Environmental Challenges 5 (2021) 100231

Contents lists available at ScienceDirect

Environmental Challenges

journal homepage: www.elsevier.com/locate/envc

Effectiveness and barriers of Pre-refurbishment Auditing for refurbishment and renovation waste management

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ARTICLE INFO

Keywords:
Refurbishment and renovation
Construction waste
Waste management strategy
Pre-refurbishment audit
Reuse and recycling

ABSTRACT

The construction industry is the major source of Construction and Demolition (C&D) waste in Hong Kong. The capacity of landfills will reach saturation in a couple of years. Refurbishment and renovation projects contribute 10 to 20% of C&D waste. There are about 50,000 buildings in Hong Kong that are more than 30 years old and may require extensive refurbishment or renovation under the Mandatory Building Inspection Scheme. Besides, most new owners/tenants will renovate their premises before moving in. There is an urgent need to explore and develop effective waste management strategies and measures for refurbishment/renovation projects in Hong Kong. This research study aims to identify the types and estimate the quantities of refurbishment and renovation (R&R) waste; and evaluate the effectiveness of Pre-refurbishment Auditing (PRA) as a waste management strategy for these projects. Desktop study, semi-structured interviews, site observations and document reviews were used as the data collection methods to achieve the objectives of this research study. Content Analysis and Thematic Analysis were used for data analysis. The findings revealed that PRA is an effective strategy to be implemented in R&R waste management. Barriers for implementing PRA include (a) lack of sorting and storage spaces; (b) high cost; (c) insufficient government supporting policy; (d) complicated recycling processes, (e) immature recycling market, and (f) insufficient public education. To tackle these obstacles, government is recommended to take lead in conducting PRA and issue guidelines as a reference. The Building Department can also consider taking up an active role in policy making and promoting PRA.

1. Introduction

The construction industry is the major source of solid waste in most countries of the world. The Canadian construction industry is generating about 4 million tonnes of Construction and Demolition (C&D) waste for buildings annually (Waste Robotics). Demolition represents 42% of total waste generation, while renovation is 47% and construction is 11%. In the United States, 600 million tonnes of C&D waste were generated in 2018. Demolition represents more than 90% of total C&D waste generation, while construction represents less than 10% (U.S. Environmental Protection Agency (USEPA)). Europe has generated around 925 million tonnes of C&D waste per year, which accounts for 35.9 of all waste generated (Taboada et al., 2020, Eurostat).

China is the largest producer who contributes over 2 billion tonnes of C&D waste annually (Zheng et al., 2017). Approximately up to 7.5 million tonnes of renovation waste is generated annually (Ding et al., 2019). The landfilling rate of decoration and renovation waste has reached 83%, of which a majority was disposed of by open dumping (Sun et al., 2020). The disposal of renovation waste is mainly based on simple landfilling which causes low recycling rate and pollution to the environment (Wu et al., 2017). Even worse, waste producers may illegally dump waste at unpermitted areas, such as farmlands, abandoned residential lands, borrow pits, river sides, and low-lying areas in nearby cities (Ding et al., 2019).

Hong Kong is a densely populated city that is under constant expansions and improvements in buildings and infrastructures. Large amount of natural resources is consumed by the new development and refurbishment projects, which generate enormous amount of construction waste. Like other metropolitan cities, Hong Kong is facing a shortage of space for public fill and landfill capacity for C&D waste (Poon et al., 2003). About 1.44 million tonnes of C&D waste was generated in 2019 (Environmental Protection Department 2020). Chua (Chua, 2021) estimates 4.46 million tonnes of potential renovation waste could have been produced from sales-related renovation works. This is around 16.8% per annum of the construction waste entering Hong Kong landfills which is going to be full in a couple of years.

Moreover, there are about 50,000 buildings in Hong Kong that are more than 30 years old (Hong Kong Special Administrative Region Government (HKSARG) 2017). Many of these buildings have lack of maintenance. The Mandatory Building Inspection Scheme (MBIS) was launched

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https://doi.org/10.1016/j.envc.2021.100231
Received 27 May 2021; Received in revised form 26 July 2021; Accepted 28 July 2021

in 2012 to tackle the building neglect problem. These buildings are required to be either demolished or refurbished/renovated according to their conditions. Consequently, the forthcoming Refurbishment and Renovation (R&R) projects will generate large amounts of construction waste and aggravate the shortage of public fill and landfill. There is an urgent need to study the problems generated by R&R waste and derive solutions subsequently.

C&D waste generation can also impose adverse effects to the environment, health and safety and even profitability of enterprises (Poon et al., 2003, Esin and Cosgun, 2007, Yuan and Shen, 2011). Ineffective C&D waste management can lead to (a) saturated landfill, (b) increase in illegal dumping, and (c) generating social opposition to environment degradation caused by demolition (Hao et al., 2007). The major impact is consuming large amount of valuable land resources for waste disposal, which causes environmental problems and wasting large amount of public money in treating waste from landfills (Yuan et al., 2012). There is an urgent need to manage C&D waste in order to reduce its negative impacts on the environment (Yuan et al., 2012, Ajayi et al., 2017).

Most of the research on C&D waste management were conducted on new construction but little on R&R works. A research project titled "Strategies and Measures for Construction and Demolition Waste Management of Refurbishing/Renovating Existing Buildings in Hong Kong" (The Project) was conducted from 2018 to 2020 aiming to develop strategies and measures for effective management of R&R waste. Pre-demolition Audit (PDA) has proven to be one of the effective R&R waste management strategies developed from The Project. This paper focuses on implementing Pre-refurbishment Audit (PRA) as an effective waste management strategy for R&R projects in a metropolitan city like Hong Kong. The aim is achieved through three objectives, which are (a) to estimate how much R&R waste is generated and the types of waste; (b) to identify barriers in implementing PRA, and (c) to recommend measures to promote PRA in waste management of R&R projects.

2. Literature Review

R&R waste is a hybrid of C&D waste from improvements and repairs to existing structures (Public Works and Government Services Canada (PWGSC)). It is mainly composed of concrete, asphalt, wood, metals, gypsum wallboard, furniture, electrical appliances and roofing (Nitivattananon and Borongan, 2007). R&R wastes are usually generated from two phases, which are demolition and new construction (Metro Vancouver). Since R&R works are mostly a combination of new construction and demolition work (Coelho and de Brito, 2011), the classification of C&D waste from the official websites can be applied to R&R waste. Table 1 presents the general R&R waste from literature review. The most common R&R wastes are "Concrete/Mortar", "Wood/Timber", "Iron/Steel" and "Glass". Table 2 lists the reusable and/or recycled items from renovation projects (Metro Vancouver).

2.1. Benefits of R&R Waste Management

Refurbishing and renovating existing buildings have both economic and environmental benefits. R&R works has the economic and environmental potentials by retaining most of the existing structure and fabric enabling reuse of the vast stock of old, redundant and obsolete buildings materials, reducing the consumption of natural resources and energy (Gorse and Highfield, 2009, Lam, 2016)as well as minimizing the disposal of construction waste to landfills. Recycling can contribute to "sustainable materials management" by reducing pressures on natural resource and save energy in producing the new materials (Organization for Economic Co-operation and Development (OECD)). Useful R&R wastes include metals, glass, rubber, concrete and plasterboards, which can be sold for reuse or recycle. Eco-brick can be manufactured from rubber and glass waste. The rebar extracted from concrete waste should be collected for recycling. Plasterboard and concrete waste are broken up into smaller sizes to be used as filler for partition walls and concrete aggregate, respectively. The cost saving achieved by waste management could be shared among the main contractor and sub-contractors. However, R&R waste is a composite construction waste rendering it complicated to be assessed and consequently difficult to be reused or recycled (Sezer, 2017). PDA is the first step towards recycling of R&R waste aiming to understand the type and amount of elements and materials that will be deconstructed and/or demolished, and to provide recommendations on their further handling (EC (European Commission) 2018).

2.2. Selective Demolition

The principles of Selective Demolition (SD) can be applied to R&R projects. SD is an effective strategy for facilitating C&D waste reuse and recycling and is 'principally' carrying out the construction processes in a revered way. It requires a concise sorting of the different material according to respective categories before and during the demolition process so as to prevent contaminating inert or recyclable parts with wood, paper, cardboard, plastics and metals (Lauritezen and Hahn, 1992: Poon and Yu, 2001; Poon et al., 2004). SD is usually carried out in three stages (Poon, 1997, Poon et al., 2004): (a) removal of remains and non-fixtures; (b) 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 (c) demolition of the building shell. SD is a labor-intensive and time-consuming activity as most of the removal work are primarily carried out by hand. The cost of SD can be 20 to 25% higher than traditional demolition (Lauritezen and Hahn, 1992, Dantata et al., 2005). Poon et al (Poon et al., 2004) presented the processes of selective demolition in a flowchart as shown in Fig. 1.

2.3. Pre-demolition Audit

Implementing Pre-demolition Audit (PDA) can facilitate selective demolition. The aim of PDA is to facilitate and maximize resource recovery of demolished materials for beneficial reuse/recycling without compromising all safety measures and practices (Building and Construction Authority (BCA)). PDA can provide a clear idea of the "to-be-demolished" building infrastructure, estimation of quantity of recoverable C&D waste and make recommendations for the waste management [(EC (European Commission) 2018, Hardie et al., 2007, Durao et al., 2014)]. It is important to develop an inventory of construction materials and their treatment according to the waste hierarchy covering the following items, which provides valuable information to clients, architects, engineers, contractors and manufacturing industry [(EC (European Commission) 2018, McGrath, 2001, Hurley, 2002, Ehlert et al., 2017)]:

- Methods to estimate materials quantities
- Nature of waste (inert, non-inert, hazardous, non-hazardous)
- Types
- Quality (clean, slightly/strongly commingled)
- Locations
- Quantities (tonnes)
- Contamination (Yes/No)
- Separate collection (Yes/No)
- Recommended treatment (reuse, recycling, energy recovery)

PDA is conducted throughout the three main phases of demolition: (a) before demolition, (b) during demolition and (c) after demolition (Building and Construction Authority (BCA)). The process of PDA includes five stages: (i) *Desktop Study*, (ii) *Field Survey*, (iii) *Inventory*, (iv) *Waste Management Recommendation*, and (v) *Reporting* (EC (European Commission) 2018).

Hurley (Hurley, 2019) started the procedures with Desktop Study of blue and sectional drawings to identify the construction techniques

Table 1
General R&R Construction Waste Type

	Bergsdal et al., 2007	Thorpe, 2010	Hardie et al., 2011	Coelho and de Brito, 2011	Appleby, 2011	Tischer et al., 2013	Mália et al., 2013	Ren, 2013	Balba et al., 2013	Hosseini, 2015	(Lu et al., 2015)	(Villoria et al., 2018)	(Ghose et al., 2017)	(Yu et al., 2018)	(Tallini and Cedola, 2018)
Inert Renovation Waste															
Brick/Tile	√	√		√	√	√	√	√	√	√	√			√	√
Bituminous mixtures						√	√	√	√	√	√				
Concrete/Mortar	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Lime Sand		√												√	
Non-Inert Renovation Waste															
Wood/Timber	√	√	√	√	√	√	√	√	√	√	√	√	√		√
Gypsum/Plaster	√	√	√	√	√	√	√		√	√		√	√		
Composite board														√	
Plastic/Rubber		√		√	√	√	√	√	√	√	√	√			
Paper/cardboard				√		√		√		√		√			
Iron/Steel	√	√	√			√	√	√	√	√	√	√	√		√
Aluminum alloy		√	√			√						√	√	√	√
Glass	√	√	√			√	√	√	√		√	√	√	√	√
Insulation materials	√	√			√	√	√				√	√	√		
Asbestos	√					√					√				

Table 2
Reusable and recyclable items from renovation projects (Metro Vancouver, 2019)

Salvageable Building Materials	Recyclable Demolition Materials
Heavy timbers	Cinder blocks
Dimensional lumber	Structural concrete
Steel beams & studs	Asphalt pavement
Wainscoting	Dimensional lumber
Insulation	Metal piping
Siding	Gypsum wallboard
Heating ducts	Electrical cable
Electrical equipment	Aluminum siding
Bricks & blocks	Metal window frames
Light fixtures	Rebar
Plumbing fittings	Cement based stucco
Interior doors & frames	Metal deck railings

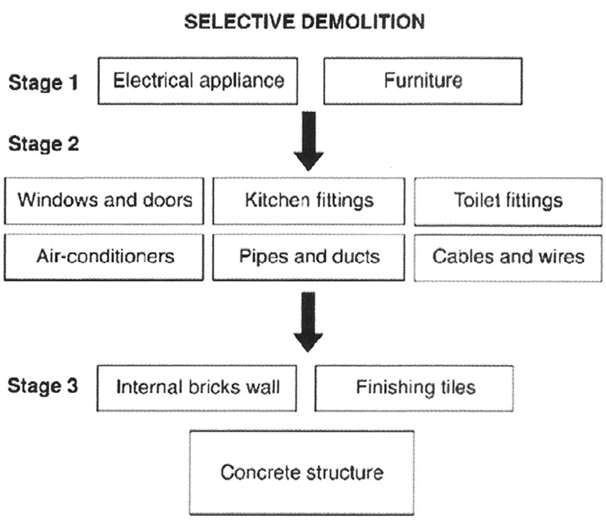

Fig. 1. Sequence of selective demolition process (Poon et al., 2004)

used in the building and their respective locations (Coelho and de Brito, 2011).

Field Survey will then be conducted to investigate the quality, condition and fixture of the products and components for assessing their economical values and availability for deconstruction and reuse (EC (European Commission) 2018).

In the Inventory stage, Quantity Report recording the overall quantity of the building materials and material assessment will be produced prior to demolition (EC (European Commission) 2018). This report facilitates the production of the Potential Report that identify the potential of reuse and recycling on each recorded material.

A Detail Auditing Report of Materials (final report) will be produced, which is based on the desk-study report, minutes of the site visit; report of materials assessment and site management recommendation (EC (European Commission) 2018). An example of Detail Auditing Report of Materials is given in Fig. 2, which facilitates to produce the Key Demolition Product of Target Report in Fig. 3. The reuse/recycling potential of the building materials depended on their fixing methods as well as the quality and conditions as summarized in Table 3.

The environmental impacts of the discharged C&D/R&R waste and the potential of financial return from reuse or recycling these wastes will be evaluated after demolition. A balance between the cost of environmental protection (including C&D/R&R waste sorting, transportation, etc.) and the financial return of reuse and recycling the C&D/R&R waste should be achieved (EC (European Commission) 2018). PDA has three outputs, which are (i) Quantity Report, (ii) Potential Report, and (iii) Detail Auditing Report of Materials. The Building and Construction Authority of Singapore (BCA) has developed a demolition checklist for waste recovery as illustrated in Table 3 that serves as a demolition checklist for waste recovery (Building and Construction Authority (BCA)).

2.4. Pre-refurbishment Audit

The principles of PDA can be applied to PRA. PRA was developed from PDA. The aim of PRA auditing is to facilitate and maximize resource recovery of demolition materials for beneficial reuse/recycling, without compromising all safety measures and practices (Hardie et al., 2007). The procedures of PRA are simplified with only four stages, which are (i) Information, (ii) Reports, (iii) Evaluation, and (iv) Reuse and Recycling (Fig. 4).

2.4.1. Information Stage

The basic information of the building to be refurbished will be studied in detail from building drawings and site visits to identify the features of the building such as age, condition, infrastructure, building components including furniture.

2.4.2. Reporting

Table 4 is an example of the Pre-refurbishment Audit Report. PRA report records the locations and quantities of the anticipated R&R waste to be generated. The potential of the R&R waste for reuse and recycling will be assessed with target quantity. The actual quantity of reused and recycled R&R waste will be recorded. The project/waste manager/main contractor should set a target recovery rate before commencement of demolition work, which will be checked against the achieved percentage.

2.4.3. Evaluation

The environmental impacts of the discharged R&R waste and the potential of financial return from reuse or recycling these wastes will be calculated.

2.4.4. Reuse and Recycling

A balance between the costs of environmental benefits (including R&R waste sorting, transportation, etc.) and the financial return of reuse and recycling the R&R waste, which is concluded from Stage 3 is used as a reference for final decision on reuse and recycling.

3. Research Methods

Desktop study, semi-structured interviews, site observations and document reviews were used as the primary and secondary data collection methods to achieve the objectives of this study. The study was carried out in five stages: (i) Literature Review, (ii) Semi-structured Interviews, (iii) Site Observations, (iv) Data Analysis and (v) Focus group Meeting and Strategy Development. Semi-structured interviews and site visits were conducted to supplement content analysis from literature review. Content analysis was also applied to analyze the collected data from interviews, site observations and documents provided by the participants in The Project. A focus group meeting was conducted to refine and validate the implementation of PDA could be an effective strategy in R&R waste management. Thematic Analysis was used to analyze the focus group transcript.

3.1. Literature Review

The aim of the literature review is to establish a theoretical foundation for the research. Extensive literature review was conducted. Previous and related works in PDA were identified through content analysis of published papers, reports and books. The findings of literature review helped to formulate an interview guide (Appendix A) to be used in semi-structured interviews.

INTERNAL FURNISHINGS	Dimensions (cm) length	width	depth	Waste Potential	Total	Target %	Achieved %
Ceiling to floor cabinet	240	103	54	Energy from waste	64		
Circular table	120	120	73	Reusable	149		
Coffee table	120	60	43	Reusable	12		
Corner desk workstation	200	80	73	Reusable	815		
Desk partition (desktop)	180	49	3	Reusable	275		
Desk partition (large)	120	120	5	Reusable	479		
Desk partition (medium)	120	80	5	Reusable	21		
Desk partition (small)	120	40	5	Reusable	314		
Desk partition (X-Large)	160	120	5	Reusable	69		
Desk shelf	180	32	2	Reusable	598		
Dexion-style shelf units	220	100	32	Recyclable	216		
Dishwasher	120	80	70	Reusable but soiled	3		
Double comfy chair	200	80	70	Reusable but soiled	33		
Double filing cabinet (mid)	120	105	47	Reusable	282		
Double filing cabinet (small)	80	70	47	Reusable	173		
Double filing cabinet (tall)	196	105	47	Reusable	170		
Electric fan	50	35	26	Reusable	361		
Fancy oblong table	180	80	73	Reusable	66		
Fridge	120	80	70	Reusable but soiled	21		
Hat stand	190	5	5	Reusable	57		
Industrial cooker	100	90	90	Reusable but soiled	3		
LCD projector	40	25	12	Reusable	3		
Metal frame plywood table	114	86	74	Recyclable	918		

Fig. 2. Example of the detailed audit of materials from a multi-storey building (Hurley, 2002)

BUILDING FABRIC	Dimensions (cm) length	width	depth	Waste Potential	B13	B8	B36	Haddon	Howland	Maple	Total
Air conditioning unit	90	90	20	Mixed landfill	0	4	51	2	5	5	62
Aluminium partitions (m)	100	269	7	Recyclable	24	34	211	162	71	0	502
Aluminium window frame	268	125	13	Recyclable	159	168	133	277	252	0	989
Ashfelt roof (m^2)	100	100	1	Mixed landfill	283	250	0	461	747	0	1741
Battery emergency light	38	14	9	Mixed landfill	7	8	12	7	9	3	46
Brick & concrete cladding	126	84	25	Inert landfill	159	168	133	277	252	0	989
BT twin supply	15	9	5	Mixed landfill	204	164	400	251	214	109	1342
Carpet (m^2)	100	100	2	Mixed landfill	260	0	890	0	0	0	1150
Carpet tiles	50	50	1	Mixed landfill	6240	8960	24920	12628	11880	3976	68604
Ceiling fan	80	80	10	Mixed landfill	8	12	18	0	4	2	42
Ceiling tiles (fibrous)	60	60	2	Mixed landfill	9066	22555	15356	8771	2376	0	57924
Ceiling tiles (metal)	60	60	2	Reusable	0	0	3072	0	0	0	3072
Ceramic tiles (m^2)	100	100	1	Inert landfill	132	176	408	469	168	72	1403
Circular light (large)	46	46	10	Mixed landfill	16	35	4	14	8	3	78
Circular light (small)	30	30	10	Mixed landfill	29	65	17	5	35	0	147
Copper pipes (m)	100	1	1	Recyclable	92	84	148	100	88	32	528
Double electric socket 240V	15	9	5	Mixed landfill	212	213	376	259	129	0	1189
Fire door & frame	218	108	10	Energy from waste	21	19	34	8	2	16	96
Fire extinguisher	50	14	14	Reusable	32	20	40	35	40	26	191
Fire hose	57	57	28	Mixed landfill	0	0	1	0	12	0	13
Kitchen cupboard	100	70	40	Energy from waste	18	26	12	23	23	2	96
Kitchen sink	105	53	33	Mixed landfill	4	0	2	6	2	2	14
Lift hardwood door frame	198	22	3	Recyclable	37	40	40	35	20	0	170
Metal heater guard (m)	100	20	1	Recyclable	483	576	938	763	625	127	3512

Fig. 3. Example of Key Demolition Product Targets for a multi-storey office (Hurley, 2002)

Table 3
Demolition Checklist for Waste Recovery [(EC (European Commission) 2018, Building and Construction Authority (BCA))]

Stages	Processes	Deliverable
Before Demolition	*Desktop Study* *Field Survey* *Inventory* *Waste Management Recommendation*	*PDA* identify waste types and quantities *Recovery/Recycle Target* (%) *Method Statement for Sequential Demolition* with demolition order and schedule *Site Waste Management Plan* to ensure proper waste segregation
During Demolition	*Phase 1* – removal of deleterious material, existing fixtures and fittings *Phase 2 Sequential demolition* allowing segregation of concrete from other debris to avoid contamination of concrete *Phase 3 Site Management Plan* to facilitate waste sorting, labeling and storing different types of C&D waste	Cleaner quality of *concrete* debris *Temporary storage areas* for categorized demolition waste for recycling/reuse
After Demolition	*Book-keeping* to record types and quantities of C&D waste generated weekly and their movement from site to destination.	*Demolition Waste Disposal and Management System* *Evaluation* of resource recovery and recycling target

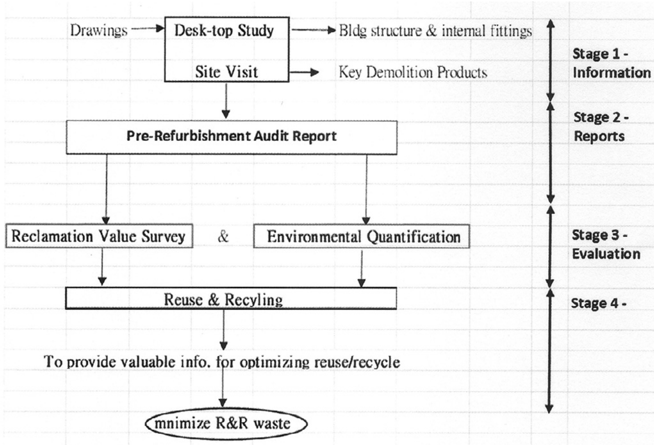

Fig. 4. Flowchart of Pre-refurbishment Audit

3.2. Semi-structured Interview

Semi-structured interview is suitable to explore attitudes, values, beliefs and motives (Richardson et al., 1965, Smith, 1992). Ten semi-structured interviews with different stakeholders and scholars were conducted. The stakeholders included developers, clients, designers, contractors, and sub-contractors. The interviewees were asked about open-ended questions based on the interview guide listed in Appendix A to collect their comments relating to R&R waste management. The questions covered the basic information of the C&D/R&R projects regarding the types and quantities of generated waste, their practices in WMP, and obstacles in implementing waste management and reuse/recycling. Considering the construction industry do not have a specific list of R&R contractors to follow, the snowball sampling method was deployed for data collection (Salganik and Heckathorn, 2004). Although the nature of snowball sampling may not be considered for a representative sample in statistical studies, this sampling technique is appropriate for conducting qualitative research with a population that is hard to locate (QuestionPro). The interviewees were asked to recommend other related/acquainted organizations that were involved in R&R projects for further interviews until this snowball sampling discontinued. Each interview conversation was recorded using a record pen and then translated from Chinese into English in a written transcript for data analysis.

3.3. Site Observation

Site observation was conducted to identify the types and processes of R&R waste generated, the WMPs applied on sites and barriers to carry out reuse and recycling. Seven site visits were conducted to cover different types of buildings, which includes religious building, public residential housing, hospital, single residential building, government quarter, and educational institution. Photographs were taken to record the site conditions, limitations in waste reduction arising from site condition, and best practices in R&R waste management. The Waste Management Plans of these projects were collected if possible and analyzed to identify various types of R&R waste, the generation processes, and the waste management practices.

3.4. Data Analysis

The collected data was subject to qualitative analysis by applying content analysis which was used to study and identify patterns in the transcribed interview scripts. In qualitative content analysis, emphasis is on determining the meaning of the data (Fellow and Liu, 2015). Initially, data was given coded allocations to categories and groups of data providers, so that a matrix of categorized data against groups were obtained. Statements were selected from each cell of the matrix to illustrate the contents of each cell. The findings of content analysis were then presented by Power point presentation in focus group meeting and journal paper for communicating to construction industry and government.

Thematic analysis allows categories/codes to emerge from the data collected, and interpretation of themes supported by the data collected in the focus group meeting (Saldana, 2009, Guest, 2012). It emphasizes pinpoint, examining and recording patterns (or themes) within data. Themes were recurring across data sets, which were important to the description of a phenomenon and associated with a specific research question.

3.5. Focus Group Meeting and Strategy Development

A focus group meeting was conducted at to serve as a Pilot Study to validate the recommendations developed from The Project. The framework of PRA and strategies/measures for promoting PRA were developed from reviewing the findings of literature review, semi-structured interviews, and site observations. The focus group included 10 participants from building professionals (clients, building designers, engineers, surveyors, contractors/subcontractors and recycling contractor) and scholars was held to discuss the research findings. Participants who were experienced in C&D waste management were selected by convenient sampling from the research team members' established network of contacts. The research team briefed the participants about the research findings and presented the strategies of promoting PRA for discussion. The discussion was recorded, transcribed and studied to identify core themes using thematic analysis (Morse, 1994). The research team analyzed the findings from focus group meeting in details and then revised the proposed strategies and measures accordingly.

4. Results and Discussion

4.1. Interviews

The PRA report in Table 4 and the flowchart of Fig. 4 were presented to interviewees for comments. Interviewees were also invited to discuss the viability and barriers of applying PRA in R&R waste management. Comments from interviewees were analyzed and summarized as follows.

Table 4
An example of Pre-refurbishment Audit Report

Building Fabric	Location	Dimension/Mass	Waste Potential	Target(%)	Achieved(%)	Remarks
Concrete	External walls					
Bricks	Internal partitioning					
Copper	Bathroom & kitchen					
Glass	Windows					
Furniture	Living & dining					
	Bedroom 1					
	Bedroom 2					
(others)						

The semi-structured interviews reviewed that refurbishment and renovation (R&R) waste contributed 10% to 20% of the C&D waste being disposed to landfills, which is in line with 16.8% estimated by Chua (Chua, 2021). The common types of waste generated from demolition and renovation projects are similar, which consist mainly of wall and floor tiles, bricks, concrete, wood, glass, PVC pipes, sanitary wares, packaging, and surplus materials (Table 1). As the buildings in Hong Kong are mainly high-rise development, the amount of R&R waste may be different from overseas renovations. The largest quantity of R&R waste is timber waste generated from discarded furniture. Currently only metal waste has recycling value. Metal (mainly copper wiring) will be recycled while bridge deck, steel and bamboo matrix scaffolding will be reused.

Literature review and semi-structured interviews revealed that the common obstacles to recycling R&R waste were similar to recycling C&D waste. The obstacles include (a) lack of sorting and storage spaces; (b) high cost; (c) insufficient government supporting policy; (d) complicated recycling processes, (e) immature recycling market, and (f) insufficient public education.

The process of sorting R&R waste is important to recycling. On-site sorting is often not possible to be carried out due to the congested site conditions in most of the R&R projects. Moreover, it is difficult to find sorting and storage spaces near landfills. The sorting process is labor intensive and time-consuming that incur high cost and may cause delay in construction period and disturbance to existing tenants/occupants. Sorting concrete waste to appropriate size and the subsequently cleaning for reuse incur high cost in recycling. The increasing complexity of product design, and the materials used has increased the cost of recovering recyclable material as well.

One of the interviewees estimated the recycling processes incur an additional of 20% and 30% of the construction cost in small and large projects, respectively. The current recycling market is under development. Downstream recycling facilities for plastic, glass and paper are limited due to low revenue return. There is only one recycling contractor manufacturing Eco-brick from C&D waste. Although the price of recyclable metal waste has decreased from HKD 3000 to 1000 per ton, the transportation cost has increased as metal waste is exported to the third world countries since the banning of exporting metal waste to Mainland by the PRC government. The recycling contractor estimated that about 100,000 square feet of land is required for developing recycling industry but land supply is scarce. The minimum set up fee of recycling industry is $100 million. However, the government does not provide sufficient funding and resources in supporting the development of recycling industry.

The financial incentive for developing recycling industry is therefore low. Recycling contractors are interested in collecting waste from large-scale renovation projects only, which could generate profitable amount of R&R waste. In commercial renovation, the developer pointed out that branded tenants preferred to discard all the furniture of outgoing tenants during renovation in keeping their brand styles. Clients' lack of incentive, workers' lack of knowledge of recycling and low public awareness in recycling R&R waste also deter the development of a mature recycling market.

In addition, the interviewees supported the implementation of PRA is an effective strategy of R&R waste management. However, the five obstacles needed to be tackled for effective implementation. The auditing processes shall be considered early in the planning stage. A detail inventory of recyclable R&R waste shall be prepared enabling contractors to estimate the amount of recyclable waste and plan for the sorting and recycling process. The main contractor was suggested to in-charge of the PRA and be responsible for estimating the amount of materials to be used and R&R waste generated. Sub-contractors should be penalized if the amount of generated waste were higher than the estimated quantity. Any cost saving that was achieved by waste management would be shared among the main contractor and sub-contractors. Implementing PRA could arouse clients' awareness in waste management and facilitate developing "green business" for consultant companies.

Pre-demolition inspection should be carried out to the plumbing and drainage pipes and other fixtures like windows for considering repair instead of total replacement. Implementing phase purchasing could help to minimize material wastage. Different lift shafts could be utilized for carrying out onsite sorting of R&R waste in large projects. Inert and non-inert waste were transported by different lifts to the respective sorting areas. R&R waste could be sorted and stored at different floors according to their types in small projects.

Presently the government is providing concrete waste free of charge to contractors of public projects, which should be extended to private contractors at basic cost. Government could also support the waste collection services by subsidizing the logistic companies that transport R&R waste. Developing a mature recycling market could improve the effectiveness of PRA implementation. Construction Industry Council should provide training courses in C&D/R&R waste management to frontline workers. Moreover, the public should be educated about the concept of carrying out environment conservation and waste management in renovating their premises.

4.2. Site observation

Detail information on site conditions, scope of renovation work, types of R&R waste, overview of waste management practices, barriers in implementing R&R waste management were collected through interviews with the Environmental Officers or Project Managers and site observations. Factors and good practices for successful waste reduction of R&R projects were identified from site visits, which supported the research findings on PRA in Sections 2.4 and 4.1. The research findings from site visits supported the viability of implementing PRA in R&R waste management.

Observation from the site visits reviewed the following good practices could facilitate successful R&R waste management:

- Apply selective demolition;
- On-site temporary reuse of demolition waste e.g., bridge deck and fences;
- Use two separate dumping skips for sorting of inert and non-insert waste (Fig. 5);
- Phase dumping to perform on-site sorting in restricted sites (Fig. 6);
- Preserve reusable demolished items for repair and making good as far as possible (Fig. 7).

Subsequent analysis on the findings from site visits had identified the following as factors for successful R&R waste management:

- Client and top management commitment in waste management;
- Clear instruction and guidelines on waste management;
- Educate worker on waste reduction;
- Carry out regular site inspection to implement the Waste Management Plan properly.

4.3. Focus Group Meeting

This meeting aims to collect comments from stakeholders on the proposed strategies and measures to reduce R&R waste. The focus group comments were summarized as below and supported the findings and recommendations from the precedent study.

Considerable opposition to the implementation of PRA is expected due to the incurred cost. Market readiness and stakeholders' acceptance shall be investigated prior to implementation. Public consultation on the process of PRA is essential. Construction Industry Council (CIC) should be responsible for the coordination of the construction industry in consultation and implementation. The auditing processes shall be considered early in the planning stage. A detail inventory of recyclable R&R waste shall be prepared enabling contractors to estimate the amount of recyclable waste and plan for the sorting and recycling process. The cost saving by implementing waste management efficiently will be shared

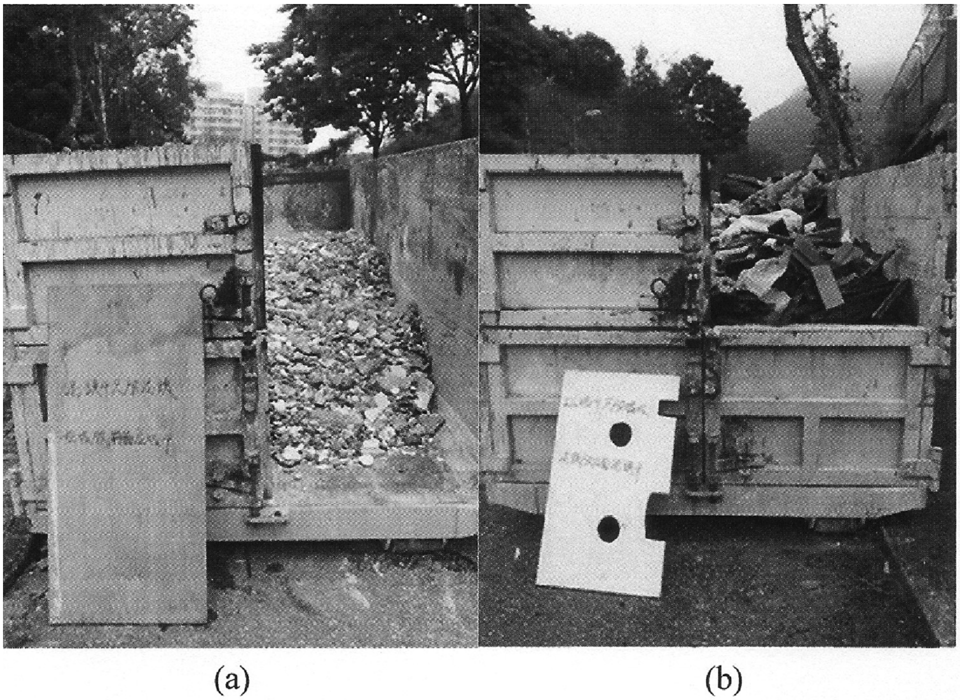

Fig. 5. Two Separate Dumping Skips for (a) Inert and (b) Non-Inert Waste Storage

Fig. 6. Phase dumping

Fig. 7. Demolished items for reuse

among the construction team. Contractor will be penalized for failing to achieve the target reduction in R&R waste. The baseline for reward and penalty must be clearly defined to avoiding misuse. There may be some differences in the baseline for public and private projects. It is recommended that the baseline should be vetted and monitored by a third party. PRA can create "green business" consultancy. The Building Department should take up an active role in policy making and promoting PRA.

However, the construction industry has reservation in using recycled products due to insufficient provisions on information and references of the recycled materials. There are no clear guidelines on recycling. Contractors worry that they may be prosecuted for using substandard materials. No proper channel has been established for recycling companies to approach different government departments for obtaining approval of their products. The threshold for developing recycling business is too high requiring three to four years in establishing recycling facilities. Recycling contractors are facing the following difficulties in addition to the expensive running cost owing to high labor demand and rent:

- The stringent laws and regulations governing recycling;
- Additional cost of conducting Environmental Impact Assessment such as impact on air quality;
- Lengthy process to obtain approval on usage of recycled products from different government departments;
- Expensive logistic cost;
- Workers lacking the knowledge of recycling;

Table 5
Recommended R&R waste management strategies and measures

Strategies	Measures
Pre-refurbishment Audit (PRA)	• Consultation with building industry • Issue guidelines on PRA • Implement PRA in public projects • Promote reuse and recycling in public and private projects • BD to take up an active role in policy making and promoting PRA
Development of Recycling Market	• Relax laws and regulations for approving recycling without jeopardizing public health and safety • Set up trading platform through CIC or other related non-profit organizations • Standardize labels for recycled building materials • Streamline the approval process • Facilitate forming R&RCA to train workers • Set up research funding for development of innovative technologies in recycling construction waste • Educate public on the importance of building maintenance & recycling

- Lack of public incentive in conducting recycling.

4.4. Recommendation to Government

After concluding that the PRA could be an effective strategy for R&R waste management, the focus group meeting focused on how to develop recommendations and measures for implementing PRA promoting the recycling market. The recommendations and measures are summarized in Table 5.

5. Conclusions

Hong Kong is a metropolitan city constantly under expansion. Most of the buildings are high-rise development with about 50,000 above 30 years of age. These aging buildings may subject to carrying out extensive refurbishment and renovation under the Mandatory Building Inspection Scheme. Moreover, many building renovation projects are carrying out in residential and commercial buildings when new owners/tenants move in. These renovation works are generating huge amount of construction waste, which constitutes to 10 to 20% of the construction and demolition waste. However, the capacity of landfills is expected to be saturated in 2020s.

Construction industry should explore effective strategies to reduce R&R waste. Reuse and recycling useful materials generated from renovation projects can effectively reduce the amount of R&R waste being disposed to landfills as well as conserving natural resources. The main types of R&R waste are concrete, timber, metal and glass, which can be reused or recycled.

Based on research findings from desktop study, semi-structured interviews and site visits, Pre-refurbishment Audit is an effective strategy to be implemented in R&R waste management. PRA consists of mainly four stages which are (i) Information, (ii) Reports, (iii) Evaluation, and (iv) Reuse and Recycling. The *Information* stage involves inspecting the location and fixing conditions of key demolition products for producing *Pre-refurbishment Reports* to record location, quantity and waste potential of the anticipated R&R waste with target quantity for reuse and recycling. The environmental impact of the discharged R&R waste and the potential financial return from reuse/recycling will be calculated in the *Evaluation* stage. The assessed balance between the environmental and financial benefits will be used for the final decision on *reuse and recycling*.

The major obstacles for reuse and recycling are congested site conditions, high cost of recycling, workers lacking the knowledge of recycling, immature recycle market and insufficient government support. To tackle these obstacles, government is recommended to take lead in conducting PRA and issue guidelines as a reference to private projects. The Building Department can consider taking up an active role in policy making and promoting Pre-refurbishment Audit. Government should investigate how to relax the laws and regulations for approving recycling materials without jeopardizing public health and safety and streamline the approval process to facilitate the development of recycling business. Other facilitating measures include setting up trading platform through CIC linking up R&R contractors with recycling contractors and/or potential buyers; establish a labeling system to standardize the quality of recycled building materials; and designate funding for development of innovative technologies in recycling construction waste. Government can encourage R&R contractors to form association for training up skillful recycling workers. The public should be educated about the importance of building maintenance, and the advantages of recycling and proper management of R&R waste.

Declaration of Competing Interests

The work of this research was fully supported by a grant from the Public Policy Research Funding Scheme of Policy Innovation and Coordination Office, the Hong Kong Administration Region, China under Project No. 2018.A6.111.18C.
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18 May 2021

Acknowledgement

The work of this research was fully supported by a grant from the Public Policy Research Funding Scheme of Policy Innovation and Coordination Office, the Hong Kong Administration Region, China under Project No. 2018.A6.111.18C.

Appendix A

Sample of Interview Guide

11. Are there any difference(s) in the C&D waste generated from construction of new buildings and refurbishment of existing buildings?

2. Are there any difference(s) in the renovation waste generated from residential and non-residential buildings? Please briefly describe the scope of renovation works and specify the types of non-residential buildings.

3. Please list the common types of C&D waste generated from the refurbishment work from (a) residential and (b) non-residential buildings.

4. Can you estimate the percentage of renovation waste responsible for the material generated from construction and demolition sector in Hong Kong?

5. Which types of renovation waste ranked the top 3 in the generated amount?

6. What types of renovation waste can be reused or recycled?

7. How do you estimate and quantify the renovation waste produced on site?

8. Do you try to reduce C&D waste in your renovation projects? OR do you reuse or recycle C&D waste? (Please elaborate)

9. (If answer to Q.9 is "NO") > What is the main reason you do not practice reuse/recycle of C&D waste in renovation projects?

10. What are the barriers and difficulties to renovation waste management and reduction practices in Hong Kong?

11. Which strategies below are effective in C&D waste reduction for building renovation?

a) Material control [ ]. Any difficulties?

b) Waste sorting [ ]. Any difficulties?

c) Reuse and recycle [ ]. Any difficulties?

d) Active & mature market of the recovered materials [ ]. Current situation?

12. Can you recommend other contractor/project manager in building refurbishment to us?

THANK YOU FOR YOUR CONTRIBUTION!

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