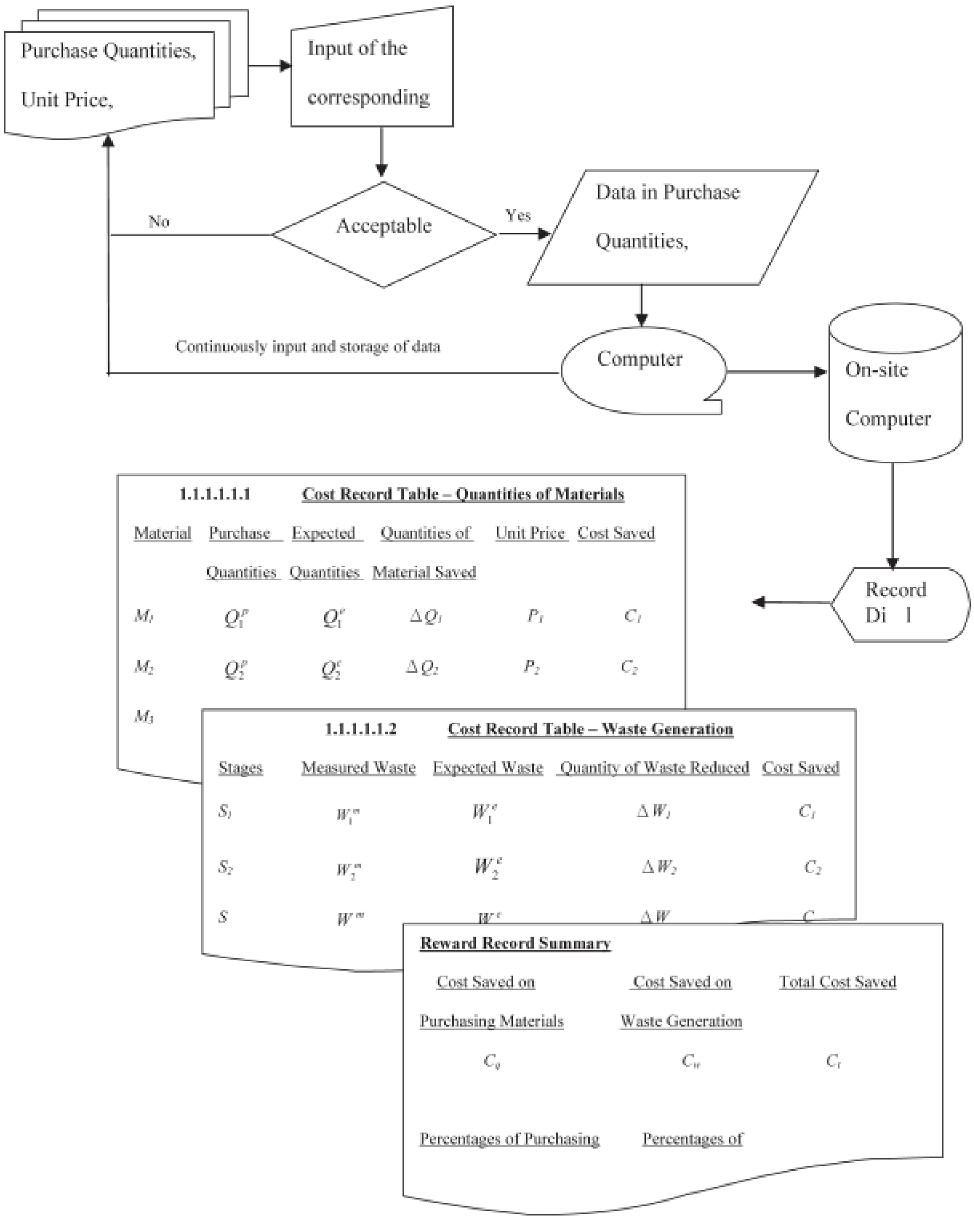

Figure 9 Procedures for the reward scheme (Tam and Tam, 2008)

1.2.8. Online waste exchange

The concept of waste exchange for industrial residues and information with the aim of reducing waste volume was introduced in the 1970s (Middleton and Stenburg, 1972). Later, professional websites for waste material and equipment trade and information exchange have been developed because they support effective multimedia communication. However, Chen et al. (2003) claimed the websites for waste exchange were not widely accepted in the construction industry because 1) contractors pay less attention to C&D waste reduction; 2) contractors can make little profit from using the waste exchange; 3) information about waste exchange is scattered on many different websites, and 4) websites lack a user-friendly and efficient operational mechanism to attract users. To tackle these issues, Chen et al. (2003) proposed an e-commerce model, which was named ‘Webfill’, for C&D waste exchange to reduce the total amount of the C&D waste disposed to the landfill in Hong Kong. The Webfill system is an on-line C&D waste exchange portal for the Hong Kong construction industry. The focus of this e-commerce model is post-construction stage. There are four kinds of users in Webfill, including contractors who are generators of the C&D waste, manufacturers who make new construction materials using the C&D waste, landfill disposers who sell recyclable C&D waste, and recyclers who do business among the contractors, the manufacturers, and the landfill disposers. The model was further improved in another research project published by (Chen et al., 2006), the design of the Webfill system is presented in Figure 10.

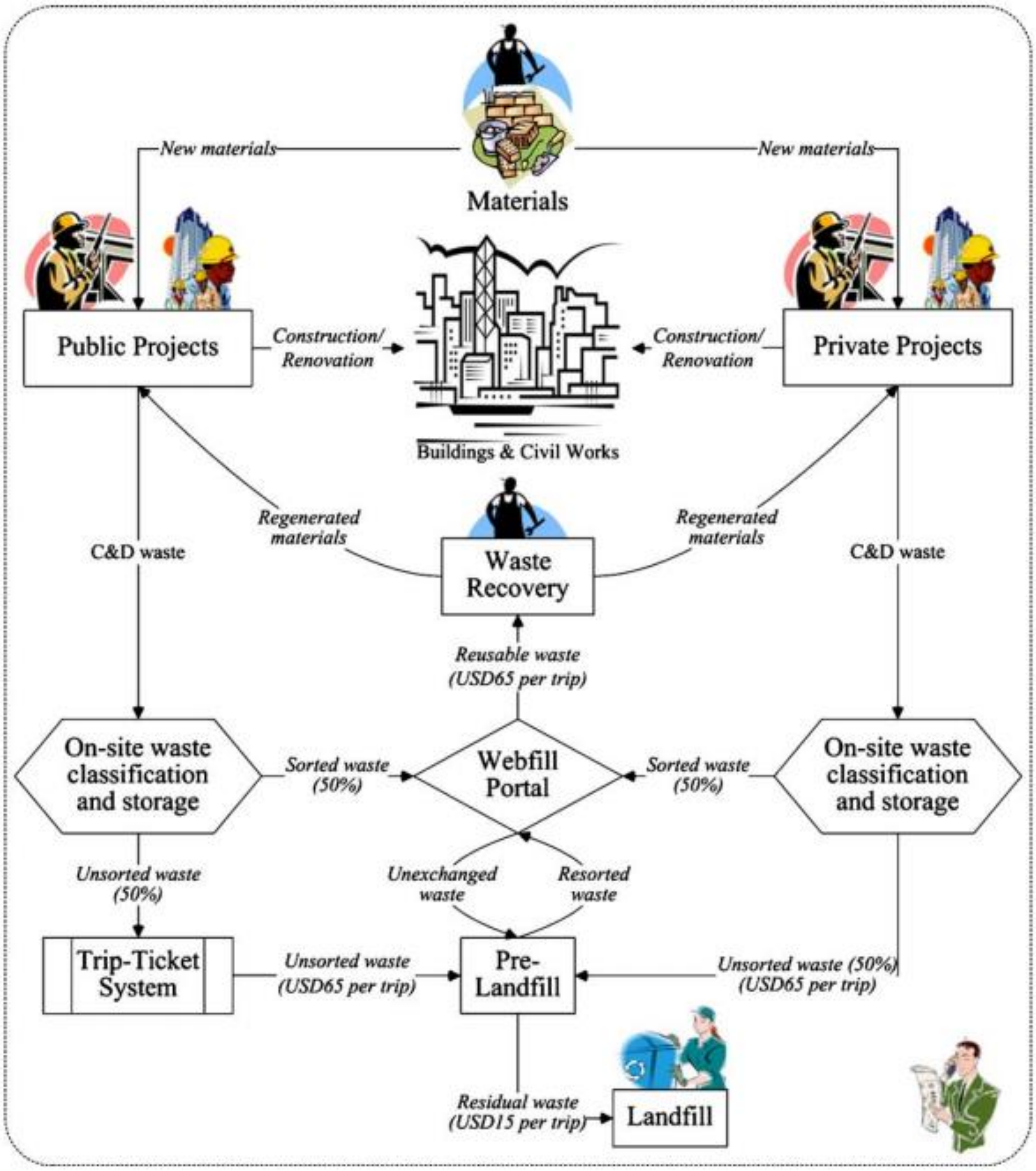

Figure 10 Design of the Webfill system (Chen et al., 2006)

The benefits of using the Webfill system are elaborated as follows:

(1) Contractors can use the Webfill system to find a buyer(s) for their residual construction materials, among other contractors, manufacturers or recyclers. Contractors can also buy residual or used materials and equipment from other contractors, or buy inexpensive recovered materials from manufacturers, or deal with recyclers, in order to lower construction costs.

(2) Manufacturers can either sell their low-cost products made from recovered materials on the Webfill system at attractive prices to contractors, or buy cheaper raw and processed

materials and used equipment from contractors. Recyclers and landfill disposers can also sell their recovered products to contractors or manufacturers.

(3) Recyclers can either sell second-hand materials to contractors and manufacturers on the Webfill system, or buy cheap materials from contractors.

(4) Landfill disposers can either sell recyclable or recoverable materials to manufacturers and recyclers at low prices or free of charge on the Webfill system in order to reduce the total amount of C&D waste tipped at public filling facilities. Consequently, the Webfill system is able to attract contractors, manufacturers, recyclers, and landfill disposers to work together as the Webfill system creates a win–win situation for all.

1.2.9. Waste management mapping model

In order to improve the management of the waste handling process on construction sites, Shen et al. (2004) developed a waste management mapping model (WMMM) based on the waste minimisation system proposed by McGrath (2001). The waste flow processes of construction wastes on site were examined with the assistance of the free-flow mapping presentation technique. The key information of six cases was selected including four elements, namely, waste source, waste facilitator, waste processing, and waste destination. After analysing the weaknesses and advantages of waste handling in the six selected cases, an alternative WMMM was developed, as shown in Figure 11. The model was expected to provide an alternative tool assisting the planning of 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.

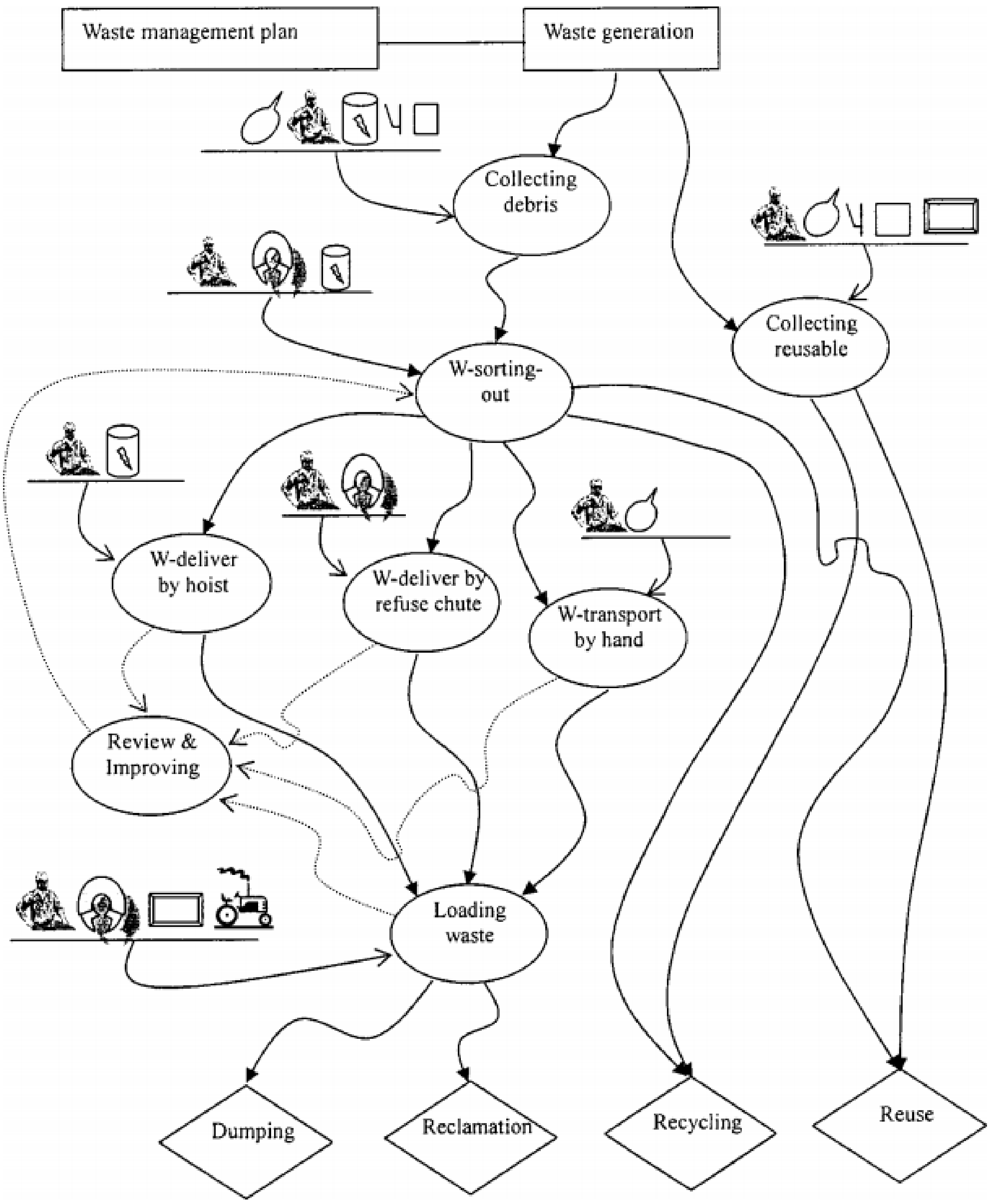

Figure 11 Waste management mapping model (Shen et al., 2004)

1.2.10. Integrated GPS and GIS technology

Li et al. (2005) applied an integrated Global Position System (GPS) and Geographacial Information System (GIS) technology for the reduction of construction waste. The purpose of integrating GPS and GIS technology is to transfer real-time location information of construction material and equipment (M&E) being carried to a construction site. The conceptual model of GPS-and-GIS-integrated M&E management system is shown in Figure 12. The GPS and GIS technology can help to improve efficiency and to increase profits by providing real-time vehicles locations and status reports, navigation assistance, drive speed and heading information, and route history collection. Experimental results indicated that the proposed system can minimise the amount of onsite material wastage.

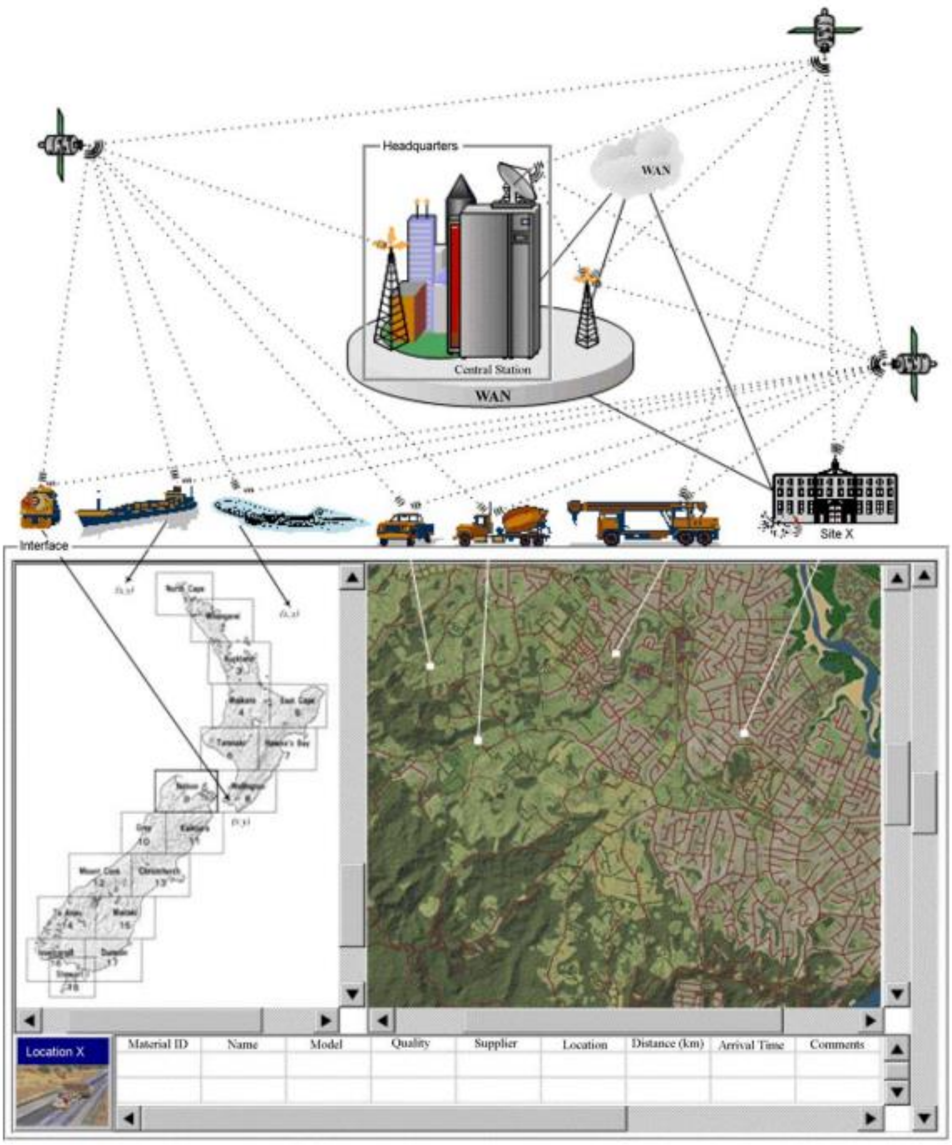

Figure 12 A conceptual model of GPS-and-GIS-integrated M&E management system (Li et al., 2005)

1.2.11. RFID technology

Lu and Yuan (2011) claimed that effective C&D waste management needs multidisciplinary efforts. In order to facilitate the cooperation among on-site contractors, pick-up truck companies, and recycling companies, Cheng et al. (2011) introduced the radio frequency identification (RFID) technology for construction waste management. The RFID technology was selected because it supports automatic identification and detection, thus providing much potential for contractors to cooperate with other stakeholders for construction waste management. In the RFID system, RFID readers can capture the data from RFID tags and transmit the data to a computer system without line of sight or physical connection. The proposed RFID system is efficient in enhancing automated waste pick-up scheduling.

1.2.12. Building information modeling (BIM)

Building information modeling (BIM) allows multi-disciplinary information to be superimposed within one digital building model. Cheng and Ma (2013) developed a BIM-based for estimating and planning demolition and renovation waste. The system operation flowchart of the developed model is shown in Figure 13. By utilising this BIM-based model, the following functions can be achieved: 1) getting detailed volume information of each element category; 2) getting detailed volume information of each material type; 3) estimating total inert and non-inert demolition and renovation waste volumes; 4) estimating demolition and renovation waste disposal charging fee; 5) estimating total number of pick-up trucks for demolition and renovation waste.

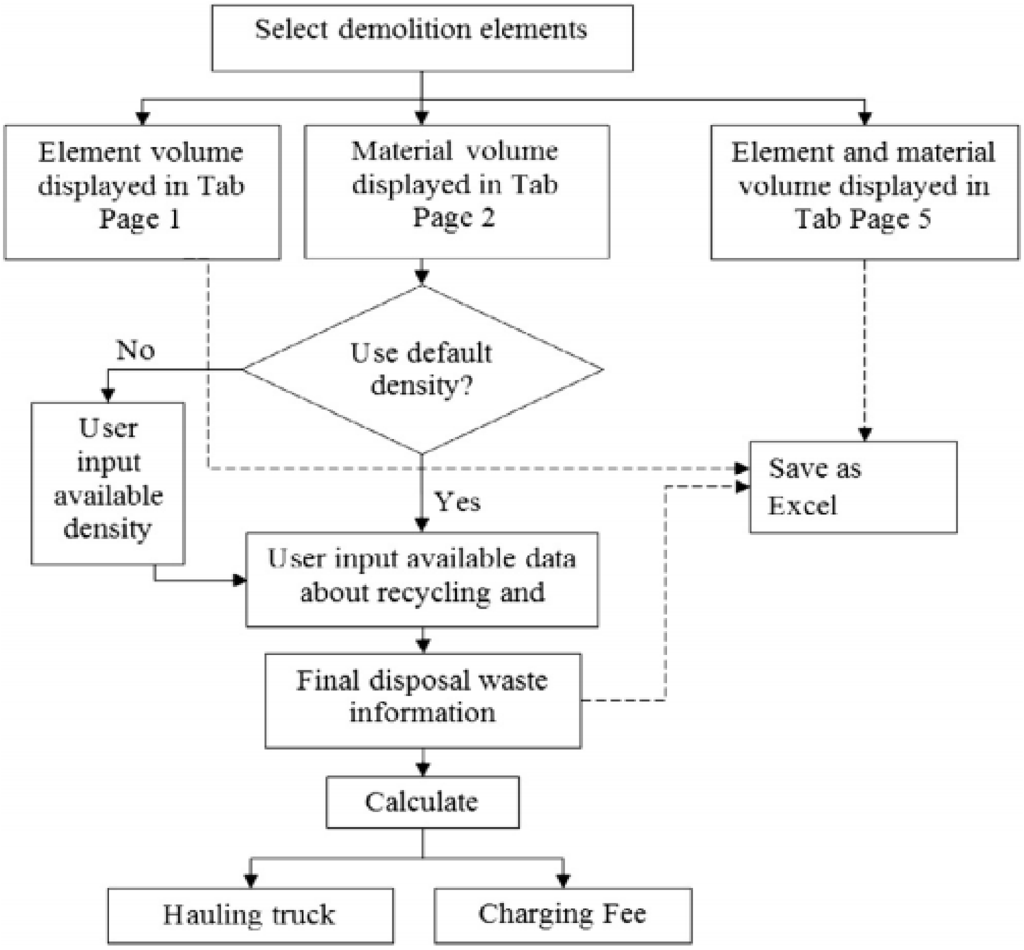

Figure 13 System operation flowchart (Cheng and Ma, 2013)

The BIM technology has become more and more popular in waste minimisation. In another paper published by Cheng et al. (2015), it was claimed that BIM technology can efficiently manage the C&D waste by avoiding design problems, changes, and rework through clash detection, quantity take-off, planning of construction activities, site utilisation planning, and prefabrication. In addition, BIM can also be used in the aspects of cost-benefit analysis of demolition waste management (Hamidi et al., 2014), development of construction waste minimisation framework (Liu et al., 2015), quantification of construction waste (Won et al., 2016).

1.2.13. System dynamics modeling

Hao et al. (2007) regarded that there is clearly a need for an integrated simulation model to be used in a highly complex and dynamic marketplace such as C&D waste management in

Hong Kong. By incorporating the relationship of major activities inherently involved in C&D waste management, Hao et al. (2007) developed a simulation model is developed based on system dynamics methodology for strategic planning of C&D waste in Hong Kong. Five components were used to formulate the integrated model: (1) on site sorting; (2) C&D waste generation; (3) municipal solid waste generation; (4) public filling; and (5) landfill. The structure of the model is shown in Figure 14.

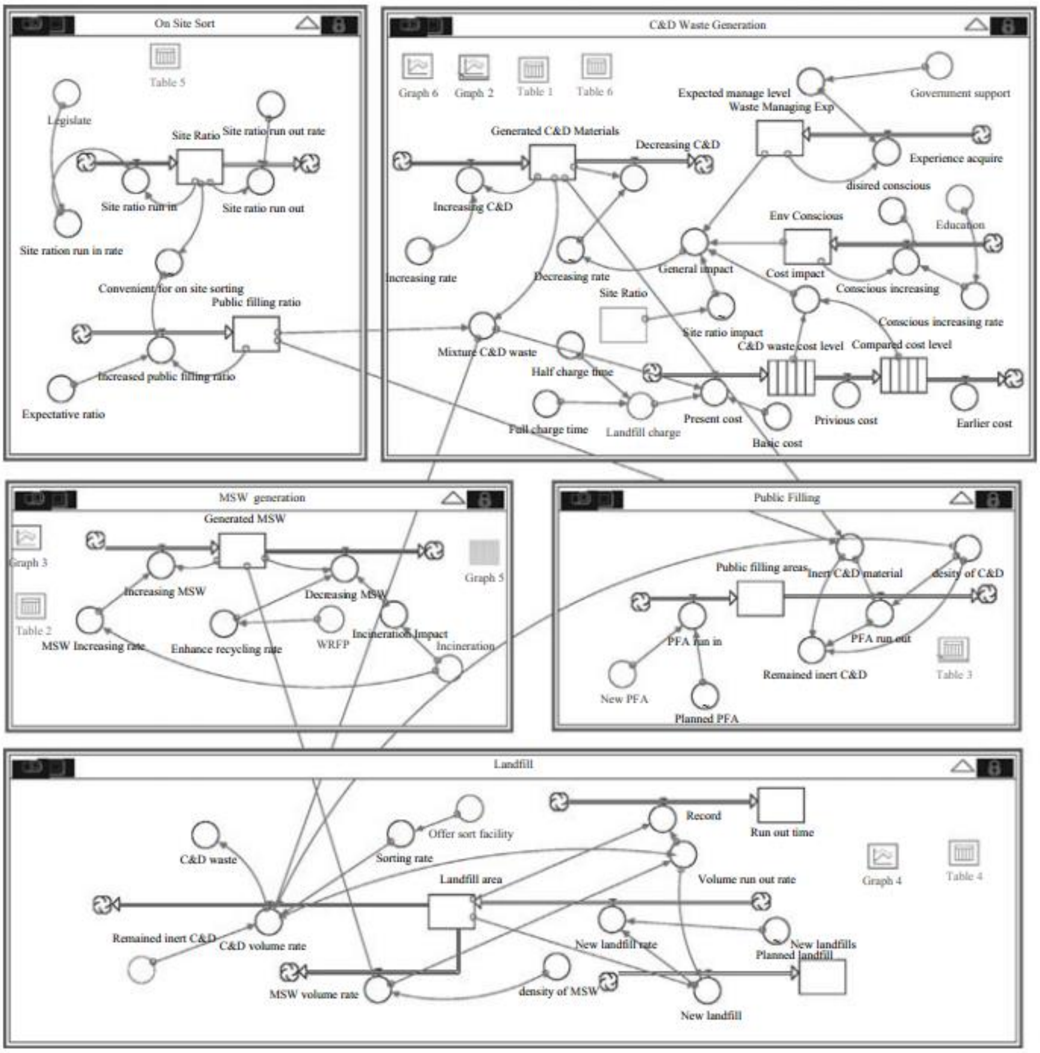

Figure 14 Structure of the simulation model (Hao et al., 2007)

The simulation results showed that the life of existing landfills can be extended to 2020 with appropriate C&D waste management measures. However, it is based on the assumption that enough public filling sites will be found. It was further argued that, in the long-term, the construction industry cannot depend only on public filling sites and importing raw materials from neighboring areas. Other outlets should be found for inert materials and other sources for raw materials. The ideal solution would be to reproduce raw materials from inert waste materials. To this end, the Hong Kong Government should commit itself to the use of recycled materials and to the development of a market for recycled materials.

As an extension of the research of Hao et al. (2007), Hao et al. (2008a) specialised on a sub-model under the general C&D waste management focusing on construction site. Hao et al. (2008a) claimed that the C&D waste generation is dynamic and interactive. Therefore, the model developed can be used as a flexible tool to help practitioners to understand the causes and effects. The proposed model is shown in Figure 15.

Since the model allows the users to fine-tune the input parameters, it is flexible to adjust the model to better reflect the reality according to different conditions. This is an advantage over other static models. This research showed that management of C&D waste can be facilitated by means of system dynamics to provide a better understanding of the dynamic interactions and interdependencies of the key areas of the C&D waste management process.

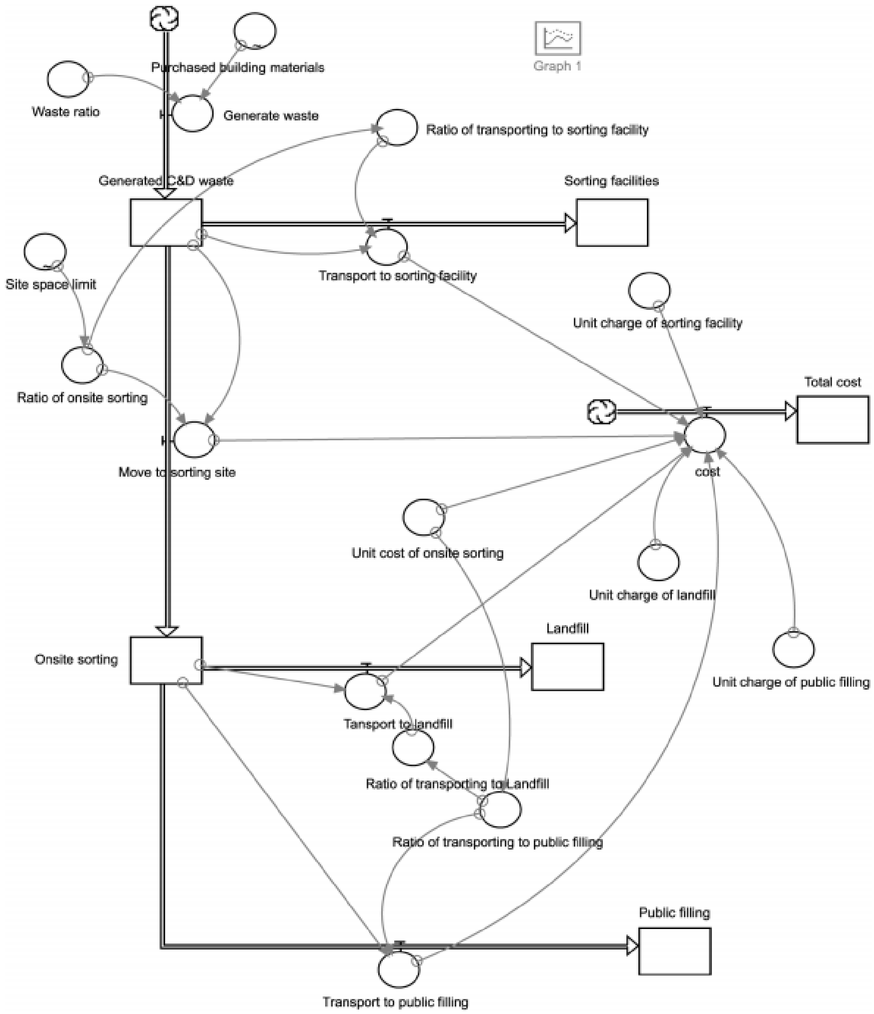

Figure 15 Simulation model for C&D waste management on-site (Hao et al., 2008a)

1.2.14. Education and training

The importance of education to general waste management has been acknowledged by Williams (2014). In terms of C&D waste management, the importance of human factors has also gained attention from researchers (Yuan and Shen, 2011). Wong and Yip (2004) claimed that a change in the attitude of contractors may be more important than changes in building technology with regards to C&D waste management. Attending trainings is an effective method for changing the culture of C&D waste management. Trainings were suggested to be initiated by some leading and influential organisations. Poon et al. (2004c) further indicated that it is important that all levels of the contractor, subcontractor and site workers are provided with the necessary training to cope with the waste management procedures throughout the construction processes. It was also suggested that the relevant government departments (e.g. Housing Authority) should consider developing guidelines in both Chinese and English about waste handling and minimisation to provide a more reliable and consistent means to educate site workers.

1.2.15. Others

There are also some other papers recommending strategies for improving C&D waste management; however, the suggested strategies were not particularly explained, so they are collectively summarised in this subsection.

Tam and Tam (2006) reviewed the technologies on C&D waste recycling and their viability. Ten material recycling practices were studied, including: (i) asphalt, (ii) brick, (iii) concrete, (iv) ferrous metal, (v) glass, (vi) masonry, (vii) non-ferrous metal, (viii) paper and cardboard, (ix) plastic and (x) timber. The viable technologies of the construction material recycling were provided as references for future applications.

Tam and Tam (2007) puts forth a scheme of economic considerations in recycling over-ordered concrete by concrete reclaimer. It was indicated that the reluctance of most concrete producers in reclaiming aggregate from the concrete waste is due to its high cost of treatment and lack of space around the plant. A concrete reclaimer for reclaiming the over-ordered fresh concrete was suggested in this paper. A comparative study on costs and benefits between the normal practices and the proposed recycling plan was examined, the results showed that recycling the over-ordered fresh concrete waste by concrete reclaimer can provide a cost-effective method for concrete batching plants.

Tam et al. (2007a) investigated the generation of construction waste on site and their relationships with subcontracting arrangements and projects types in Hong Kong. Nineteen construction projects were studied by in-depth interviews for collecting the relevant data. Four methods were proposed to mitigate the generation of waste:

(1) Development of cost effective waste control approach. 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.

(2) Integrated waste minimisation at the tender stage. Waste minimisation should be integrated into the construction processes and planned at the tender stage.

(3) Provision and motivation of waste reduction training. This can raise environmental awareness and help site staff to generate a better working procedure to reduce generation of materials wastage.

(4) A waste control system as a part of site management functions. This system can collect waste generation data, identifies the major areas of waste generation, analyses 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.

Ng and Chau (2015) performed a life cycle energy assessment for the end-of-life phase of a high rise concrete commercial building. The energy associated with different waste management strategies was calculated to identify the options that can produce the highest energy saving in embodied energy. It was found that recycling strategy has the highest energy saving potential of 53% while the energy saving potential of reusing was 6.2% and that of incineration was only 0.4%. In addition, recycling strategy should be implemented for the building elements containing large amount of concrete (e.g. upper floor construction) while reusing should be adopted for the building parts with high aluminium content (e.g. windows).

2. Current statutory and administrative measures from websites of governments and industrial associations

Among the governmental departments of Hong Kong, the Environmental Protection Department (EPD) and the Civil Engineering and Development Department (CEDD) are the two main departments undertaking C&D waste management. In addition, there are some other governmental departments and industrial associations having regulations/recommendations relating to C&D waste management, such as Housing Department (HD), Development Bureau (DB), Transport and Housing Bureau (THB), and Hong Kong Construction Association (HKCA). The current C&D waste management statutory and administrative measures from the above-mentioned organisations are summarised as follows.

2.1. Environmental Protection Department (EPD)

The Environmental Protection Department (EPD) has a dedicated website for C&D waste management. In the website, the 'C&D waste' is named as 'construction waste'. The definition of construction waste is given as 'any substance, matter or thing which is generated as a result of construction work and abandoned whether or not it has been processed or stockpiled before being abandoned. It is a mixture of surplus materials arising from site clearance, excavation, construction, refurbishment, renovation, demolition and road works' (EPD, 2015). It is estimated that over 90% of construction waste are inert (e.g. rubbles, earth and concrete). The inert materials are suitable for land reclamation and site formation. The non-inert substances include bamboo, timber, vegetation, packaging waste and other organic materials (EPD, 2015). It is claimed that, with the current trend, the landfills will be full in mid to late-2010s, and the public fill capacity will be fully depleted in the near future (EPD, 2015).

In order to achieve C&D waste minimisation, five construction waste management strategies are summarised by EPD, such as avoid, minimise, recycle, treat, and dispose, as shown in Figure 16. The desirability of the five strategies are decreasing in order.

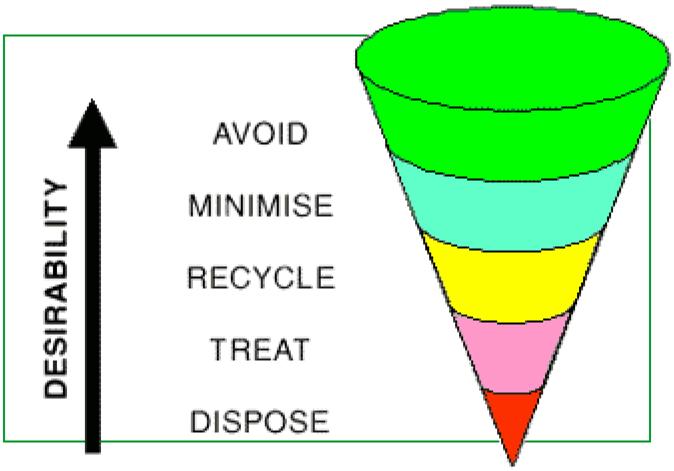

Figure 16 Management strategy for construction waste (EPD, 2009b)

Five actions are proposed to achieve better C&D waste management (EPD, 2009b):

(1) 'Maintain a well-managed public filling programme with sufficient public fill reception facilities and barging points at convenient locations;

(2) Encourage sorting of mixed construction waste;

(3) Encourage reuse and recycling of construction waste;

(4) Avoid and minimise construction waste through better design and construction management;

(5) Introduce construction waste disposal charging scheme'.

The EPD website also introduced the existing facilities for disposal of C&D waste (EPD, 2009b):

(1) 'Public fill reception facilities. These facilities are managed by the CEDD, including public filling areas, public filling barging points, public fill stockpiling areas, fill banks and C&D material recycling facility.

(2) Sorting facilities. The sorting facilities deal with mixed construction waste containing more than 50% by weight of inert construction waste. This arrangement helps waste producers, particularly small construction sites that do not have enough space to carry out on-site sorting.

(3) Landfills. The landfills dispose mixed construction waste containing not more than 50% by weight of inert construction waste. Three strategic landfills are managed by the EPD;

they are the West New Territories (WENT) Landfill, the South East New Territories (SENT) Landfill and the North East New Territories (NENT) Landfill.

(4) Outlying Islands Transfer Facilities'.

The distribution of the existing C&D waste management facilities is shown in Figure 17.

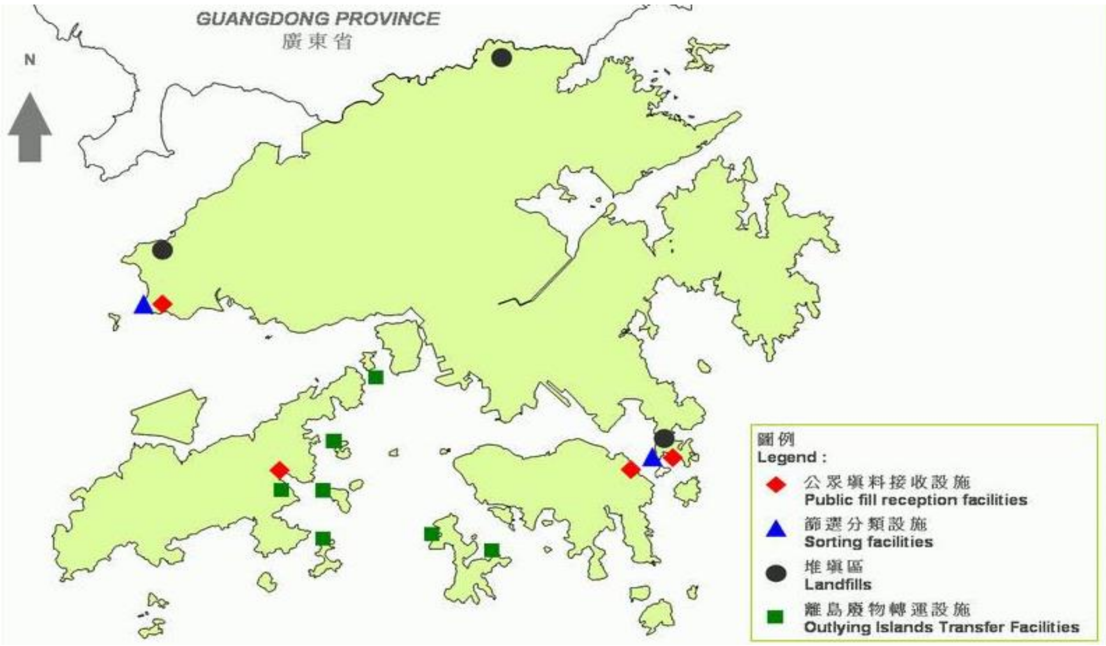

Figure 17 Distribution of C&D waste disposal facilities (EPD, 2009b)

In order to encourage the reduction and recycling of C&D waste, a legislation of 'Construction Waste Disposal Charging Scheme' (CWDCS) was enacted in January 2005. The legislation requires that 'construction waste producers, such as construction contractors, renovation contractors or premises owners, prior to using government waste disposal facilities, need to open a billing account with the EPD and pay for the construction waste disposal charge' (EPD, 2016a). Any person needs to open an account before using waste disposal facilities for construction waste disposal (EPD, 2016a). The current charges for different types of disposal facilities are presented in Table 2. In order to achieve full cost recovery, the landfill and public fill charges will increase from $125 per ton and $27 per ton to $200 per ton and $71 per ton respectively since April 2017. Similarly, the sorting charge is proposed to be increased from $100 per ton to $175 per ton (Legislative Council, 2016).

Table 2 Charging fee for different types of disposal facilities (EPD, 2016a)

Disposal facilities	**Type of construction waste accepted**	**Charge per ton**	**Proposed charge in April 2017**
Public fill reception facilities	Consisting entirely of inert construction waste	HK$27	HK$71
Sorting facilities	Containing more than 50% by weight of inert construction waste	HK$100	HK$175
Landfills	Containing not more than 50% by weight of inert construction waste	HK$125	HK$200

Hong Kong has kept good continuous statistics on the C&D waste generation amount, the statistics are presented on EPD website (EPD, 2011). The annual C&D waste amount is included in the annual report of 'Monitoring of Solid Waste in Hong Kong'. The disposal records of construction waste arising from government contracts are also provided on the website. The aim of providing such data is helping the construction stakeholders to check their proper disposal of construction waste.

Waste reduction guidelines are provided by EPD from five aspects (EPD, 2009c):

(1) 'Planning for Waste Reduction. Proper planning for waste reduction should be carried out before site operation. It can be achieved by preparing a Waste Management Plan to identify key waste types, set out waste reduction programmes and targets, and also arrange on-site sorting and proper waste disposal.

(2) Low Waste Construction Designs and Technologies. The recommendations include lean construction; balance cut and fill; modular building designs and precasting of building components; designs for long-life; reuse and recycle; and selective demolition.

(3) Raw Material Management. a) To better control and maintain materials, the right amount of raw materials should be ordered at the right time with proper control and documentation on material flow. Besides, surplus materials should be returned to stock in centralised area with suitable protective measures. b) To increase material utilisation, raw materials should be fully utilised to avoid wastage. Besides, broken items or offcuts

should be considered for sections when small lengths are required.

(4) Waste Management. a) Reuse and recycling. This can be achieved through balancing cut and fill, reusing items such as hoardings, formworks and scaffoldings and recycling materials such as metals, concrete and asphalt. Demolition waste can also be reused and recycled on-site in new construction as bricks and tiles in new fixtures. Besides, on-site crushing of concrete could also enhance use of recycled aggregates in new buildings. b) On-site soring. To facilitate on-site sorting, a specific area should be allocated for on-site sorting of waste while suitable containers should be provided to temporary store the sorted materials such as metals, concrete, timber, plastics, glass, excavated spoils, bricks and tiles. If small area of the site limits detailed sorting, waste material should at least be separated into inert and non-inert portions. c) Orderly disposal. Prior to disposal, all materials should be sorted and reused on-site or off-site while recyclable materials should be collected for recyclers' reuse. Public fill should then be transported to public fill reception facilities while remaining construction waste should be disposed of at landfill. To avoid fly tipping, contractors should follow Government's practice under the Trip-Ticket System to ensure that truck drivers dispose of construction waste at proper places.

(5) Education and Training. Site workers are encouraged to attend waste reduction seminars and workshops such as those organised by the Construction Industry Council. Site managers should discuss waste handling requirements with subcontractors and workers prior to beginning a project. They should also post easy to read signs and provide written information about the waste reduction programme. Information and training on ‘Green Construction’ jointly developed by EPD and Construction Industry would also be a good reference’.

In order to give practitioners more useful information, the EPD also provides List of Recyclers (EPD, 2016b), List of Recycled Construction Products (EPD, 2010a), Recycled Materials for Construction Industry (EPD, 2013), Case Studies (EPD, 2009a), and Reference Material (EPD, 2010b).

2.2. Civil Engineering and Development Department (CEDD)

The Civil Engineering and Development Department (CEDD) mainly focuses on the disposal of inert C&D waste which is also known as public fill in Hong Kong. On the CEDD website, the Construction Waste Disposal Charging Scheme (CWDCS) is also introduced (CEDD, 2015a). It is specified that the CEDD is responsible for Public Fill Reception Facilities (PFRF) and Construction Waste Sorting Facilities (CWSF). In addition, 'Briefing on Overloading Control Measures under Charging System' and 'Tips for Using Public Fill Reception Facility Safely' are provided. The website also publishes daily inert C&D waste disposal records at PFRF and CWSF (CEDD, 2016a).

In order to minimise dust nuisance during the transportation of construction waste, the Government requires Dump Truck owners must have their dump trucks installed with mechanical covers and registered in the Scheme at CEDD. After the implementation of the Scheme, it is reported that 'about 80% of dump trucks which dispose construction waste at the CEDD's Designated Waste Disposal Facilities have already been equipped with mechanical covers' (CEDD, 2015b).

The management strategies of public fill are given by CEDD as follows (CEDD, 2016b):

(1) 'Reducing public fill at source through better planning, design and construction management to reduce the overall volume of public fill produced. Government departments are required to prepare management plans for public works projects to critically examine alternatives to reduce public fill produced during design stage and to monitor its implementation during construction.

(2) Separating out waste such as timber, paper, plastic, etc. to prevent public fill that could be reused or recycled from going to landfills. Contractors of Government works contracts are required to prepare and implement waste management plan to carry out on-site sorting and implement a trip-ticket system to ensure that public fill and waste are delivered to the appropriate reception sites/facilities.

(3) Reusing public fill in reclamation and site formation works where possible. However, this is becoming increasingly difficult because of the drastic reduction of reclamation

and site formation works. To tackle the problem, two fill banks were commissioned to temporary stockpile the public fill until new reclamation projects are available. The Government has also entered into the agreement of the State Oceanic Administration to deliver the public fill to the Mainland for beneficial reuse in reclamation projects.

(4) Recycling suitable public fill as recycled aggregates. For example, the crushing plant at Tuen Mun Fill Bank has been relocated to Tseung Kwan O Fill Bank to produce G200 recycled rockfill (CEDD, 2015c). Selective demolition and on-site sorting are recommended to increase recycling efficiency. Guidelines of the two strategies are provided by CEDD (CEDD, 2004)'.

The Public Fill Committee (PFC) is responsible for overseeing and implementing measures for inert C&D waste minimisation (CEDD, 2016b). It also manages public filling operations and facilities. Truck owners shall apply licences (Dumping Licences) within the CEDD public fill reception facilities from Fill Management Division. The Licences are free of charge, valid for one year and could be renewed (CEDD, 2016b).

In order to minimise illegal dumping, a trip-ticket system has been promulgated in public works contracts (CEDD, 2016b). It is required that the project officer shall seek confirmation from the Public Fill Committee (PFC) in the planning stage of a contract. The availability of the disposal of public fill will be checked through the Secretary of PFC.

2.3. Development Bureau (DB)

The Development Bureau (DB) has issued many Technical Circulars concerning C&D waste management. The identified regulations and sources are presented in Table 3. It should be noted that only the current effective Technical Circulars are included in the table; the out of date Technical Circulars are excluded. For example, the 'WBTC No. 6/92 - Fill Management' was superseded by 'WBTC No. 12/2000 - Fill Management', thus only 'WBTC No. 12/2000 - Fill Management' is included in Table 3.

Table 3 Technical Circulars concerning C&D waste management

Technical Circulars	Year	Source
Public Dumps	1993	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/245/1/WB0293.pdf
Public Filling Facilities	1993	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/190/1/Wb0293b.pdf
Use of Public Fill in Reclamation & Earth Filling Projects	1998	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/207/1/wb0498.pdf
Fill Management	2000	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/177/1/wb1200.pdf
Incorporation of Information on Construction and Demolition Material Management in Public Works Subcommittee Papers	2001	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/c/1/wb2599c.pdf
Metallic Site Hoardings and Signboards	2001	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/153/1/wb1901.pdf
Enhanced Specification for Site Cleanliness and Tidiness	2002	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/141/1/wb0602.pdf
Control of Site Crushers	2002	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/139/1/wb1102.pdf
Implementation of Site Safety Cycle and Provision of Welfare Facilities for Workers at Construction Sites	2002	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/129/1/C-2002-30-0-1.pdf
Role of Departmental Safety and Environmental Advisor on Health, Safety and Environmental Protection on Construction Sites	2003	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/102/1/c-2003-14-0-1.pdf
Specification Facilitating the Use of Concrete Paving Units Made of Recycled Aggregates	2004	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/48/1/C-2004-24-0-1.pdf
Environmental Management on Construction Sites	2005	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/19/1/C-2005-19-0-1.pdf
Trip ticket system for disposal of Construction & Demolition Materials	2010	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/308/1/C-2010-06-01.pdf

Technical Circulars	Year	Source
Green Government Buildings	2015	http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/336/1/C-2015-02-01.pdf

2.4. Architecture Service Department (ASD)

The Architecture Service Department (ASD) provides C&D waste management strategies from the sustainable building design aspect. In the Sustainability Report 2015, common sustainable construction methods (such as prefabrication, pollution control during construction and the adoption of 3R principles) and sustainable materials (such as recycled materials and timber from well-managed sources) are used (ASD, 2015).

In the General Specification for Building (ASD, 2012), many C&D waste requirements are proposed. In terms of the removal of demolition waste, it is specified that 'the storage, segregation and disposal of demolition waste shall be in accordance with the guidelines stipulated in the Guidelines for Selective Demolition and On-Site Sorting and the contract requirements. The handling of demolition waste shall follow in the Environmental Management Plan prepared by the Contractor'. A complete record is required to be kept on site and regularly updated on the disposal, reuse and recycling of all demolition waste with respect to their dates of disposal and the quantities involved. The management of asbestos waste is specified in this Specification.

A study of Sustainable Design for Buildings is presented in details (ASD, 2016). In terms of sustainable planning, reuse existing structure and materials is suggested. In terms of green procurement, three kinds of materials, such as sustainable resources, recycle materials, and rapidly renewable materials, are recommended. In terms of waste management, three strategies are suggested: '1) use of prefabricated materials to minimise construction waste generated on site during fabrication; 2) substitution of traditional timber formwork by metal formwork to save timber consumption up to 30 percent; and 3) on-site sorting to separate inert materials (e.g. excavated rock and soil) from non-inert materials (e.g. bamboo, timber, organic materials) before disposal'. After sorting, inert materials suitable for land reclamation and site formation are disposed of at public fills for subsequent reuse.

2.5. Building Department (BD)

In the Buildings Department Environmental Report 2014 (BD, 2016), it is clarified that ‘the Building Department (BD) would continue to collaborate with the stakeholders on the review of the use of environmentally friendly construction methods with a view to minimising construction and demolition waste and the performance in 2014 includes the use of precast concrete, operation of the validation scheme for unauthorised household minor works to reduce the need for removal of such unauthorised structures’.

A ‘Code of Practice for Demolition of Buildings 2004’ has been promulgated. In the Code, on-site sorting of surplus C&D material is strongly recommended. All inert C&D waste to be disposed of at public filling areas shall be sorted and broken down according to the Dumping Licence conditions. The Registered Specialist Contractor (Demolition) is advised to submit a waste management plan for the sorting, processing and disposal of C&D materials arising from or in connection with the demolition work to the Authorised Person/Registered Structural Engineer for his approval before the commencement of the works.

A Practice Note, AP114 has been re-issued under categorisation in August 2009. ‘It has been suggested, arising from reports of sanitary fitments and other fixtures/fittings in new buildings being discarded upon occupation, that requirements for the provision of such fitments and fittings prior to completion of new buildings should not be insisted upon to reduce waste’. It is also recommended that modification of the relevant building regulation could be undertaken by Authorised Person ‘to permit certain sanitary fitments be not installed at the time of issuing an occupation permit on merits of individual case’.

2.6. Housing Authority (HA)

The Housing Authority (HA) provides several strategies and technologies for C&D waste management.

The application of Building Information Modeling (BIM) is introduced. It is mentioned that ‘the implementation of BIM in construction projects can improve building quality by optimising designs, improving coordination and reducing construction waste’ (HA, 2016a).

In order to raise the recovery rate of C&D waste effectively, the HA establishes ‘an open and transparent Information Platform on Recyclable Non-inert C&D Waste to consolidate the comprehensive data of non-inert recyclables generated by the superstructure works of all public housing construction sites in the coming month’ (HA, 2016b). This information platform which includes information such as site locations, contact details and forecast on types and quantities of non-inert recyclables is updated monthly. It is hoped that through wider dissemination of information in the recycling industry, the platform can facilitate a larger scale of C&D waste recovery in Hong Kong (HA, 2016b).

The HA also promotes the use of prefabricated components, such as precast facades, semi-precast slabs, and precast staircases (HA, 2016c). In addition, the HA attempts to increase the usage of recycled aggregates in construction projects (HA, 2015).

2.7. Hong Kong Construction Association (HKCA)

The Hong Kong Construction Association (HKCA) does not have specific suggestions on C&D waste management. However, in the ‘Brief Summaries of all approved HKCA Business Plans (2015-2017)’, one of the SME Committee objectives is to establish a construction resources platform to increase co-operating opportunities, and also to support environmental work and recycling waste materials (HKCA, 2015).

3. C&D waste management measures in BEAM Plus

Nowadays, green building assessment is getting more and more popular; it plays an important role in promoting sustainable construction. In Hong Kong, the most important green building rating system is BEAM Plus. In order to derive comprehensive insights of C&D waste management from BEAM Plus, the requirements related to C&D waste management are explored as follows.

3.1. Overview of BEAM Plus

The early version of BEAM Plus was named as 'Hong Kong Building Environment Assessment Method (i.e. HK BEAM)'. In 1996, the first two rating systems, 'BEAM for New Office Designs (Version 1/96)' and 'Existing Office Premises (Version 2/96)', were launched. After several years' development, the Hong Kong Green Building Council (HKGBC) was established 2009. Two new assessment tools were further launched in 2010, namely 'BEAM Plus for New Buildings Version 1.1' and 'BEAM Plus for Existing Buildings Version 1.1'. After two years, the two assessment tools were enhanced and the BEAM Plus Version 1.2 for New Buildings and Existing Building were launched. From 1 January 2013, both new buildings and existing buildings registered would be assessed using these two tool mandatorily. Later, a new BEAM Plus assessment tool, 'BEAM Plus Interiors', was launched in 2013. The most recent update of BEAM Plus is the launch of the new 'BEAM Plus Existing Buildings Version 2.0'.

In order to keep the literature review most recent, the latest versions of the three assessment tools are selected. The main information of the three tools is summarised in Table 4.

Table 4 Information of the reviewed BEAM Plus tools

Category	Version Name	Launch Year
New building	BEAM Plus New Buildings Version 1.2	2012
Existing building	BEAM Plus Existing Building Version 2.0 (Comprehensive Scheme)	2015
	BEAM Plus Existing Building Version 2.0 (Selective Scheme)	2015
Interiors	BEAM Plus Interiors	2013

3.2. Waste management requirements in BEAM Plus New Buildings

In BEAM Plus New Buildings Version 1.2 (BEAM Plus NB), the performance aspects are grouped into the following categories: 1) Site Aspects; 2) Materials Aspects; 3) Energy Use; 4) Water Use; and 5) Indoor Environmental Quality. The requirements regarding to C&D waste management are allocated in the category of *Materials Aspects* (MA). Three main contents are included in the Materials Aspects: 1) selection of materials; 2) efficient use of materials; and 3) waste disposal and recycling. The weighting of the five performance categories in BEAM Plus NB are presented in Table 5. From Table 5, it can be seen the Materials Aspects get the least weighting. However, it does not mean this aspect is not important.

Table 5 Weighting of the five performance categories in BEAM Plus NB

Performance category	Weighting (%)
Site aspects	25
Materials aspects	8
Energy use	35
Water use	12
Indoor environmental quality	20

Table 6 shows the specific requirements in the Materials Aspects category. The attainable credits, description of the requirement, and corresponding objective are also presented. From Table 6, it can be seen there are four prerequisites in the Materials Aspects, two of the prerequisites are C&D waste management related, namely ‘Construction/Demolition Waste Management Plan’ and ‘Waste Recycle Facilities’. In order to increase the efficiency of materials use, four strategies are introduced: 1) Building Reuse; 2) Modular and

Standardised Design; 3) Prefabrication; and 4) Adaptability and Deconstruction. In terms of materials selection, it is encouraged to use 1) Rapidly Renewable Materials, and 2) Recycled Materials. Furthermore, best practices of C&D waste are encouraged in relation to sorting, recycling, and disposal.

Table 6 C&D waste management requirements in BEAM Plus NB

Code	Requirement	Attainable credit	Description	Objective
P	**Prerequisite**			
MAP1	Timber Used for Temporary Works	-	Virgin forest products are not used for temporary works during construction.	Encourage the well-managed use of timber.
MAP2	Use of Non-CFC Based Refrigerants	-	Using non-chlorofluorocarbon (CFC)-based refrigerants in HVAC&R systems.	Reduce the release of chlorofluorocarbon into the atmosphere.
MAP3	Construction/Demolition Waste Management Plan	-	Implementation of a waste management system that provides for the sorting, recycling and proper disposal of construction/ demolition materials.	Encourage best practices in the management of construction and demolition wastes, including sorting, recycling and disposal of construction waste.
MAP4	Waste Recycle Facilities	-	Provision of facilities for the collection, sorting, storage and disposal of waste and recovered materials.	Reduce pressure on landfill sites and help to preserve non-renewable resources by promoting recycling of waste materials.
1	**Efficient Use of Materials**			
MA1	Building Reuse	2 + 1 bonus	1 credit for the reuse of 30% or more of existing sub-structure or shell. 2 credits for the reuse of 60% or more of existing sub-structure or shell. 1 additional BONUS credit for use of 90% or more of existing sub-structure or shell.	Encourage the reuse of major elements of existing buildings, to reduce demolition waste, conserve resources and reduce environmental impacts during construction.
MA2	Modular and Standardised Design	1	1 credit for demonstrating the application of modular and standardised design.	Encourage increased use of modular and standardised components in

Code	Requirement	Attainable credit	Description	Objective
				building design in order to enhance buildability and to reduce waste.
MA3	Prefabrication	2	1 credit when the manufacture of 20% of listed prefabricated building elements has been off-site. 2 credits where the manufacture of 40% of listed prefabricated building elements has been off-site.	Encourage prefabrication building elements in order to reduce wastage of materials and quantities of on-site waste.
MA4	Adaptability and Deconstruction	3	1 credit for designs providing spatial flexibility that can adapt spaces for different uses, and allows for expansion to permit additional spatial requirements to be accommodated. 1 credit for flexible design of services that can adapt to changes of layout and use. 1 credit for designs providing flexibility through the choice of building structural system that allows for change in future use, and which is coordinated with interior planning modules.	Encourage the design of building interior elements and building services components that allow modifications to space layout, and to reduce waste during churning, refurbishment and deconstruction.
2	**Selection of Materials**			
MA5	Rapidly Renewable Materials	2	1 credit for demonstrating 2.5% of all building materials/products used in the project are rapidly renewable materials. 2 credits where 5% of all building materials/products used in the project are rapidly renewable materials.	Encourage the wider use of rapidly renewable materials in appropriate applications.
MA6	Sustainable Forest Products	1	1 credit for demonstrating at least 50% of all timber and composite timber products used in the project are from sustainable sources/recycled timber.	Encourage the use of timber from well-managed forests.
MA7	Recycled Materials	3	1 credit for use of recycled materials contributing to at	Promote the use of recycled

Code	Requirement	Attainable credit	Description	Objective
			least 10% of all materials used in site exterior surfacing work, structures and features. 1 credit where at least 10% of all building materials used for facade and structural components are recycled materials. 1 credit where at least 10% of all building materials used for interior nonstructural components are recycled materials	materials in order to reduce the consumption of virgin resources.
MA8	Ozone Depleting Substances	2	1 credit for the use of refrigerants with a value less than or equal to the threshold of the combined contribution to ozone depletion and global warming potentials using the specified equation. 1 credit for the use of products in the building fabric and services that avoids the use of ozone depleting substances in their manufacture, composition or use.	Reduce the release of chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) into the atmosphere.
MA9	Regionally Manufactured Materials	2	1 credit for the use of materials manufactured locally within 800km from the site, which contribute to at least 10% of all building materials used in the project. 2 credits for the use of materials manufactured locally within 800km from the site, which contribute to at least 20% of all building materials used in the project.	Encourage the use of materials manufactured locally so as to reduce the environmental impacts arising from transportation.
3	**Waste Management**			
MA10	Demolition Waste Reduction	2	1 credit for demonstrating that at least 30% of demolition waste is recycled. 2 credits for demonstrating that at least 60% of demolition waste is recycled.	Encourage best practices in the management of waste, including sorting, recycling and disposal of demolition waste.

Code	Requirement	Attainable credit	Description	Objective
MA11	Construction Waste Reduction	2	1 credit for demonstrating that at least 30% of construction waste is recycled. 2 credits for demonstration that at least 60% of construction waste is recycled.	Encourage best practices in the management of waste, including sorting, recycling and disposal of construction waste.

3.3. Waste management requirements in BEAM Plus Existing Buildings

In order to encourage building owners of existing buildings to adopt green building management and upgrading the building services systems, the new version of BEAM Plus Existing Buildings was launched in 2015. There are two major schemes under BEAM Plus Existing Buildings Version 2.0 (BEAM Plus EB), namely Comprehensive Scheme and Selective Scheme. In the Comprehensive Scheme, the 'Plan-Do-Check-Act' approach is adopted for the continual improvement of the buildings; in the Selective Scheme, the 'Better than yesterday' principal is embraced to recognise the efforts made by the building management of the aged existing buildings to achieve better building performance. As the requirements on C&D waste management in the two schemes are different, the two schemes will be discussed separately.

3.3.1. BEAM Plus Existing Buildings Comprehensive Scheme

In BEAM Plus Existing Buildings Comprehensive Scheme (BEAM Plus EBCS), the performance aspects are grouped into the following categories: 1) Management; 2) Site Aspects; 3) Materials and Waste Aspects; 4) Energy Use; 5) Water Use; and 6) Indoor Environmental Quality. The requirements regarding to C&D waste management are allocated in the category of Materials and Waste Aspects (MWA). Two main contents are included in the Materials and Waste Aspects: 1) Selection of Materials; and 2) Waste Management and Reduction. The weighting of the six performance categories in BEAM Plus NB are presented in Table 7. From Table 7, it can be seen the weighting of Materials and waste aspects is not the least.

Table 7 Weighting of the five performance categories in BEAM Plus NB

Performance category	Weighting (%)
Management	24
Site aspects	10
Materials and waste aspects	14
Energy use	24
Water use	14
Indoor environmental quality	14

Table 8 shows the specific waste management requirements in the Materials and Waste Aspects category. The attainable credits, description of the requirement, and corresponding objective are also presented. From Table 8, it can be seen there are two prerequisites in the Materials and Waste Aspects, one of the two prerequisites is ‘Waste Recycling Facilities’, aiming to preserve nonrenewable resources by promoting recycling of waste materials. In the Selection of Materials, there is no specific requirement on C&D waste management. In the Waste Management and Reduction, a waste management plan is suggested to be developed for sorting, recycling and disposal of waste. In addition, waste stream audit and waste/recycling records are considered in the assessment. From the analysis, it can be seen that C&D waste is not particularly focused in the BEAM Plus EBCS. Instead, the emphases are given to household waste, food waste and WEEE.

Table 8 C&D waste management requirements in BEAM Plus EBCS

Code	Requirement	Attainable credit	Description	Objective
P	**Prerequisite**			
WMAP1	Waste Recycling Facilities	-	Providing spaces for collection, sorting, storage and disposal of waste and recovered materials.	To reduce pressure on landfill sites and help to preserve nonrenewable resources by promoting recycling of waste materials.
WMAP2	Materials Purchasing Plan	-	Demonstrating that the plan of material procurement and its procedures for both on-going consumables and durable goods either following the internal company guideline or other international standards are in place.	To encourage purchasing practices which aim at reducing the environmental impacts of products used through formulating the purchasing procedure or plan into a more environmentally friendly way.
1	**Selection of Materials**			
WMA1	Materials Purchasing Practices	5 + 1 Bonus	1 to 2 credit(s) for demonstrating at least 50% or 70% of purchased on-going consumables are environmentally friendly products for the past 12 months as minimum. 1 to 2 credit(s) for demonstrating at least 50% or 70% of purchased durable goods are environmentally friendly products for the past 12 months as minimum. 1 credit for demonstrating at least 70% of purchased both ongoing consumables and durable goods are environmentally friendly products for the past 24 months.	To encourage purchasing practices which reduce the environmental impacts of products used by implementing Materials Purchasing Plan.

Code	Requirement	Attainable credit	Description	Objective
			1 Bonus credit for demonstrating at least 70% of purchased both on-going consumables and durable goods are environmentally friendly products for the past 36 months.	
WMA2	Use of Certified Green Products	2 Bonus	Maximum 2 Bonus credits for purchasing green products certified by Construction Industry Council Carbon Labelling Scheme/ Hong Kong Green Building Council Green Product Accreditation and Standards or other internationally recognised schemes.	To encourage the purchase of certified green products that have low environmental impacts.
WMA3	Ozone Depleting Substances	3	a) Newly and Existing Installed Equipment using Refrigerants 1 credit for all the equipment (both newly purchased and existing) using the refrigerants with Global Warming Potential (GWP) less than 1,900. Alternatively, for equipment with refrigerant GWP value > 1,900, credit can be achieved when the Applicant can demonstrate a phased programme of refrigerant replacement. 1 credit for using refrigerants with a combined value less than or equal to the threshold for the combined contributions to ozone depletion and global warming potentials for all new and existing HVAC&R equipment that under the control of Applicant. b) Fire Suppression and Other Materials	To reduce the release of ozone depletion substances into the atmosphere.

Code	Requirement	Attainable credit	Description	Objective
			1 credit for using the fire suppression and other materials that avoids the use of ozone depleting substances in their manufacture, composition or use.	
2	**Waste Management and Reduction**			
WMA4	Waste Management Plan	1	1 credit for developing a waste management plan.	To encourage best practice for the management of waste, including sorting, recycling and disposal of waste.
WMA5	Recycling Facilities for Different Waste Streams	4	Maximum 4 credits for providing the following listed on-site recycling facilities and implementing the materials collection arrangement: i. Fluorescent lamp (CFLs and fluorescent tubes); ii. Glass bottle; iii. Rechargeable battery; and iv. Waste Electrical and Electronic Equipment (WEEE).	To reduce pressure on landfill sites and help to preserve nonrenewable resources by promoting recycling of waste materials.
WMA6	Food Waste Management	1 + 1 Bonus	1 credit for signing the Food Wise Charter and demonstrating the implementation of food waste reduction good practice guide as per Hong Kong Food Wise Campaign. 1 Bonus credit for providing on-site used cooking oil collection facility and implementing the collection arrangement.	To reduce pressure on landfill sites by promoting the reduction and recycling of food waste.
WMA7	Waste Treatment Equipment	1 Bonus	1 Bonus credit for providing at least one set of waste treatment equipment.	To reduce the environmental impact arising from the transportation of waste

Code	Requirement	Attainable credit	Description	Objective
				to the landfill sites by promoting on-site waste treatment.
WMA8	Action to Waste Reduction	3 + 2 Bonus	a) Implementation of the Waste Management Plan 1 credit for demonstrating the implementation of the waste management plan. b) Waste Stream Audit 1 Bonus credit for undertaking a waste stream audit. c) Waste and Recycling Records 1 credit for the collection of the waste and recycling records for past 12 months. 1 Bonus credit for the collection of the waste and recycling records for the past 24 months. d) New Targets on Waste Recycle/Reduction 1 credit for providing new targets on the waste recycle items, recycle rate and reduction rate based on the performance of the past 12 months.	To advocate the continual improvement for waste management.

3.3.2. BEAM Plus Existing Buildings Selective Scheme

In BEAM Plus Existing Buildings Selective Scheme (BEAM Plus EBSS), the performance aspects are grouped into the following categories: 1) Management; 2) Site Aspects; 3) Materials and Waste Aspects; 4) Energy Use; 5) Water Use; and 6) Indoor Environmental Quality. The assessment categories are same with the ones in BEAM Plus EBCS; however, the category weighting is not applicable under Selective Scheme. The requirements regarding to C&D waste management are allocated in the category of Materials and Waste Aspects (MWA) as well. Three main contents are included in the Materials and Waste Aspects: 1) Selection of Materials; 2) Waste Management and Reduction; and 3) Innovations and Additions.

Table 9 shows the specific requirements in the Materials and Waste Aspects category. The attainable credits, description of the requirement, and corresponding objective are also presented. From Table 9, it can be seen that there is no prerequisite in the Materials and Waste Aspects compared with BEAM Plus EBSS. The allocated credits to the requirements in Materials and Waste Aspects are more than the attainable credits in BEAM Plus EBCS. For example, the attainable credits for the requirement of ‘Materials Purchasing Practices’ are 20. However, similarly to BEAM Plus EBCS, the emphases are given to household waste, food waste and WEEE, C&D waste is not particularly specified in BEAM Plus EBSS. The recommended waste reduction actions in BEAM Plus EBSS are different from BEAM Plus EBCS: Waste Management Plan and Waste/Recycling Records are recommended in both schemes, while BEAM Plus EBSS additionally proposed Continual Improvement and Dissemination and Feedback. Furthermore, the Innovations and Additions concerning materials and waste are integrated into Materials and Waste Aspects in BEAM Plus EBSS.

Table 9 C&D waste management requirements in BEAM Plus EBSS

Code	Requirement	Attainable credit	Description	Objective
1	**Selection of Materials**			
MWA1	Materials Purchasing Plan	3	1 credit for providing an endorsed policy. 1 credit for providing a materials purchasing plan with objectives, 5R principles and targets. 1 credit for the plan is endorsed by top management of Building Owner/Building Management Company.	To encourage purchasing practices which aim at reducing the environmental impacts of products used through formulating the purchasing procedure or plan into a more environmentally friendly way.
MWA2	Materials Purchasing Practices	20	a) Environmentally Purchasing Practices Maximum 10 credits for purchasing environmentally friendly ongoing consumables: i. Printing paper – 50% recycle content; ii. Printing paper – Certified (e.g. FSC); iii. Printing paper – Chlorine free; iv. Printing paper – Coating free; v. Envelop – 50% recovered fibre by weight; vi. Paper towel and toilet tissue – Chlorine; vii. Printing ink – 20% vegetable or soybean oil; viii. Toner cartridge – Refillable; ix. Pen – Refillable ink and provide refill; x. Plastic garbage bags – 50% recycle content; xi. Plastic bag – Biodegradable; xii. Battery – Rechargeable; xiii. Detergent – Low VOC and without halogenated substances; xiv. Computer – With energy label;	To encourage purchasing practices which reduce the environmental impact of products used by implementing Materials Purchasing Plan.

<table>
<tr><th>Code</th><th>Requirement</th><th>Attainable credit</th><th>Description</th><th>Objective</th></tr>
<tr><td></td><td></td><td></td><td>xv. LCD Monitor – With energy label;
xvi. Printer – With energy label and energy saving mode;
xvii. Fluorescent Lamp – Grade 1 energy label;
xviii. Furniture – 2nd hand product;
xix. Water dispenser – Bottleless; and
xx. Other ongoing consumables with environmental attributes proposed by the Applicant.
<table>
<tr><td>Credit No.</td><td>2</td><td>4</td><td>6</td><td>8</td><td>10</td></tr>
<tr><td>Percentage of environmentally friendly items purchased</td><td>30%</td><td>35%</td><td>40%</td><td>45%</td><td>50%</td></tr>
</table>
Maximum 5 credits for purchasing environmentally friendly product during refurbishment:
i. Sustainable/ recycled timber (e.g. FSC);
ii. Recycled/ reused materials;
iii. Regionally manufactured materials (within 800km);
iv. Second-hand products;
v. Glue/ Adhesive – <5% VOC;
vi. Paint – VOC free;
vii. Carpet – Removable & reusable tiles;
viii. Carpet – PVC free;
ix. Product certified under CIC Carbon Labelling Scheme, HKGBC Green Building Product</td><td></td></tr>
</table>

<table>
<tr><th>Code</th><th>Requirement</th><th>Attainable credit</th><th>Description</th><th>Objective</th></tr>
<tr><td></td><td></td><td></td><td>Accreditation and Standards (HK GPASS); and
x. Other products for refurbishment with environmental attribute proposed by the Applicant.
<table>
<tr><td>Credit No.</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Percentage of environmentally friendly items purchased</td><td>30%</td><td>35%</td><td>40%</td><td>45%</td><td>50%</td></tr>
</table>
Maximum 3 credits for increment of purchasing amount of environmentally friendly items when compared with last year.
<table>
<tr><td>Credit No.</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Percentage increment of purchased environmentally friendly items</td><td>3%</td><td>5%</td><td>10%</td></tr>
</table>
b) Targets on Environmentally Procurement
2 credits for providing new target on procurement rate of environmentally purchasing based on the past 12 months performance.</td><td></td></tr>
<tr><td>MWA3</td><td>Ozone Depleting Substances</td><td>4</td><td>a) Phase Out Plan for Existing Equipment with Ozone Depleting Substances
Maximum 2 credits for providing phase out plan for existing equipment with ozone depleting substances:
i. Refrigerants; and
ii. Fire suppression.
(Note: 2 credits are achieved if there is no</td><td>To reduce the release of ozone depletion substances into the atmosphere.</td></tr>
</table>

Code	Requirement	Attainable credit	Description	Objective
			equipment with ozone depleting substances in the building.) b) Newly Installed Equipment using Refrigerants 1 credit for newly installed equipment using the refrigerants with Global Warming Potential (GWP) less than 1,900. (Note: Credit can be excluded for no equipment using the refrigerants is installed in the past 12 months.) c) Fire Suppression Materials 1 credit for using the fire suppression and other materials that avoids the use of ozone depleting substances in their manufacture, composition or use.	
2	**Waste Management and Reduction**			
MWA4	Waste Management Plan	3	1 credit for providing a waste management policy endorsed by top management. 1 credit for providing a waste management plan with objectives and 5R principles. 1 credit for the waste management plan is endorsed by top management.	To encourage best practice for the management of waste, including sorting, recycling and disposal of waste.
MWA5	Basic Waste Recycling Facilities	3	Maximum 3 credits for providing on-site recycling facilities for paper, plastic and metal waste at easily accessible locations.	To reduce pressure on landfill sites and help to preserve nonrenewable resources by promoting recycling of waste materials.
MWA6	Recycling Facilities for	6	a) On-site Recycling Facilities	To reduce pressure on landfill sites

Code	Requirement	Attainable credit	Description	Objective
	Different Waste Streams		Maximum 5 credits for providing the following listed on-site recycling facilities: i. Clothes; ii. Fluorescent lamp (CFLs and fluorescent tubes); iii. Glass bottle; iv. Rechargeable battery; v. Waste Electrical and Electronic Equipment (WEEE); and vi. Others to be proposed by the Applicant. b) Notification to Building Users 1 credit for notifying the building users the locations of the above mentioned recycling facilities.	and help to preserve nonrenewable resources by promoting recycling of waste materials.
MWA7	Food Waste Management	4	1 credit for signing the Food Wise Charter. Maximum 3 credits for adopting the following good practices as per Hong Kong Food Wise Campaign: i. Promote best practices and behavioural changes to reduce food waste; ii. Provide a food waste management plan; iii. Implement the plan with measurable targets; iv. Encourage the building management to conduct in-house waste audit and improve the performance in accordance with the results; v. Promote and adopt recipes that make use of food trimmings; vi. Engage in Government's/ non-governmental organisations' food waste reduction activities;	To reduce pressure on landfill sites by promoting the reduction and recycling of food waste.

Code	Requirement	Attainable credit	Description	Objective
			vii. Support the Food Wise Hong Kong Campaign and similar initiatives; viii. Donate surplus food; and ix. Others to be proposed by the Applicant.	
MWA8	Action to Waste Reduction	7	a) Implementation of the Waste Management Plan 1 credit for demonstrating the implementation of the waste management plan. b) Waste and Recycling Records Maximum 2 credits for the collection of the waste and recycling records: i. 1 credit for past 6 months; and ii. 2 credits for past 12 months. c) Continual Improvement Maximum 3 credits for providing new targets on the following, based on the performance of the past 12 months: i. Waste recycle items; ii. Recycle rate; and iii. Reduction rate. d) Dissemination and Feedback 1 credit for disseminating the waste reduction and recycle target to building users and providing feedback channels.	To advocate the continual improvement for waste management.
3	**Innovations and Additions**			
MWA9	Achievement of	1	1 credit for obtaining the Wastewi$e Certificate of	To encourage business/ organisations

Code	Requirement	Attainable credit	Description	Objective
	Wastewi$e Certificate		Hong Kong Green Organisation Certification (HKGOC).	adopting measures to achieve waste reduction. To recognise the business/ organisations attaining specified environmental requirements and achieving a self-improvement goals. To benchmark the participating business/organisations within the same sectors.
MWA10	Educational and Promotional Programme	2	2 credits for Building Owner/Building Management Company to educated and advocate the behavioural change of building users in respect of Materials and Waste Aspects by: i. Organising educational seminar/ promotion campaign; or ii. Promoting or participating in Hong Kong Green Building Week organised by Construction Industry Council (CIC) and the Hong Kong Green Building Council Limited (HKGBC).	To encourage behavioural change through educational and promotional programme.
MWA11	Innovative Techniques/ Performance Enhancements	2 Bonus	a) Innovative Techniques 1 Bonus credit for applying innovative technique in respect of Materials and Waste Aspects that will improve the performance of the building. b) Performance Enhancements	To encourage adoption of practices, new technologies and techniques in respect of Materials and Waste Aspects that have yet to find application in Hong Kong or provide

Code	Requirement	Attainable credit	Description	Objective
			1 Bonus credit for building with exemplary performance over and above the criteria identified in Materials and Waste Aspects of the BEAM Plus for Existing Buildings.	for performance enhancements over and above stated performance criteria in BEAM Plus for Existing Buildings.

3.4. Waste management requirements in BEAM Plus Interiors

In BEAM Plus Interiors Version 1.0 (BEAM Plus In), the performance aspects are grouped into the following categories: 1) Green Building Attributes; 2) Management; 3) Materials Aspects; 4) Energy Use; 5) Water Use; 6) Indoor Environmental Quality; and 7) Innovations. The requirements regarding to C&D waste management are allocated in the category of *Materials Aspects* (MA). Table 10 shows the specific requirements in the Materials Aspects category. The attainable credits, description of the requirement, and corresponding objective are also presented. From Table 10, it can be seen that there are three prerequisites in the Materials Aspects, two of the prerequisites are related to C&D waste management, namely ‘Minimum Waste Recycling Facilities’ and ‘Timber Used for Temporary Works’. The non-inert materials are emphasised in BEAM Plus Interiors, for example, in the Minimum Waste Recycling Facilities requirement, the collection of paper, plastic and metal waste is proposed. In addition, timber used in temporary works is suggested from sustainable forestry or reused timber. Besides the required recycling facilities for paper, plastic and metal, recycling facilities for glass, small electrical appliance, and food waste are recommended. Interior components, such as walls, glazing, doors, ceilings, flooring, furniture and partitions are suggested to be reused directly. Modular design materials and disassembly design are suggested for effective separation and collection. Rapidly renewable products for ceiling, wall, and door are also recommended. Particularly, best practices of construction and demolition waste are encouraged in relation to sorting, recycling, and disposal.

Table 10 C&D waste management requirements in BEAM Plus In

Code	Requirement	Attainable credit	Description	Objective
MAP1	Use of Non-CFC Based Refrigerants	-	No CFC-based refrigerants in HVAC&R systems installed by the Applicant.	Prevent the release of chlorofluorocarbon (CFC) into the atmosphere.
MAP2	Minimum Waste Recycling Facilities	-	Provide storage facilities at prominent location for the collection of paper, plastic and metal waste.	Reduce pressure on landfill sites and help to preserve non-renewable resources by promoting the recycling of waste materials.
MAP3	Timber Used for Temporary Works	-	All timber used for all temporary works shall originate from sustainable forestry or existing material was reused.	Encourage the use of well-managed timber.
MA1	Waste Recycling Facilities	2	1 credit for storage for anyone of the following items: 2 credits for storage for any two of the following items: i. Recycling of glass; ii. Recycling of used small electrical appliance; iii. Recycling of food waste.	Reduce pressure on landfill sites and help to preserve non-renewable resources by promoting the recycling of waste materials.
MA2	Interior Components Reuse	3	1 credit for reusing at least 30% of prior condition walls, glazing, doors, ceilings, and flooring. 2 credits for reusing at least 50% of prior condition walls, glazing, doors, ceilings, and flooring. 3 credits for reusing at least 70% of prior condition walls, glazing, doors, ceilings, and flooring.	Extend the life cycle of the existing wall, doors, and glazing in the premises to conserve resources, reduce waste, and lower the environmental impact.
MA3	Furniture and Partitions	3	1 credit for at least 30% of the total furniture and partitions were reused from salvaged furniture and partitions. 2 credits for at least 50% of the total furniture and	Extend the life cycle of existing furniture and partitions to conserve resources, reduce waste and lower environmental impact.

Code	Requirement	Attainable credit	Description	Objective
			partitions were reused from salvaged furniture and partitions. 3 credits for at least 70% of the total furniture and partitions were reused from salvaged furniture and partitions.	
MA4	Modular Design Materials	1	1 credit for designing modular elements which contributed at least 50% of the newly installed elements in the project.	Encourage to increase the use of modular design elements for project in order to enhance buildability and reduce waste.
MA5	Designed for Disassembly	1	1 credit for installed construction elements and fixings that are easy to dismantle, and disassemble at the end of serviceable life, and contributed at least 50% by area of the newly installed elements.	Encourage forward looking planning, design, and installation to permit easy dismantling, separation and collection of the construction elements.
MA6	Sustainable Flooring Products	4	a) Rapidly Renewable Materials/Recycled Materials/Sustainable Timber 1 credit for flooring comprising rapidly renewable material, recycled material, sustainable timber flooring, or a combination of those prescribed materials that contributed at least 50% of all newly installed flooring. 2 credits for demonstrating 100% achievement; b) Regionally Manufactured Materials 1 credit for flooring materials manufactured locally within 800km radius from the project space, and contributed to at least 50% of the newly installed flooring material.	Promote the use of environmentally friendly materials, manufacturing processing, and minimise impacts arising from material transportation.

Code	Requirement	Attainable credit	Description	Objective
			c) Environmentally Manufactured Materials 1 credit for flooring material (or composite material) manufactured by organisations which ALL have implemented an Environmental Management System (EMS) and contributed to at least 50% of the newly installed flooring materials.	
MA7	Sustainable Ceiling Products	4	a) Rapidly Renewable Materials/Recycled Materials/Sustainable Timber 1 credit for ceiling materials either rapidly renewable materials, recycled materials and sustainable timber (or a combination) which contribute at least 50% of all newly installed ceiling. 2 credits for demonstrating 100% achievement; b) Regionally Manufactured Materials 1 credit for ceiling materials manufactured locally within 800 km radius from the project space, which contributed to at least 50% of the newly installed ceiling materials. c) Environmentally Manufactured Materials 1 credit for ceiling materials from ALL organisations with manufacturing facilities which implemented an Environmental Management System (EMS) and contributed at least 50% of the newly installed ceiling materials.	Promote the use of environmentally friendly materials, manufacturing processes, and reduced impacts arising from transportation.
MA8	Sustainable Wall and Door Products	4	a) Rapidly Renewable Materials/Recycled Materials/Sustainable Timber 1 credit for wall and door materials made from rapidly	Promote the use of environmentally friendly materials and manufacturing

Code	**Requirement**	**Attainable credit**	**Description**	**Objective**
			renewable material, recycled materials, or sustainable timber or a combination of any three which contributed at least 50% of all newly installed wall and door materials. 2 credits for demonstrating the achievement of 100%. b) Regionally Manufactured Materials 1 credit for wall and door materials manufactured within 800km radius from the project space, which contributed to at least 50% of the newly installed wall and door materials used in the project. c) Environmentally Manufactured Materials 1 credit for wall and door materials from ALL organisation(s) which implemented an EMS and contributed to at least 50% of the newly installed wall and door materials used in the project.	processes, and reduced environmental impacts arising from transportation.
MA9	Zero PVC	1	1 credit for using alternative products and materials with zero PVC content for the project.	Avoid the use of Poly Vinyl Chloride (PVC) products.
MA10	Ozone Depleting Substances	1	1 credit for products in the project space without ozone depleting substances (CFC & HCFC) in either the manufacturing process or composition.	Prevent the use and release of chlorofluorocarbons and hydro chlorofluorocarbons into the atmosphere.
MA11	Demolition and Construction Waste Reduction	2	1 credit for demonstrating that at least 30% of demolition and construction waste was recycled. 2 credits for demonstrating that at least 60% of demolition and construction waste was recycled.	Encourage best practice for the management of waste, including sorting, recycling and disposal of demolition and construction waste.

4. Summary of C&D waste management in Hong Kong

This report presents the current statutory and administrative C&D waste management policies and measures in Hong Kong. The reviewed literature includes academic papers, governmental and industrial association websites, and BEAM Plus.

From the academic papers, four regional policies in Hong Kong were abstracted from the academic literature, such as ‘regulations, codes, and initiatives’, ‘construction waste disposal charging scheme’, ‘waste management plan’, and ‘development of waste recycling market’. In addition, fourteen specific C&D waste management measures were summarised, including ‘proper design’, ‘use of prefabrication’, ‘on-site sorting’, ‘off-site sorting’, ‘selective demolition’, ‘accurate waste quantification’, ‘incentive reward programme’, ‘online waste exchange’, ‘waste management mapping model’, ‘integrated GPS and GIS technology’, ‘RFID technology’, ‘building information modeling’, ‘system dynamics modeling’, and ‘education and training’. Other C&D waste management measures which were not explained in detail were also presented in section 1.1.15. The advantages and potential limitations of using these policies and measures are summarised in Table 11 considering the particular Hong Kong circumstances.

Table 11 Advantages and potential limitations of the identified policies and measures in Hong Kong

Policy/measure	Advantages	Potential limitations
Regulations, codes, and initiatives	C&D waste management has been emphasised in regulations (i.e. Waste Disposal Ordinance) since 1980; Particular regulations have been published by Hong Kong government, such as the Trip Ticket System, etc.	No more initiatives since the implementation of the Construction Waste Disposal Charging Scheme.
Construction waste disposal charging scheme	The charging scheme has been established since 2005; C&D waste are classified into	The current disposal charges are low compared with other countries limiting the

Policy/measure	Advantages	Potential limitations
	inert and non-inert categories in order to encourage sorting.	incentives for better waste management.
Waste management plan	Waste management plans are generally required before the commencement of construction projects.	Enforcement of implementation of the waste management plan is lacking.
Development of a mature waste recycling market	A mature recycling market will increase the willingness of construction stakeholders to sort, reuse or recycle materials.	Potential worries about the quality of recycled materials; Lack of quality specifications; Lack of sufficient support from government to the recycling industry.
Proper design	Several C&D waste minimisation measures have been recommended by government and BEAM Plus for proper design.	No minimum requirement on MA Credits in BEAM Plus and credits for C&D waste management BEAM Plus are not compulsory.
Use of prefabrication	The technology has been mature; Hong Kong government has promoted the implementation of this technology.	Higher initial and transportation costs; Last minutes design changes limit its use.
On-site sorting	Benefit-earning from selling sorted valuable materials; Cost-saving from disposal at public fills rather than landfilling; Recommendations from government and green building rating tools.	Space demanding; Time demanding; Cost demanding; Labor demanding; Lack of a mature recycling market to absorb the sorted materials.
Off-site sorting	Lower cost than landfilling disposal.	Double handling as a high percentage of waste received need to go the landfills eventually; Need proper locations of the off-site sorting facilities in order to reduce transportation cost; Potential generation of noise and dust at the off-site sorting facilities.

Policy/measure	Advantages	Potential limitations
Selective demolition	Benefit-earning from selling sorted valuable materials; Cost-saving from disposal at public fills rather than landfilling; Recommendations from government and green building rating tools.	Space demanding; Time demanding; Cost demanding; Labor demanding; Lack of a mature recycling market; Lack of coordination in contract arrangement limits its use.
Accurate waste quantification	Continuous recording of waste disposal data by EPD and CEDD; Computer-aided data mining techniques.	Lack of detailed waste generation classification records at project levels.
Incentive reward programme	Waste reduction intentions of construction workers can be stimulated.	Lack of benchmarks to evaluate material savings; Lack of awareness from project managers or developers.
Online waste exchange	Techniques for developing an online waste platform are mature.	Lack of promotion from the government and related organisations.
Waste management mapping model	The free-flow mapping presentation technique is mature.	Lack of staff on monitoring the waste flows; Lack of awareness from project managers.
Integrated GPS and GIS technology	The GPS and GIS technologies are mature.	Lack of GIS information; Lack of successful practices; Increase of cost.
RFID technology	The RFID technology is mature.	Increase of cost; More staff need to be assigned for using this technology.
Building information modeling (BIM)	The BIM technology has been used in Hong Kong.	More modules need to be developed for C&D waste management; Increase of cost for establishment.
System dynamics modeling	The system dynamics modeling has been used by many scholars in Hong Kong.	Lack of sufficient and reliable data; Uncertainty of whether industrial practitioners can

Policy/measure	Advantages	Potential limitations
		easily handle the modeling technique.
Education and training	Hong Kong government has held workshops and trainings for increasing safety awareness.	Lack of emphasis from government and other construction stakeholders; Increase of cost.

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REPORT 3

REPORT OF INTERVIEWS & FOCUS GROUP MEETINGS

August 2017

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Interviews were conducted to collect views and comments from private and public sectors of construction industry, which were followed by focus group meetings. The aim of focus group meetings was to discuss the findings from interviews and allow interaction of the participants.

1. Interviews

A total of 11 interviews were carried out in August 2016. Interviewees include developers, main contractors, demolition contractor, building designers, building surveyor and representatives from government departments.

1.1. List of Participants

Private Sector

- Gammon Construction Ltd. (main contractor);
- Leighton Contractor (Asia) Ltd. (main contractor);
- P & T Group (architect);
- Ronald Lu & Partners (architect);
- Swire Properties (developer);
- Y.I. & Associates Ltd. (architect);
- YSK2 Engineering Co. Ltd. (demolition contractor).

Associations/Institutes

- Hong Kong General Building Contractors Associations (building contractor);
- The Hong Kong Institute of Architects (architect);
- The Hong Kong Institute of Surveyors (building surveyor);
- The Real Estate Development Association of Hong Kong (developer).

Public Sector

- Architectural Services Department

- Civil Engineering and Development Department;
- Development Bureau;
- Environmental Protection Department;
- Housing Department.

1.2. Experience Sharing

Implementation of construction and demolition (C&D) waste management is time consuming. Control of C&D waste is more successful in public projects than private projects as the construction periods of public projects are comparatively longer. In spite of the time limitation, the private sector has managed to reduce C&D waste in some projects: Leighton crushed the concrete waste on site and reused as hardcore for site filling in a demolition project; two refuse chutes were used to perform on-site sorting in Hysan Place and Maxim Headquarter projects; the Science Park 3AB project used recyclable packaging materials.

1.3. Construction Industry's Concerns

The three public landfills have already reached 80% of their capacity. Development of effective control and management of C&D waste is crucial. It is difficult to reduce C&D waste once it is produced in construction projects. Addition and alteration (A & A) projects are the major source of C&D waste which constitutes 10% of the dumped waste. Demolition projects have higher potential to reuse and recycle the generated waste.

As the proportion of private to public projects is 1:1, successful implementation of C&D waste management in private projects can significantly reduce the amount of waste. Clients' initiative and support play a very important role in waste reduction. As the cost of revitalisation is usually higher than redevelopment, owners have little incentive to reduce waste by revitalising their properties due to commercial consideration. Contractors' role in waste reduction is passive. Their main concern is how to complete the project within the limited construction period and budget in order to maximise their profits. The current subcontracting system further discourages the incentive of main contractor to reduce waste. Moreover, most contractors do not consider adjusting method statements to site requirements so as to reduce abortive works which produce large amount of waste.

The current practice of waste reduction in building industry does not align with government policy. Measures to manage and reduce C&D waste production worth to study. Any waste reduction policy and strategies should not upset the level-playing field and recommended to be tested prior to implementation. The effects should be able to be quantified. Side effects of recycling and disturbance to public, such as air pollution, should be considered.

1.4. Barriers and Difficulties

The identified barriers and difficulties can be categorised into three main aspects.

1.4.1. Economic Considerations

C&D waste management is not a priority issue in design stage due to clients' low interest in reducing waste. Shorter construction period means faster revenue return and sorting of waste is time-consuming. Various activities are carrying out simultaneously within construction site. The compact site condition is another major obstacle to perform on-site sorting. Temporary storage space for reusable/recyclable C&D wastes is insufficient. The high labour and transportation costs of recycling, particularly for timber and concrete, impede recycling. Clients are not confident to use recycled materials. The recycling industry is poorly developed owing to lack of local supporting recycling industry and government support. Currently there are only two concrete and one timber recycling contractors resulting in expensive recycling cost. Public object to construct recycling sites in urban area while transportation cost is expensive for remote areas. The capacity of recycling contractors cannot match with the amount of waste produced. Conventional temporary works, such as bamboo scaffolding, are preferred as the cost is cheaper than reusable metal formwork and scaffolding. There are insufficient skillful labours to handle aluminium formwork. Furthermore, it is difficult to reduce packaging for protection fragile materials like tiles.

1.4.2. Government Policies/Operations

The dumping area in Tap Shek Kok is too remote and under-utilised. Hong Kong Island has no landfill sites. Illegal dumping is serious and the amount of penalty is insignificant comparing to cost of minimising waste. The complicated procedures of applying recycling subsidies and the short tenancy period of public land for recycling discourages the development of recycling industry. Government is too conservative in approving innovative green technologies and the approving procedures are complicated and lengthy deterring future development of recycling industry.

1.4.3. Influence of BEAM Plus

Clients are not interested in C&D waste reduction as the requirements of 30% and 60% of recycling C&D waste for BEAM Plus accreditation are too stringent but contribute only one credit and two credits respectively. The requirements of waste reuse/recycle in demolition projects are not comprehensive and practical. Many potential C&D waste minimising methodologies and measures are not considered in BEAM Plus, such as reducing use of steel, backfilling, revitalising and reuse of existing foundation and structural framework, revising method statement addressing different site conditions to reduce abortive work. There is no monitoring system for compliance with the accreditation requirements.

1.5. Highlights of Interviewees' Suggestions

1.5.1. Design Stage

Reducing C&D waste at source is most effective. Waste reduction and management should be considered early in design stage. Project team should consider no-frills and fuss-free design solutions and low-waste building technologies. Integrated Project Design worth to be considered, which involves multi-disciplines at design stage aiming to minimise abortive works. Applying Building Information Modelling (BIM) software can assist to review any crashes in the tentative construction sequences.

1.5.2. Tender Stage

Introduction of “recycling rates” and “Award and Penalty” scheme in tender document can encourage contractors to reduce C&D waste. Contractors shall be rewarded for satisfying the reduction targets as proposed in their Waste Management Plan. Non-compliance will be penalised. Applying List Management of contractors in tendering can encourage waste minimisation. The List includes acquainted contractors who have satisfactory performance records in waste management.

1.5.3. Construction Stage

Longer construction period allows sufficient time for contactors to plan and carry out C&D waste sorting and implementation of Waste Management Plan. Off-site sorting can be considered if on-site sorting is not feasible. Phasing construction period facilitates reuse of temporary works. Contractors can set up a communication platform for coordinating reuse and recycling C&D waste among themselves.

1.5.4. Roles of Government

Government should take up the roles to promote green construction technologies/materials; encourage reuse/recycling of C&D waste in construction industry; facilitate development of local recycling and prefabrication industry; and educate the public the importance of C&D waste reduction and management. Study and public consultation on strategies and measures to improve C&D waste management and reduction is recommended.

2. Focus Group Meetings

Two focus group meetings were conducted on 15 and 22 of September 2016 at Building and Real Estate Department of The Hong Kong Polytechnic University. The aim of the meetings is to gather comments on the findings of the interviews and innovative ideas to reduce C&D waste. Participants included architect, surveyor, main contractor, SME contractor, and representatives from Housing Department, Environmental Protection Department, Civil Engineering and Drainage Department and Hong Kong Green Building Council.

2.1. Participants

Eight representatives from Gammon Construction Ltd., Crownity Engineering Co. Ltd., Hong Kong Green Building Council, Hong Kong Institute of Surveyors, Housing Department, Civil and Development Department, and Environmental Protection Department attended the focus group meetings.

2.2. Participants' Comments

Waste reducing design and technologies, such as precast/prefabrication, no-frills design, standard/modular and adaptive design, reuse of existing building foundations and structure, reusable temporary works, sustainable/recyclable building materials, dry wall system, should be explored in design stage. The cost of importing prefabricated components is increasing. Government can facilitate local prefabrication industry by providing land for manufacturing. Using "Design and Build" contract can be used in infrastructure projects to formulate custom-designed Waste Management Plan to suit site conditions.

Clients should allow longer construction period, minimise design change at construction stage and encourage contractor to engage in waste reduction. A percentage of contract sums can be set aside as financial bonus to be awarded to contractors upon achieving targeted amount of waste reduction. Allowing sufficient construction time can also reduce the wastage of temporary works, which is used only to satisfy the basic requirements for issue of Occupation Permit. Contractors will also be financially awarded on proposing and satisfactorily completion of innovative Waste Management Scheme.

About 50% of C&D waste is contaminated timber which is difficult to be recycled. The incinerator in T-Park of Tsuen Mun can be utilised for burning timber waste to recover energy, which can be used in cement manufacturing factories. To encourage revitalisation of buildings, Building Department is recommended revise the classification of extensive reuse of existing buildings under New Buildings instead of Alteration and Addition Works in order to allow more flexibility in design. Providing more public sorting sites can enhance off-site sorting, which should be adjacent to landfill in 1:1 ratio. Government is recommended to privatise the management of sorting sites and let market create the momentum for developing the recycling industry. Creating more recycle outlets will reduce the recycling cost and attract contractors to participate in waste reduction. Packaging is a major source of waste. Plastic packings, which are reusable and offer economic value to recycling contractors, should be promoted. In views of space limitation to carry out on-site sorting of all C&D waste, mandatory selective sorting for timber and plastic is recommended. Tremendous increase in dumping charge, say $500/ton can significantly reduce C&D waste. Building Department (BD) can work with Construction Industry Council (CIC) and Hong Kong Green Building Council (HKGBC) to support green building construction through streamlining the approval procedures of low-waste technologies and reusable materials, and credit-award to projects using low-waste technologies/reusable materials. The standards for recycling virtue materials are suggested to be reviewed by an Environmental Committee.

3. Proposed Measures

Success in implementing C&D waste reduction measures requires participation and cooperation of clients, designers, contractors, government and general public. Proposed measures can be classified as short (S), medium (M) and long (L) terms. Short term measures relate to readily available means/actions. Long term is mostly associated with public policies and research. The proposed measures are summarised in Tables 1 and 2.

3.1. Short Term

The proposed short term measures are summarised as follows:

- Reuse of existing foundations and infrastructure whenever possible;
- Use standard/modular components;
- Reduce wet trade e.g. using dry wall and painting to replace tiling;
- Minimise revision in design;
- Use low-waste construction technologies;
- Choose durable/recyclable materials;
- Use reusable temporary works e.g. aluminium formwork, metal scaffolding;
- Apply BIM to review any crashes in tentative construction sequences;
- Include recycling rates in Bills of Quantities;
- Reuse excavated soil in other projects;
- Reuse demolished concrete for paving bicycle tracks;
- Carry out on-site/off-site sorting;
- Phasing construction period to allow reuse of temporary works;
- Use T-Park for burning timber waste to recover energy for cement factories.

3.2. Medium Term

Below is the summarised list of proposed medium term measures:

- Apply No-Frills Design;

- Consider Adaptive Design to cater for future change in use;
- Consider waste reduction and management in design stage;
- Explore low-waste construction technologies;
- Adopt Integrated Project Design approach;
- Develop a list of contractors for "List Management";
- Use "Design and Build" contract in infrastructure projects;
- Introduce "Award and Penalty" scheme;
- Encourage contractors to propose innovative Waste Management Scheme subject to auditing and assessment;
- Introduce waste reduction procurement in nominated subcontracts;
- Allow longer construction period;
- Review Method Statement to reduce abortive works and facilitate recycling/reuse;
- Improve existing dry wall system to suit local requirements;
- Government to provide more public sorting sites adjacent to landfill in 1:1 ratio;
- Mandatory selective on-site sorting for timber and plastic;
- Mandatory use of reusable formwork;
- Government to provide low-rent sites for prefabrication industry;
- Revitalisation of buildings to be classified as "New Buildings";
- BD to work with CIC and HKGBC to streamline the approving process of low-waste technologies and reusable materials;
- Award GFA concession for precast/prefabricated facade;
- Setting up a central coordination team to streamline and simplify the approving process of recycle subsidise;
- Introduce interim percentages to the 60% requirement of recycling C&D waste in BEAM Plus and increase the awarding score.

3.3. Long Term

The following is the summary of proposed long term measures:

- Set up communication platform to coordinate contractors reusing C&D waste among themselves;
- Government to set up C&D waste reduction policy and monitor implementation;
- Educate clients and contractor to take up their social responsibilities of reducing C&D waste;
- Educate the general public the importance and necessity to minimise C&D waste;
- Government to act as facilitator in developing green building technologies;
- Government to facilitate the developments of local recycling and prefabrication industries;
- Privatise management of sorting sites to create market momentum for recycling industry;
- Government to facilitate lining up with Mainland’s demand on recyclable materials;
- Government to set up research funding for C&D waste management and reduction;
- CIC to set up recycling standards and study implementation method;
- HKGBC to review the list of construction activities for granting credits and revise the scoring system based on comments from construction industry.

Table 1 Proposed Measures for C&D Waste Management and Reduction for Clients, Designers and Contractors

Measures	Client	Designer	Contractor	Term
Design Stage				
➢ No-Frills Design	X	X		M
➢ Adaptive design	X	X		M
➢ Integrated Project Design		X	X	M
➢ Consider waste reduction and management	X	X		M
➢ Use Design and Build contract for infra-structure projects	X	X	X	M
➢ Use low-waste technologies	X	X	X	S/M
➢ Use precast concrete/prefabricated building components	X	X		S
➢ Reuse existing foundation/structures	X	X		S
➢ Use reusable temporary work		X		S
➢ Use dry wall system and external painting	X	X		S
➢ Use durable/recycled building materials	X	X		S
➢ Minimise design change	X	X		S
➢ Apply BIM to review construction sequences		X		S
Tender Stage				
➢ List Management of contractors	X	X	X	M
➢ Introduce "Award and Penalty" scheme	X	X	X	M
➢ Contractors propose innovative waste management scheme	X	X	X	M
➢ Introduce waste reduction procurement for nominated subcontracts	X	X	X	M
➢ Allow recycle rates in BQ	X	X	X	S
Construction Stage				
➢ Set up contractor communication platform for reuse and recycling			X	L
➢ Allow longer construction period	X			M
➢ Review Method Statement for Construction		X	X	M
➢ Phasing construction period		X	X	S
➢ On-site/off-site sorting			X	S
➢ Consider off-site sorting when on-site sorting is not feasible			X	S
➢ Reuse excavated soil in other projects			X	S
➢ Reuse demolished concrete for paving bicycle tracks			X	S

Table 2 Proposed Measures for Government/Public Organisations to Reduce C&D Waste

Proposed Actions: C&D waste reduction should become a government policy	**Term**
Interim Measures	
➢ Use T-Park to burn timber waste for energy recovery	S
Promote green technologies & materials	
➢ Set up a central coordinating team for approving alternative recyclable/reusable materials	M
➢ Simplify and streamline the approval process of innovative waste reducing technologies	M
➢ BD to work with CIC and HKGBC to streamline approving process of low-waste technologies and reusable materials	M
Encourage reuse/recycling of C&D waste	
➢ Significant increase in dumping charge	S
➢ Revitalisation of buildings to be classified under "New Buildings"	M
➢ Mandatory selective on-site sorting for timber & plastic wastes	M
➢ Mandatory use of reusable formwork	M
➢ Introduce interim percentages to the 60% requirement of recycling C&D waste in BEAM Plus	M
➢ Set up C&D waste reduction policy and monitor implementation	L
➢ CIC to set up recycle standards and study implementation method	L
➢ Line up with Mainland's demand on recyclable materials	L
➢ HKGBC to review and revise the scoring system based on comments from construction industry	L
Facilitate the development of recycling industry	
➢ Set up a central coordination team to streamline and simplify the approving process of recycle subsidise	M
➢ Provide more public sorting sites	M
➢ Privatise the sorting facilities to let market decide the appropriate development patterns	L
➢ Publicise the potential of lining up with recycling factories in Mainland	L
Facilitate the development of local prefabrication industry	
➢ Award GFA concession for precast/prefabricated facade	M
➢ Provide low-rent sites for manufacturing	M
Research and Education	
➢ Set up research funding for C&D waste reduction and management	L
➢ Educate clients and contractor on social responsibility of reducing C&D waste	L
➢ Educate the general public the importance and necessity to minimise C&D waste	L

REPORT 4

REPORT OF SITE VISITS

August 2017

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Site visits were arranged to three different building sites at different stages of construction (such as end stage of construction, mid-stage of construction, and initial to mid-stage of construction). The results of the three site visits are presented as follows.

1. Site A

Three visits to Site A were conducted on 19, 20 and 26 July 2016 respectively. During the site visits, a meeting with the on-site Environmental Officer was held and different parts of the site were visited.

The works of Site A consist of construction of 13 numbers of 2-storeyed house, nine blocks of low-rise 7 to 11-storeyed building with commercial podium, clubhouse, basement car park and associated external works. Figure 1 shows the general view of the site.

Figure 1 General View of Site A

At the time of the visits, the site work was at its end stage of construction. Works were carried out in the low-rise buildings. The main site activities included installing of electrical fittings, installation of sanitary fillings, brickwork, tiling and floor finishing etc.

The concise notes (mainly in point form) of the meeting with the Environmental Officer and a summary of observations made during the site visits are as follows.

1.1. Notes/Points Taken During the Meeting with Environment Officer

The notes of meeting with the Environmental Office are summarised and organised under the following topics: Measures to Reduce Waste, General Practice, Waste Handling and Disposal, and Construction Activity Highlights.

Measures to Reduce Waste:

- The use of green practices of Beam Plus on C&D waste management;
- On-site practice to minimise waste;
- Off-site sorting.

General Practice:

- Methods of transporting wastes from buildings;
- Methods of maintaining records of disposed and recycled materials.

Waste Handling and Disposal:

- Packaging wastes handling;
- Locations of fills being used.

Construction Activity Highlights:

- Installation of Sanitary Fittings;
- Screeding;
- Tiling.

1.1.1. Measures to Reduce Waste

<u>The use of green practices of Beam Plus on C&D waste management</u>

- Use of waste recycling facilities: such as use of bins;
- Use of modular and standardised design for typical floor: such as mechanical and electrical system, and building services system;
- Use of prefabrication: such as mechanical and electrical system, building services system, precast façade and curtain wall;
- Use of sustainable forest products to wardrobes, doors and floor tiles;
- Target of construction waste reduction: 30%;
- Actual construction waste reduction: 39%.

On-site practice to minimise waste

- Use of steel hoarding;
- Use of metal falsework;
- Use of metal scaffolding;
- Use of large panel formwork;
- Use of aluminium formwork;
- Use of precast façade;
- Use of sprayed plaster;
- Use of on-site sorting for separating inert and non-inert wastes;
- Use of chit ticket system;
- Separate collection of inert and non-inert wastes;
- Reuse of materials whenever possible: such as reuse of timber, reuse of metal and reuse of scaffolding members;
- Use of a refuse chute to transport construction wastes from each building;
- Sorting of mixed wastes at the ground level.

Off-site sorting

- Off-site sorting not being used.

1.1.2. General Practice

Methods of transporting waste from buildings

- Refuse chutes are used to remove the waste from buildings;
- One refuse chute for each building.

Methods of maintaining records of disposed and recycled materials

- Use of Chit ticket system:
  - Main contractor to keep Part A;

- Waste hauler to retain Part B;
- Government to retain Part C.

1.1.3. Waste Handling and Disposal

Packaging wastes handling

• Corrugated paper boxes (from sanitary fittings)	to land fill;
• Paper bags (from sanitary fittings)	to land fill;
• Pallets (from transportation of materials)	to recycler;
• Timbers (from door installation)	to land fill;
• Metal Cans (from painting)	to land fill;
• Plastic Cans (from tiling)	to land fill;
• Plastic films (from sanitary fittings)	to land fill.

Locations of fills being used:

• Public fill: TKO	about 212 tonnes per month;
• Land fill: SENT	about 153 tonnes per month.

1.1.4. Construction Activity Highlights

Installation of sanitary fittings

- The main contractor is responsible for ordering the materials. Based on estimation from drawings and contract documents, excessive ordering is minimised;
- Sanitary supplier is responsible for delivering the materials to site and the subsequent unloading of the materials;
- The materials are mainly purchased from Mainland and Italy;
- The allowable excessive ordering is 5-10%;

- The subcontractor is responsible for storing and transporting the materials to the working levels;
- Crane and hoist are being used;
- The subcontractor is responsible for the installing process of sanitary fittings.

Screeding

- The types of cement and bonding agent are as recommended by the proprietary suppliers;
- The subcontractor is responsible for ordering the materials;
- The main contractor keeps the quantity record of cement/bonding agent ordered;
- The main contractor checks and monitors the materials ordering process to avoid and minimise excessive ordering. So far, there is no excessive ordering on screeding materials;
- The supplier is responsible for delivering the ordered materials to site by using lorry with crane;
- Screeding materials are purchased from Mainland;
- The subcontractor is responsible for unloading and storing the materials on site;
- The subcontractor is responsible for transporting the material to the working levels;
- Crane and hoist is being used;
- The subcontractor is responsible for the screeding process;
- The main contractor is responsible for quality checking;
- The allowable wastage level is low;
- The subcontractor is responsible for avoiding wastage of the materials during careless unloading, improper storage, excess mixing and careless usage;
- The wastage of screeding materials during unloading, storage, mixing and application is low;
- The subcontractor is responsible for handling the waste: 1) collecting packaging wastes, and 2) disposing the wastes daily.

Tiling

- The main contractor is responsible for ordering the materials. Based on estimation from drawings and contract documents, excessive ordering is minimised;
- The allowable excessive ordering is 5-10%;
- The tile supplier is responsible for delivering the ordered materials to site by using lorry with crane;
- The materials are purchased from Mainland and Italy;
- The subcontractor is responsible for unloading and storing the materials on site;
- The subcontractor is responsible for transporting the materials to the working levels;
- Crane and hoist is being used;
- The subcontractor is responsible for the tiling process;
- The main contractor is responsible for quality checking;
- To minimise wastage, the subcontractor plans and tailors the tiling process for each case.

1.2. Work Trades Observed on Site

During the three-day site visit, the following work trades in operation were observed:

- Electrical System (Photos 1-3).
  - Electrical fittings and system were being installed in buildings.
- Sanitary and Kitchen Fittings (Photos 4-6).
  - Sanitary fittings and kitchen wares were being installed in buildings.
- Tiling.
  - Materials were in place ready for brickwork and tiling (Photo 7).
  - Screeding material was being prepared at the spot of tiling work (Photo 8).
  - Primer/Sealant was being applied to wall surface (Photo 9).
  - Detailed measurement was made before tile cutting (Photo 10).
  - Tile was cut to size (Photo 11).

- ➢ Tile fixing was in process (Photo 12).
- ➢ New tiled wall was protected with plastic sheet (Photo 13).

1.3. Waste Observed on Site

Main construction wastes observed during the three-day site visit were as follows:

- Broken bricks were noted at a brickwork working area (Photo 14).
- Floor slabs were broken due to transportation or material handling (Photo 15).
- Excessive cutting might produce tile scraps (Photo 16).
- Construction wastes consisting of packaging paper, broken tiles, metal pipes and timber pallet were noted at a working area (Photo 17).
- Construction wastes consisting of packaging paper, plastic cans, styrofoam and domestic waste were noted at another working area (Photo 18).
- Wet and humid storing and working conditions might have harmful effect to construction materials (Photos 19 and 20).
- Bolding material/agent was damaged by water (Photo 21).
- Packaging materials would become construction wastes after unwrapping (Photos 22 - 25).
- Packaging wastes produced after installing sanitary fittings (Photo 26).
- Construction wastes of timber pallet, used wooden boxes, plastic containers, plastic sheets, timber, excessive masonry bricks were noted at the first temporary dumping location, Area A, (Photo 27).
- Construction wastes of timber pallets, timber, packaging remains, ends of metal pipes, and hardened cement mortar were noted at the second temporary dumping location, Area B, (Photo 28).
- Construction wastes of timber, scraps of metal hoarding, cuts of plastic tubes, ends of metal pipes and hardened cement mortar were noted at the third temporary dumping location, Area C, (Photo 29).

- Construction wastes of timber, plastic, metal scraps, ends of metal pipes, domestic waste and hardened cement mortar were noted at the fourth temporary dumping location, Area D, (Photo 30).

1.4. Waste Management Measures Observed on Site

The site was registered under the BEAM PLUS for new buildings version 1.1. Site operations were organised to reduce waste generation. The management measures observed on site were:

- A specific area was set for temporary storage of construction materials delivered to site (Photo 31).
- Construction wastes were dumped at specific locations on site (Photos 27-30)
- Large plastic rubbish bins were provided for collecting light-weight construction wastes (Photos 32 and 33).
- Ends of timber and metal channels were to be reused (Photo 34)
- Prefabricated glass window/curtain wall was used as the façade of building (Photo 35)
- A refuse chute to transport construction waste from height was provided to each block of buildings (Photo 36).

Photo 1: Electrical Connection Setting (1)

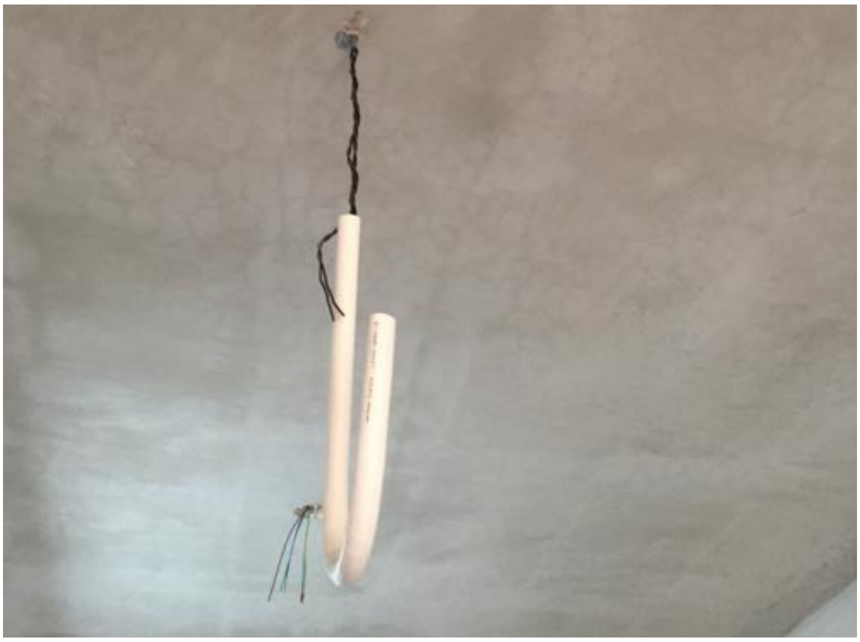


Photo 2: Electrical Connection Setting (2)

Photo 3: Wires for Electrical System

Photo 4: Sanitary Fittings in Bathroom (1)

Photo 5: Sanitary Fittings in Bathroom (2)

Photo 6: Kitchen Fittings

Photo 7: Materials Ready for Brickwork and Tiling

Photo 8: Mixing Materials for Screeding

Photo 9: Application of Sealing Primer

Photo 10: Planning/Measurement before Tile Cutting

Photo 11: Cutting Tiles

Photo 12: Fixing Tiles

Photo 13: Protection to New Tiled Wall

Photo 14: Broken Bricks at a Brickwork Working Area

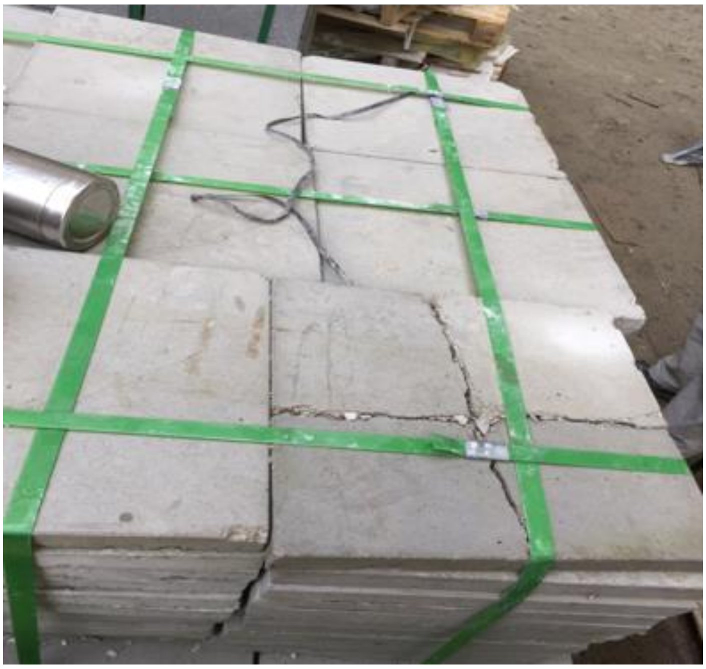


Photo 15: Broken Tile due to Transportation

Photo 16: Ends after Tile Cutting

Photo 17: Construction Wastes Noted in a Working Area (1)

Photo 18: Construction Wastes Noted in a Working area (2)

Photo 19: Wet Storage Area (1)

Photo 20: Wet Storage Area (2)

Photo 21: Damaged Bolding Agent due to Water

Photo 22: Packaging for Protection

Photo 23: Packaging Boxes of Furniture

Photo 24: Packaging Boxes of Lighting Appliance

Photo 25: 3-Layers Packaging for Tiling Agent (Kraft Paper, Plastic Wrap and Paper)

Photo 26: Packaging Wastes in a Working Area of Installing Sanitary Fittings

Photo 27: First Temporary Dumping Location (Area A)

Photo 28: Second Temporary Dumping Location (Area B)

Photo 29: Third Temporary Dumping Location (Area C)

Photo 30: Fourth Temporary Dumping Location (Area D)

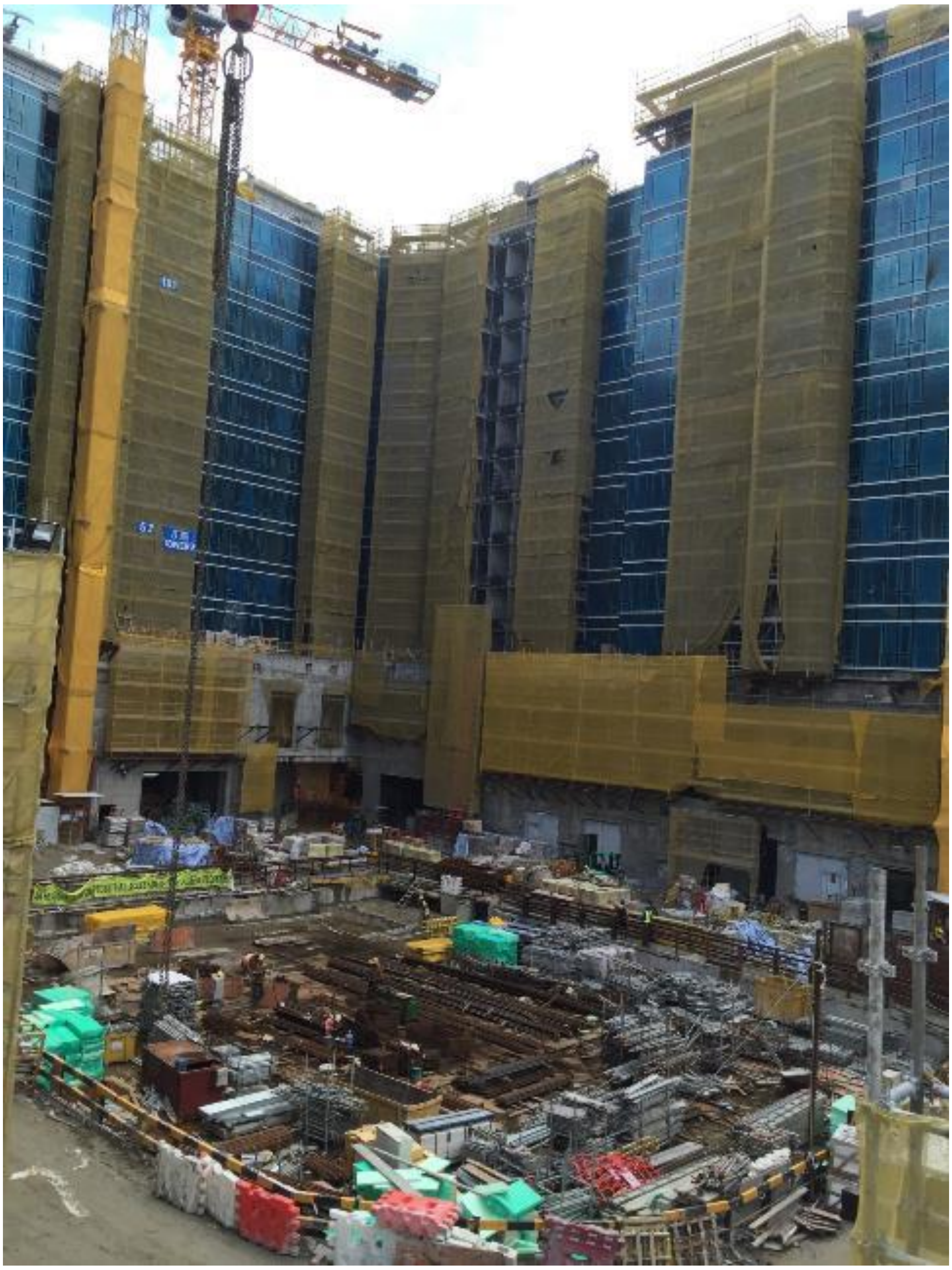


Photo 31: Specific Construction Material Temporary Storage Space

Photo 32: Rubbish Bin for Packaging Wastes

Photo 33: Collecting Packaging Wastes

Photo 34: Ends of Timber and Metal Channels to be Reused

Photo 35: Using Curtain Wall for Building Façade

Photo 36: Use of Refuse Chute to Transport Construction Waste from Building

2. Site B

Two visits to Site B were conducted on 21 and 22 July 2016 respectively. During the site visit, a meeting with the on-site Environmental Officer was held and different parts of the site were visited.

The works of Site B consist of construction of five blocks of high-rise 40-storeyed building and three blocks of low-rise 12-storeyed building, and five numbers of footbridge. Figure 2 shows the plan of the site and the locations of on-site waste storage arrangement.

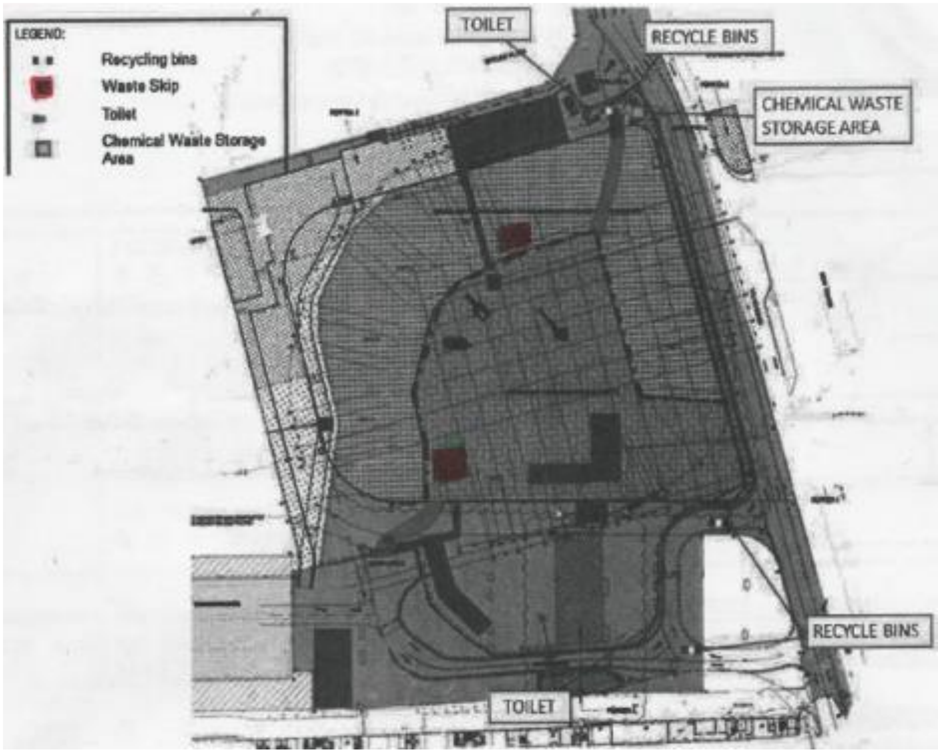


Figure 2 Site Plan (with On-Site Waste Storage Arrangement)

The construction period of the site is 1200 days. At the time of the visits, the site work was at its mid-stage of construction (at about 500 days). Construction activities were carried out on the 11th floor of the high-rise buildings and construction of the low-rise buildings was at the podium level. Others construction activities included external works such as provision of temporary roads and sub-surface construction etc. Construction of footbridges had not been started yet.

The concise notes (mainly in point form) of the meeting with the Environmental Officer and a summary of observations made during the site visits are as follows.

2.1. Notes/Points Taken During the Meeting with Environment Officer

The notes of meeting with the Environmental Office are summarised and organised under the following topics: Waste Estimation, Measures to Reduce Waste, General Practice, Waste Handling and Disposal, and Construction Activity Highlights.

Waste Estimation:

- Sources of waste related trade estimated;
- Types and quantities of waste estimated;
- Types and quantities of waste proposed to be salvaged, reused or recycled.

Measures to Reduce Waste:

- Management measures to minimise waste;
- The use of green practices of Beam Plus on C&D waste management;
- On-site practice to minimise waste;
- Rebar recycling;
- Off-site sorting.

General Practice:

- Methods of transporting wastes from buildings;
- Methods of maintaining records of disposed and recycled materials.

Waste Handling and Disposal:

- Waste handling;
- Quantities of waste sent/reused;
- Locations of fills being used.

Construction Activity Highlights:

- Timber formworking;
- Aluminium system formworking;
- Concreting.

2.1.1. Waste Estimation

<u>Sources of waste related trade estimated</u>

• Site clearance and preparation	(10%)
• Temporary works	(2%)
• Excavation and backing	(10%)
• Foundation	(1%)
• Base Construction	(1%)
• Superstructure	(10%)
• Internal finishes	(30%)
• Façade finishes	(10%)
• Plumbing and drainage	(1%)
• MCAC installation	(5%)
• Electrical installation	(5%)
• Fire services installation	(5%)
• Lifts and escalators	(5%)
• External works and landscaping	(5%)
Total:	(100%)

Types and quantities of waste estimated

• Chemical waste		(1%)
• Timber waste		(30%)
• Metal waste		(25%)
• Paper waste		(2%)
• Plastic waste		(2%)
• General Refuse		(10%)
• C&D waste		(30%)
	Total:	(100%)

Note: General refuse includes food waste and debris arising from site force and site housekeeping (e.g. office paper, drink cans and bottles, and lunch boxes etc).

Types and quantities of waste proposed to be salvaged, reused or recycled

• Bamboo scaffold	(90% reused);
• Metal scaffold	(100% reused);
• Surplus concrete	(80% reused);
• Timber formwork	(reused for 3-4 times).

2.1.2. Measures to Reduce Waste

Management measures to minimise waste

- Sufficient guidelines to workers to follow;
- Plan to have a monthly housekeeping day with concerned persons;
- Continuously informing workers to raise awareness of good housekeeping;
- Subcontractors being responsible for cleaning up their work areas.

The use of green practices of Beam Plus on C&D waste management

- Use of waste recycling facilities: such as use of skips;
- Use of modular and standardised design for typical floor;

- Use of prefabrication: such as precast façade and footbridges;
- Use of sustainable forest products: such as FSC timber and PEFC softwood;
- Use of recycled material;
- Construction waste reduction: 30% reduction estimated.

<u>On-site practice to minimise waste</u>

- Use of steel hoarding;
- Use of metal falsework;
- Use of metal scaffolding;
- Limited use of bamboo scaffolding (only for non-typical areas);
- Use of aluminium formwork;
- Use of precast façade;
- Use of precast footbridge;
- Use of on-site sorting;
- Use of chit ticket system;
- Separate collection of inert and non-inert wastes;
- Use of separate skips for inert waste and non-inert wastes;
- Use of 3-colour bins;
- Reuse of materials whenever possible: such as reuse of timber, reuse of concrete as fill);
- Isolation of materials of reselling value from waste.

<u>Rebar recycling</u>

- Estimated amount: 55 tonnes per month from May 2016;
- Name of recyclers: Po Hung Metal Company Limited, Win Link Trading Limited and Xun Xiang Metalware Co. Limited.

Off-site sorting

- Off-site sorting not being used.

2.1.3. General Practice

Methods of transporting waste from buildings

- Refuse chutes not being used and waste being removed by using lift cage at the moment;
- In the future: provision of chutes for removing inert waste from upper floors of high-rise buildings, and keeping the use lift cage for removal of non-inert waste.

Methods of maintaining records of disposed and recycled materials

- Use of EPD website for updating records monthly;
- Use of filing system for keeping delivery form and receipts for individual waste (e.g. tonnage records of waste steel and waste paper from subcontractors);
- Use of Chit ticket system:
    - Main contractor to keep Part A;
    - Waste hauler to retain Part B;
    - Government to retain Part C.

2.1.4. Waste Handling and Disposal

Waste handling

- Hardcore/rubble — to public fill;
- Concrete — to public fill;
- Concrete blocks — 20% to recycler, 80% to public fill;
- Paving — to public fill;
- Timber — to land fill;
- Paper/cardboard — to paper recycler;
- Plastic — to Yan Oi Tong Eco Park Plastic

Resources Recycling Centre;

- Rebar scraps — collected by Po Hung Metal Company Limited, Win Link Trading Limited and Xun Xiang Metalware Co. Limited;
- Other scrap metals — 90% to 3R Hong Kong International Eco-action Limited, 10% to land fill;
- General reuse — 10% to recycler, 90% to land fill;
- Chemical wastes — collected by Kam Ming E.P. Engineering Company Limited;
- Toilet waste — collected by Toi Toi Hong Kong Ltd.

Quantities of waste sent/reused

• Public fill	(50%)
• Land fill	(20%)
• C&D waste recycling facility	(5%)
• Recycler	(5%)
• On-site reused	(20%)
Total:	100%

Locations of fills being used:

- Public fill: TM38 and TKO137;
- Land fill: SENT, NENT.

2.1.5. Construction Activity Highlights

Timber formworking

- The architect is responsible for choosing the timber as formwork material;
- The reason of choosing timber is that it is suitable for untypical design;
- The types of timber used are FSC timber and PEFC softwood from Mainland;

- The main contractor is responsible for storing the material. No specific location is assigned for timber storage;
- The subcontractor is responsible for ordering the material, recording the quantity, delivery, unloading, cutting and installation;
- Both the main contractor and the subcontractor are responsible for transporting the formwork material to working levels;
- Crane is used to transport timber on site;
- Timber can be reused as formwork three to four times.
- The subcontractor is responsible for reusing the timber scraps on site and handing the waste – waste generated is about three trucks per day;
- The disposal location is TM38;
- It is suggested that good planning, better design and use of typical design could minimise timber waste.

Aluminium system formworking

- The subcontractor is responsible for choosing the formwork material/system;
- The reasons of choosing aluminium system are: 1) it is easier to employ skillful labour; 2) it incurs lower materials cost; and 3) it can be fabricated at higher speed in comparison with timber formworking;
- The aluminium system formwork was purchased from Mainland;
- The subcontractor is responsible for storing the material. No specific location is assigned for storage;
- The subcontractor is responsible for ordering the material, recording the quantity, delivery, unloading and installation;
- Both the main contractor and subcontractor are responsible for transporting the system formwork to working levels;
- Crane is used to transport timber on site;
- The aluminium system formwork can be reused 40 times;

- The subcontractor is responsible for handing the aluminium waste – sold and recycled.

Concreting

- The allowable wastage level of concrete is 3%;
- The actual wastage level is 2.9%;
- There is no penalty even if the allowable wastage level of concrete cannot be achieved;
- Based on the information of AUTOCAD drawings, the quantities of concrete are calculated;
- The main contractor is responsible for calculating the concrete quality, and the subsequent ordering and recording. There is no record of mishandling in these processes (i.e. there is no waste generated due to mishandling);
- The quantity of concrete ordered is slightly more than that from calculation to avoid possible inadequate concrete for the last order. The foreman of the main contractor would handle the excessive concrete. Generally, the excessive material would be used as backfilling material. Nevertheless, the quantity of excessiveness is negligible;
- It is suggested that measuring the actual volume during concreting might further reduce the amount of excess concrete of the last order;
- The site laboratory operated by the subcontractor is responsible for conducting slump test; so far, all concrete ordered passed the slump test;
- Concrete supplier is responsible for transporting the material to site;
- The subcontractor is responsible for unloading the concrete and transporting the material to the working levels. Crane and pump are used. Waste concrete generated during these operations is very little;
- Both the main contractor and the subcontractor are responsible for the concreting process. There is no record of careless handling from workers (i.e. no waste is generated due to worker mishandling).

2.2. Work Trades Observed on Site

During the two-day site visit, the following work trades in operation were observed:

- Use of Bamboo and Metal Scaffolding (Photos 37-38)
  - Bamboo scaffolding was used for the construction of low-rise buildings;
  - Metal scaffolding was used for the construction of high-rise buildings.
- Fixing of Timber Formwork (Photos 39-43)
  - Timber formwork was mainly used for the construction of low-rise buildings.
- Installation of Aluminium System Formwork (Photos 44-45)
  - Aluminium system formwork was used for the construction of high-rise buildings.
- Concreting (Photos 46-50)
  - Pumping was the main method being used for transporting concrete for construction;
  - The conventional method "crane + skip" was also used. This method was particularly for concreting low-rise buildings.

2.3. Waste Observed on Site

Main construction wastes observed during the two-day site visit were as follows:

- Wastes of plastic drinking bottles, plastic food package, disused gloves and carton box were noted inside a bin (Photo 51).
- Near to a concreting area of the high-rise buildings, the construction waste noted included ends of PVC pipes, solvent container, paper bag, nylon bag, disused glove, steel tube scraps and small pieces of metal channel (Photo 52).
- At a location of installation of aluminium system formwork, the construction waste included metal scarps (such as ends of metal channel and pipe) and cardboard box (Photo 53).
- At a location with construction work associated with timber formwork, the waste included timber scarps and used canvas (Photo 54).

- There were two skips for storing construction waste on site. The construction waste in the first skip (Skip A) mainly included timber, reinforcement bars and concrete/aggregates in nylon bags (Photo 55).
- The second skip (Skip B) mainly contained construction waste of timber and carton boxes (Photo 56).
- Apart from the two skips, there were two temporary dumping locations on site. Construction waste found at the first location (Area A) mainly consisted of timber, cartoon boxes and plastic tubes (Photo 57).
- Construction waste observed at the second location (Area B) mainly consisted of timber, scraps of metal hoarding and cuts of plastic tube (Photo 58).

2.4. Waste Management Measures Observed on Site

The site was registered under the BEAM PLUS for new buildings version 1.1. Site operations were organised to reduce waste generation. The management measures observed on site were:

- A specific storage area was set for construction materials delivered to site (Photo 59).
- Each material was stored neatly at a dedicated location in the storage area. (Photos 60-62).
- Precast panels were used (Photo 63).
- Metal scaffolding was used for the construction of high-rise buildings (Photo 38).
- Aluminium System Formwork was used. This type of formwork was expected to be used for more than 40 times (i.e. until the end of the project) (Photos 44-45).
- Pumping was the main method being used for transporting concrete for construction (Photos 46-47).
- Construction waste was temporary stored in skips. There were two skips noted on site (Photos 64-65).
- Special metal bin for chemical waste and plastic bin for food waste were provided (Photo 66).
- 3-coloured bins for collecting domestic waste for recycling were provided (Photo 67).

- Construction wastes were reused on site. Surplus concrete was used for temporary road surfacing (Photo 68) and for forming concrete blocks for temporary usage (Photo 69). Scraps of timber were reused as door frame (Photo 70). Larger pieces of timber remains were put aside for reuse (Photo 71).

Photo 37: Bamboo Scaffolding

Photo 38: Metal Scaffolding

Photo 39: Timber Formwork for Decking of Low-Rise Buildings

Photo 40: Timber Formwork for Beam of Low-Rise Buildings (1)

Photo 41: Timber Formwork for Beam of Low-Rise Buildings (2)

Photo 42: Preparation Area of Timber Formwork

Photo 43: Cutting Timber on Site

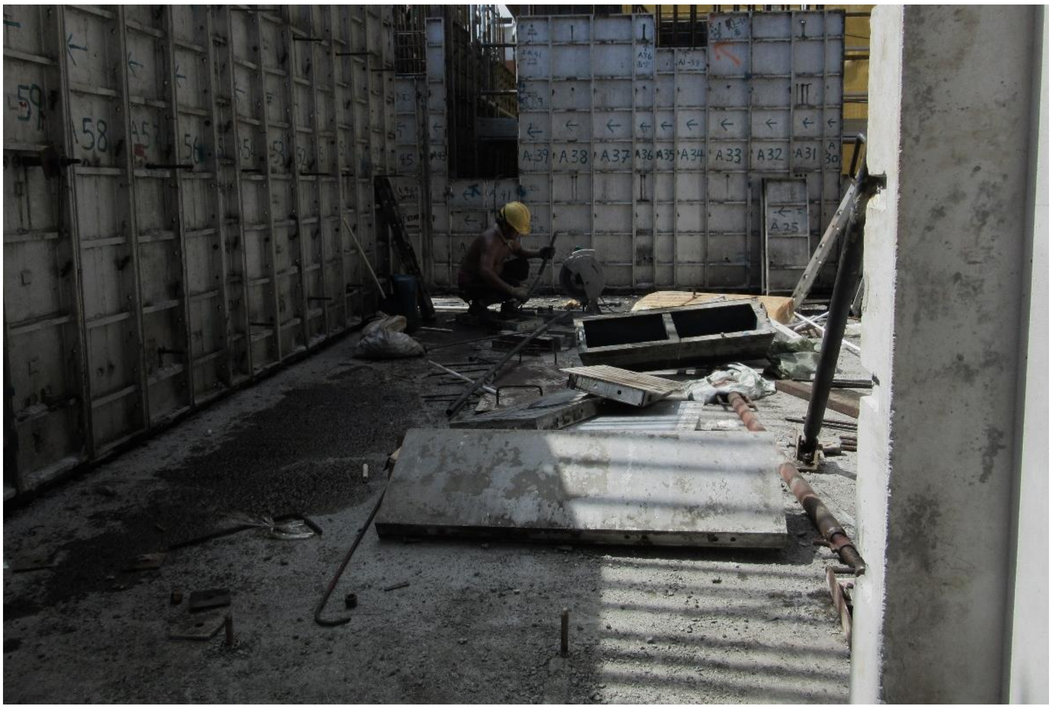


Photo 44: Aluminium System Formwork (1)

Photo 45: Aluminium System Formwork (2)

Photo 46: Concreting by Pumping

Photo 47: Concreting – in Progress

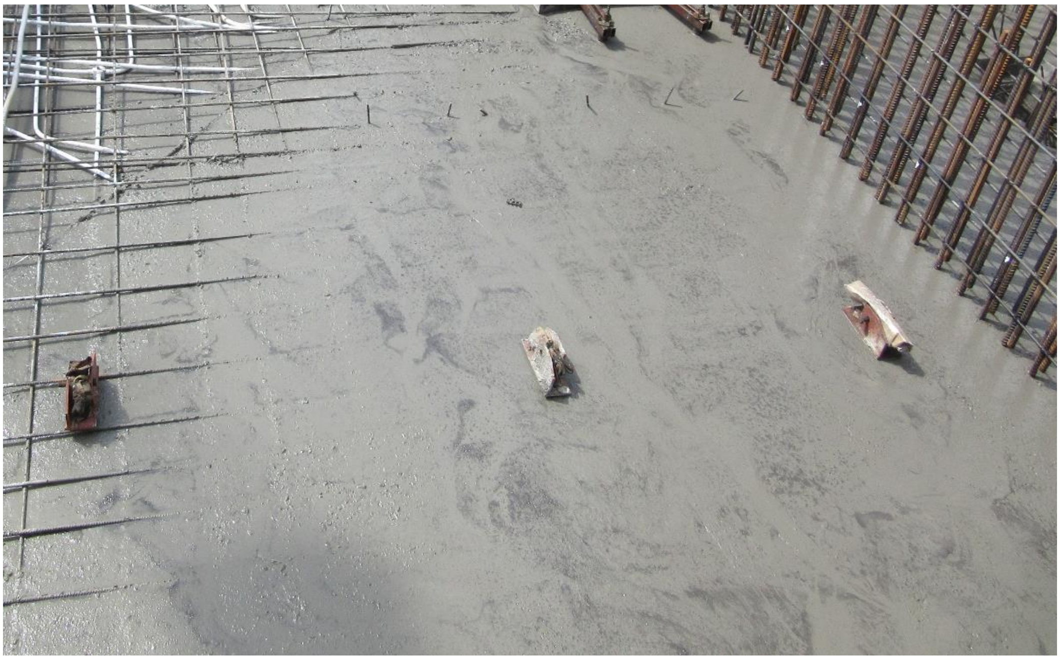


Photo 48: Concreting – Half of the Floor Completed

Photo 49: Completion of Concreting

Photo 50: Concreting by "Crane + skip"

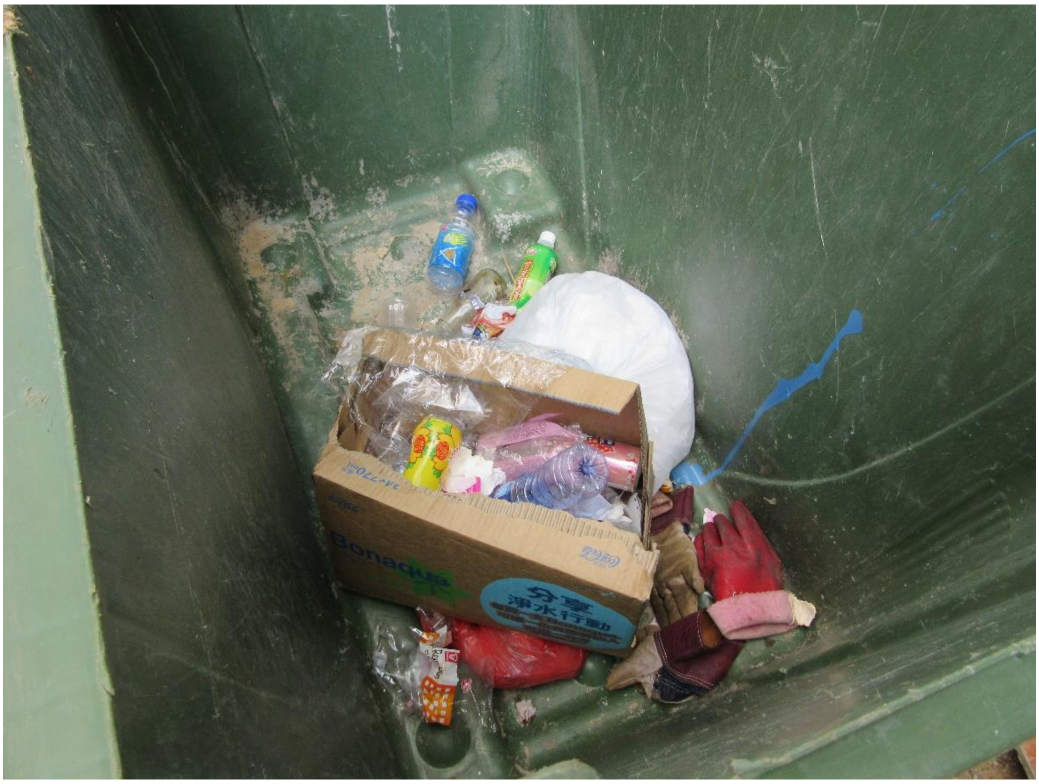


Photo 51: Wastes inside Bin

Photo 52: Construction Wastes Noted Near to Concreting Area

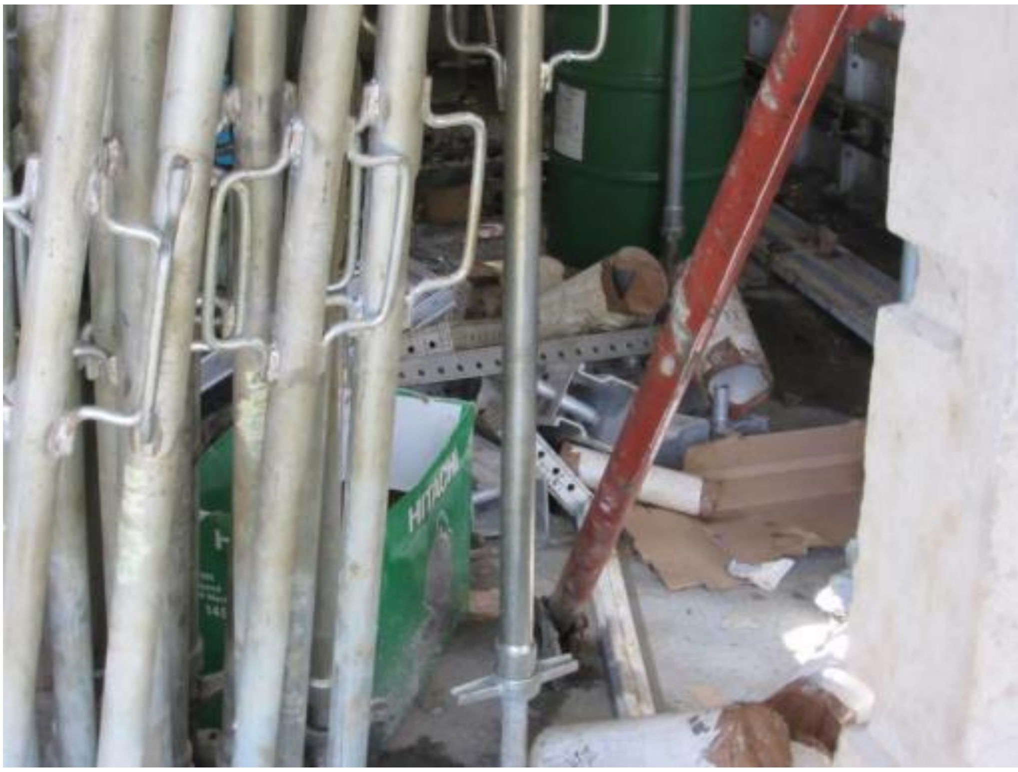


Photo 53: Construction Wastes Noted in the Working area of Aluminium System Formwork

Photo 54: Used Timber to be sorted after Removal of Timber Formwork

Photo 55: Contents of Construction Waste in Skip A

Photo 56: Contents of Construction Waste in Skip B

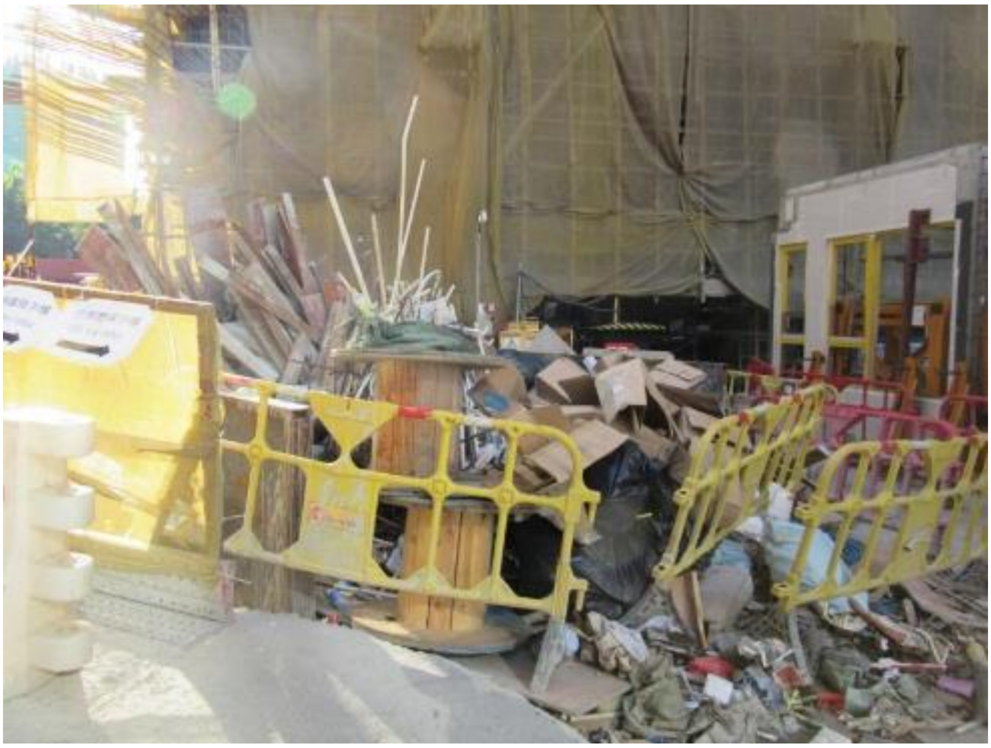


Photo 57: First Temporary Dumping Location (Area A)

Photo 58: Second Temporary Dumping Location (Area B)

Photo 59: Specific Construction Material Temporary Storage Space

Photo 60: Metal Scaffold Temporary Storage

Photo 61: Temporary Storage for Reinforcement Bars

Photo 62: Temporary Storage for Timber

Photo 63: Use of Precast Units

Photo 64: Storing Construction Waste in Skip A

Photo 65: Storing Construction Waste in Skip B

Photo 66: Special Metal Bin for Chemical Waste and Plastic Bin for Food Waste

Photo 67: 3-coloured Bins for Collecting Domestic Waste for Recycling

Photo 68: Surplus Concrete for Paving Temporary Access

Photo 69: Concrete blocks made of Surplus Material for Temporary Usage

Photo 70: Reuse of Scraped Timber for Frame of Temporary Door

Photo 71: Scraped Timber to be Reused on Site

3. Site C

Two visits to Site C were conducted on 25 and 26 July 2016 respectively. During the site visit, a meeting with the on-site Environmental Officer was held and different parts of the site were visited.

The works of Site C consist of construction of 22 numbers of 2-storeyed house, eight blocks of 9 to 15-storeyed building with commercial podium, clubhouse, basement car park and associated external works. Figure 3 shows the general view of the site.

Figure 3 General View of Site C

At the time of the visits, the site work was at its initial to mid-stage of construction. Construction activities were carried out on the basement car park, podium and low floor levels. Others construction activities included external works such as provision of temporary roads and sub-surface construction etc.

The concise notes (mainly in point form) of the meeting with the Environmental Officer and a summary of observations made during the site visits are as follows.

3.1. Notes/Points Taken During the Meeting with Environment Officer

The notes of meeting with the Environmental Office are summarised and organised under the following topics: Measures to Reduce Waste, General Practice, Waste Handling and Disposal, and Construction Activity Highlights.

Measures to Reduce Waste:

- Management measures to minimise waste;
- The use of green practices of Beam Plus on C&D waste management;
- On-site practice to minimise waste;
- Steel scrap recycling;
- Off-site sorting.

General Practice:

- Methods of transporting wastes from buildings;
- Methods of maintaining records of disposed and recycled materials.

Waste Handling and Disposal:

- Locations of fills being used.

Construction Activity Highlights:

- Timber formworking;
- Reinforcement fixing;

- Concreting.

3.1.1. Measures to Reduce Waste

Management measures to minimise waste

- Subcontractors being responsible for the provision of most construction materials to minimise waste.

The use of green practices of Beam Plus on C&D waste management

- Use of waste recycling facilities: such as use of different skips to contain different types of construction waste;
- Use of modular and standardised design for typical floor to facilitate the use of aluminium system formwork;
- Use of prefabrication: such as precast façade, kitchen and toilet etc;
- Use of dry wall;
- Use of rapidly renewable materials: such as eco-friendly timber;
- Use of sustainable forest products;
- Use of recycled material;
- Construction waste reduction: 30% reduction estimated.

On-site practice to minimise waste

- Use of steel hoarding;
- Use of metal falsework;
- Use of metal scaffolding;
- Use of large panel formwork;
- Use of aluminium formwork;
- Use of precast façade;
- Use of dry wall in masonry work;
- Use of on-site sorting;

- Use of chit ticket system;
- Separate collection of inert and non-inert wastes;
- On-site sorting of different types of waste;
- Reuse of materials whenever possible: such as reuse of timber, reuse of metal, reuse of concrete as hardcore;
- Use of two refuse chutes to transport inert and non-inert wastes from buildings in the future.

Steel Scraps Recycling

- Recycling of scraps of reinforcement bars;
- Recycling of ends/remains of structural steel beams;
- Recyclers: recyclers at container terminals and other authorised recyclers.

Off-site sorting

- Off-site sorting not being used.

3.1.2. General Practice

Methods of transporting waste from buildings

- Use of crane to transport the skips of construction wastes to the temporary waste storage area at the ground level.

Methods of maintaining records of disposed and recycled materials

- Estimation of the required materials before each work starts;
- Use of QS measurement;
- Use of monthly environmental report to monitor;
- Use of filing system for notes of delivery;
- Use of Chit ticket system:
  - Main contractor to keep Part A;

- Waste hauler to retain Part B;
- Government to retain Part C.

3.1.3. Waste Handling and Disposal

<u>Locations of fills being used:</u>

- Public fill: TKO;
- Land fill: SENT.

3.1.4. Construction Activity Highlights

<u>Timber formworking</u>

- The main contractor is responsible for choosing the competent company that is capable to select types of timber to fulfill specification requirements.
- The reasons of choosing timber are: 1) less time in planning; 2) higher construction speed; and 3) flexible to change design if needed;
- The types of timber used are plywood from Mainland and softwood timber from Canada respectively;
- The timber supplier is responsible to deliver the material to site;
- The main contractor assigns the area for timber storage. The subcontractor is responsible for storing the material.
- The subcontractor is responsible for ordering the material, recording the quantity, unloading, cutting and installation;
- The subcontractor is responsible for transporting the formwork material to working levels;
- Crane is being used to transport timber on site;
- The main contractor is responsible for handling the timber waste.
- Timber scraps are sent to land fill sites;
- There is no market value of timber scraps. The main contractor has not contacted any recycling company.

Reinforcement fixing

- The allowable wastage level of reinforcement is 4%;
- The actual wastage level is below 4%;
- The subcontractors will be fined if the allowable wastage level of reinforcement cannot be achieved;
- Based on the construction drawings, the quantities of reinforcement are calculated;
- The subcontractor is responsible for calculating the reinforcement quantity and initiate the subsequent ordering procedure. Upon receiving the request from the subcontractor, the main contractor place order to the supplier;
- Reinforcement supplier is responsible for delivering the material to site.
- A laboratory is employed to check the material quality;
- The subcontractor is responsible for unloading, transporting and storing the material to the working levels.
- Crane is being used to transport the material on site;
- The subcontractor is responsible for reinforcement cutting.
- The subcontractor is responsible for handling cutting scraps. The cutting scraps are sent to recycler;
- The subcontractor is responsible for the reinforcement fixing process. There is no record of careless handling from workers (i.e. no waste is generated due to worker mishandling).

Concreting

- The allowable wastage level of concrete is 4%;
- The actual wastage level is below 3%;
- The subcontractors will be fined if the allowable wastage level of concrete cannot be achieved;
- Based on the information of working drawings and the actual volume measured on site, the quantities of concrete are calculated;

- The main contractor is responsible for calculating the concrete quality, and the subsequent ordering and recording. There is no record of mishandling in these processes (i.e. there is no waste generated due to mishandling);
- Both the main contractor and the consultant are responsible for quality checking;
- A laboratory operated by a specialist company is responsible for conducting slump test; so far, all concrete ordered passed the slump test;
- Concrete supplier is responsible for transporting the material to site.
- The subcontractor is responsible for unloading the concrete and transporting the material to the working levels. Crane and pump are used.
- No waste concrete generated during these operations. It is suggested that the fitness of concreting machinery is checked frequently to avoid unnecessary waste generation;
- The subcontractor is responsible for the concreting process. There is no record of careless handling from workers (i.e. no waste is generated due to worker mishandling).

3.2. Work Trades Observed on Site

During the two-day site visit, the following work trades in operation were observed:

- Preparation of Reinforcement Bars (Photo 72).
    - ➢ Reinforcement bars were cut to size and bent to required shapes.
- Fixing of Timber Formwork (Photo 73).
    - ➢ Timber formwork was used for the construction work at levels of podium and basement.
- Installation of Aluminium System Formwork (Photos 74-76).
    - ➢ Aluminium system formwork was used for the construction of building structure above podium level.
- Concreting (Photos 77-79).
    - ➢ Pumping was used for transporting concrete for construction.

3.3. Waste Observed on Site

Main construction wastes observed during the two-day site visit were as follows:

- A lot of timber scraps were found at different locations at the ground floor level (Photos 80-81).
- Wastes of water bottles, timber and metal scraps were noted at another location of the ground level (Photo 82).
- Contents of construction waste in a skip (Skip A) mainly consisted of nylon canvas, ends of plastic tube, steel bars and cables (Photo 83).
- Contents of construction waste in another skip (Skip B) mainly consisted of nylon net and softwood timber (Photo 84).
- Contents of construction waste in the third skip (Skip C) mainly consisted of paper boxes, cloth and domestic waste (Photo 85).
- The contents of construction waste at a temporary dumping location mainly consisted of timber pallet, cable, damaged aluminium formwork, nylon bags and steel scraps (Photo 86).

3.4. Waste Management Measures Observed on Site

The site was registered under the BEAM PLUS for new buildings version 1.1. Site operations were organised to reduce waste generation. The management measures observed on site were:

- A temporary space at the ground level was set specifically for storing construction materials (Photo 87).
- Steel scaffolding members were stacked in rack at the temporary storage area (Photo 88).
- Small skips were used for collecting construction waste at each working location (Photos 89-90).
- Large skip for collecting waste was used at the ground level (Photo 91).
- There was a temporary dumping location at the ground level for collecting construction waste (Photo 92).

- Grab mounted lorry was used to remove waste from waste storage area at ground level daily (Photos 93-94).
- Reinforcement scraps were sorted for recycling (Photos 95-96).
- Ends of steel beams are to be recycled (Photo 97).
- Large pieces of used plywood were put aside for reuse (Photo 98).
- Plastic packaging of aluminium system formwork are to be reused (Photo 99).

Photo 72: Preparation of Reinforcement Bars

Photo 73: Timber Formworking

Photo 74: Installing of Aluminium Formwork (1)

Photo 75: Installing of Aluminium Formwork (2)

Photo 76: Installation of Aluminium Formwork (3)

Photo 77: Pouring Concrete to the Pumping Machine

Photo 78: Pipe System of Concrete Pumping Machine

Photo 79: Concreting by Pumping

Photo 80: Timber Waste after Removal of Timber Formwork (1)

Photo 81: Timber Waste after Removal of Timber Formwork (2)

Photo 82: Waste of Water Bottles, Timber and Metal Scraps

Photo 83: Contents of Construction Waste in Skip A (Mainly Consisting of Nylon Canvas, Steel Bar & Cable etc.)

Photo 84: Contents of Construction Waste in Skip B (Mainly Consisting of Nylon Net, Timber etc.)

Photo 85: Contents of Construction Waste in Skip C (Mainly Consisting of Paper Box, Cloth and Domestic Waste etc.)

Photo 86: Contents at a Temporary Dumping Location (Mainly Consisting of Timber Pallet, Cable, nylon bags and Steel Scraps etc.)

Photo 87: Specific Construction Material Temporary Storage Space

Photo 88: Metal Scaffold Temporary Storage

Photo 89: Small Skip for Collecting Waste at the Working Area (1)

Photo 90: Small Skip for Collecting Waste at the Working Area (2)

Photo 91: Large Skip for Collecting Waste at Ground Level

Photo 92: Dedicated Location for Collecting Construction Waste

Photo 93: Removal of Construction Waste by Grab Mounted Lorry (1)

Photo 94: Removal of Construction Waste by Grab Mounted Lorry (2)

Photo 95: Reinforcement Scraps Sorted for Recycling (1)

Photo 96: Reinforcement Scraps Sorted for Recycling (2)

Photo 97: Ends of Steel Beams for Recycling

Photo 98: Timber for Reused

Photo 99: Plastic Packaging of Aluminium System Formwork for Reuse

REPORT 5

REPORT OF CONSTRUCTION WASTE SORTING

August 2017

Table of Contents

1. Introduction

Sorting of non-inert construction wastes from three residential building sites (Site A, Site B and Site C) were conducted on 29-30 July 2016 and 8-10 August 2016. During these periods of time, a total of ten trucks of construction waste were sorted: four from Site A, three from Site B and three from Site C. (Waste sorting works were stopped by adverse weather in the period between 31 July and 7 August 2016.)

Table 1 Date of Construction Waste Sorting

Site	Time
Site A	29 and 30 July 2016
Site B	8 and 9 August 2016
Site C	8 and 10 August 2016

Site A consists of construction of thirteen numbers of 2-storeyed house, nine blocks of low-rise 7 to 11-storeyed building with commercial podium, clubhouse, basement car park and associated external works. The site work was at its end stage of construction – construction activities were being carried out in the low-rise buildings. The main site activities included installing of electrical fittings, installation of sanitary fillings, brickwork, tiling and floor finishing etc.

Site B consists of construction of five blocks of high-rise 40-storeyed building and three blocks of low-rise 12-storeyed building, and five numbers of footbridge. The construction period of the site is 1200 days. The site work was at its mid-stage of construction (at about 500 days) – construction activities were being carried out on the 11th floor of the high-rise buildings and construction of the low-rise buildings was at the podium level. Other construction activities included external works such as provision of temporary roads and sub-surface construction etc. Construction of footbridges had not been started yet.

Site C consists of construction of twenty-two numbers of 2-storeyed house, eight blocks of 9 to 15-storeyed building with commercial podium, clubhouse, basement car park and associated external works. The site work was at its initial to mid-stage of construction – construction activities were being carried out at the basement car park, podium and low floor levels. Other construction activities included external works such as provision of temporary roads and sub-surface construction etc.

Upon receiving each truck of the construction waste, the material was unloaded on a concrete platform, spread out and divided into four equal parts (as shown in Figure 1). Sorting was carried out on two of the parts according to Table 2.

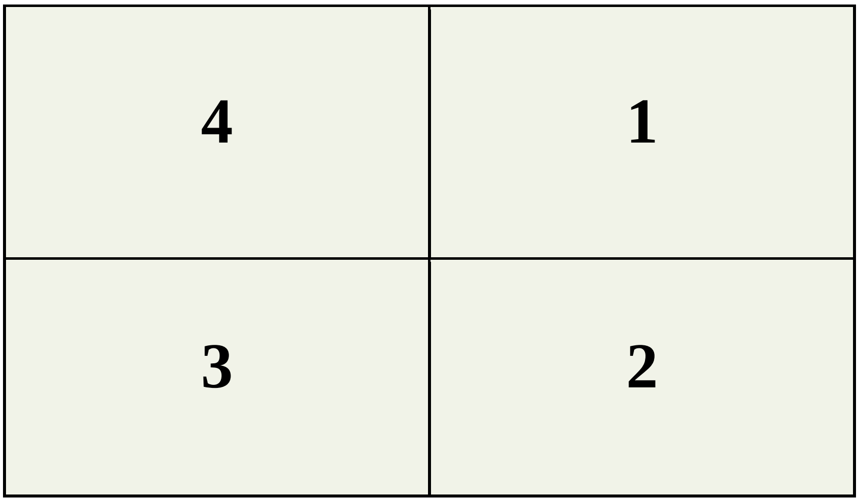


Figure 1 Construction Waste Divided into four Parts

Table 2 Selection of Part

Truck No.	**Site**	**Part**			
		1	**2**	**3**	**4**
1	A	✓		✓	
2			✓		✓
3		✓		✓	
4			✓		✓
5	B	✓		✓	
7			✓		✓
8		✓		✓	
6	C		✓		✓
9		✓		✓	
10			✓		✓

This report provides a summary of observations and sorting result analysis of the construction wastes obtained from the three sites. Section 1 gives a concise introduction of the work arrangement. Section 2 reports the waste sorting work at the site at Shek Mun, and Section 3 presents the results of analysis and the findings.

2. Waste Sorting

The construction waste sorting activities were conducted at the research ground of PolyU at Shek Mun (Figure 2). The sorting area was a concrete platform with a surface area of 24m by 7.3m (Photo 1).

Figure 2 Location Plan of Waste Sorting at Shek Mun

Photo 1 Waste Sorting Area

Non-inert wastes from the three sites were sorted into 33 types/groups: bamboo, wooden floor tile, formwork, wooden pallet, wooden door, packaging timber, metal door, metal window frame, iron/copper pipe, metal sink, rebar, aluminium scrap, metal container, steel scraps, cardboard, packaging paper, other paper, plastic wrapping, plastic container, PVC duct, cable, plastic traffic barrier, window seal container, rubber, WEEE, vegetation, textile fiberglass, nylon, biodegraded waste, sanitary ware, Styrofoam, gypsum board and glass. After separating the non-inert waste from the construction waste, there was no further sorting for the inert waste. The inert wastes consisted of rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt and brick etc. Table 3 presents the form for recording the different types of construction waste. As shown in the table, apart from recording details of different types of construction waste, the table also collects information of date, weather, person taking record, site number (relating to where the waste came from), in-coming truck (arrival time and licence plate number), beginning and completion time of sorting, selected portions for sorting, grab mounted lorry after sorting (licence plate number), chit ticket number, and the total load of construction waste stated on chit ticket.

2.1. Staff and Equipment

The site working team consisted of twelve trained students/research assistants (on average), a technical officer and a manager. A 6-tonne backhoe was used to even and move the construction waste at the sorting platform. A grab mounted lorry was hired to send the construction waste away after completion of the sorting work of each load. Other equipment used were digital camera with video capturing function, mobile phones, three numbers of 120-150kg balance, thirty numbers of container/bucket, six numbers of shovel, and some hand tools. (A big nylon canvas was used at the beginning of the sorting process to separate the construction waste from the sorting platform; however, it was found that use of the canvas was unnecessary.)

2.2. Health and Safety

For the working team, drinking water, standard personal protection equipment (such as safety helmet, dust mask, general purpose gloves, blade cut resistance gloves, goggles against flying particles and fluorescent jacket etc.), first aid box and "Level C" safety equipment for handling chemical waste were provided. Insect/mosquito repellent and sunburn lotion were supplied. Two temporary tents and a large-sized umbrella were also provided.

2.3. Work Sequence (photos of work sequence are presented in Appendix A)

When a truck of construction waste arrived, the manager or the technical officer directed the truck to the waste sorting area for unloading. Photos A1 – A6 show the materials from the three sites. After unloading the waste on the sorting platform, the backhoe spread the construction waste evenly on the platform (Photos A7-A8). The team divided the waste into 4 equal portions with nylon string (Photos A9 and A10). Materials in two of the parts were sorted manually (Photos A13-14). Bags containing wastes were emptied for sorting. The sorted materials were weighted (Photos A17-A19). The remaining materials (i.e. the inert wastes) after separating the non-inert material from the bulk of construction waste were grouped together and weighted. For large blocks of concrete, the dimensions (length, width and height) of the blocks were measured (Photo A20) and their weights were estimated by using a standard density. Upon finishing all the sorting and weighting works, the construction waste was removed by a grab mounted lorry.

Table 3 Record Form for Waste Sorting

Date:	**Weather:**			**Site no.:**
Lorry arrival time:			**Grab mounted truck arrival time:**	
Lorry no.:			**Grab mounted truck licence plate no.:**	
Lorry licence plate no.:			**Chit ticket no.:**	
Sorting time (beginning):			**Total load of construction waste stated on chit ticket:**	
Sorting time (completion):				
Parts sorted:			**Recorded by:**	
Remark:				

Material	**Group**	**Waste type (Group)**	**Sub-group number**	**Sub-group type**	**Weight (kg)**
Non-inert	1	Bamboo	-	no sub-group	
	2	Wood & Timber	2a	wooden floor tile	
			2b	formwork	
			2c	wooden pallet	
			2d	wooden door	
			2e	packaging timber	
			2f	others	
	3	Metal	3a	metal door	
			3b	metal window frame	
			3c	iron / copper pipe	
			3d	metal sink	
			3e	rebar	
			3f	aluminum	
			3g	metal containers for material packaging	
			3h	steel scrap	
			3i	others	
	4	Paper & Cardboard	4a	cardboard	
			4b	packaging paper	
			4c	others (newspaper, office paper etc.)	
	5	Plastic & Rubber	5a	plastic wrapping	
			5b	plastic container	
			5c	PVC duct	
			5d	cable	
			5e	plastic traffic barrier	
			5f	window seal container	
			5g	rubber	
			5h	others	
	6	WEEE	-	Electric appliance, electric socket, lighting, water pump, electric motor, transformer (i.e. no sub-group)	
	7	Vegetation	-	Tree trunk etc. (no sub-group)	
	8	Textile	-	no sub-group	
	9	Fibreglass	-	no sub-group	
	10	Nylon	-	no sub-group	
	11	Domestic Waste	-	Food waste etc. (i.e. no sub-group)	
	12	Sanitary Ware	-	Porcelain water closet, porcelain wash hand basin, kitchen solid surface material etc. (i.e. no sub-group)	
	13	Styrofoam	-	no sub-group	
	14	Gypsum Board	-	Gypsum drywall etc. (i.e. no sub-group)	
	15	Glass	-	no sub-group	
	16	Others (to be	-	-	
Inert	17	Inert	-	Rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt, brick & tile etc (i.e. no sub-group)	
				Total weight:	

3. Analysis and Findings

The sorting results, together with the respective pie charts, are presented in Appendix B, in which the appendix includes four parts (Part 1 for Site A, Part 2 for Site B and Part 3 for Site C). The overall analysis is presented in Part 4. As shown in the Tables B1, B2 and B3 of the appendix, materials of similar nature were also grouped into categories. Materials of wooden floor tile, formwork, wooden pallet, wooden door and packaging timber were grouped into the category of "Wood & Timber". Materials of metal door, metal window frame, iron/copper pipe, metal sink, rebar, aluminium, metal container for material packing and steel scrap were under the category of "Metal". Materials of cardboard and packaging paper were under "Paper & Cardboard". Materials of plastic wrapping, plastic container, PVC duct, cable, plastic traffic barrier, window seal container and rubber were under "Plastic & Rubber". The main observations and findings of the analysis are:

- As expected, there were great variation of components, in terms of type and quantity, between trucks, partly due to the limited sample size and partly due to the different stages of construction.
- For the ten trucks of construction waste, chemical waste was not noted; and vegetation, fibreglass, gypsum board and glass were not found in this sorting study.
- Table 4 presents the grand summary, showing the overall average compositions of the contents of the three sites. The percentages of non-inert waste in the construction waste were 38% in Site A, 61% in Site B, 40% in Site C and 47% overall.
- Wood & Timber was the major non-inert waste: 19% in Site A, 53% in Site B, 32% in Site C and 36% overall.
- Comparison between the three sites suggests that Site B, at its middle construction stage, generated the highest percentage of "Wood & Timber" waste (53%). Site C, at its initial to middle construction stage also produced relatively high amount of "Wood & Timber" waste (32%). In both cases, the high "Wood & Timber" waste generation was due to the use of formwork timber.

Table 4 Grand Summary of Construction Waste Composition

Waste	**Site A**	**Site B**	**Site C**	**All sites**
Wood & Timber	19%	53%	32%	36%
Metal	7%	5%	5%	6%
Paper & Cardboard	5%	0%	0%	2%
Plastic & Rubber	3%	1%	1%	2%
Other Non-inert	4%	2%	2%	2%
Total Non-inert	**38%**	**61%**	**40%**	**47%**
Total Inert	62%	39%	60%	53%

Appendix A - Photos of Sorting Works

Photo A1: Debris from Site A (I)

Photo A2: Debris from Site A (II)

Photo A3: Debris from Site B (I)

Photo A4: Debris from Site B (II)

Photo A5: Debris from Site C (I)

Photo A6: Debris from Site C (II)

Photo A7: Using Backhoe to Even the Debris (I)

Photo A8: Using Backhoe to Even the Debris (II)

Photo A9: Division of Debris into 4 Parts (I)

Photo A10: Division of Debris into 4 Parts (II)

Photo A11: Sorting Process (I)

Photo A12: Sorting Process (II)

Photo A13: Sorting Process (III)

Photo A14: Sorting Process (IV)

Photo A15: Completion of Sorting (I)

Photo A16: Completion of Sorting (II)

Photo A17: Quantifying of Each Type of Materials (I)

Photo A18: Quantifying of Each Type of Materials (II)

Photo A19: Quantifying of Each Type of Materials (III)

Photo A20: Quantifying of Each Type of Materials (IV)

Photo A21: Major Construction Waste from Site A (I)

Photo A22: Major Construction Waste from Site A (II)

Photo A23: Some Other Construction Waste from Site A (I)

Photo A24: Some Other Construction Waste from Site A (II)

Photo A25: Major Construction Waste from Site B (I)

Photo A26: Major Construction Waste from Site B (II)

Photo A27: Some Other Construction Waste from Site B (I)

Photo A28: Some Other Construction Waste from Site B (II)

Photo A29: Major Construction Waste from Site C (I)

Photo A30: Major Construction Waste from Site C (II)

Photo A31: Some Other Construction Waste from Site C (I)

Photo A32: Some Other Construction Waste from Site C (II)

Photo A33: Clearing Construction Waste after Sorting (I)

Photo A34: Clearing Construction Waste after Sorting (II)

Appendix B - Details of Analysis

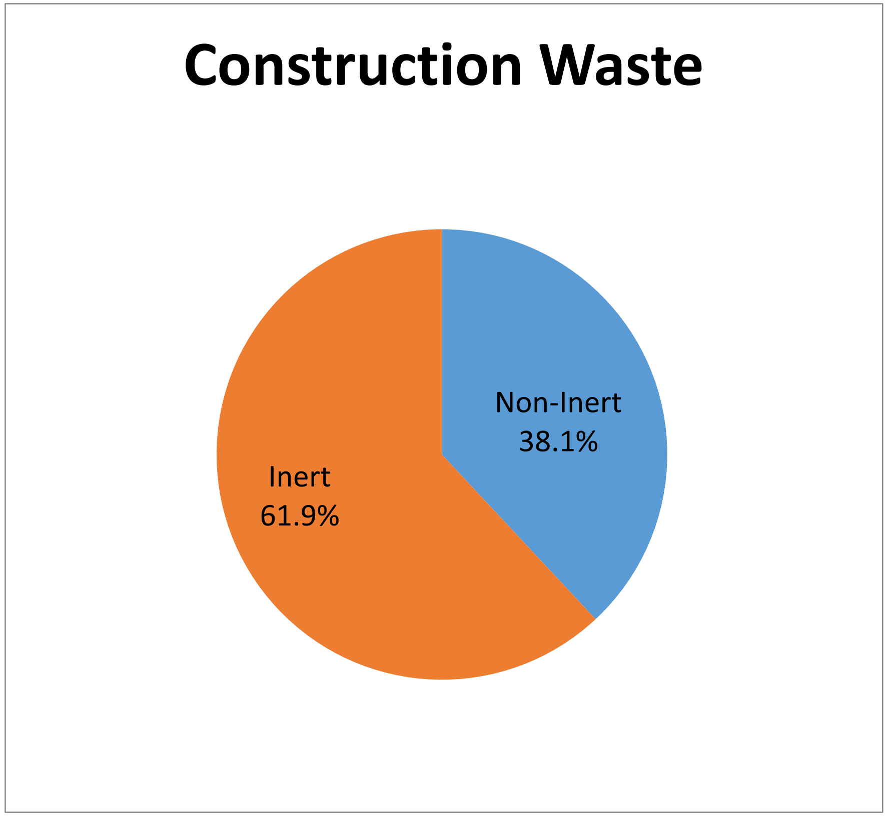
Part 1

Site A

Table B1: Site A

					A-1	A-2	A-3	A-4	A-1	A-2	A-3	A-4	Site A	
Material	Group	Waste type (Group)	Sub-group	Sub-group type	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)	Percentage (%)	Percentage (%)	Percentage (%)	Percentage (%)	Weight (kg)	Percentage (%)
Non-inert	1	Bamboo	-	no sub-group	-	-	-	-	-	-	-	-	-	-
	2	Wood & Timber	2a	wooden floor tile	-	-	-	-	-	-	-	-	-	-
			2b	formwork	102.2	29.5	75.5	199.6	40.1%	4.0%	9.9%	14.2%	406.9	12.9%
			2c	wooden pallet	108.5	44.9	-	11.0	42.6%	6.1%	-	0.8%	164.3	5.2%
			2d	wooden door	-	-	-	-	-	-	-	-	-	-
			2e	packaging timber	39.4	-	-	-	15.5%	-	-	-	39.4	1.2%
			2f	others	0.9	2.4	-	2.0	0.4%	0.3%	-	0.1%	5.3	0.2%
					-	-	-	-	-	-	-	-	-	-
				Total weight of sub-group:	251.0	76.8	75.5	212.6	98.5%	10.5%	9.9%	15.1%	615.9	19.5%
	3	Metal	3a	metal door	-	-	-	-	-	-	-	-	-	-
			3b	metal window frames	-	-	-	-	-	-	-	-	-	-
			3c	iron / copper pipe	-	-	-	-	-	-	-	-	-	-
			3d	metal sink	-	-	-	-	-	-	-	-	-	-
			3e	rebar	0.8	16.2	12.9	3.0	0.3%	2.2%	1.7%	0.2%	32.8	1.0%
			3f	aluminum	-	2.4	1.9	4.8	-	0.3%	0.2%	0.3%	9.1	0.3%
			3g	metal container for material packaging	-	0.2	-	7.7	-	0.0%	-	0.5%	7.9	0.2%
			3h	steel scrap	-	37.9	74.9	43.3	-	5.2%	9.8%	3.1%	156.0	4.9%
			3i	others	-	-	-	-	-	-	-	-	-	-
				Total weight of sub-group:	0.8	56.6	89.6	58.8	0.3%	7.7%	11.7%	4.2%	205.8	6.5%
	4	Paper & Cardboard	4a	cardboard	0.1	18.3	28.9	42.0	0.0%	2.5%	3.8%	3.0%	89.2	2.8%
			4b	packaging paper	0.1	36.6	9.1	8.6	0.0%	5.0%	1.2%	0.6%	54.4	1.7%
			4c	others (newspaper, office paper etc.)	-	-	9.1	8.6	-	-	1.2%	0.6%	17.7	0.6%
				Total weight of sub-group:	0.2	54.9	47.1	59.1	0.1%	7.5%	6.1%	4.2%	161.2	5.1%
	5	Plastic & Rubber	5a	plastic wrapping	2.5	18.0	6.1	18.7	1.0%	2.5%	0.8%	1.3%	45.2	1.4%
			5b	plastic container	-	-	-	3.4	-	-	-	0.2%	3.4	0.1%
			5c	PVC duct	-	4.7	1.6	2.9	-	0.6%	0.2%	0.2%	9.2	0.3%
			5d	cable	-	5.6	1.1	2.6	-	0.8%	0.1%	0.2%	9.2	0.3%
			5e	plastic traffic barrier	-	13.0	-	-	-	1.8%	-	-	13.0	0.4%
			5f	window seal container	-	6.3	0.8	5.2	-	0.9%	0.1%	0.4%	12.3	0.4%
			5g	rubber	-	0.8	-	1.9	-	0.1%	-	0.1%	2.7	0.1%
			5h	others	-	-	2.3	-	-	-	0.3%	-	2.3	0.1%
				Total weight of sub-group:	2.5	48.4	11.8	34.7	1.0%	6.6%	1.5%	2.5%	97.3	3.1%
	6	WEEE	-	Electric appliance, electric socket, lighting, water pump, electric motor, transformer (i.e. no sub-group)	-	-	1.5	-	-	-	0.2%	-	1.5	0.0%
	7	Vegetation	-	Tree trunk etc. (no sub-group)	-	-	-	-	-	-	-	-	-	-
	8	Textile	-	no sub-group	-	0.3	6.9	11.7	-	0.0%	0.9%	0.8%	18.9	0.6%
	9	Fibreglass	-	no sub-group	-	-	-	-	-	-	-	-	-	-
	10	Nylon	-	no sub-group	0.1	3.2	11.5	34.5	0.0%	0.4%	1.5%	2.4%	49.2	1.6%
	11	Domestic Waste	-	Food waste etc. (i.e. no sub-group)	-	2.6	23.0	9.0	-	0.3%	3.0%	0.6%	34.5	1.1%
	12	Sanitary Ware	-	Porcelain water closet, porcelain wash hand basin, kitchen solid surface material etc. (i.e. no sub-group)	-	-	-	2.4	-	-	-	0.2%	2.4	0.1%
	13	Styrofoam	-	no sub-group	0.2	3.4	0.8	12.1	0.1%	0.5%	0.1%	0.9%	16.5	0.5%
	14	Gypsum Board	-	Gypsum drywall etc. (i.e. no sub-group)	-	-	-	-	-	-	-	-	-	-
	15	Glass	-	no sub-group	-	-	-	-	-	-	-	-	-	-
	16	Others (to be descripted)	-	-	-	-	-	-	-	-	-	-	-	-
				Total weight of non-inert	254.8	246.1	267.5	434.7	100.0%	33.6%	34.9%	30.9%	1203.2	38.1%
Inert	17	Inert	-	Rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt, brick & tile etc (i.e. no sub-group)	-	487.1	498.0	973.8	-	66.4%	65.1%	69.1%	1958.9	61.9%
				Total weight:	254.8	733.2	765.5	1408.5	100.0%	100.0%	100.0%	100.0%	3162.0	100.0%

Site A



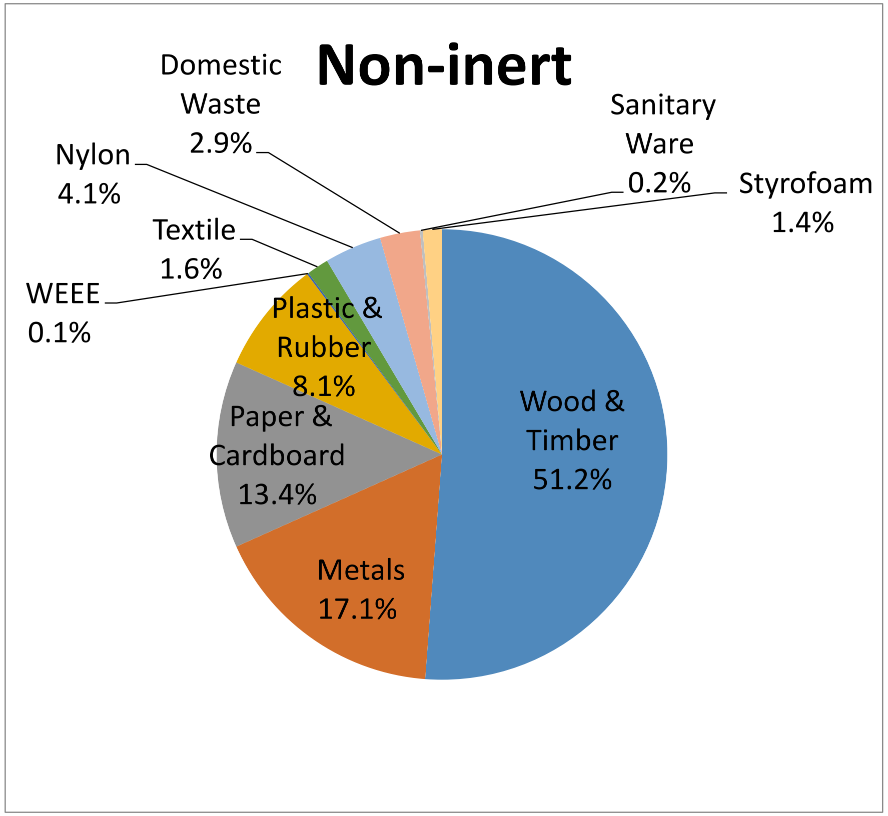


Figure B1: Sorting Results of Site A (I)

Site A

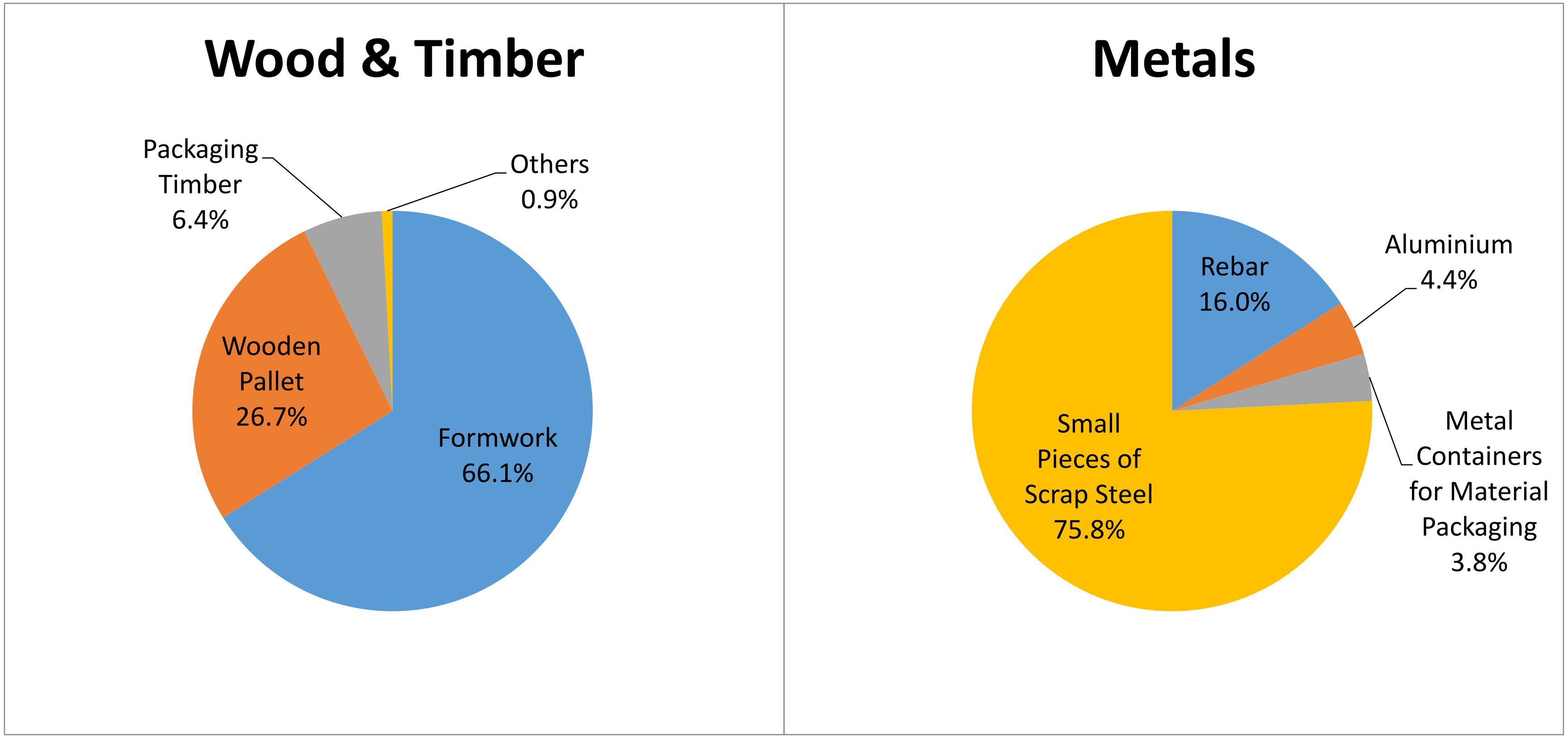


Figure B2: Sorting Results of Site A (II)

Site A

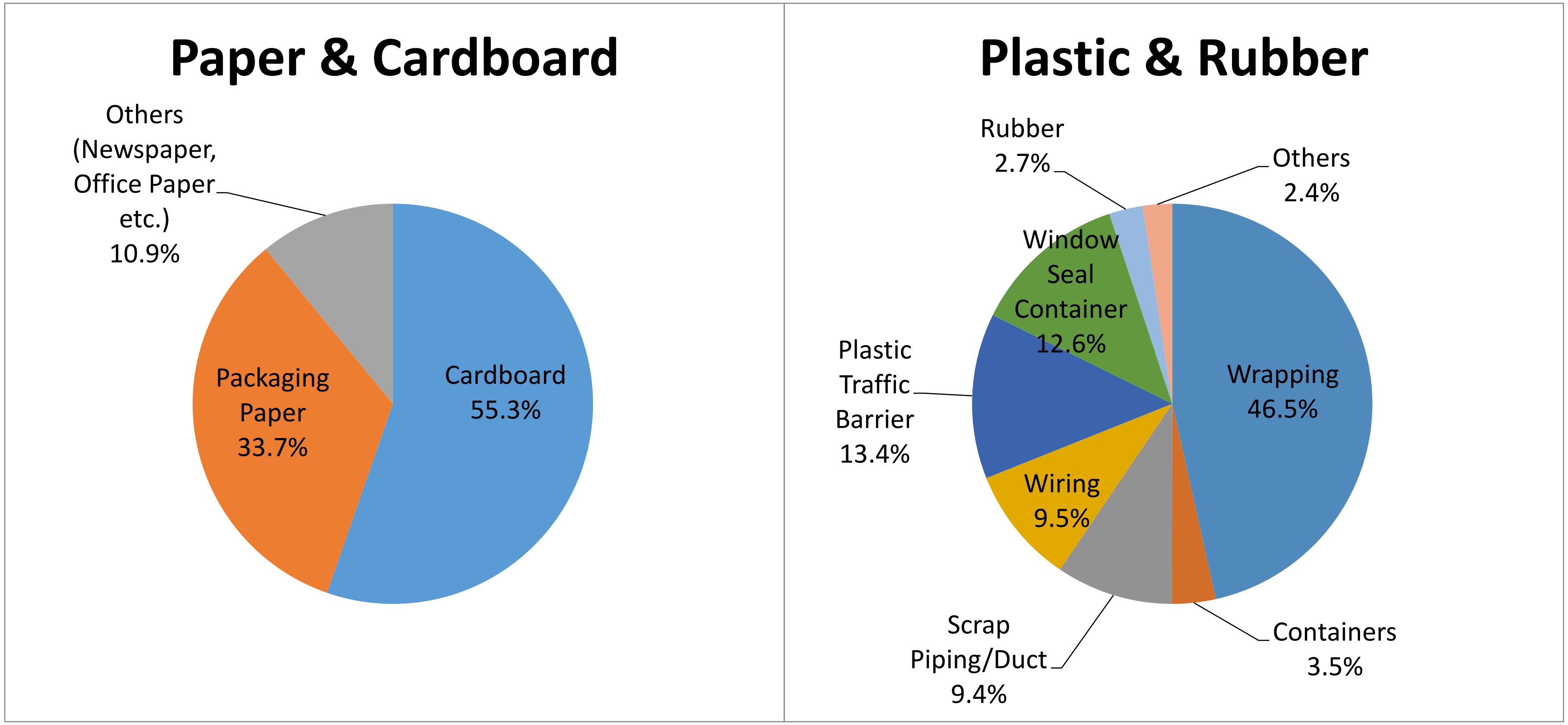


Figure B3: Sorting Results of Site A (III)

Part 2

Site B

Table B2: Site B

					B-1	B-2	B-3	B-1	B-2	B-3	Site B	
Material	**Group**	**Waste type (Group)**	**Sub-group number**	**Sub-group type**	**Weight (kg)**	**Weight (kg)**	**Weight (kg)**	**Percentage (%)**	**Percentage (%)**	**Percentage (%)**	**Weight (kg)**	**Percentage (%)**
Non-inert	1	Bamboo	-	no sub-group	-	-	-	-	-	-	-	-
	2	Wood & Timber	2a	wooden floor tile	-	-	-	-	-	-	-	-
			2b	formwork	992.4	659.4	343.3	85.3%	56.7%	24.4%	1995.2	53.4%
			2c	wooden pallet	-	-	-	-	-	-	-	-
			2d	wooden door	-	-	-	-	-	-	-	-
			2e	packaging timber	-	-	-	-	-	-	-	-
			2f	others	-	-	-	-	-	-	-	-
					-	-	-	-	-	-	-	-
				Total weight of sub-group:	992.4	659.4	343.3	85.3%	56.7%	24.4%	1995.2	53.4%
	3	Metal	3a	metal door	-	-	-	-	-	-	-	-
			3b	metal window frames	-	-	-	-	-	-	-	-
			3c	iron / copper pipe	1.6	-	-	0.1%	-	-	1.6	0.0%
			3d	metal sink	-	-	-	-	-	-	-	-
			3e	rebar	71.9	34.3	6.1	6.2%	3.0%	0.4%	112.3	3.0%
			3f	aluminum	-	-	8.1	-	-	0.6%	8.1	0.2%
			3g	metal container for material packaging	-	-	-	-	-	-	-	-
			3h	steel scrap	24.4	24.8	12.0	2.1%	2.1%	0.8%	61.1	1.6%
			3i	others	-	2.3	7.3	-	0.2%	0.5%	9.5	0.3%
				Total weight of sub-group:	97.8	61.3	33.4	8.4%	5.3%	2.4%	192.5	5.2%
	4	Paper & Cardboard	4a	cardboard	0.6	-	1.1	0.1%	-	0.1%	1.7	0.0%
			4b	packaging paper	-	0.7	1.5	-	0.1%	0.1%	2.1	0.1%
			4c	others (newspaper, office paper etc.)	-	1.1	9.4	-	0.1%	0.7%	10.5	0.3%
				Total weight of sub-group:	0.6	1.8	11.9	0.1%	0.2%	0.8%	14.3	0.4%
	5	Plastic & Rubber	5a	plastic wrapping	1.0	1.9	3.4	0.1%	0.2%	0.2%	6.3	0.2%
			5b	plastic container	-	-	-	-	-	-	-	-
			5c	PVC duct	3.3	4.8	5.9	0.3%	0.4%	0.4%	13.9	0.4%
			5d	cable	-	-	-	-	-	-	-	-
			5e	plastic traffic barrier	7.4	-	-	0.6%	-	-	7.4	0.2%
			5f	window seal container	-	-	-	-	-	-	-	-
			5g	rubber	-	-	-	-	-	-	-	-
			5h	others	2.3	4.8	-	0.2%	0.4%	-	7.1	0.2%
				Total weight of sub-group:	13.9	11.5	9.3	1.2%	1.0%	0.7%	34.7	0.9%
	6	WEEE	-	Electric appliance, electric socket, lighting, water pump, electric motor, transformer (i.e. no sub-group)	-	-	-	-	-	-	-	-
	7	Vegetation	-	Tree trunk etc. (no sub-group)	-	-	-	-	-	-	-	-
	8	Textile	-	no sub-group	1.7	1.3	5.0	0.1%	0.1%	0.4%	8.0	0.2%
	9	Fibreglass	-	no sub-group	-	-	-	-	-	-	-	-
	10	Nylon	-	no sub-group	2.0	1.9	11.3	0.2%	0.2%	0.8%	15.2	0.4%
	11	Domestic Waste	-	Food waste etc. (i.e. no sub-group)	1.9	3.2	29.4	0.2%	0.3%	2.1%	34.5	0.9%
	12	Sanitary Ware	-	Porcelain water closet, porcelain wash hand basin, kitchen solid surface material etc. (i.e. no sub-group)	-	-	-	-	-	-	-	-
	13	Styrofoam	-	no sub-group	0.3	0.3	1.6	0.0%	0.0%	0.1%	2.1	0.1%
	14	Gypsum Board	-	Gypsum drywall etc. (i.e. no sub-group)	-	-	-	-	-	-	-	-
	15	Glass	-	no sub-group	-	-	-	-	-	-	-	-
	16	Others (to be descripted)	-	-	-	-	-	-	-	-	-	-
				Total weight of non-inert	1110.6	740.6	445.1	95.4%	63.7%	31.6%	2296.4	61.5%
Inert	17	Inert	-	Rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt, brick & tile etc (i.e. no sub-group)	53.4	422.7	963.5	4.6%	36.3%	68.4%	1439.5	38.5%
				Total weight:	1164.0	1163.3	1408.6	100.0%	100.0%	100.0%	3735.9	100.0%

Site B

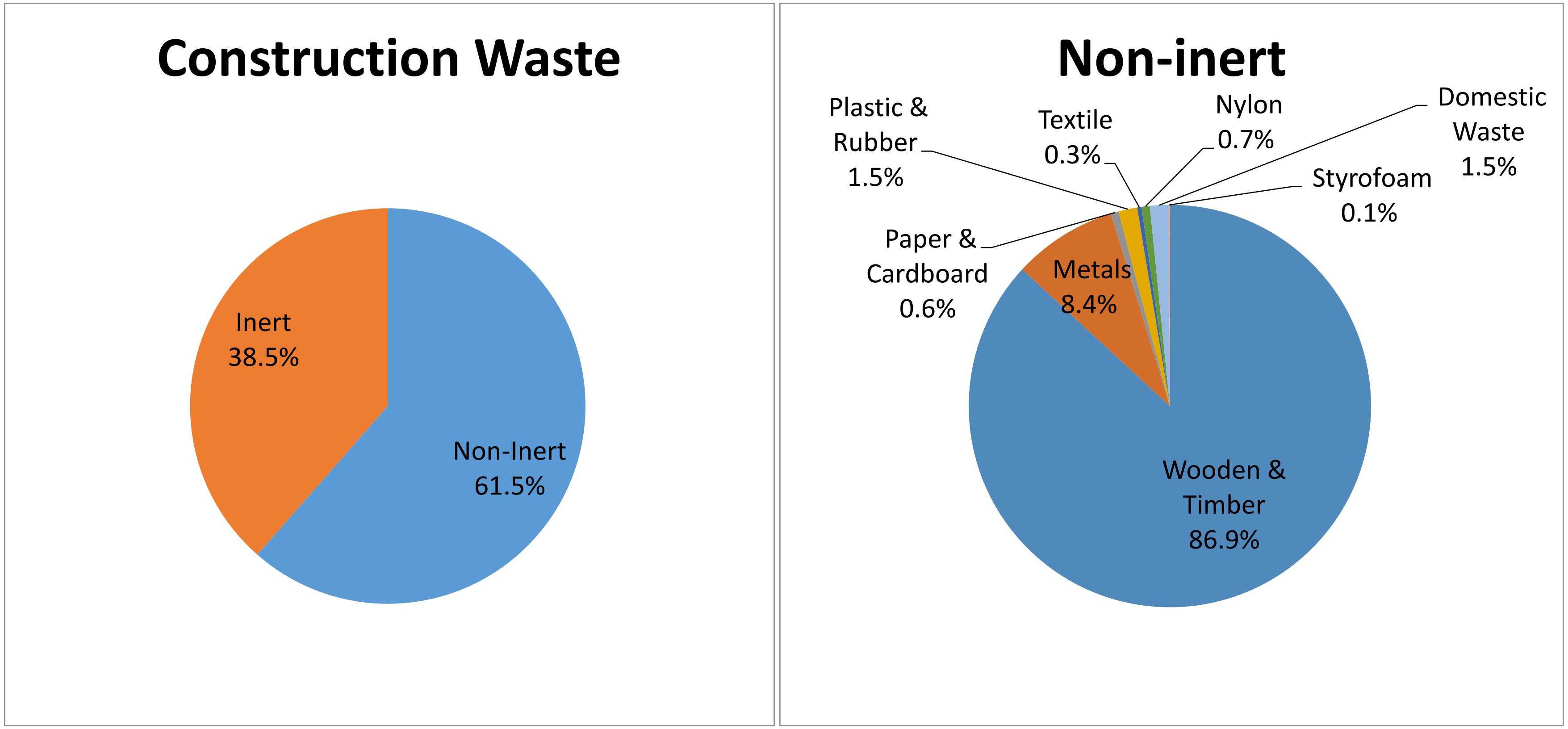


Figure B4: Sorting Results of Site B (I)

Site B

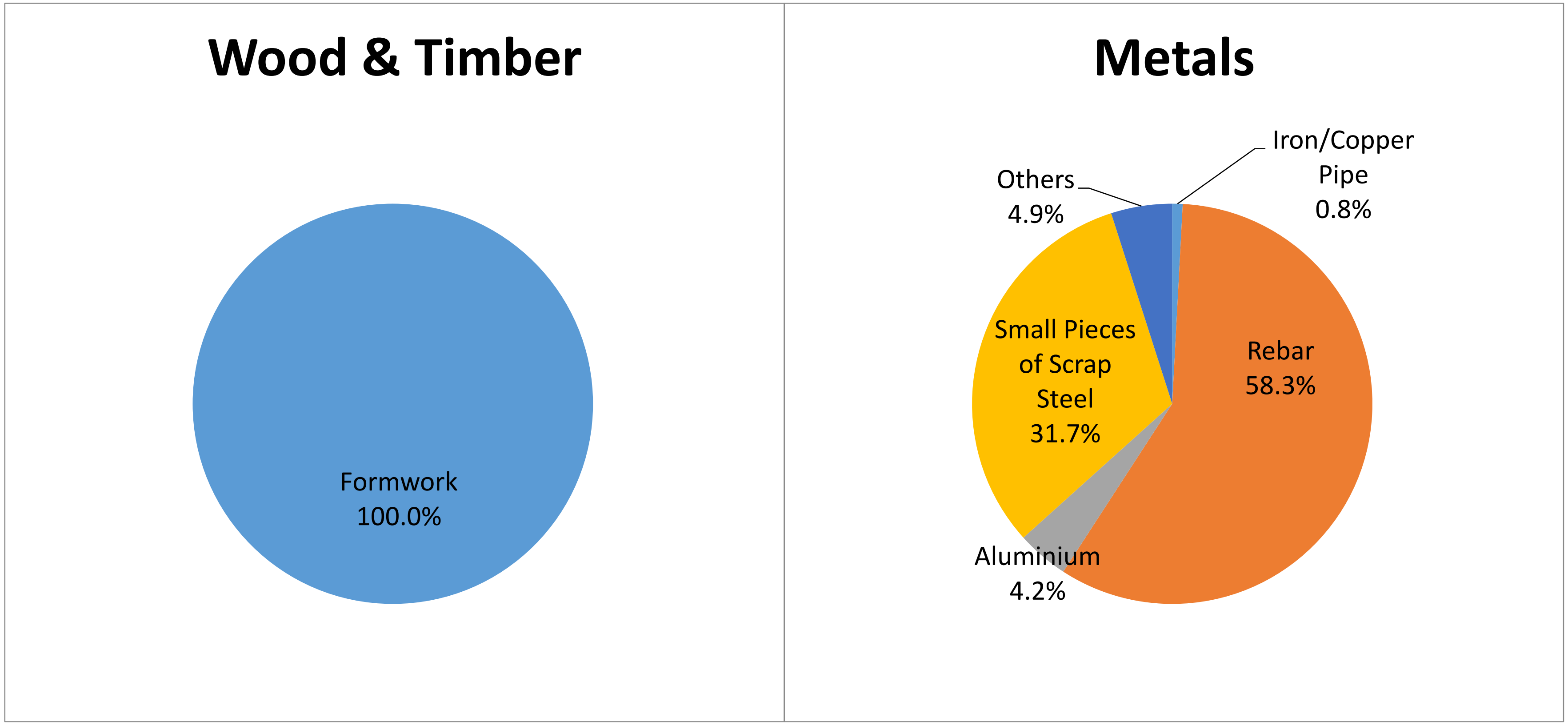
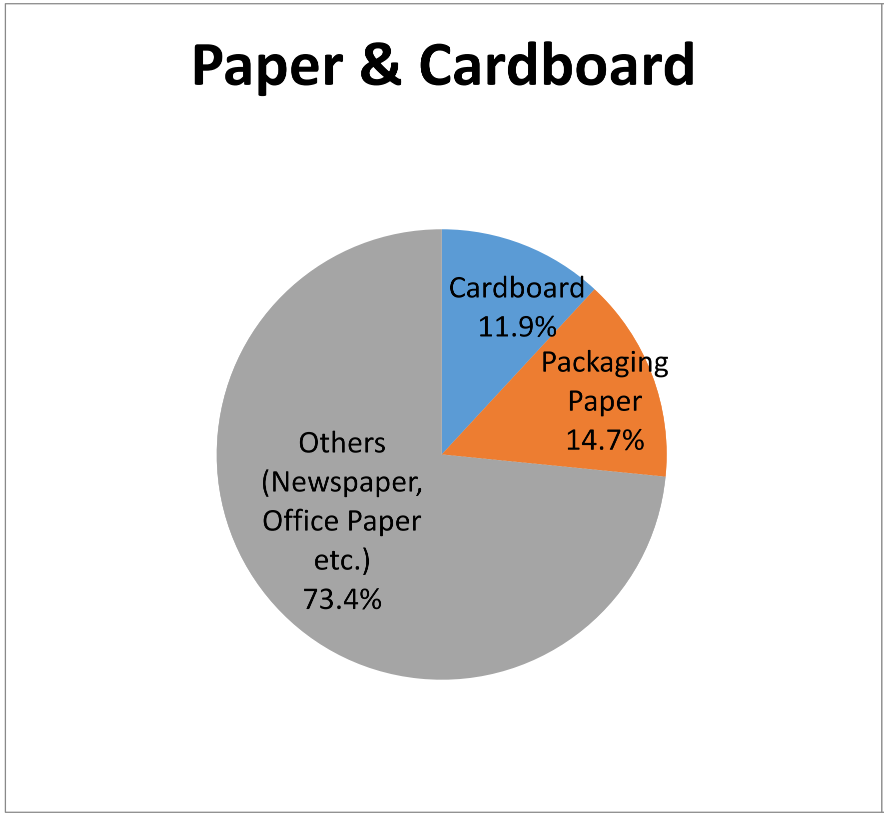


Figure B5: Sorting Results of Site B (II)

Site B



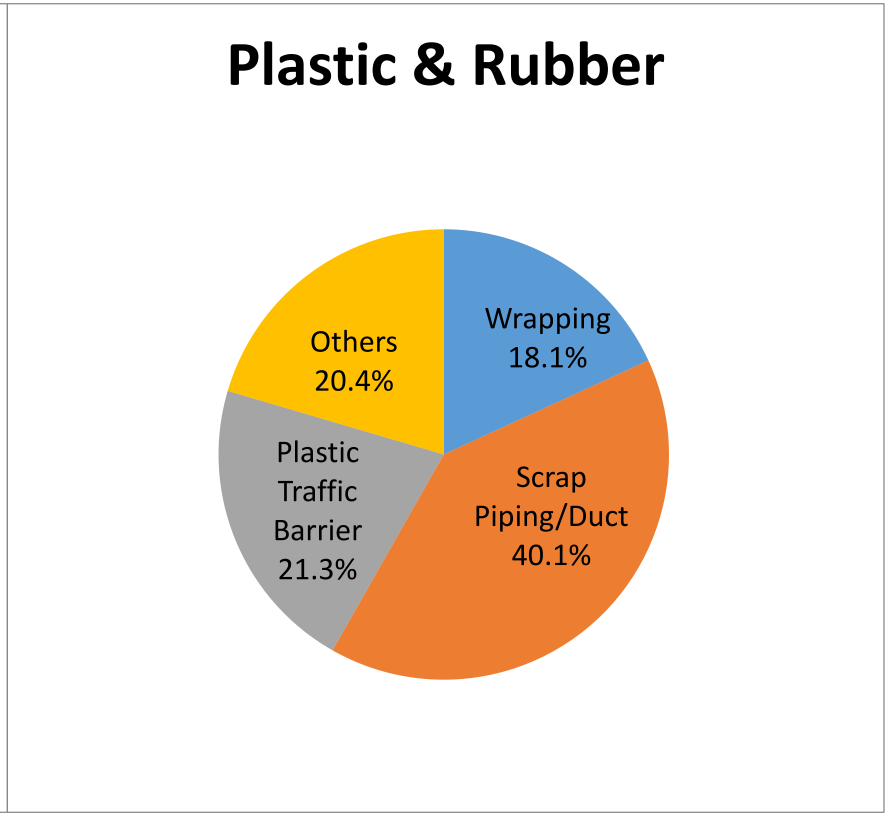


Figure B6: Sorting Results of Site B (III)

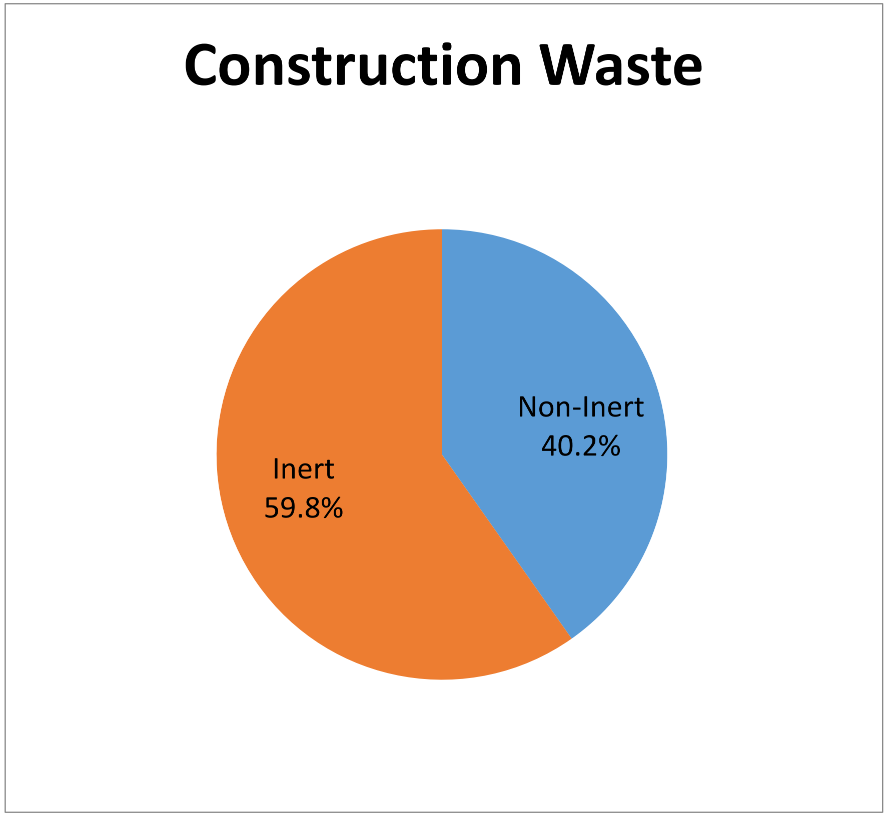
Part 3

Site C

Table B3: Site C

					C-1	C-2	C-3	C-1	C-2	C-3	Site C	
Material	**Group**	**Waste type (Group)**	**Sub-group number**	**Sub-group type**	**Weight (kg)**	**Weight (kg)**	**Weight (kg)**	**Percentage (%)**	**Percentage (%)**	**Percentage (%)**	**Weight (kg)**	**Percentage (%)**
Non-inert	1	Bamboo	-	no sub-group	-	-	-	-	-	-	-	-
	2	Wood & Timber	2a	wooden floor tile	-	-	-	-	-	-	-	-
			2b	formwork	362.0	487.7	300.8	24.1%	43.6%	31.1%	1150.5	32.1%
			2c	wooden pallet	-	-	-	-	-	-	-	-
			2d	wooden door	-	-	-	-	-	-	-	-
			2e	packaging timber	-	-	-	-	-	-	-	-
			2f	others	-	-	-	-	-	-	-	-
					-	-	-	-	-	-	-	-
				Total weight of sub-group:	362.0	487.7	300.8	24.1%	43.6%	31.1%	1150.5	32.1%
	3	Metals	3a	metal door	-	-	-	-	-	-	-	-
			3b	metal window frames	-	-	-	-	-	-	-	-
			3c	iron / copper pipe	-	1.2	-	-	0.1%	-	1.2	0.0%
			3d	metal sink	-	-	-	-	-	-	-	-
			3e	rebar	17.5	33.3	53.2	1.2%	3.0%	5.5%	103.9	2.9%
			3f	aluminum	1.0	-	0.5	0.1%	-	0.0%	1.5	0.0%
			3g	metal container for material packaging	0.1	-	0.2	0.0%	-	0.0%	0.3	0.0%
			3h	steel scrap	15.0	58.3	9.7	1.0%	5.2%	1.0%	83.0	2.3%
			3i	others	-	-	-	-	-	-	-	-
				Total weight of sub-group:	33.6	92.8	63.5	2.2%	8.3%	6.6%	189.9	5.3%
	4	Paper & Cardboard	4a	cardboard	4.7	9.0	3.0	0.3%	0.8%	0.3%	16.6	0.5%
			4b	packaging paper	-	-	-	-	-	-	-	-
			4c	others (newspaper, office paper etc.)	-	-	-	-	-	-	-	-
				Total weight of sub-group:	4.7	9.0	3.0	0.3%	0.8%	0.3%	16.6	0.5%
	5	Plastic & Rubber	5a	plastic wrapping	0.2	3.3	1.3	0.0%	0.3%	0.1%	4.7	0.1%
			5b	plastic container	-	-	-	-	-	-	-	-
			5c	PVC duct	7.1	3.2	10.8	0.5%	0.3%	1.1%	21.0	0.6%
			5d	cable	-	0.4	-	-	0.0%	-	0.4	0.0%
			5e	plastic traffic barrier	-	-	-	-	-	-	-	-
			5f	window seal container	-	-	-	-	-	-	-	-
			5g	rubber	-	-	-	-	-	-	-	-
			5h	others	0.1	0.2	0.7	0.0%	0.0%	0.1%	0.9	0.0%
				Total weight of sub-group:	7.4	6.9	12.7	0.5%	0.6%	1.3%	26.9	0.8%
	6	WEEE	-	Electric appliance, electric socket, lighting, water pump, electric motor, transformer (i.e. no sub-group)	-	-	-	-	-	-	-	-
	7	Vegetation	-	Tree trunk etc. (no sub-group)	-	-	-	-	-	-	-	-
	8	Textile	-	no sub-group	1.9	2.6	5.1	0.1%	0.2%	0.5%	9.5	0.3%
	9	Fibreglass	-	no sub-group	-	-	-	-	-	-	-	-
	10	Nylon	-	no sub-group	8.7	4.4	18.5	0.6%	0.4%	1.9%	31.5	0.9%
	11	Domestic Waste	-	Food waste etc. (i.e. no sub-group)	11.1	2.6	3.6	0.7%	0.2%	0.4%	17.2	0.5%
	12	Sanitary Ware	-	Porcelain water closet, porcelain wash hand basin, kitchen solid surface material etc. (i.e. no sub-group)	-	-	-	-	-	-	-	-
	13	Styrofoam	-	no sub-group	-	0.7	-	-	0.1%	-	0.7	0.0%
	14	Gypsum Board	-	Gypsum drywall etc. (i.e. no sub-group)	-	-	-	-	-	-	-	-
	15	Glass	-	no sub-group	-	-	-	-	-	-	-	-
	16	Others (to be descripted)	-	-	-	-	-	-	-	-	-	-
				Total weight of non-inert	429.3	606.4	407.1	28.6%	54.3%	42.1%	1442.7	40.2%
Inert	17	Inert	-	Rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt, brick & tile etc (i.e. no sub-group)	1072.1	511.2	559.9	71.4%	45.7%	57.9%	2143.2	59.8%
				Total weight:	1501.4	1117.6	966.9	100.0%	100.0%	100.0%	3585.9	100.0%

Site C



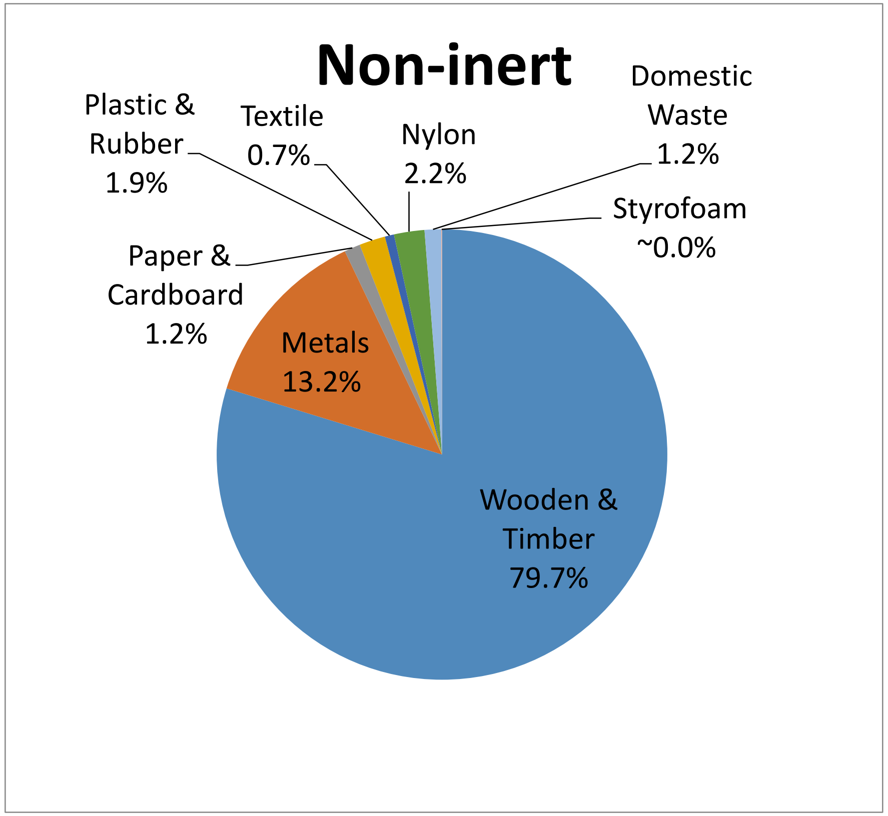
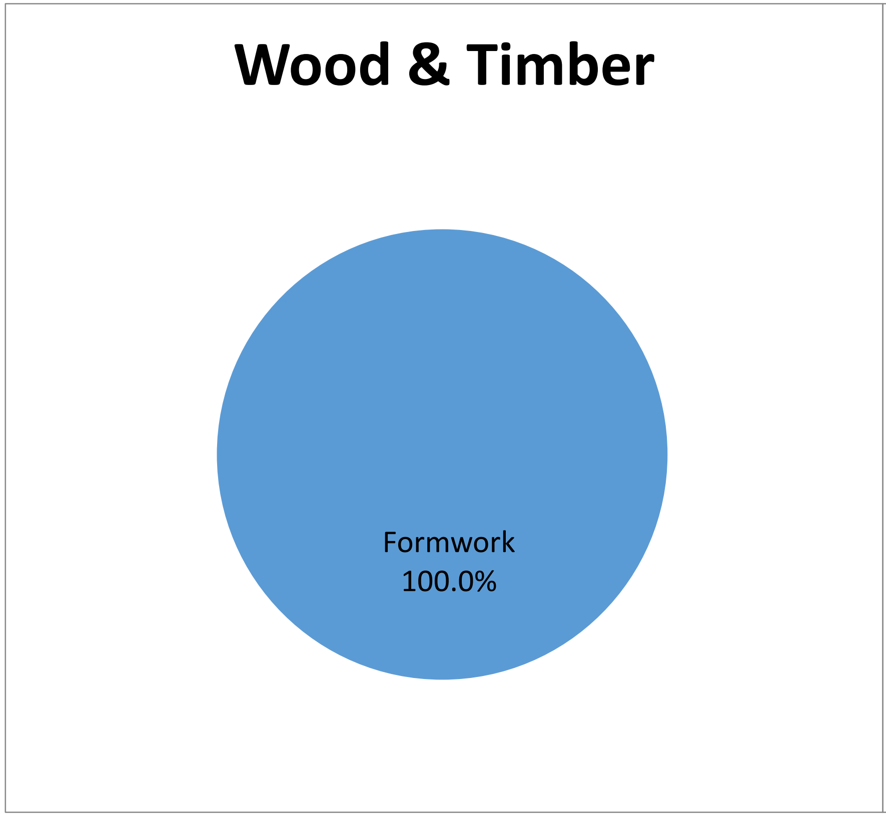


Figure B7: Sorting Results of Site C (I)

Site C



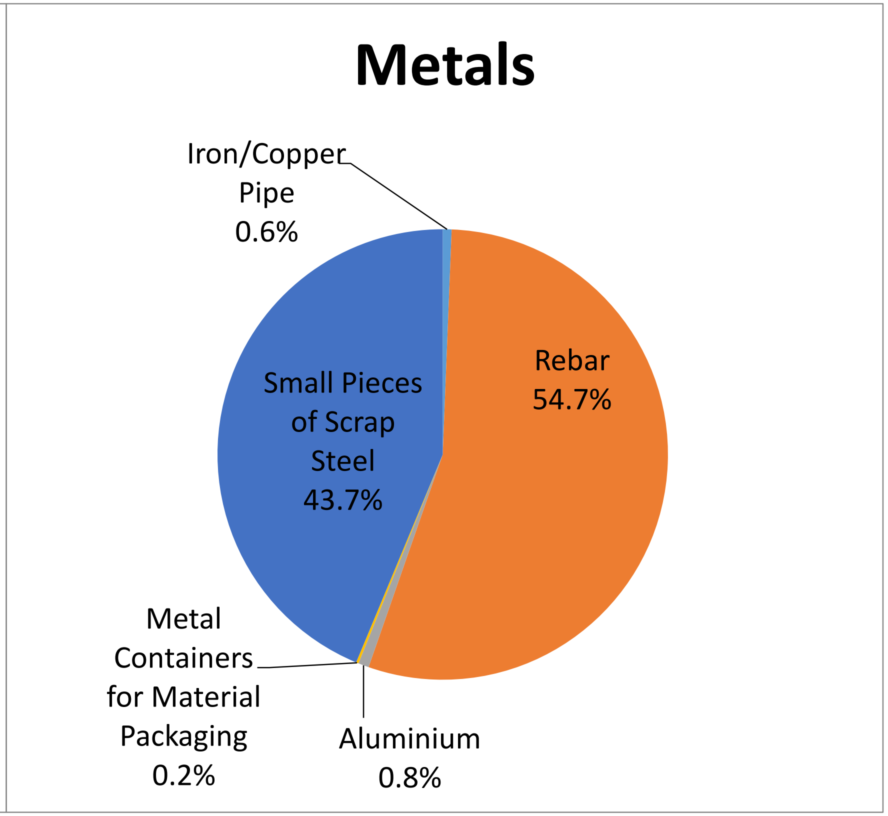


Figure B8: Sorting Results of Site C (II)

Site C

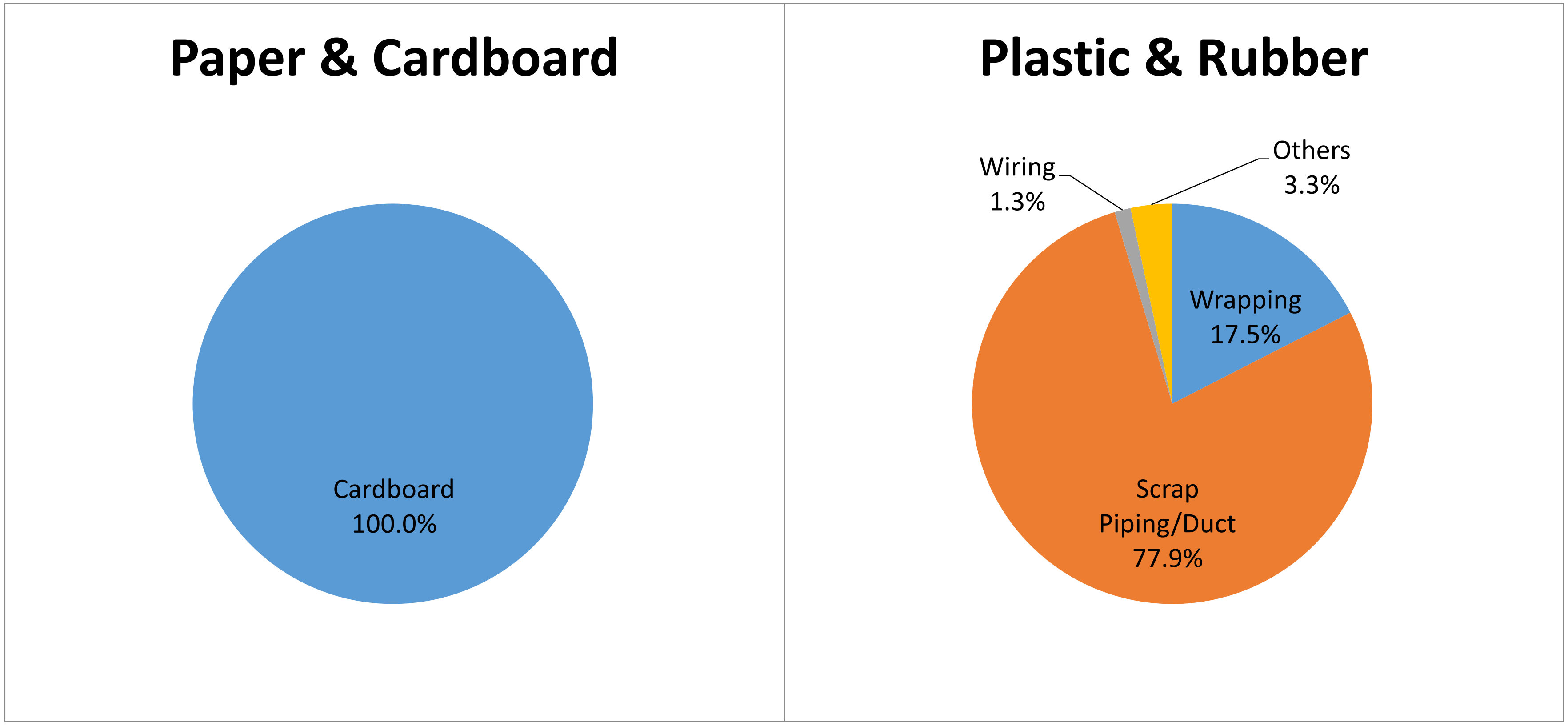


Figure B9: Sorting Results of Site C (III)

Part 4

Overall (All Sites)

Table B4: Overall (All Sites)

					Site A	Site B	Site C	Site A	Site B	Site C	All sites	
Material	**Group**	**Waste type (Group)**	**Sub-group number**	**Sub-group type**	**Weight (kg)**	**Weight (kg)**	**Weight (kg)**	**Percentage (%)**	**Percentage (%)**	**Percentage (%)**	**Weight (kg)**	**Percentage (%)**
Non-inert	1	Bamboo	-	no sub-group	-	-	-	-	-	-	-	-
	2	Wood & Timber	2a	wooden floor tile	-	-	-	-	-	-	-	-
			2b	formwork	406.9	1995.2	1150.5	12.9%	53.4%	32.1%	3552.5	33.9%
			2c	wooden pallet	164.3	-	-	5.2%	-	-	164.3	1.6%
			2d	wooden door	-	-	-	-	-	-	-	-
			2e	packaging timber	39.4	-	-	1.2%	-	-	39.4	0.4%
			2f	others	5.3	-	-	0.2%	-	-	5.3	0.1%
					-	-	-	-	-	-	-	-
				Total weight of sub-group:	615.9	1995.2	1150.5	19.5%	53.4%	32.1%	3761.5	35.9%
	3	Metal	3a	metal door	-	-	-	-	-	-	-	-
			3b	metal window frames	-	-	-	-	-	-	-	-
			3c	iron / copper pipe	-	1.6	1.2	-	0.0%	0.0%	2.8	0.0%
			3d	metal sink	-	-	-	-	-	-	-	-
			3e	rebar	32.8	112.3	103.9	1.0%	3.0%	2.9%	249.0	2.4%
			3f	aluminum	9.1	8.1	1.5	0.3%	0.2%	0.0%	18.6	0.2%
			3g	metal container for material packaging	7.9	-	0.3	0.2%	-	0.0%	8.2	0.1%
			3h	steel scrap	156.0	61.1	83.0	4.9%	1.6%	2.3%	300.1	2.9%
			3i	others	-	9.5	-	-	0.3%	-	9.5	0.1%
				Total weight of sub-group:	205.8	192.5	189.9	6.5%	5.2%	5.3%	588.2	5.6%
	4	Paper & Cardboard	4a	cardboard	89.2	1.7	16.6	2.8%	0.0%	0.5%	107.5	1.0%
			4b	packaging paper	54.4	2.1	-	1.7%	0.1%	-	56.5	0.5%
			4c	others (newspaper, office paper etc.)	17.7	10.5	-	0.6%	0.3%	-	28.2	0.3%
				Total weight of sub-group:	161.2	14.3	16.6	5.1%	0.4%	0.5%	192.1	1.8%
	5	Plastic & Rubber	5a	plastic wrapping	45.2	6.3	4.7	1.4%	0.2%	0.1%	56.2	0.5%
			5b	plastic container	3.4	-	-	0.1%	-	-	3.4	0.0%
			5c	PVC duct	9.2	13.9	21.0	0.3%	0.4%	0.6%	44.1	0.4%
			5d	cable	9.2	-	0.4	0.3%	-	0.0%	9.6	0.1%
			5e	plastic traffic barrier	13.0	7.4	-	0.4%	0.2%	-	20.4	0.2%
			5f	window seal container	12.3	-	-	0.4%	-	-	12.3	0.1%
			5g	rubber	2.7	-	-	0.1%	-	-	2.7	0.0%
			5h	others	2.3	7.1	0.9	0.1%	0.2%	0.0%	10.3	0.1%
				Total weight of sub-group:	97.3	34.7	26.9	3.1%	0.9%	0.8%	158.9	1.5%
	6	WEEE	-	Electric appliance, electric socket, lighting, water pump, electric motor, transformer (i.e. no sub-group)	1.5	-	-	0.0%	-	-	1.5	0.0%
	7	Vegetation	-	Tree trunk etc. (no sub-group)	-	-	-	-	-	-	-	-
	8	Textile	-	no sub-group	18.9	8.0	9.5	0.6%	0.2%	0.3%	36.4	0.3%
	9	Fibreglass	-	no sub-group	-	-	-	-	-	-	-	-
	10	Nylon	-	no sub-group	49.2	15.2	31.5	1.6%	0.4%	0.9%	95.9	0.9%
	11	Domestic Waste	-	Food waste etc. (i.e. no sub-group)	34.5	34.5	17.2	1.1%	0.9%	0.5%	86.2	0.8%
	12	Sanitary Ware	-	Porcelain water closet, porcelain wash hand basin, kitchen solid surface material etc. (i.e. no sub-group)	2.4	-	-	0.1%	-	-	2.4	0.0%
	13	Styrofoam	-	no sub-group	16.5	2.1	0.7	0.5%	0.1%	0.0%	19.3	0.2%
	14	Gypsum Board	-	Gypsum drywall etc. (i.e. no sub-group)	-	-	-	-	-	-	-	-
	15	Glass	-	no sub-group	-	-	-	-	-	-	-	-
	16	Others (to be descripted)	-	-	-	-	-	-	-	-	-	-
				Total weight of non-inert	1203.2	2296.4	1442.7	38.1%	61.5%	40.2%	4942.3	47.1%
Inert	17	Inert	-	Rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt, brick & tile etc (i.e. no sub-group)	1958.9	1439.5	2143.2	61.9%	38.5%	59.8%	5541.6	52.9%
				Total weight:	3162.0	3735.9	3585.9	100.0%	100.0%	100.0%	10483.8	100.0%

All Sites

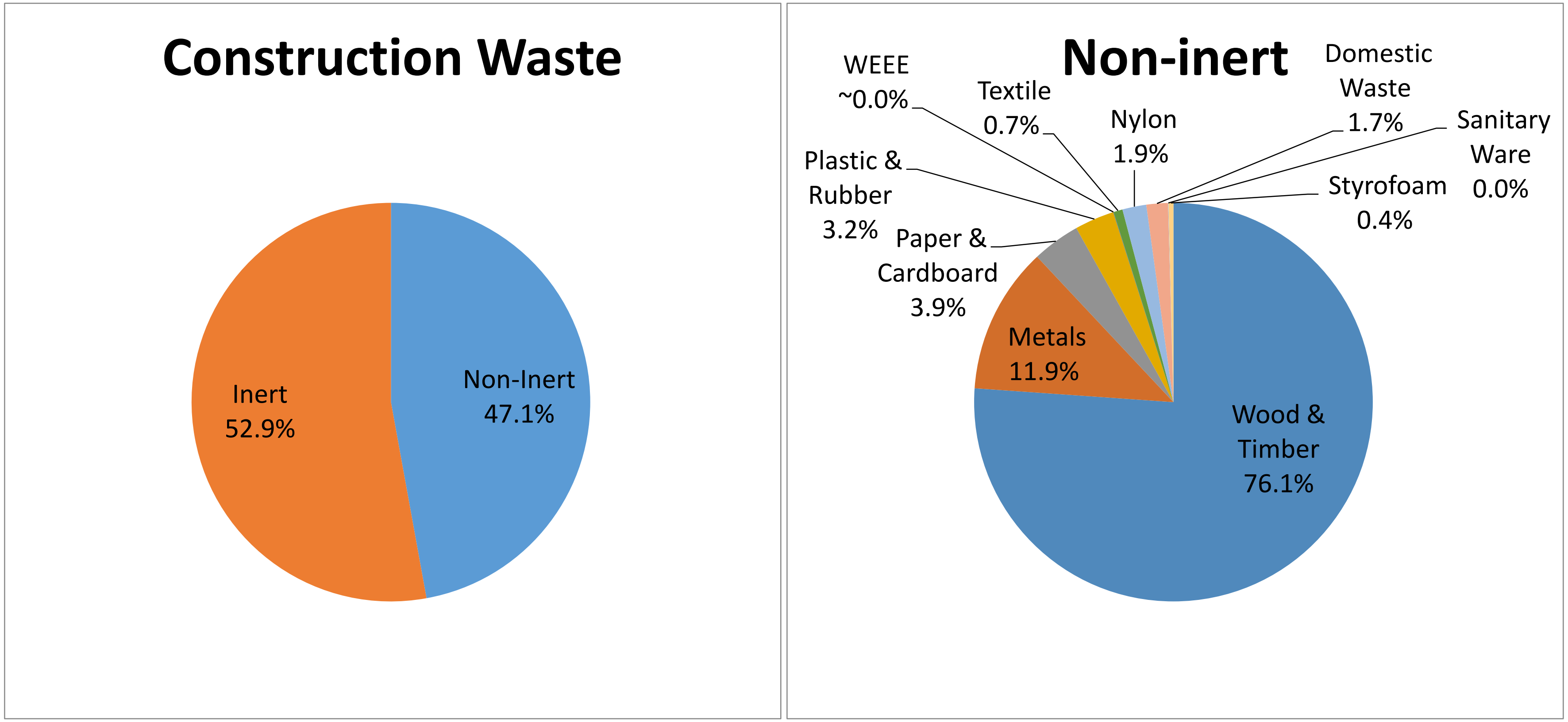


Figure B10: Sorting Results of All Site (I)

All Sites

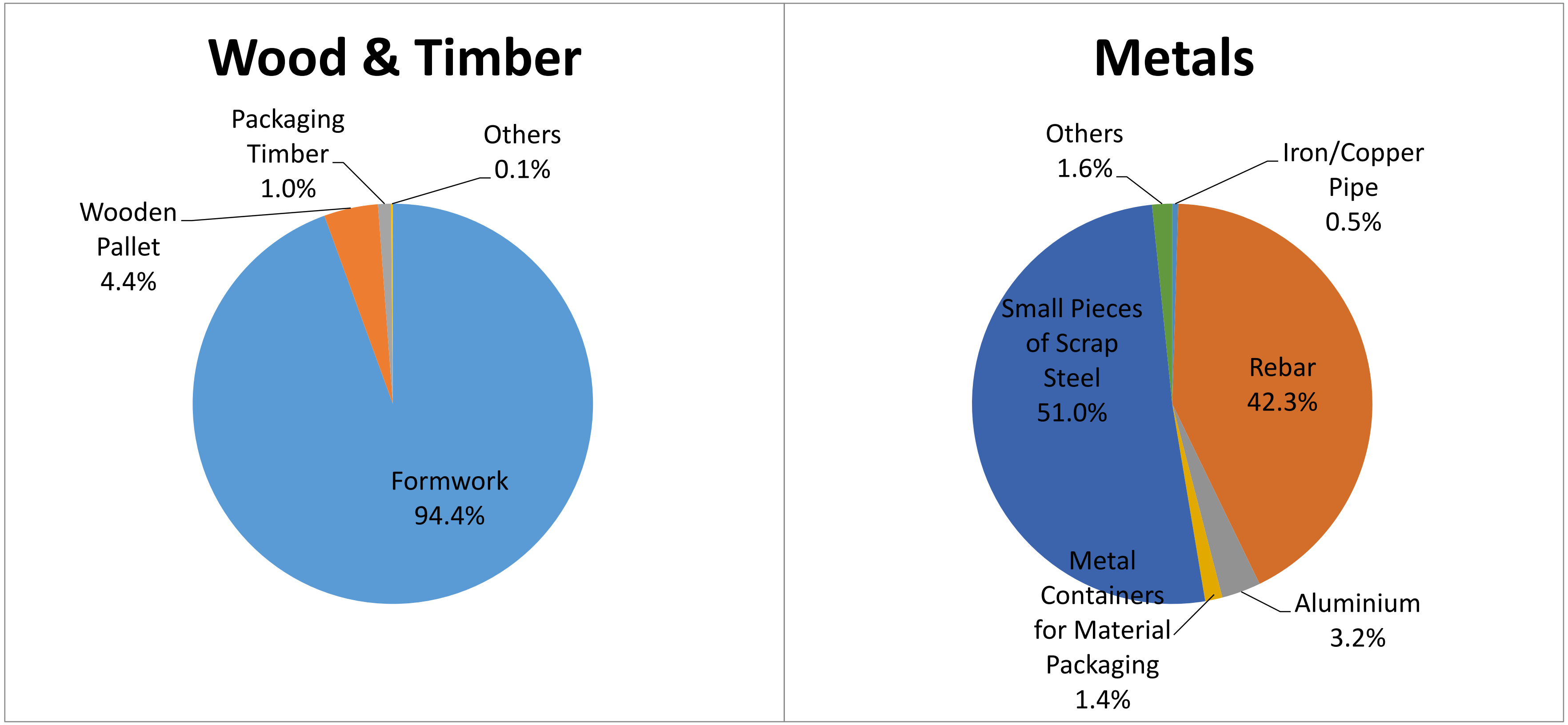
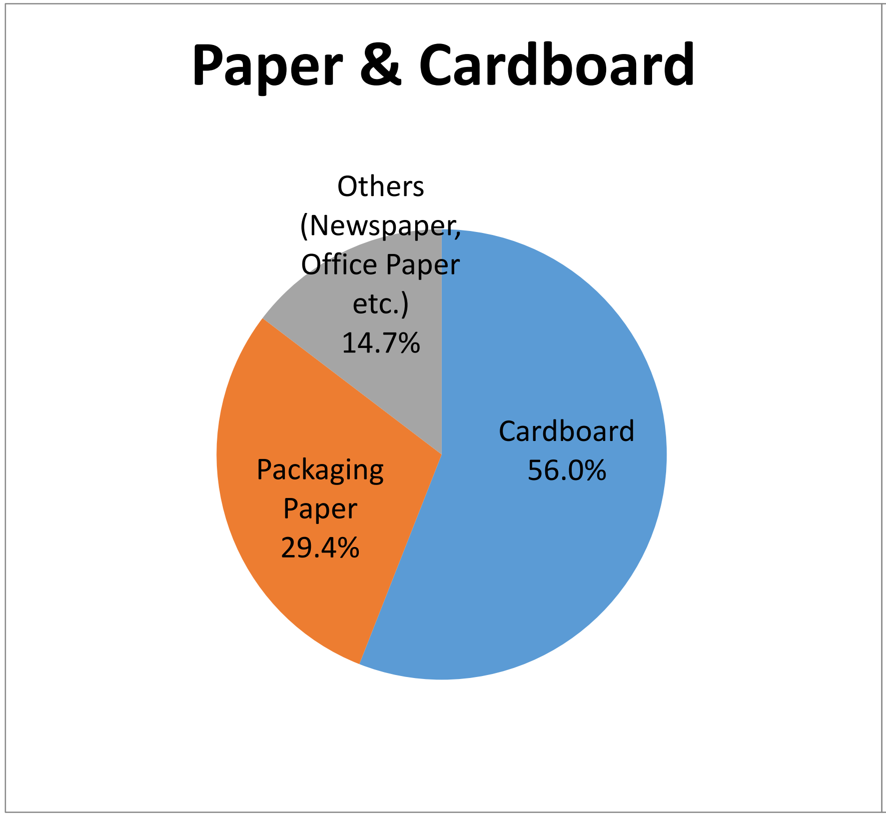


Figure B11: Sorting Results of All Site (II)

All Sites



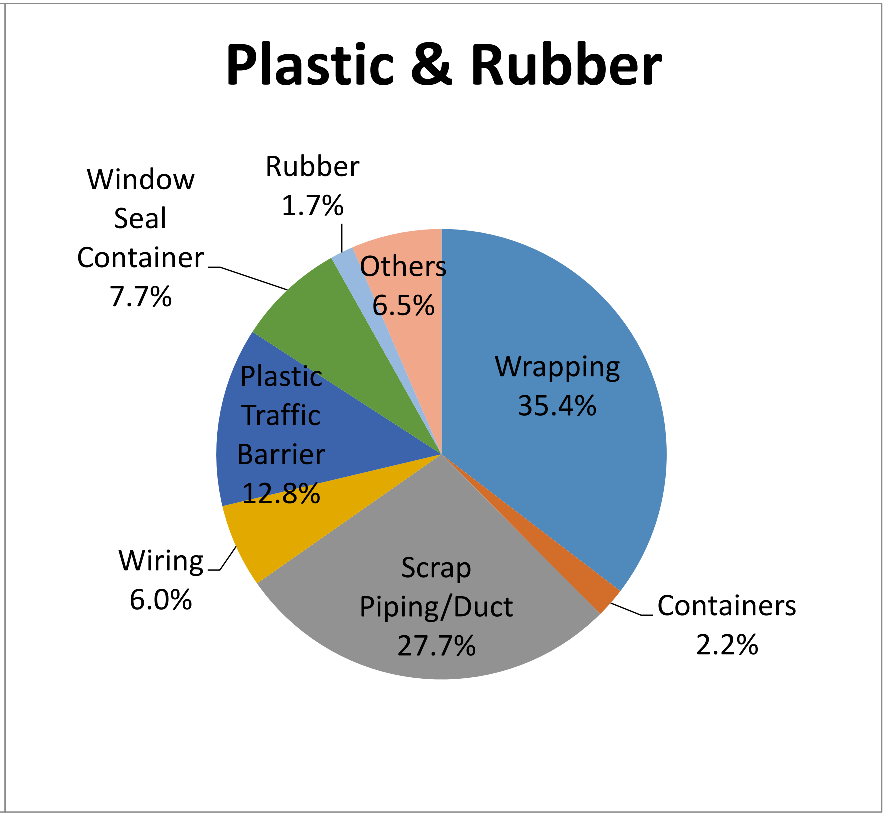


Figure B12: Sorting Results of All Site (III)

REPORT 6

PROPOSED METHODOLOGY FOR NON-INERT CONSTURCTION WASTE COMPOSITION

August 2017

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This report introduces the proposed upstream and downstream approaches for non-inert construction waste composition study.

1. Upstream Estimation of Non-Inert Construction Waste

For effective waste management, it is beneficial for project team members to predict the approximate quantities of waste of individual projects (e.g., to comply with trip ticket procedures of the Development Bureau) based on the complete design information, especially when near to the tender stage for the main building contract for a project using the traditional procurement approach.

For a single project, the estimated quantities and types of waste will enable the consultants and contractors to take appropriate waste management action even before the project commences. In the long run, such estimates can form benchmarks when they are related to the scope (say on unit m^2 basis) and nature of the projects. Efforts can then be made to reduce waste as far as practisable during the design stage in the choice of materials and dimensional coordination.

Since the bulk volume of waste is a critical concern for waste management, the conversion of design quantities into waste is based on bulk volume estimate, but if for some justifiable reasons, weight will be of concern, the calculation may be extended to include weights where necessary.

1.1. Approach (A) – Bills of Quantities (BoQs) being available from professional quantity surveyors

Since piling usually forms a separate contract, the extraction of quantities starts from the pile cap (if it is incorporated in the main contract; if not, account for the quantities since pile cap formwork is usually of timber which would eventually be scrapped after use). Excavated spoil for foundations is excluded.

For BoQs presented in elemental format, add similar items appearing in different elements (e.g., screedings in floors and walls).

For waste management purpose, wastes arising from the use of the materials and their containers/packaging materials are included.

A proforma similar to Appendix A may be used to tabulate the summary quantities extracted from BoQs but separate compilation sheets should be attached to show the break-down.

The general principle of arriving at the bulk volume of materials:

(1) Convert materials into absolute volume (in m^3) from their given quantities and dimensions, if any (e.g., areas multiplied by thickness);
(2) Convert weights into absolute volume using absolute densities;
(3) Estimate waste allowances and bulking ratios (for example, by referring to tables as listed in Appendix B);
(4) Estimate bulk volume using absolute volume multiplied by a bulking ratio.

Multiply each bulk volume by the respective suggested waste percentage as shown in Appendix A, which is estimated based on normal urban site conditions (for multi-storey construction with common plant usage on flat ground). Where site conditions differ significantly from the said scenario, suitable adjustments may be made to reflect the envisaged wastage levels.

If timber is envisaged as formwork materials, the no. of re-use for typical floors needs to be differentiated from non-typical floors, depending on the complexity of design. Zero waste may be assumed for metal formwork, if specified, but again this is dependent on the design.

For the following types of materials (not exhaustive), extra allowance shall be made for:

- Timber pellets and crating for materials delivered in them (assuming not returnable to suppliers);
- Cement for plastering, mortar, screeding and the like to be mixed on site: - paper bags;
- Liquid membrane waterproofing/roofing: - metal/plastic containers;
- Joint sealant: - plastic containers and cartons;
- Off-site manufactured doors: - assumed corrugated cardboards as protection;
- Paper boxes for tiles and ironmongery;
- Painting (including sealer): - metal containers;

- Sanitary fittings: - pellets/crating/wrapping;
- Hardwood flooring: - pellets/crating;
- Kitchen cabinet/countertops: - wrapping.

For building services equipment, estimation of waste arising from packaging materials may be based on the number of accommodation units, differentiating into large and small units where applicable. Reference may also be made to the prime cost sums allowed in the main contract as to the relative scale of works. All equipment is assumed to be fully fixed on completion and cause no waste.

1.2. Approach (B) – no BoQ available (e.g., for contracts based on specifications and drawings)
Major quantities as shown in the proforma in Appendix A may be taken off from tender drawings, or the estimation may be deferred until the contract is awarded. The successful contractor's schedule of quantities may be used as a good reference, although errors in measurement need to be mindful of.

A similar process of estimation applies as in Method (A).

1.3. Intended use of the results
Whilst the estimated waste volume may be used in the currently enforced trip ticket system, statistical figures may be built up after a sufficient pool of samples (say more than 30 projects assuming normal distribution) have been processed. A useful benchmarking statistic would be estimated waste volume per m^2 of Construction Floor Area.

Construction Floor Area is defined as the summation of all areas at all floor levels, including basements, mezzanine floors, balconies and enclosed rooftop structures, measured to outer face of external wall. It is measured over all partitions, columns, walls, stair wells, lift wells, escalator openings, etc.

2. Downstream Estimation of Non-Inert Construction Waste

Based on the experience gained from the construction waste sorting of the current study, the methodology for the "*future non-inert construction waste composition study"* is proposed. The methodology includes the following main parts:

(1) Number of lorry/truck load of construction waste to be studied;
(2) Duration and time;
(3) Method of non-inert waste estimation;
(4) Sorting list;
(5) Sorting area and location;
(6) Manpower;
(7) Large equipment;
(8) Small equipment/tools/set-up for operation and safety requirements;
(9) Appropriate contractor and budget.

2.1. Number of lorry/truck load of construction waste to be studied

Table 1 presents the extent of the future study proposed. The study covers three types of building construction site ("residential", "commercial" and "hotel"), and three stages of construction ("superstructure", "immediate after superstructure completion" and "before occupation").

Table 1 Extent of the future study proposed

<table>
<tr><th>Type of Site</th><th>Stage of Construction</th><th>Scale of Site</th><th>Set</th></tr>
<tr><td>• Residential</td><td rowspan="2">• Superstructure
• Immediate after superstructure completion
• Before occupation</td><td>• 1 block
• >1 block</td><td>1</td></tr>
<tr><td>• Commercial
• Hotel</td><td>-</td><td>2</td></tr>
</table>

For the residential building, two scales of construction site ("1 block" and ">1 block") will be studied. For the commercial building and the hotel building, two sets of sites for each type will be included. Hence, the study will include 18 numbers of building construction site. It is suggested that each of the sites provides three lorry/truckloads of construction waste. In total, there will be 54 lorry loads of construction waste for the study.

2.2. Duration and time

With reference to the observation of the construction waste sorting of the current study, it is possible that 3 lorries of construction waste can be sorted in an eight-hour working day. Hence, the estimated time for waste sorting is about 18 working days.

The sorting exercise should avoid the raining season and the typhoon season prevailing in Hong Kong. The best time period for the sorting is, therefore, between November and March of the year.

2.3. Method of non-inert waste estimation

Non-inert wastes are more than likely to be mingled together with inert wastes due to the fact that effective sorting at construction site is difficult to be implemented in most cases. Hand sorting, together with manual weighing, is recommended as the method for non-inert waste estimation.

Construction waste delivered to the sorting ground is to be spread out and divided into four equal parts (as shown in Figure 1). Sorting is then carried out on two of the parts according to a pre-fixed plan.

4	**1**
3	**2**

Figure 1 Construction waste divided into four parts

2.4. Sorting list

Table 2 shows a sample list for sorting non-inert wastes. The table includes two main sections:

(1) General information registration;

(2) Non-inert wastes to be identified (29 types).

The general information registration contains:

- Date;
- Weather;
- Site number;
- Lorry number;
- Lorry arrival time;
- Lorry licence plate number;
- Sorting time (beginning);
- Sorting time (completion);
- Parts sorted;
- Grab mounted lorry arrival time;
- Grab mounted lorry licence plate number;
- Chit ticket number;
- Total load of construction waste stated on chit ticket;
- Person taking the record;
- Remark.

The list of non-inert wastes includes the following items:

- Bamboo;
- Formwork;
- Wooden pallet;
- Packaging timber;
- Iron/copper pipe;
- Rebar;
- Aluminium scrap;
- Metal container;
- Steel scraps;
- Cardboard;
- Packaging paper;

- Plastic wrapping;
- Plastic container;
- PVC duct;
- Cable;
- Plastic traffic barrier;
- Window seal container;
- Rubber;
- WEEE;
- Vegetation;
- Textile;
- Fibreglass;
- Nylon;
- Domestic waste;
- Sanitary ware;
- Styrofoam;
- Gypsum board;
- Glass;
- Others.

Table 2 A sample list for sorting non-inert waste

Date:		**Weather:**		**Site no.:**	
Lorry arrival time:				**Grab mounted lorry arrival time:**	
Lorry no.:				**Grab mounted lorry licence plate no.:**	
Lorry licence plate no.:				**Chit ticket no.:**	
Sorting time (beginning):				**Total load of construction waste stated on chit ticket:**	
Sorting time (completion):					
Parts sorted:				**Recorded by:**	
Remark:					

Material	Group No.	Group	Type No.	Type	Weight (kg)
Non-inert	1	Bamboo	1	no sub-group	
	2	Wood & Timber	2a	formwork	
			2b	wooden pallet	
			2c	packaging timber	
			2d	others	
	3	Metal	3a	iron / copper pipe	
			3b	metal sink	
			3c	rebar	
			3d	aluminium scrap	
			3e	metal containers for material packaging	
			3f	steel scrap	
			3g	others	
	4	Paper & Cardboard	4a	cardboard	
			4b	packaging paper	
			4c	others (newspaper, office paper etc.)	
	5	Plastic & Rubber	5a	plastic wrapping	
			5b	plastic container	
			5c	PVC duct	
			5d	cable	
			5e	plastic traffic barrier	
			5f	window seal container	
			5g	rubber	
			5h	others	
	6	WEEE	1	electric appliance, electric socket, lighting, water pump, electric motor, transformer (i.e. no sub-group)	
	7	Vegetation	1	tree trunk etc. (i.e. no sub-group)	
	8	Textile	1	no sub-group	
	9	Fibreglass	1	no sub-group	
	10	Nylon	1	no sub-group	
	11	Domestic Waste	1	food waste etc. (i.e. no sub-group)	
	12	Sanitary Ware	1	porcelain water closet, porcelain wash hand basin, kitchen solid surface material etc. (i.e. no sub-group)	
	13	Styrofoam	1	no sub-group	
	14	Gypsum Board	1	Gypsum drywall etc. (i.e. no sub-group)	
	15	Glass	1	no sub-group	
	16	Others (to be descripted)	1	-	
Inert	17	Inert	1	rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt, brick & tile etc. (i.e. no sub-group)	
				Total weight:	

2.5. Sorting area and location

The sorting platform should be strong enough to sustain loadings of lorries and movements of backhoe without deterioration that could generate additional waste to the construction waste being sorted. Platform of C40 concrete of 200mm thick with a proper foundation is recommended. The platform should also be large enough for construction waste spreading and sorting. A minimum area of 12m by 8m is suggested.

2.6. Manpower

Apart from the backhoe operator, who is usually supplied by the backhoe hiring company, the construction waste sorting team will include a foreman and six site workers. Based on 18 working days, as suggested in Part 2 of the current document, the total man-days of the foremen and the site worker are 18 and 108 respectively for the sorting operation. The foreman is responsible for all on-site management and communication works – including taking full record of site work and sorting measurements, and communication with different construction sites, grab mounted lorry and the site workers etc. The site workers work on all manual works related to waste sorting and weighing.

2.7. Large equipment

A 6-tonne backhoe or a large backhoe will be used to even and move the construction waste on site. And a grab mounted lorry will be hired to send the construction waste away after completion of the sorting work of each load.

2.8. Small equipment/tools/set-up for operation and safety requirements

The list of small equipment/tools/set-up for operation and safety requirements includes:

- Digital camera with video capturing function;
- Mobile phone;
- 120-150kg balance;
- Containers/buckets of different sizes;
- Hand shovel;
- Small hand tools;
- Site office;
- Temporary electricity supply;
- Temporary water supply;

- Temporary toilet;
- First aid box;
- Insect/mosquito repellent;
- Sunburn lotion;
- Personal Protection Equipment (PPE) for each on-site staff:
  - safety helmet;
  - safety shoes;
  - dust mask;
  - general purpose gloves;
  - blade cut resistance gloves;
  - goggles against flying particles;
  - fluorescent jacket;
  - “Level C” safety equipment for handling chemical waste.

2.9. Appropriate contractor and budget

Any contractors, who have previous experience on waste sorting, are considered appropriate for providing the service.

Major items for budget estimation are shown in the list below. The list covers three main areas – “provisions for works before conducting the actual waste sorting operation”, “provisions for works during the sorting operation” and “provision for site clearing and restoration after completion of the sorting operation”.

Provisions for works before conducting the waste sorting operation

- Provision of sorting site (including site clearance);
- Provision of temporary water;
- Provision of temporary electricity;
- Provision of temporary toilet;
- Provision of site office;
- Provision of fencing / hoarding for site boundary;
- Provision of concrete slab platform of 12m x 8m x 0.2m with a proper foundation;
- Insurance - contractor all risks and 3rd party liability insurance;
- Insurance - personal accident for the backhoe operator and grab mounted lorry.

Provisions for works during the sorting operation

- Provision of foreman (18 man-days during sorting operation + other man-days as necessary for management and administration tasks before and after the sorting operation);
- Provision of site worker (108 man-days);
- Hiring of backhoe including operator (18 working days);
- Hiring of grab mounted lorry (54 trips);
- Dumping charge to landfills;
- Provision of small equipment, hand tools and personal protection equipment.

Provision for works after completion of the sorting operation

- Site clearing and restoring subsequent to completion of operation.

Appendix A - Proposed Form for the Estimation of Construction Waste Generated from New Building Construction

Proposed Form for the Estimation of Construction Waste Generated from New Building Construction

Project Type: ____ **CFA**: _________m²
Date: __________________________________ **Recorded by:** __________________________

Substructure (with basement ☐; with pile caps ☐)

Superstructure Structure (including ground floor) ☐ (separate form for standalone clubhouse)

Site activities	**Material/Location**	**B.Q. Qty**	**Unit**	**Wastage Level (%)**	**Remarks**
Formworking (excluding left-in formwork)	Wall/Column		**M²**		Differentiate no. of reuses for non-typical and typical floors. After reuse, timber formwork is scrapped
	Slab & Beam		**M²**		
	Others				
Reinforcement Fixing (all locations)	Steel bars (Y & R)		**Kg**	2-3%	
	Steel fabric mesh		**M²**	5%	
Concreting	Wall (int'l & ext'l)		**M³**	3-5%	
	Column		**M³**		
	Slab & Beam		**M³**		
	Transfer plate/pile cap		**M³**		
Envelope	Precast Façades		**M²**	1%	

Finishing

Site activities	**Material/Location**	**B.Q. Qty**	**Unit**	**Wastage Level (%)**	**Remarks**
Brickwork	Wall		**M²**	15%	Add pellet
	Others				
Blockwork	Wall		**M²**	10%	Add pellet
	Others				
Drywall (plaster board)				4-6%	
Masonry and Granite/Marble Work (backing deemed to be included)	Internal wall		**M²**	8-12%	Add packing
	External wall		**M²**		Add packing
Plastering (wet) (ct/sand backings deemed to	Internal: wall		**M²**	10%	
	Internal: ceiling		**M²**		

Site activities	Material/Location	B.Q. Qty	Unit	Wastage Level (%)	Remarks
be included)	External wall		M^2	15%	
Roofing, Waterproofing and Expansion Joints	Cement/sand screed		M^3	10%	
	Roof waterproofing		M^2	Coating5% Membrane10%	
	Roof tile		M^2	5%	
	Decorative roof feature (steel or concrete)		**Kg or** M^3		
	Expansion joint		**M**		All cans
	Insulation board		M^2	10%	
Carpentry/Joinery *(convert to m^3 of timber content unless otherwise stated***)**	Cabinet/wardrobe		M^3		
	Door (all sizes)		M^2	0%	Manufactured off-site
	Frame		**M**	3%	Converted into length from BQ door area
Ironmongery	Lockset		**Set**		All boxes
	Hinges		**Pair**		
	Door knob		**Set**		
Staircases Railings and Handrails (assume 1.1m high)	Balustrade		**M**	1%	
	Railing		**M**		
	Handrail		**M**		
Metal Windows and Doors	Window		M^2	1%	
	Louvre		M^2	3%	
	Metal Door		M^2	1%	
Glazing, Curtain Wall and Cladding	Site fixed		M^2	2%	
	Factory fixed		M^2		
Floor Finishes (by types: all assumed site-fixed unless otherwise stated)	All types of tiles		M^2	10%	Add packing
Screeding to be converted into total volume using designed thicknesses	Screeding		M^3	10%	
Wall tile/cladding (by types: all assumed site-fixed unless otherwise stated)	Internal		M^2	10%	Add packing
	Pre-fixed (on precast)		M^2		
	External		M^2	10%	Add packing
Screeding to be converted	Pre-fixed tiles (on precast)		M^2	0%	

Site activities	Material/Location	B.Q. Qty	Unit	Wastage Level (%)	Remarks
into total volume using designed thicknesses	Screeding		**M^3**	10%	
False ceiling, if applicable (by types)	Gypsum board		**M^2**	5%	
	Aluminium board		**M^2**	3%	
Painting (by types)	Wall				
	Sealer		**M^2**		All cans
	Paint		**M^2**		All cans
	Ceiling				
	Sealer		**M^2**		All cans
	Paint		**M^2**		All cans
Sanitary Fittings	WC		**No**	0-1%	Add packing
	Urinal		**No**		
	Wash basin		**No**		
	Cistern		**No**		
	Bath tub		**No**		
	Mixer		**No**		
External Work and Landscape Work	Paving (insitu, e.g. Grano)		**M^2**	10%	
	Paving (preformed, e.g. slab)		**M^2**	5%	
	Screeding		**M^3**	10%	
	Kerb		**M**	3%	
	Drain pipe		**M**	3%	
	Turfing		**M^2**	5%	
Others (pls state): e.g. swimming pool to itemise					

Appendix B - Published Sources for Converting Design Work Quantities into Bulk Wastage Quantities

Based on the waste percentages, several published sources may be used to convert the design work quantities into bulk wastage quantities, including the following:

- Construction Waste Guide, New Zealand, May 1999;
- Volume-to-Weight Conversion Factors, US Environmental Protection Agency, April 2016;
- FEECO International Handbook, FEECO International Inc. May, 2010;
- Conversion factors, UK Waste Classification Scheme, DEFRA;
- Construction and Demolition Waste Management Toolkit, WasteCap Resource Solutions, Inc., 2011.

REPORT 7

SPECIFICATION FOR UPSTREAM ESTIMATION OF NON-INERT CONSTRUCTION WASTE COMPOSITION

August 2017

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1. Preamble

For effective waste management, the approximate quantities of waste for a construction project shall be estimated based on the complete design information, especially when near to the tender stage for the main building contract for a project using the traditional procurement approach.

For a single project, the estimated quantities and types of waste should enable the consultants and contractors to take appropriate waste management action even before the project commences. In the long run, such estimates shall form benchmarks by relating to the scope (expressed in Construction Floor Area basis) and nature of the projects. Efforts should then be made to reduce waste as far as practicable during the design stage in the choice of materials and dimensional coordination.

Since the bulk volume of waste is a critical concern for waste management, the conversion of design quantities into waste is based on bulk volume estimate, but if the Contract provides that weights shall be of concern of the Council, the calculation shall be extended to include weights where specified.

2. Scenario (A) – Bills of Quantities (BoQs) being available from professional quantity surveyors

Since piling usually forms a separate contract, the extraction of quantities shall start from the pile cap (if it is incorporated in the main contract; if not, account shall be taken of the quantities since pile cap formwork is usually of timber which would eventually be scrapped after use). Excavated spoil for foundations shall be excluded, unless a special disposal method is specified.

For BoQs presented in elemental format, add similar items appearing in different elements (e.g., screedings in floors and walls). Differentiate materials (e.g., concrete, tiles, marble, asphalt, etc.) giving rise to inert wastes from those generating non-inert wastes, and they should be separately accounted for.

For waste management purpose, wastes arising from the use of the materials and their containers/packaging materials shall be included.

A proforma similar to Appendix A may be used to tabulate the summary quantities extracted from BoQs but separate compilation sheets shall be attached to show the break-downs for major sections such as podium (including car parts, if any), towers, standalone club house, external works (including swimming pools). These breakdowns and summaries shall form part of the deliverables of the Contract.

The general principles of arriving at the bulk volumes of materials shall be as follows:

(1) Convert materials into their absolute volume (in m^3) from their given dimensions, if any (e.g., area multiplied by thickness);

(2) Convert weights into absolute volumes using absolute densities;

(3) Estimate bulking ratios (by referring to tables from published sources, the citations for which shall be included in the deliverables as an appendix);

(4) Estimate bulk volume of waste using absolute volume multiplied by a bulking ratio.

Multiply each bulk volume by the respective suggested waste percentage for each material (including cutting waste and operational waste) similar but not necessarily based on those percentages shown in Appendix A, which is estimated based on normal urban site conditions (for multi-storey construction with common plant usage on flat ground). Where site conditions differ significantly from the said scenario, suitable adjustments shall be made to reflect the envisaged wastage levels for a particular project.

If timber is envisaged as formwork materials, the no. of re-use for typical floors shall be differentiated from non-typical floors, depending on the complexity of design. Left-in formwork shall be excluded from the waste calculation. Zero waste may be assumed for metal formwork, if specified, but judgement shall be made dependent on each particular project's design.

For the following types of materials (not exhaustive), extra allowance shall be made for:

- Timber pellets and crating for materials delivered in them (assuming not returnable to suppliers);
- Cement for plastering, mortar, screeding and the like to be mixed on site: - paper bags;
- Liquid membrane waterproofing/roofing: - metal/plastic containers;
- Joint sealant: - plastic containers and cartons;
- Off-site manufactured doors: - assumed corrugated cardboards as protection;
- Paper boxes for ironmongeries and tiles;
- Painting (including sealer): - metal containers;
- Sanitary fittings: - pellets/crating/wrapping;
- Hardwood flooring: - pellets/crating;
- Kitchen cabinet/countertops: - wrapping.

For building services equipment, estimation of waste arising from packaging materials may be based on manufacturers' data as far as practicable. Permanent work material quantities shall be obtained from the specialist contracts and/or sub-contracts where obtainable, otherwise reference may be made to the prime cost and/or provisional sums allowed in the main contract as to the relative scale of these works. All equipment shall be assumed to be fully fixed on completion and cause no waste, but judgement shall be made dependent on the particular project's design.

Where recycling is envisaged, due allowance shall be made to account for the volume/weight of wastes to be recycled.

3. Scenario (B) – no BoQ available (e.g., for contracts based on specifications and drawings)

Major quantities as shown in the proforma in Appendix A may be taken off from tender drawings, or the estimation may be deferred until the main building contract is awarded. The successful contractor's schedule of quantities may be used as a good reference, although errors in measurement need to be mindful of.

A similar process of estimation shall be carried out as in Scenario (A), with similar deliverables.

[Note: Construction Floor Area (in m^2) is defined as the summation of all areas at all floor levels, including basements, mezzanine floors, balconies and enclosed rooftop structures, measured to outer face of external wall. It is measured over all partitions, columns, walls, stair wells, lift wells, escalator openings, etc.]

4. Deliverables

- Total bulk volume of construction waste (X m^3);
- Bulk volume of non-inert construction waste (Y m^3);
- Total Bulk volume of construction waste per CFA;
- Bulk volume of non-inert construction waste per CFA;
- Percentage of timber formwork waste (expressed as % of X);
- One hard copy and soft copy of summary sheets as specified above, including percentages of wastage assumed for permanent works;
- Cited sources of absolute densities and bulk densities.

Appendix A - Standard Form for the Estimation of Construction Waste Generated from New Building Construction

Standard Form for the Estimation of Construction Waste Generated from New Building Construction

Project Type: ____ **CFA**: _________m^2
Date: ________________________________ **Recorded by:** __________________________

Substructure (with basement ☐; with pile caps ☐)
Superstructure Structure (including ground floor) ☐ **(separate form for standalone clubhouse)**

Site activities	Material/Location	B.Q. Qty	Unit	Wastage Level (%)	Remarks
Formworking (excluding left-in formwork)	Wall/Column		**M²**		Differentiate no. of reuses for non-typical and typical floors. After reuse, timber formwork is scrapped
	Slab & Beam		**M²**		
	Others				
Reinforcement Fixing (all locations)	Steel bars (Y&R)		**Kg**	2-3%	
	Steel fabric mesh		**M²**	5%	
Concreting	Wall (int'l & ext'l)		**M³**	3-5%	
	Column		**M³**		
	Slab & Beam		**M³**		
	Transfer plate/pile cap		**M³**		
Envelope	Precast Façades		**M²**	1%	

Finishing

Site activities	Material/Location	B.Q. Qty	Unit	Wastage Level (%)	Remarks
Brickwork	Wall		**M²**	15%	Add pellet
	Others				
Blockwork	Wall		**M²**	10%	Add pellet
	Others				
Drywall (plaster board)				4-6%	
Masonry and Granite/Marble Work (backing deemed to be included)	Internal wall		**M²**	8-12%	Add packing
	External wall		**M²**		Add packing
Plastering (wet) (ct/sand backings deemed to be included)	Internal: wall		**M²**	10%	
	Internal: ceiling		**M²**		
	External wall		**M²**	15%	
Roofing,	Cement/sand screed		**M³**	10%	

Site activities	Material/Location	B.Q. Qty	Unit	Wastage Level (%)	Remarks
Waterproofing and Expansion Joints	Roof waterproofing		**M^2**	Coating5% Membrane10%	
	Roof tile		**M^2**	5%	
	Decorative roof feature (steel or concrete)		**Kg or M^3**		
	Expansion joint		**M**		All cans
	Insulation board		**M^2**	10%	
Carpentry/Joinery *(convert to m^3 of timber content unless otherwise stated)*	Cabinet/wardrobe		**M^3**		
	Door (all sizes)		**M^2**	0%	Manufactured off-site
	Frame		**M**	3%	Converted into length from BQ door area
Ironmongery	Lockset		**Set**		All boxes
	Hinges		**Pair**		
	Door knob		**Set**		
Staircases Railings and Handrails (assume 1.1m high)	Balustrade		**M**	1%	
	Railing		**M**		
	Handrail		**M**		
Metal Windows and Doors	Window		**M^2**	1%	
	Louvre		**M^2**	3%	
	Metal Door		**M^2**	1%	
Glazing, Curtain Wall and Cladding	Site fixed		**M^2**	2%	
	Factory fixed		**M^2**		
Floor Finishes (by types: all assumed site-fixed unless otherwise stated)	All types of tiles		**M^2**	10%	Add packing
Screeding to be converted into total volume using designed thicknesses	Screeding		**M^3**	10%	
Wall tile/cladding (by types: all assumed site-fixed unless otherwise stated)	Internal		**M^2**	10%	Add packing
	Pre-fixed (on precast)		**M^2**		
	External		**M^2**	10%	Add packing
	Pre-fixed tiles (on precast)		**M^2**	0%	
Screeding to be converted into total volume using designed thicknesses	Screeding		**M^3**	10%	
False ceiling, if applicable (by types)	Gypsum board		**M^2**	5%	
	Aluminium board		**M^2**	3%	

Site activities	Material/Location	B.Q. Qty	Unit	Wastage Level (%)	Remarks
Painting (by types)	Wall				
	Sealer		**M²**		All cans
	Paint		**M²**		All cans
	Ceiling				
	Sealer		**M²**		All cans
	Paint		**M²**		All cans
Sanitary Fittings	WC		**No**	0-1%	Add packing
	Urinal		**No**		
	Wash basin		**No**		
	Cistern		**No**		
	Bath tub		**No**		
	Mixer		**No**		
External Work and Landscape Work	Paving (insitu, e.g. Grano)		**M²**	10%	
	Paving (preformed, e.g. slab)		**M²**	5%	
	Screeding		**M³**	10%	
	Kerb		**M**	3%	
	Drain pipe		**M**	3%	
	Turfing		**M²**	5%	
Others (pls state): e.g. swimming pool to itemise					

REPORT 8

SPECIFICATION FOR DOWNSTREAM ESTIMATION OF NON-INERT CONSTRUCTION WASTE COMPOSITION

August 2017

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The Specification for downstream estimation of non-inert construction waste composition study includes the following main parts:

(1) Number of lorry/truck load of construction waste to be studied;

(2) Duration and time;

(3) Method of non-inert waste estimation;

(4) Sorting list;

(5) Sorting area and location;

(6) Manpower;

(7) Large equipment;

(8) Small equipment/tools/set-up for operation and safety requirements;

(9) Appropriate contractor and work provisions

1. Number of lorry/truck load of construction waste to be studied

Table 1 presents the extent of the non-inert construction waste composition study. The study shall cover three types of building construction site (“residential”, “commercial” and “hotel”), and three stages of construction (“superstructure”, “immediate after superstructure completion” and “before occupation”).

Table 1 Extent of the non-inert construction waste composition study

Type of Site	Stage of Construction	Scale of Site	Set
• Residential	• Superstructure • Immediate after superstructure completion • Before occupation	• 1 block • >1 block	1
• Commercial • Hotel		-	2

For the residential building, two scales of construction site (“1 block” and “>1 block”) shall be studied. For the commercial building and the hotel building, two sets of sites for each type shall be included. Hence, the study shall include 18 numbers of building construction site. Each of the sites shall provide three lorry/truckloads of construction waste. In total, there are 54 lorry loads of construction waste for the study.

2. Duration and time

The work for waste sorting shall be targeted for completion within 27 working days of fine weather. The sorting exercise should avoid the raining season and the typhoon season prevailing in Hong Kong. The best time period for the sorting is, therefore, between November and March of the year.

3. Method of non-inert waste estimation

Non-inert wastes are more than likely to be mingled together with inert wastes due to the fact that effective sorting at construction site is difficult to be implemented in most cases. Hand sorting, together with manual weighing, shall be the method for the non-inert waste composition study.

Construction waste delivered to the sorting ground shall be spread out and divided into four equal parts (as shown in Figure 1). Sorting shall then be carried out on two of the parts according to a pre-fixed plan.

4	**1**
3	**2**

Figure 1 Construction waste divided into four parts

4. Sorting list

Table 2 shows the list for sorting non-inert wastes. The table includes two main sections:

(1) General information registration;

(2) Non-inert wastes to be identified (29 types).

The general information registration contains:

- Date;
- Weather;
- Site number;
- Lorry number;
- Lorry arrival time;
- Lorry licence plate number;
- Sorting time (beginning);
- Sorting time (completion);
- Parts sorted;
- Grab mounted lorry arrival time;
- Grab mounted lorry licence plate number;
- Chit ticket number;
- Total load of construction waste stated on chit ticket;
- Person taking the record;
- Remark.

The list of non-inert wastes includes the following items:

- Bamboo;
- Formwork;
- Wooden pallet;
- Packaging timber;
- Iron/copper pipe;
- Rebar;
- Aluminium scrap;
- Metal container;
- Steel scraps;

- Cardboard;
- Packaging paper;
- Plastic wrapping;
- Plastic container;
- PVC duct;
- Cable;
- Plastic traffic barrier;
- Window seal container;
- Rubber;
- WEEE;
- Vegetation;
- Textile;
- Fibreglass;
- Nylon;
- Domestic waste;
- Sanitary ware;
- Styrofoam;
- Gypsum board;
- Glass;
- Others.

Table 2 The list for sorting non-inert waste

<table>
<tr><td colspan="2">Date:</td><td>Weather:</td><td></td><td>Site no.:</td><td></td></tr>
<tr><td>Lorry arrival time:</td><td></td><td></td><td></td><td colspan="2">Grab mounted lorry arrival time:</td></tr>
<tr><td colspan="3">Lorry no.:</td><td></td><td colspan="2">Grab mounted lorry licence plate no.:</td></tr>
<tr><td>Lorry licence plate no.:</td><td></td><td></td><td></td><td colspan="2">Chit ticket no.:</td></tr>
<tr><td colspan="3">Sorting time (beginning):</td><td></td><td>Total load of construction waste stated on chit ticket:</td><td></td></tr>
<tr><td colspan="3">Sorting time (completion):</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Parts sorted:</td><td></td><td>Recorded by:</td><td></td></tr>
<tr><td colspan="6">Remark:</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Material	Group No.	Group	Type No.	Type	Weight (kg)
Non-inert	1	Bamboo	1	no sub-group	
	2	Wood & Timber	2a	formwork	
			2b	wooden pallet	
			2c	packaging timber	
			2d	others	
	3	Metal	3a	iron / copper pipe	
			3b	metal sink	
			3c	rebar	
			3d	aluminium scrap	
			3e	metal containers for material packaging	
			3f	steel scrap	
			3g	others	
	4	Paper & Cardboard	4a	cardboard	
			4b	packaging paper	
			4c	others (newspaper, office paper etc.)	
	5	Plastic & Rubber	5a	plastic wrapping	
			5b	plastic container	
			5c	PVC duct	
			5d	cable	
			5e	plastic traffic barrier	
			5f	window seal container	
			5g	rubber	
			5h	others	
	6	WEEE	1	electric appliance, electric socket, lighting, water pump, electric motor, transformer (i.e. no sub-group)	
	7	Vegetation	1	tree trunk etc. (i.e. no sub-group)	
	8	Textile	1	no sub-group	
	9	Fibreglass	1	no sub-group	
	10	Nylon	1	no sub-group	
	11	Domestic Waste	1	food waste etc. (i.e. no sub-group)	
	12	Sanitary Ware	1	porcelain water closet, porcelain wash hand basin, kitchen solid surface material etc. (i.e. no sub-group)	
	13	Styrofoam	1	no sub-group	
	14	Gypsum Board	1	Gypsum drywall etc. (i.e. no sub-group)	
	15	Glass	1	no sub-group	
	16	Others (to be descripted)	1	-	
Inert	17	Inert	1	rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt, brick & tile etc. (i.e. no sub-group)	
				Total weight:	

5. Sorting area and location

The sorting platform should be strong enough to sustain loadings of lorries and movements of backhoe without deterioration that could generate additional waste to the construction waste being sorted. Platform of C40 concrete of 200mm thick with a proper foundation should be used. The platform should also be large enough for construction waste spreading and sorting. A minimum area of 12m by 8m should be provided.

6. Manpower

Apart from the backhoe operator, who is usually supplied by the backhoe hiring company, the construction waste sorting team shall include a foreman and six site workers. The foreman shall be responsible for all on-site management and communication works – including taking full record of site work and sorting measurements, and communication with different construction sites, grab mounted lorry and the site workers etc. The site workers shall work on all manual works related to waste sorting and weighing.

7. Large equipment

A 6-tonne backhoe or a large backhoe shall be used to even out and move the construction waste on site. And a grab mounted lorry shall be hired to send the construction waste away after completion of the sorting work of each load.

8. Small equipment/tools/set-up for operation and safety requirements

The list of small equipment/tools/set-up for operation and safety requirements shall at least include:

- Digital camera with video capturing function;

- Mobile phone;
- 120-150kg balance;
- Containers/buckets of different sizes;
- Hand shovel;
- Small hand tools;
- Site office;
- Temporary electricity supply;
- Temporary water supply;
- Temporary toilet;
- First aid box;
- Insect/mosquito repellent;
- Sunburn lotion;
- Personal Protection Equipment (PPE) for each on-site staff:
  - safety helmet;
  - safety shoes;
  - dust mask;
  - general purpose gloves;
  - blade cut resistance gloves;
  - goggles against flying particles;
  - fluorescent jacket;
  - “Level C” safety equipment for handling chemical waste.

9. Appropriate contractor and work provisions

Any contractors, who have previous experience on waste sorting, are considered appropriate for providing the service.

Major items for work provision are shown in the list below. The list covers three main areas – "provisions for works before conducting the actual waste sorting operation", "provisions for works during the sorting operation" and "provision for site clearing and restoration after completion of the sorting operation".

Provisions for works before conducting the waste sorting operation

- Provision of sorting site (including site clearance);
- Provision of temporary water;
- Provision of temporary electricity;
- Provision of temporary toilet;
- Provision of site office;
- Provision of fencing / hoarding for site boundary;
- Provision of concrete slab platform of 12m x 8m x 0.2m with a proper foundation;
- Insurance - contractor all risks and 3rd party liability insurance;
- Insurance - personal accident for the backhoe operator and grab mounted lorry.

Provisions for works during the sorting operation

- Provision of foreman (18 man-days during sorting operation + other man-days as necessary for management and administration tasks before and after the sorting operation);
- Provision of site worker (108 man-days);
- Hiring of backhoe including operator (18 working days);
- Hiring of grab mounted lorry (54 trips);
- Dumping charge to landfills;
- Provision of small equipment, hand tools and personal protection equipment.

Provision for works after completion of the sorting operation

- Site clearing and restoring subsequent to completion of operation.

SUMMARY REPORT

August 2017

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The objectives of the Consultancy are:

1. To conduct literature review on overseas policies and measures for management and reduction of construction waste;
2. To conduct literature review on the current statutory and administrative measures for management and reduction of construction waste in public works and private works projects;
3. To propose strategy and measures for management and reduction of construction waste;
4. To conduct feasibility study of on-site snapshot survey for the non-inert construction waste composition in Hong Kong;
5. To propose an appropriate methodology (upstream or downstream approach) for the non-inert construction waste composition study after the feasibility study;
6. To prepare a service specification for the suggested methodology (upstream or downstream approach) to carry out the snapshot survey for the non-inert construction waste composition.

This summary report aims to provide the main findings of the 8 reports with an overall recommendation for C&D Waste Minimisation in Hong Kong.

1. Literature Review on Overseas C&D Waste Management Policies and Measures

The information of overseas policies and measures was collected from three main sources: a) academic publications; b) official websites of overseas governments; and c) overseas green building rating tools. The investigated overseas countries/regions include United States, European Union, Sweden, the Netherlands, Japan, Singapore, Korea, Australia, and Taiwan. The following green building rating tools were also reviewed: LEED for United States, BREEAM for United Kingdom, Green Globes for Canada, Green Mark for Singapore, and Assessment standard for green building (GB/T50378-2014) for Mainland China.

The policies and measures identified from academic literature review are presented in Table 1.

Table 1 Summary of the identified overseas policies and measures.

Policy/measure	Remarks
Legislation	Legislation on C&D waste management can provide legal basis for implementing C&D waste minimisation. However, most countries have no legislation particularly focusing on C&D waste. The C&D waste related requirements are usually embedded in the regulation of general waste related regulations or solid waste related regulations.
Market-based instruments	The recycling market is a critical factor that influence the stakeholders' waste reuse/recycling intentions, because most of them are benefit-earning oriented. Meanwhile, a certification system is suggested to ensure the quality of recycled materials.
Vehicle impoundment policy	The vehicle impoundment policy is efficient to prevent illegal dumping, especially in developing countries. An effective supervision system should be established to oversee the illegal dumping behaviour.
Proper design	Proper design is an effective measure that can avoid waste before it is generated. However, the awareness of C&D waste minimisation is not optimistic among designers. Publicity should be made to let the designers know their roles in waste reduction.
Use of prefabrication	Prefabrication is an effective strategy for not only minimising C&D waste, but also carbon emissions. It is an emerging strategy that has been encouraged by many studies.
Waste sorting	Waste sorting can be conducted on-site or off-site according project conditions; on-site sorting is highly recommended. Potential limitations of employing on-site sorting include space limitation, time limitation,

Policy/measure	Remarks
	labour limitation, and cost limitation. However, cost limitation is the most important factor concerned by the contractors. A high landfill disposal fee can facilitate the improvement of on-sorting.
Selective demolition	Selective demolition is also named as deconstruction in some literature, it is a reverse process of construction. The separated waste can be reused directly or sold to recyclers. However, selective demolition faces the same limitations as waste sorting; cost is the major consideration factor.
Accurate waste quantification	Accurate waste quantification is essential for good management at both regional and project levels. Regional waste generation can be estimated through forecasting techniques if historical generation data are well collected and stored. At project level, a feasible waste management plan can be made based on the accurate waste estimation. However, the main obstacle is that reliable estimation of C&D waste generation is rare.
Incentive reward program	The incentive reward program can promote the waste reduction intentions of construction workers. However, an efficient system should be established and benchmarks should be set up to monitor how many materials saved by the construction workers.
Online waste exchange	Online waste exchange can increase the C&D waste reuse/recycling rate by avoiding disposal at landfills. A reliable platform is needed for efficient exchanging of waste generation information. Meanwhile, the government should permit such exchange. Thus, the platform is suggested to be established by the government.
GIS (Geographic Information System) technology	GIS technology can be used at a project to monitor the distribution of materials storage. The advantages include visual representation and quantification of the waste flows. However, this technology need comprehensive GIS data.
Building information modeling (BIM)	BIM can be used to minimise C&D waste from many aspects, such as estimation of waste amount, flexible design change, etc. However, this is a comparatively novel technology, more modules should be developed for C&D waste management.
Education and training	The aim of education and training is to increase the construction practitioners' awareness of C&D waste management and enhance their relevant skills. This needs project managers' support and a better C&D waste management culture.

The successful overseas experiences were identified from governmental websites of the investigated countries, as shown in Table 2.

Table 2 Overseas successful experiences on C&D waste management

Country/region	Successful experience
United States	• implementation of source reduction; • implementation of deconstruction; • illustrative manuals and practical cases; • development of mature waste trade market.
European Union	• implementation of Waste Framework Directive; • mature reuse/recycling market; • life-cycle thinking; • support for research projects.
Sweden	• implementation of legislative initiatives; • improved and better controlled quality of C&D waste; • implementation of landfill taxes; • ban on landfilling of combustible waste fractions.
The Netherlands	• implementation of legislative initiatives; • implementation of landfill and incineration taxes; • development of mature secondary material market.
Japan	• implementation of Construction Recycling Law; • mature C&D waste recycling technologies and facilities.
Singapore	• efficient waste sorting; • strict supervision on illegal dumping; • mature waste recycling technologies and facilities.
Korea	• implementation of Construction Waste Recycling Promotion Act; • quality certification system for recycled aggregates; • construction waste information management system for waste exchange.
Australia	• implementation of legislative initiatives; • implementation of landfill tax; • supply chain management.
Taiwan	• implementation of legislative initiatives; • effective sorting.

The waste management requirements identified from the investigated green building rating tools were presented in the overseas report in detail. The results showed that LEED and BREEAM have very detailed requirements and specifications for C&D waste management. However, Green Globes and Green Mark do not have too much emphasis on C&D waste management. Although GB/T50378-2014 gives emphasis on C&D waste management, the detailed specifications are not adequate.

2. Literature Review on Current Statutory and Administrative C&D Waste Management Measures in Hong Kong

The current statutory and administrative measures in Hong Kong were reviewed from academic papers, governmental and industrial association websites, and BEAM Plus. The main findings are shown in Table 3.

Table 3 Advantages and potential limitations of the identified policies and measures in Hong Kong

Policy/measure	Advantages	Potential limitations
Regulations, codes, and initiatives	C&D waste management has been emphasised in regulations (i.e. Waste Disposal Ordinance) since 1980; Particular regulations have been published by Hong Kong government, such as the Trip Ticket System.	No more initiatives since the implementation of the Construction Waste Disposal Charging Scheme.
Construction waste disposal charging scheme	The charging scheme has been established since 2005; C&D waste are classified into inert and non-inert categories in order to encourage sorting.	The current disposal charges are low compared with other countries limiting the incentives for better waste management.
Waste management plan	Waste management plans are generally required before the commencement of construction projects.	Enforcement of implementation of the waste management plan is lacking.
Development of a mature waste recycling market	A mature recycling market will increase the willingness of construction stakeholders to sort, reuse or recycle materials.	Potential worries about the quality of recycled materials; Lack of quality specifications; Lack of sufficient support from government to the recycling industry.
Proper design	Several C&D waste minimisation measures have been recommended by government and BEAM Plus for proper design.	No minimum requirement on MA Credits in BEAM Plus and credits for C&D waste management BEAM Plus are not compulsory.
Use of	The technology has been	Higher initial and transportation costs;

Policy/measure	Advantages	Potential limitations
prefabrication	mature; Hong Kong government has promoted the implementation of this technology.	Last minutes design changes limit its use.
On-site sorting	Benefit-earning from selling sorted valuable materials; Cost-saving from disposal at public fills rather than landfilling; Recommendations from government and green building rating tools.	Space demanding; Time demanding; Cost demanding; Labour demanding; Lack of a mature recycling market to absorb the sorted materials.
Off-site sorting	Lower cost than landfilling disposal.	Double handling as a high percentage of waste received need to go the landfills eventually; Need proper locations of the off-site sorting facilities in order to reduce transportation cost; Potential generation of noise and dust at the off-site sorting facilities.
Selective demolition	Benefit-earning from selling sorted valuable materials; Cost-saving from disposal at public fills rather than landfilling; Recommendations from government and green building rating tools.	Space demanding; Time demanding; Cost demanding; Labour demanding; Lack of a mature recycling market; Lack of coordination in contract arrangement limits its use.
Accurate waste quantification	Continuous recording of waste disposal data by EPD and CEDD; Computer-aided data mining techniques.	Lack of detailed waste generation classification records at project levels.
Incentive reward program	Waste reduction intentions of construction workers can be stimulated.	Lack of benchmarks to evaluate material savings; Lack of awareness from project managers or developers.
Online waste exchange	Techniques for developing an online waste platform are mature.	Lack of promotion from the government and related organisations.
Integrated GPS	The GPS and GIS technologies	Lack of GIS information;

Policy/measure	Advantages	Potential limitations
and GIS technology	are mature.	Lack of successful practices; Increase of cost.
RFID technology	The RFID technology is mature.	Increase of cost; More staff need to be assigned for using this technology.
Building information modeling (BIM)	The BIM technology has been used in Hong Kong.	More modules need to be developed for C&D waste management; Increase of cost for establishment.
Education and training	Hong Kong government has held workshops and trainings for increasing safety awareness.	Lack of emphasis from government and other construction stakeholders; Increase of cost.
Waste Minimisation: Provision of Fitments and Fittings in New Buildings	Requirements for the provision of fitments and fittings prior to issue of an occupation permit for a new building should not be insisted upon to reduce waste.	Construction waste generated from fitting out works carried out by individual contractors; Chaotic condition arising from individual owners engaging their own contractor to carry out the fitting out works; The practicality of testing plumbing and drainage system without fitments for compliance with regulation; Mostly applicable to restaurants and hotels for which extensive renovation and fitting out will be carried out by a restaurant or hotel operator after the issue of occupation permit; and in the process any sanitary fitting installed prior to the issue of an occupation permit would be dismantled in the course of such renovation work.

3. Report of Interviews & Focus Group Meetings

In order to propose appropriate strategies and measures for construction waste management and reduction in Hong Kong, 11 face-to-face interviews and two focus group meetings were implemented with construction stakeholders including client, designer, contractor, and government officer. The face-to-face interviews were conducted in August 2016, and the two focus group meetings were conducted on 15 and 22 of September 2016 respectively. The proposed strategies and measures for managing and reducing C&D waste are summarised in Table 4. A summary of proposed actions for government to reduce C&D waste is tabulated in Table 5.

Table 4 Proposed strategies and measures for C&D waste minimisation

Strategies & Measures	Client	Designer	Contractor
Design Stage			
• No-Frills Design	X	X	
• Adaptive design	X	X	
• Integrated Project Design		X	X
• Consider waste reduction and management	X	X	
• Use Design and Build contract for infrastructure projects	X	X	X
• Use low-waste technologies	X	X	X
• Use precast concrete/prefabricated building components	X	X	
• Reuse existing foundation/structures	X	X	
• Use reusable temporary work		X	
• Use dry wall system and external painting	X	X	
• Use durable/recycled building materials	X	X	
• Minimise design change	X	X	
• Apply BIM to review construction sequences		X	
Tender Stage			
• List Management of contractors	X	X	X
• Introduce “Award and Penalty” scheme	X	X	X
• Contractors propose innovative waste management scheme	X	X	X

Strategies & Measures	Client	Designer	Contractor
• Introduce waste reduction procurement for nominated subcontracts	X	X	X
• Allow recycle rates in BQ	X	X	X
Construction Stage			
• Set up contractor communication platform for reuse and recycling			X
• Allow longer construction period	X		
• Review Method Statement for Construction		X	X
• Phasing construction period		X	X
• On-site sorting			X
• Consider off-site sorting when on-site sorting is not feasible			X
• Reuse excavated soil in other projects			X
• Reuse demolished concrete for paving bicycling tracks			X

Table 5 Proposed actions for government to reduce C&D waste

Proposed Actions: C&D waste reduction should become a government policy	Term
Interim Measures	
• Use T-Park to burn timber waste for energy recovery	Short
Promote Green Technologies & Materials	
• Setup a central coordinating team for approving alternative recyclable/reusable material	Medium
• Simplify and streamline the approval process of innovative waste reducing technologies	Medium
• BD to work with CIC and HKGBC to streamline approving process of low-waste technologies and reusable materials	Medium
Encourage Reuse/Recycling of C&D waste	
• Significant increase in dumping charge	Short
• Revitalisation of buildings to be classified under “New Buildings”	Medium
• Mandatory selective onsite sorting for timber & plastic wastes	Medium
• Mandatory use of reusable formwork	Medium
• Introduce interim percentages to the 60% requirement of recycling C&D waste in BEAM Plus	Medium
• Set up C&D waste reduction policy and monitor implementation	Long
• CIC to set up recycle standards and study implementation method	Long
• Line up with Mainland’s demand on recyclable materials	Long

Proposed Actions: C&D waste reduction should become a government policy	**Term**
• HKGBC to review and revise the scoring system based on comments from construction industry	Long
Facilitate the Development of Recycling Industry	
• Set up a central coordination team to streamline and simplify the approving process of recycle subsidise	Medium
• Provide more public sorting sites	Medium
• Privatise the sorting facilities to let market decide the appropriate development patterns	Long
• Publicise the potential of lining up with recycling factories in Mainland	Long
Facilitate the Development of Local Prefabrication Industry	
• Award GFA concession for precast/prefabricated facade	Medium
• Provide low-rent sites for manufacturing	Medium
Research and Education	
• Set up research funding for C&D waste reduction and management	Long
• Educate clients and contractor on social responsibility of reducing C&D waste	Long
• Educate the general public the importance and necessity to minimise C&D waste	Long

4. Report of Site Visits

In order to conduct the feasibility study of on-site snapshot survey, three sites in different construction stages were visited and 10 trucks of construction waste were sorted.

Site observations were arranged to three different building sites at different stages of construction, such as end stage of construction (Site A), mid-stage of construction (Site B), and initial to mid-stage of construction (Site C). Prior to site observations, meetings were held with Environmental Officers of each project to get an overview of the waste management situation. Then, the work trades, waste types, and waste management measures of each site were observed by our team members. Photos 1-3 show the pictures taken during the site visits.

Photo 1 Site visit at Site A

Photo 2 Site visit at Site B

Photo 3 Site visit at Site C

5. Report of Construction Waste Sorting

A total of 10 trucks of waste from the three observed residential building sites were collected for sorting. Waste composition analysis was carried out from 29 July 2016 to 10 August 2016 (29/7, 30/7, 8/8, 9/8, 10/8). Upon receiving each lorry of the construction waste, the material was unloaded on a concrete platform, spread out and divided into four equal parts. Two of each set of four parts were selected for measuring and recording corresponding weights. Photos 4-6 show the activities during construction waste sorting.

Photo 4 Using backhoe to even the debris

Photo 5 Sorting process

Photo 6 Quantifying of each type of materials

The sorting results are presented in Figure 1-4. It can be seen that the percentages of non-inert waste in the construction waste were 38% in Site A, 61% in Site B, 40% in Site C and 47% overall. Wood & Timber was the major non-inert waste: 19% in Site A, 53% in Site B, 32% in Site C and 36% overall. Comparison between the three sites suggests that Site B, at its middle construction stage, generated the highest percentage of "Wood & Timber" waste (53%). Site C, at its initial to middle construction stage also produced relatively high amount of "Wood & Timber" waste (32%). In both cases, the high "Wood & Timber" waste generation was due to the use of timber formwork.

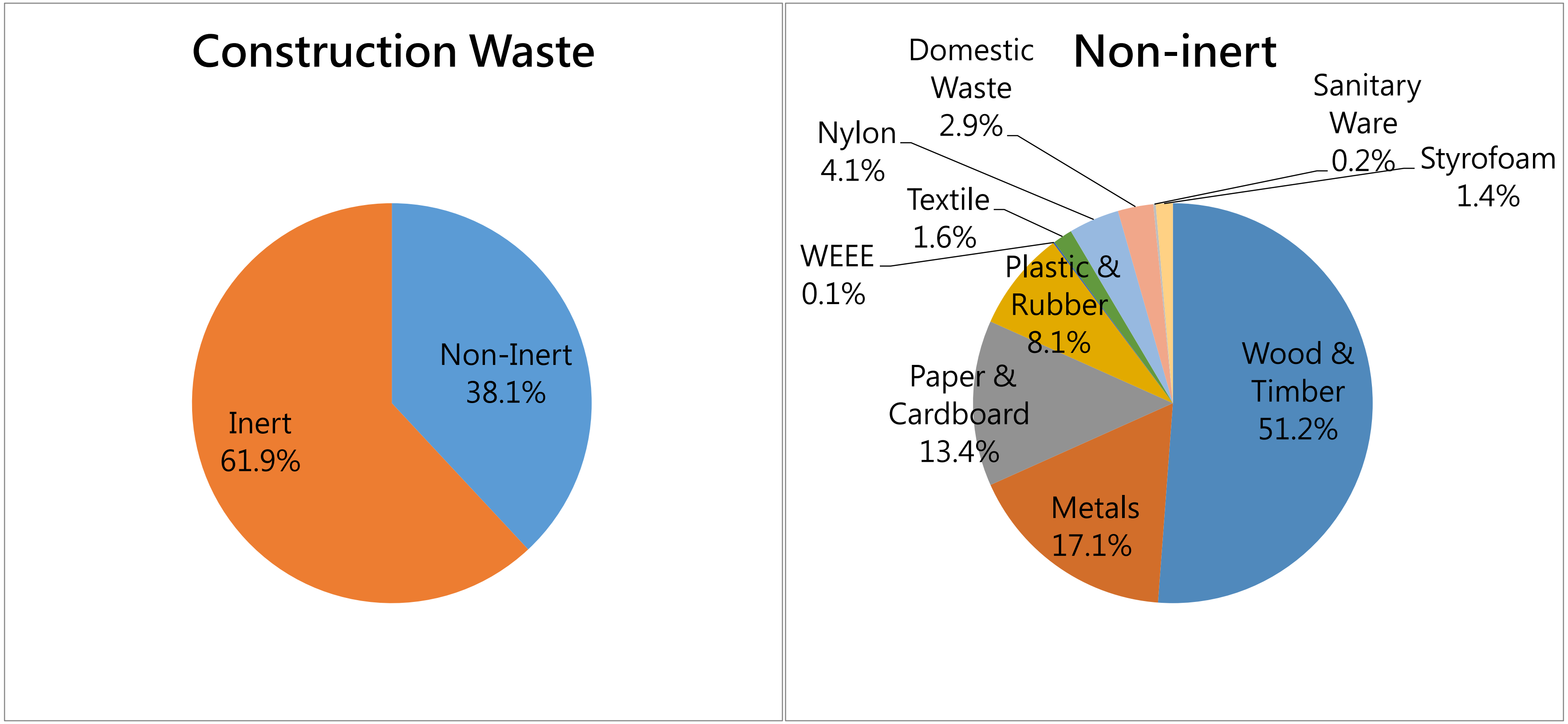

Figure 1 Sorting results of Site A

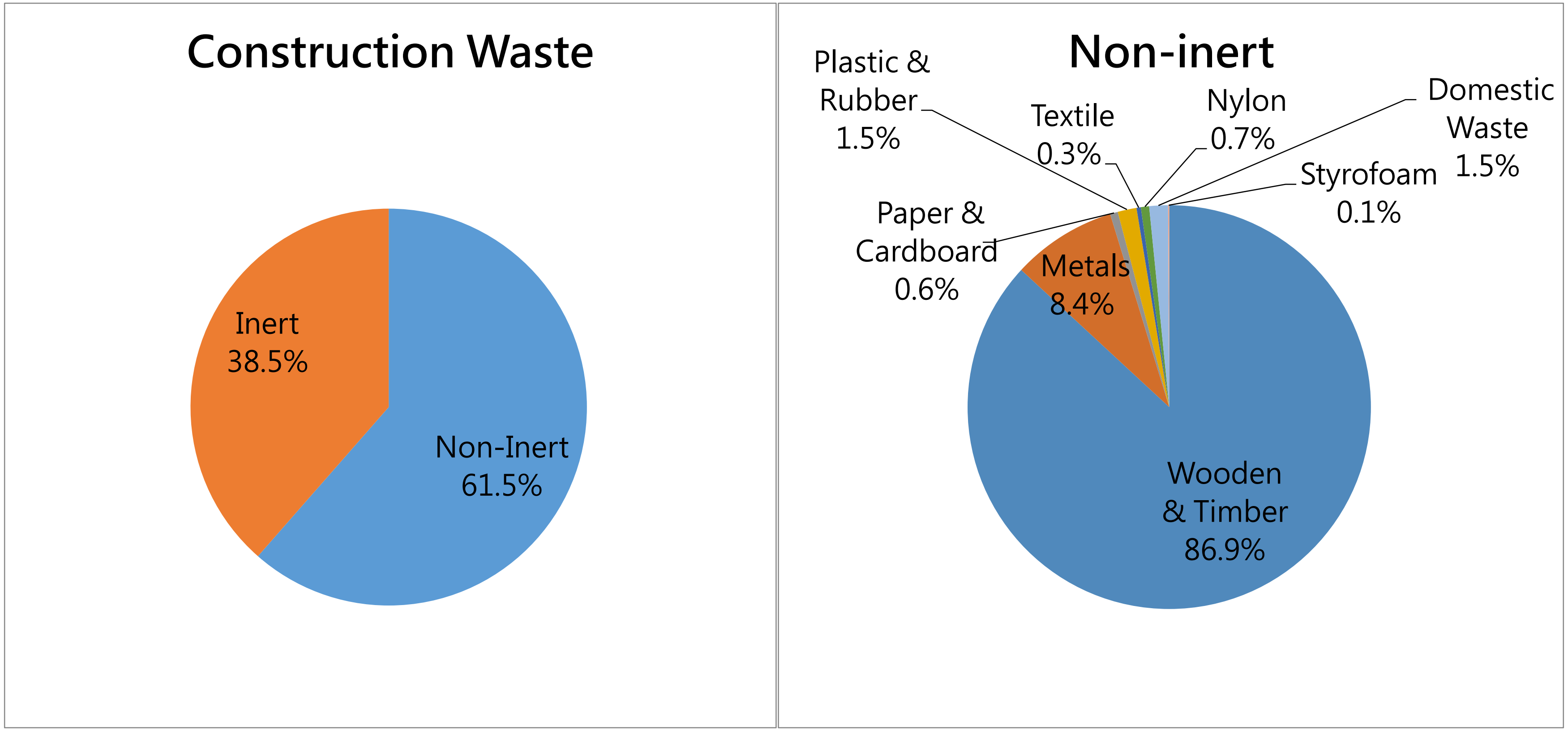

Figure 2 Sorting results of Site B

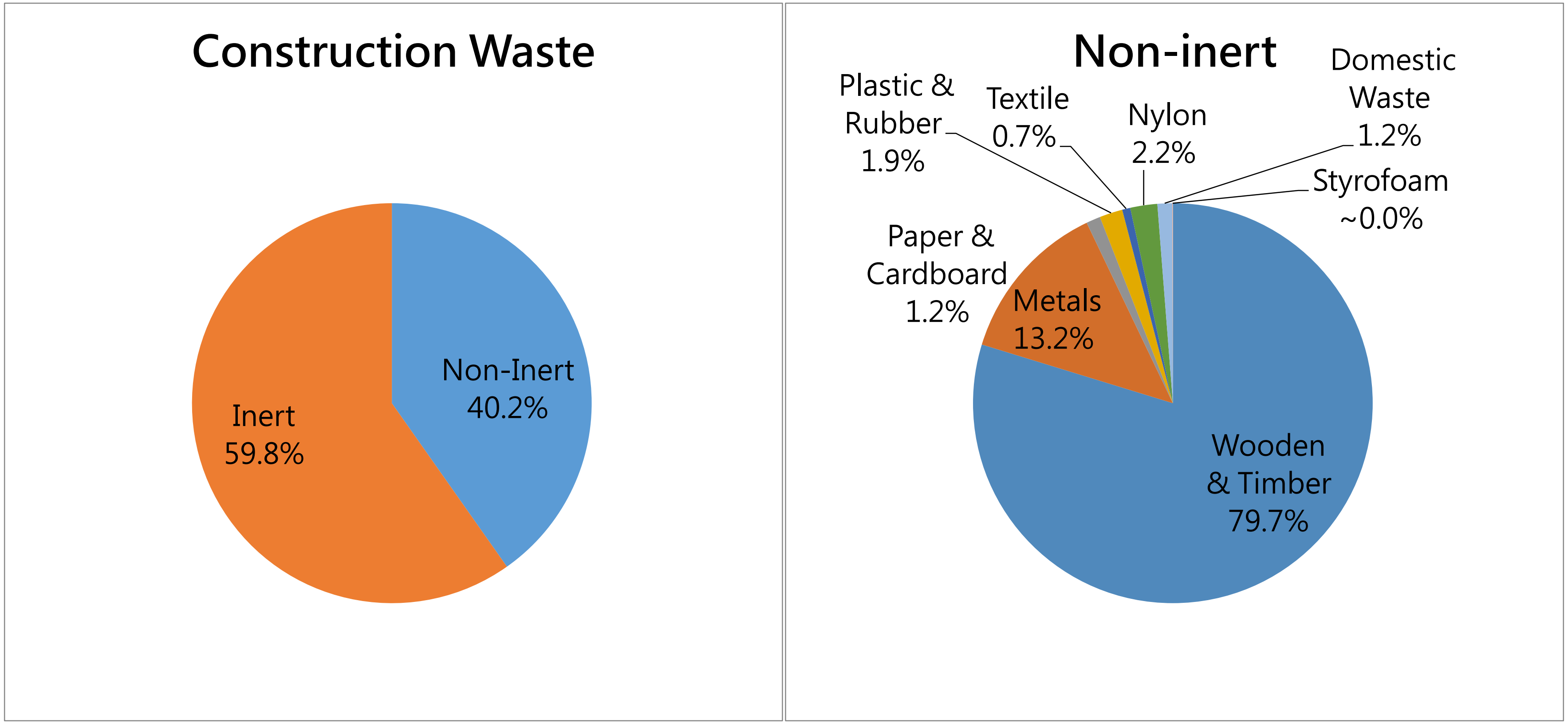

Figure 3 Sorting results of Site C

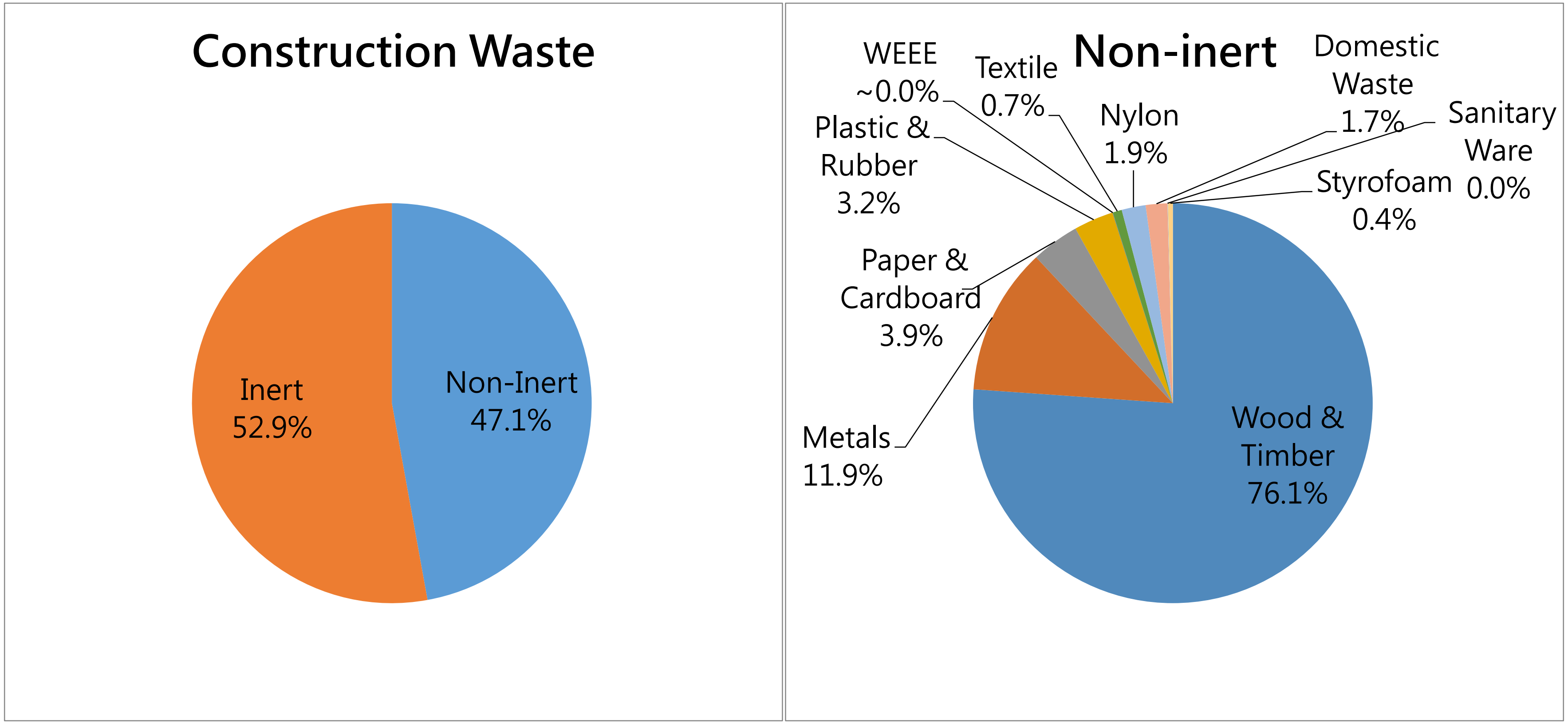

Figure 4 Sorting results of All Sites

6. Proposed Methodology for Non-Inert Construction Waste Composition

Two approaches have been proposed for non-inert construction waste composition study: upstream approach and downstream approach.

In terms of the upstream approach, Bills of Quantities should be considered for the estimation. A useful benchmarking statistic of waste volume would be estimated per m^2 of Construction Floor Area.

When conducting downstream approach, the following nine parts should be included:

(1) Number of lorry/truck load of construction waste to be studied;

(2) Duration and time;

(3) Method of non-inert waste estimation;

(4) Sorting list;

(5) Sorting area and location;

(6) Manpower;

(7) Large equipment;

(8) Small equipment/tools/set-up for operation and safety requirements;

(9) Appropriate contractor and budget.

7. Specification for Upstream Estimation of Non-Inert Construction Waste Composition

For effective waste management, it is beneficial for individual project team members to predict the approximate quantities of waste based on the complete design information (including Bills of Quantities). The general principle of arriving at the bulk volume of waste is given as follows:

(1) Convert materials into absolute volume (in m^3) from their given quantities and dimensions (e.g., areas multiplied by thicknesses);

(2) Convert weights into absolute volume using absolute densities;

(3) Estimate waste allowances and bulking ratios;

(4) Estimate bulk volume using absolute volume multiplied by the waste allowance and a bulking ratio.

According to the above method, the tender document samples of five selected building projects (i.e., three residential projects, one commercial project, and one hotel project) were studied to estimate the bulk volume of waste and the formwork proportion therein. The results are listed in Table 6.

Table 6 Estimated waste volume from document review (as calculated from samples)

No.	**Project Sample** **(superstructure only unless otherwise stated)**	**Waste (m^3/m^2)**	**Timber formwork (%)**
1	Multi-storey residential towers with basement carparks & club house	0.60	37.5
2	Multi-storey residential towers with 6-storey podium carparks*	0.56	33.7
3	Multi-storey residential towers with 7-storey podium carparks*	0.54	35.9
4	Multi-storey commercial building	0.56	49
5	Multi-storey 3-star economy hotel	0.48	47

Note: * represents projects with about half of their formwork using aluminium in tower construction. All residential projects have part of their facades using precast concrete.

CFA stands for Construction Floor Area.

8. Specification for Downstream Estimation of Non-Inert Construction Waste Composition

Based on the experience gained from the construction waste sorting of the current study, the methodology for the "future non-inert construction waste composition study" is proposed. The methodology includes the following main parts:

(1) Number of Lorry/Truck Load of Construction Waste to be Studied;

(2) Duration and Time;

(3) Method of Non-Inert Waste Estimation;

(4) Sorting List;

(5) Sorting Area and Location;

(6) Manpower;

(7) Large Equipment;

(8) Small Equipment/Tools/Set-up for Operation and Safety Requirements;

(9) Appropriate Contractor and Budget.

Table 7 shows a sample of sorting list for non-inert waste.

Table 7 A sample list for sorting non-inert waste

Date:		**Weather:**		**Site no.:**	
Lorry arrival time:				**Grab mounted lorry arrival time:**	
				Grab mounted lorry licence plate no.:	
Lorry licence plate no.:				**Chit ticket no.:**	
Sorting time (beginning):				**Total load of construction waste stated on chit ticket:**	
Sorting time (completion):					
Parts sorted:				**Recorded by:**	
Remark:					

Material	Group No.	Group	Type No.	Type	Weight (kg)
Non-inert	1	Bamboo	1	no sub-group	
	2	Wood & Timber	2a	formwork	
			2b	wooden pallet	
			2c	packaging timber	
			2d	others	
	3	Metal	3a	iron / copper pipe	
			3b	metal sink	
			3c	rebar	
			3d	aluminium scrap	
			3e	metal containers for material packaging	
			3f	steel scrap	
			3g	others	
	4	Paper & Cardboard	4a	cardboard	
			4b	packaging paper	
			4c	others (newspaper, office paper etc.)	
	5	Plastic & Rubber	5a	plastic wrapping	
			5b	plastic container	
			5c	PVC duct	
			5d	cable	
			5e	plastic traffic barrier	
			5f	window seal container	
			5g	rubber	
			5h	others	
	6	WEEE	1	electric appliance, electric socket, lighting, water pump, electric motor, transformer (i.e. no sub-group)	
	7	Vegetation	1	tree trunk etc. (i.e. no sub-group)	
	8	Textile	1	no sub-group	
	9	Fibreglass	1	no sub-group	
	10	Nylon	1	no sub-group	
	11	Domestic Waste	1	food waste etc. (i.e. no sub-group)	
	12	Sanitary Ware	1	porcelain water closet, porcelain wash hand basin, kitchen solid surface material etc. (i.e. no sub-group)	
	13	Styrofoam	1	no sub-group	
	14	Gypsum Board	1	Gypsum drywall etc. (i.e. no sub-group)	
	15	Glass	1	no sub-group	
	16	Others (to be descripted)	1	-	
Inert	17	Inert	1	rock, soil, sand, aggregate, rubble, boulder, masonry, concrete, asphalt, brick & tile etc. (i.e. no sub-group)	
				Total weight:	

9. Overall Recommendations for C&D Waste Minimisation in Hong Kong

Based on the literature review, site visits, waste sorting results, interviews with professionals and focus group meetings, the current sustaining good practices to reduce C&D waste are identified and listed in Table 8. New recommendations to reduce and manage C&D waste are proposed in Table 9.

9.1. Current good practices

Currently, the Government and building industry are working together to reduce C&D waste. Various measures and strategies of waste reduction and management are practising in both the public and private sectors. Existing good practices should be further reinforced particularly on the following measures as listed in Table 8.

Table 8 Enhancement of existing good practices

Existing good practices	Reference	Enhancement
Minimise design change	Poon (2007)	• Consider "Integrated Project Design" approach
Construction Waste Disposal Charging Scheme	Poon et al. (2013); Yu et al. (2013); Lu et al. (2015)	• Effective in first 2 years but not sustaining as the charge is insignificant comparing with project sum • Consider to revise charge
Prefabrication	Chiang et al. (2006); Tam et al. (2007); Jaillon and Poon (2008); Jaillon et al. (2009)	• Successfully implemented by Housing Department but not so common in the private sector • More incentives should be provided
Waste Management Plan	Poon et al. (2004b); Tam and Tam (2008)	• Can enhance on-site reuse of materials • Require further study on reduction of overhead cost
On-site Sorting	Poon et al. (2001); Lu et al. (2006)	• Not commonly practised, especially in the private sector due to space, time and labour issues • Should identify more outlets for sorted waste

Existing good practices	Reference	Enhancement
		• Government can explore measures to promote on-site sorting in the private sector
Selective demolition	Poon et al. (2004a)	• Effective in improving waste recycling rate • Requires more outlets for recovered waste
Waste recycling	Poon (1997); Ling et al. (2013)	• Reduce and revitalise C&D waste • Demand various types of recycling outlets

9.2. New recommendations

Success in implementing C&D waste reduction measures requires participation and cooperation of clients, designers, contractors, and government. Government plays a dual role acting as a policy maker and a facilitator. Construction waste generation can be regulated by laying down appropriate policies and legislations which target at waste reduction and reuse/recycling. Government can also facilitate the development of green technologies and the recycling industry by creating favorable conditions for growth of the industries. Implementation of reducing C&D waste can be enhanced by design and contract management. Fourteen new recommendations are proposed and summarised in Table 9 below:

Table 9 New recommendations for management and reduction of C&D waste

New Recommendations	Implementations
Government Initiatives	
Promote the use of timber & bamboo waste as biofuel	• Encourage industrial users to using timber & bamboo waste to recover energy as an interim measure *please see remarks below • Develop waste to energy facilities for burning timber & bamboo waste in the long run
Appointment of Environmental Officer	• Mandatory requirement of appointing Environmental Officers on construction sites to supervise the implementation of Waste Management Plan (WMP)

New Recommendations	Implementations
Mandatory auditing of Waste Management Plan	• To formulate (e.g. through BEAM-Plus) a system for mandatory auditing of WMP by qualified persons to ensure compliance and satisfactory implementation. The eligibility of the qualified persons need to further consult with the industry.
Concession of Gross Floor Area	• When awarding GFA concession, Buildings Department should incorporate the use of precast/prefabrication as one of the additional requirements to effectively reduce construction waste. The exact details will need to discuss and consult with the industry.
Revise construction waste disposal charge	• Review and revise the charge to a level similar to other countries which have good performance in C&D waste reduction and management and at a shorter regular timeframe (e.g., 2 or 3 years)
Facilitate development of local recycling and prefabrication industries and sorting facilities	• Provide low-rent sites for recycling and prefabrication industry • Purposely design and build multi-storey mega factory buildings to maximum land use • Propose to set up central recycling construction material centre for trade-in & out of recycled materials
Improving the efficiency of the existing C&D waste sorting facilities	• Government should carry out studies to review the current operation of the existing C&D waste sorting facilities to improve efficiency
Promote incentive to use non-timber and no-bamboo temporary work	• Provide incentives to use of reusable temporary work (e.g. Al or metal formworks and steel scaffolding)
Facilitate R&D	• Setup a research unit on robotic construction methods
Provide optional "Bare-shell" housing for public housing	• Develop policies for optional housing for "Bare-Shell" standard for public and private residential buildings to save unnecessary demolition due to renovation/interior design of individual owners
Clients/Building Designers	
Encourage minimising design changes	• Encourage the use of BIM to review crashes in tentative construction sequences to avoid abortive works

New Recommendations	Implementations
Hong Kong Green Building Council (HKGBC) and Construction Industry Council (CIC)	
Revise BEAM Plus to encourage waste reduction and recycling	• HKGBC to introduce "category threshold" in Materials and other related Aspects through BEAM-Plus to encourage C&D waste minimisation and recycling.
Setup communication platform for reusing C&D waste	• CIC to consider to take lead to set up website for encouraging C&D waste exchange among building contractors, and study implementation method to be posted on website for reference and provide links to other websites • CIC to consider to take lead to carry out research to specify "recycling standard" of recycled materials.
Education	• CIC to consider to take lead to introduce C&D waste management as a CPD course for technical supervisors

Remarks:

***Biofuel from wood waste to energy**

Wood waste is an inherently renewable resource that can be recycled and utilised for the production of renewable energy. A feasibility study was conducted in Hong Kong to assess the environmental sustainability of converting recycled wood wastes (generated from construction and demolition activities and other wood product waste) to produce wood pellets for direct energy generation. The chemical and physical characteristics of wood wastes were tested. A life cycle assessment (LCA) approach was used to assess and compare the environmental impacts for energy generation from the pelletised bio-fuel and coal. The test results showed that the energy content, chemical compositions and the trace metal concentrations of the waste wood all met the relevant standards. The LCA results also showed that significant environmental impacts can be potentially avoided by using wood pellets instead of coal for energy generation. The study concluded that the proposed "energy recovery" approach for using wood pellets as a bio-fuel in Hong Kong is environmentally sustainable, which can provide an alternative route for managing wood product wastes with the added benefits of energy recovery.

For more information

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