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Reduce, Reuse and Recycle: Grand Challenges in Construction Recovery Process

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Abstract**—**Hurling a successful Construction and Demolition Waste (C&DW) recycling operation around the globe is a challenge today, predominantly because secondary materials markets are yet to be integrated. Reducing, Reusing and recycling of (C&DW) have been employed over the years, and various techniques have been investigated. However, the economic and environmental viability of its application seems limited. This paper discusses the costs and benefits in using secondary materials and focus on investigating reuse and recycling process for five major types of construction materials: concrete, metal, wood, cardboard/paper and plasterboard. Data obtained from demolition specialists and contractors are considered and evaluated. The research paper found that construction material recovery process fully incorporate a 3R's principle contributing to saving energy and natural resources. This scrutiny leads to the empathy of grand challenges in construction material recovery process. Recommendations to deepen material recovery process are also discussed.

Keywords**—**Construction & Demolition Waste (C&DW), 3R concept, Recycling, Reuse, Life-Cycle Assessment (LCA), Waste Management.

I. Introduction

In a broad sense, recycling is part of an ethic of resource efficiency – of using products to their fullest potential. When a recycled material, rather than a raw material, is used to make a new product, natural resources and energy are conserved. This is because recycled materials have already been refined and processed once; manufacturing the second time is much cleaner and less energy-intensive than the first [1]. Waste generated in construction works seemed to have caused serious environmental problems in many cities around the world for so many years [2]. In the United Kingdom, construction and demolition sectors generate more waste and are known as the largest producers of hazardous waste. These sectors are responsible for producing over 36 million tonnes of landfill waste every year. This is approximately 35% of total waste generated, with domestic residential waste accounting for an additional 10%. The construction and demolition sectors are under increasing pressure to improve performance, reduce, reuse and increase recycling opportunities [3]. Public opinion in the UK has emphasised the difficulties of minimising construction waste, but with Germany recycling over 80% of its construction waste and Denmark over 90%, this is clearly a misperception. The UK has recently improved the recovery capacity in recent times [4]. Construction, demolition, and refurbishment works account for around 100 million tonnes of waste in the UK every year [6]. In the US, about 250 million tonnes of municipal solid waste (MSW) was generated each year [5]. At the current per capita rate, an average US weighing 180 pounds generates their own weight in MSW every 41 days. In comparison, the generation rates are 2.8 in Sweden, 3.5 in Germany, and 3.2 in the UK [7]. Interestingly, the US reuse and recycling practices as well as the regulations differ by locality, but still major cities can boost of having significant effort to reduce the amount of C&D waste going to landfill.

Reducing waste is a priority for the European Union and the UK Government and there are many new regulations, measures and targets to reduce waste within the construction. Despite the significant effort seen in reuse and recycling opportunities local construction and demolition contractors are still facing greater challenges in reducing waste to a minimum around the globe. The practice involve reduce, reuse, recycle (3Rs) as well as regulation for C&DW have been influenced by the EU legislation related to waste national recycling goals and incentives. In 2007, a waste strategy was introduced in England [3]. This strategy drives the initiative to reduce the amount of C&D waste being diverted to landfill through reuse and recycling incentives. Following these incentives, there is a duty to ensure that construction materials and activities within adhere with environmental demands through waste minimisation process.

One of the great challenges to waste minimisation on a number of construction sites is the inability to devise an appropriate method of reducing and/or preventing waste In order to close this gap, a unique waste minimisation tool known Site Methodology to Audit Reduced Target Waste (SMART Waste) was proposed by McGrath in 2001. This tool is designed as a benchmark in order to audit, reduce, and target construction waste to enhance greater material recovery for reuse and recycling waste [8]. Despite the significant effort seen in producing secondary materials (i.e. recyclable materials such as concrete, metal, wood, paper, plastics etc.) there are key challenges local contractors are facing in terms of lack of incentives and economic incitement [1]. Yet, there are limited studies within the field of construction waste management indicating why specific measures are set and how effective these really are in practice.

This paper reviews existing literature within waste management practices and discuss the costs and benefits in using secondary materials as well as it focused on

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investigating reuse and recycling process for five major types of construction materials: concrete, metal, wood, cardboard/paper and plasterboard. Data obtained from demolition specialist and contractors are considered and evaluated. The key challenges in construction material recovery process by incorporating the 3R's principle (reduce, reuse and recycle) are discussed. Consequently, the research findings can lead to developing techniques to enhance better reuse and recycling operations and promotes better economic viability for specific construction waste materials.

A. 3R's Principle – Managing Construction Waste

Managing C&D waste has become one of the major environmental problems in the world. Tremendous amounts of waste have been generated from ongoing new construction works, as well as refurbishment and demolition works. Waste management covers the collection, transporting, storage, treatment, recovery and disposal of waste [9]-[11]. On-site sorting of construction and demolition is one of the most effective and reliable techniques to manage C&D waste [12]. C&DW is made up of both inert (soil, bricks, concrete etc.) and non-inert waste such as plastics, glass, wood, paper etc. [13]. The separation techniques often attract advance technology options and legislative control.

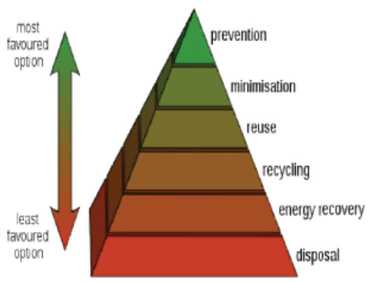

Fig. 1 Waste Management Hierarchy [19]

Waste management concept is guided by level of hierarchy known as the 3R's principle explained by El-Haggar in 2007[19]. This model produces an integrated approach in which options of waste management can be considered and thus serves as a systematic tool for those who generate and manage waste [10]. El-Haggar argued that when waste is being managed effectively it could generate various benefits through the whole life cycle of the waste from its generation to its end disposal [10]. Significantly, it is believed that proper construction waste management will provide both economic and environmental benefits. A number of construction firms as well as the environment at large will benefit through the cost reduction process involved in waste management.

The economic and environment benefits expected from waste minimization are relatively essential as it drives towards the opportunity seen in recycling and the possibilities of selling secondary waste materials as well as the meeting targets on reducing the number of C&D waste being diverted to landfill [14]. Although the transfer of waste to landfill often attracts associated fees/charges and this can be minimized if only waste stream from construction are effectively managed. Interestingly, the process of waste minimization can enhance high competition among local contractors through reducing production cost and create better company profile. Sadly, only a few local contractors had focused on the impact of waste on the environment and have created the idea of recycling construction and demolition waste in a number of municipals [15]. Apart from the two benefits (i.e. economic and the environment), waste minimization can also contribute positively to the following: reduction of landfill spaces, enhance resource management and improve productivity and quality management [13].

1. Life Cycle Assessment (LCA)

Environmental impacts is considered for all waste products and from a resource standpoint the waste hierarchy often led to the most resource-efficient and environmentally sound choice and positive outcomes. LCA support decision-making in the field of waste management and also support determine environmental viability. This approach can help policy makers understand the benefits and trade-offs they have encounter when making decisions on waster management strategies. Significantly, LCA provides a scientifically sound approach to ensure that the best outcome for the environment can be identified and implemented [16]. The LCA is a popular tool used in a number of tools [15]. The tool is often used to investigate the potential environmental impacts, throughout a product's life. A number of research studies believed that waste is produced in different types and quantities throughout the lifecycle of a building with the bulk of the waste produced by from building operations such as construction and demolition phases and not necessarily that generated by building occupants [17]. The lifecycle of a building can be determined by the use of materials and the waste generated throughout the building lifecycle. The most innovative approach to this is the challenge to reduce, recover, reuse and recycle these waste that follow the variety of waste streams leading to landfill.

B. Key Challenges

Managing construction and demolition waste on-site is a complex and challenging activity. Many barriers and opportunities exist in developing a strategy of waste reduction on construction sites. The major problem with managing waste in construction is the increase in management and recycling operation cost, lack of government legislation control, environmental impact, lack of trained staffs and expertise, lack of reuse and recycling incentives [18]. The rise in recycling operation cost may be the major concern for local contractors and other recycling consultants. With the view of these problems outlined above, there is a need to understand and consider various options that could be utilized; a hierarchy of disposal options needs to be considered from low to high impacts. Important waste management strategies known as the '3Rs' (reusing, recycling and reducing) is a way forward in achieving a better outcome in managing construction waste stream as well as driving economic and environment viability [5]. Local and regional authorities often face challenges by

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issues when applying the waste hierarchy approach. Other issues and concerns may involve:

- Waste management strategy implementation process with coherent process where it started at direct management without the property level of hierarchy.
- Lack of data available on waste management strategies must be overcome and extensive monitoring requirements must be met to successfully implement the waste programs
- Effective enforcement and control of sound business plans and practices be established and applied to maximize economic and environmental benefits.
- Lack of administrative capacity at regional and local level. The lack of funding, information and technical expertise must be overcome for effective implementation and success of policies, practices and procedures.

II. Research Methodology

Reduce, reuse and recycle are recognised today around the world as an important principles of waste management strategy in order to prevent huge tipping fees due to the scarcity of landfill sites. The idea of 'reuse' and 'recycle' of many construction materials is a smart decision for all builders and/or demolition contractors, whether they are interested in environmentally-friendly building or not. Significantly, the direct reuse of building waste in its original state and/or slightly improved products often involves reprocessing of used materials into secondary of new materials. The success of recycling C&DW is determined by some key factors such as favorable construction site and location, proper resources and equipment, experience gain overtime by recyclers and contractors to determine the merits of individual materials, trained construction workers, market knowledge of secondary materials, financial implications and knowledge of environmental and legislative and control.

The objectives of the research were:

- To investigate construction waste recovery practices on site activities.
- To identify key challenges of adopting waste management in managing construction
- To identify the cost benefits of using secondary materials

Equation formulated for rate of reusing and recycling of C&DW is:

$$RR = RSM/TWP \tag{1}$$

where: RR is the Rate of Recovery of C&DW; RSM is the Real Secondary Material; TWP is the Total Waste Processed.

The rate of developing secondary materials indicates that waste management practices involving reusing and recycling construction waste in the two case studies (See Table II). Following the outcome of the equation adopted for individual material, '1' indicates fully development of secondary materials, '0' shows that all construction waste is to be diverted landfill. Theoretically, research shows that the value of rate of developing secondary materials is unswerving based on the articulated equation presented above. To investigate the reusing and recycling process for construction materials, two case studies are under investigation on costs and benefits in using secondary materials and the construction recovery process for five major types of construction materials: concrete, metal, wood, cardboard/paper and plasterboard. Data obtained from demolition specialist and contractors from Site A and B. the study consider two stage process.

First stage look at total waste processed for Site A and B as well as the outcome of construction material recycling and recovery process will be outline. Stage 2 focused on cost consideration for using secondary (reusable and recyclable) materials. Finally the study provides practical examples of the economics behind the development of secondary materials. Individual face-to-face interviews are arranged with each case study, including demolition contractors, site managers and supervisors, on-site construction workers. The involvement of all participants helps the field study to arrive at a more quality approach to reusing and recycling construction waste and helps determine the merits of individual materials in eth construction recovery process. Two personal interviews are arranged for each case study. First face-to-face interview focus on making clarity on research goals, visions, study details and data required. The second face-to-face interview focused on comments on data collected from Site A and B. The personal interviews are intended for obtaining additional comments, perceptions and views related to data required.

III. Results and Discussions

Tables I & II exemplify the 2012/2013 survey outcomes on the total waste processed % recycled, and % send to landfilled for five types of construction waste materials from the two case studies (Site A and B). As shown in Fig. 2, there is a large volume of concrete and wood waste from demolition works process and recycled in 2012 as compared to 2013. As show in the chart above, there has been a high percentage of all five construction waste materials been diverted to landfill in 2013 in Site A as compared to Site B. Also Site B has focused on recycling more wood and metal in 2013 due to available market for secondary material.

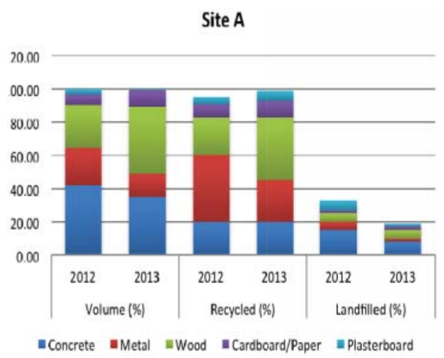

Fig. 2 Composition of mixed C&DW Debris (Case study 1)

TABLE I
COMPOSITION OF MIXED C&DW DEBRIS (CASE STUDY 1: SITE A)

Recycling Operations at Site A							
2012				2013			
Construction Waste	Volume (%)	Recycled (%)	Landfilled (%)	Construction Waste	Volume (%)	Recycled (%)	Landfilled (%)
Concrete	41.9	20	15	Concrete	35.09	20	8
Metal	22.86	40	5	Metal	13.92	25	2
Wood	25.71	23	5	Wood	40.2	38	5
Cardboard/Paper	6.19	8	2	Cardboard/Paper	10.37	10	2
Plasterboard	3.33	4	6	Plasterboard	0.41	6	2
Total Waste	100	95	33	Total Waste	100	99	19

TABLE II
COMPOSITION OF MIXED C&DW DEBRIS (CASE STUDY 2: SITE B)

Recycling Operations at Site B							
2012				2013			
Construction Waste	Volume (%)	Recycled (%)	Landfilled (%)	Construction Waste	Volume (%)	Recycled (%)	Landfilled (%)
Concrete	33.56	17	15	Concrete	27.01	15	6
Metal	17.54	22	5	Metal	15.05	25	0
Wood	27.06	35	5	Wood	38	42	0
Cardboard/Paper	12	15	2	Cardboard/Paper	19.08	12	2
Plasterboard	9.84	8	6	Plasterboard	0.86	6	1
Total Waste	100	97	33	Total Waste	100	100	9

TABLE III
RATE OF RECOVERY OF C&DW (CASE STUDY 1 & 2)

Case studies	2012			2013		
	Total Waste Processed (Tonnes)	Real Secondary Material (Tonnes)	Rate of Recovery	Total Waste Processed (Tonnes)	Real Secondary Material (Tonnes)	Rate of Recovery
Site A						
Concrete	880	820	0.93	835	775	0.93
Metal	480	480	1	345	232	0.67
Wood	540	120	0.22	945	912	0.97
Cardboard/Paper	130	60	0.46	102	19	0.19
Plasterboard	70	10	0.14	96	6	0.06
Site B						
Concrete	820.54	789.34	0.96	940.06	856.23	0.91
Metal	325.37	300.76	0.92	143.06	143.06	0.69
Wood	940.04	923.06	0.98	1076	1076	1
Cardboard/Paper	242.56	98	0.4	114.56	79.76	0.7
Plasterboard	9.67	0.4	0.04	1.86	0.34	0.18

TABLE IV
MEASURES FOR 3R'S CONCEPT

	Reduction	Reuse	Recycle	Remarks
Concrete	Precision, Accuracy in measuring amount of concrete needed according to organisation policy and procedure	Reuse concrete waste for minor works	Recycling concrete as aggregate for construction	n/a
Metal	Precision and Accuracy in cutting, welding and fixing to minimise waste	Reuse metal scraps	Recycle metal scraps and develop new products/secondary materials	n/a
Wood	Use alternative materials in substitute to wood (e.g. carbon fibre, aluminum, steel etc. Use modular/prefab construction units	Wood waste products such as props, pods, formworks etc. should be shored and reused for other construction works. Cutting waste should be keep at minimum	Wood can be recycled to demolition contractors and local recyclers	n/a
Cardboard/ paper	Minimize the use of cardboard paper, use alternative construction materials	Reuse cardboard/paper such as packaging	Recycle cardboard/paper to develop new products	Adopting environment-friendly paper

Table III indicates the survey outcome on the rate of recovery of C&DW for five major types of construction materials for the case study (concrete, metal, wood, cardboard/paper and plasterboard). 'Plasterboard' measured low rate of recover for the each case study. The study also found that '0.04' outcome on rate of recovery of plasterboard in 2012 that indicates that 'plasterboard' is relatively low to develop a secondary material. The interviewed site manager explained that best practice to apply the 3Rs to many of the construction waste materials particularly concrete waste is to use prefabricated/modular construction methods rather than the traditional in-situ concrete process.

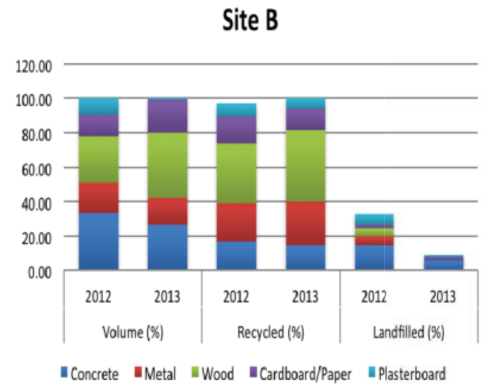

Fig. 3 Composition of mixed C&DW Debris (Case study 2)

An interview carried out with site demolition contractors and site managers revealed that plasterboard and cardboard/paper is very difficult to reuse and recycle on-site. Site manager for both Site A and B clarified that the lack of advance technology is responsible for the low recycling rate of plasterboard. The survey result also found that concrete, metal and wood have shown a high recovery rate [i.e. concrete range between 0.91 and 0.96; metal range between 0.67 to 1; wood 0.22 to 0.98]. This clearly indicates that there is a significant economic and environmental awareness on reusing and recycling concrete, metal and wood. Significantly, 'wood' has show an improved rate of recovery and it has proven to be more reusable for construction works and/or made available for secondary market.

The interviewed site manager made positive comments on 'wood' as a possible secondary material (reusable & recyclable construction waste). The site manager further explained that wood is easy to reuse and recycle with proper arrangement. Interestingly, interviewed site manager explained that there are key contributing factors such as supply and demand, legislation, incentives affecting the economics of recycling wood on construction sites. The market for wood waste varies according to region and its consumption in the UK has dropped sharply since 2007 from 12% to 6% in 2013 [4]. According to Tolvik report, UK wood waste increased by 4.3 Million tonnes and further increase in wood waste will be seen end of 2015 [4].

A. Cost Consideration for Recycling Operations

Key issues with construction waste recover operations are the failure to perform a detailed cost benefits analysis at the early stage of business development. It is important for the recycling operations to carefully consider the stream of materials that will be flowing into the construction site in order to prepare the operation for processing the waste material into secondary materials with practically high value.

Tables I & II show a breakdown of the five constriction materials for each case study identified herein this study. It is obvious that the composition of C&DW varies from construction sites over time depending on the ration of commercial to residential construction as well as the proportion of demolition activities in the two construction sites. Traditionally, the diversion of C&DW gives income (tipping fees) by charging a fee for allowing waste to be transferred to landfill. This recycling gate fees coupled with the marketability of the byproduct as well as regulatory enforcement to control illegal dumping and properly manage landfills. The identification of a construction site for recycling operations and associated cost can be considered by applying recycling fee. However, it is imperative to fully define the aggregate selling price of secondary materials in such a manner that allows recyclers to compete against the cost of the raw material and more importantly provide adequate incentive for contractors to opt for managing C&DW.

1. Costs/Benefits of Reducing Waste Example: A Case Study

Reducing, reusing and recycling waste can help to reduce costs on construction projects. Clients and contractors can secure best practice for waste minimization from an early stage in the design and planning process, can locked these savings and demonstrate corporate responsibility. Such action can be linked to corporate commitments in support of the target for halving waste to landfill. Case study identifies at design stage the costs and benefits through waste reduction and recovery in their construction activities. The main case study is a £1.5m redevelopment project of a new enterprise center. The project is to be constructed using steel frame, clad in mixture of brickwork, render and wood cladding. This project also involved external paving and landscaping, provision of car parking and an access road.

TABLE V
DESIGN POTENTIAL

	Value of materials wasted (£)	Cost of waste disposal (£)	Total cost of waste	Total cost of waste as % of construction value
Best practice	281,765	65,498	347,263	1.54%
Good practice (all components)	122,623	24,266	146,889	0.65%
Targeted practice (top opportunities)	155,880	30,785	30,785	0.83%
Improvement over baseline	**£125,885**	**£34,713**	**£160,598**	**0.71%**

TABLE VI
CHANGE IN ENVIRONMENT PERFORMANCE

	Total waste arisings (t)	Waste sent to landfill (£)	Recovery rate	Carbon (t) 1	Recycled content
Baseline	1,264	561	55%	1,180	20.50%
Good practice	567	113	80.00%	480	42.40%
Targeted	671	135	80.00%	522	32.80%
Improvement over baseline	**593 (47%)**	**426 (47%)**	**25.00%**	**658 (56%)**	**12.30%**

This compulsory fee is considered as an income according to local jurisdiction. Interviewed site manager commented on cost benefits of developing secondary materials. This participant argued that the feasibility of introducing a new recycling facility is highly dependent of the interrelationship between the landfill-tipping fee and the targeting good waste reduction practice can make optimum saving in the value of material wasted. To complement the cost benefits, actions be demonstrate resource efficient also delivery key changes in environmental performance. Costs and benefits can be better understood in the case study in terms of waste reduction and recovery processes required to delivery-targeted savings. Achieving cost reductions (i.e. benefits) require to key perspectives: value of material wasted and cost of waste disposal.

Construction is considered as valuable resource and yet waste level of waste is seen considerably high. It is obvious that reducing this waste saves money. At the baseline, cost is £281,765 with targeted practice of £155,880 (improvement - 0.6% of construction value seen around £125,885 as indicated in Table IV). Cost of waste disposal is around £65,498 at baseline and £30,785 (improvement - 0.2% of construction value seen around a total of £34,713) can be substantially save cost simply by reducing quantity of waste generated. This savings is achievable by incorporating specific management actions to change behaviour during design phase. According to practical solutions to good practice for this case study an estimated £28,940 will be incurred to achieve savings of £160,598. The 'benefits' of using secondary material is considered alongside a reduction in value of materials wasted and reduction in cost of waste disposal. The *'costs'* needed to reduce waste or increase recovery' on the other hand is achieved by the contractor through planning and effective management.

IV. Recommendations

To minimise construction waste generation, improve material recovery process there is a need for an effective coordination among construction professionals involved in the design and construction phase to coordinate waste management operations. Study suggests that the main contractor will predictably benefit from the reduction in the cost of waste disposal, but more benefits will be seen from waster reduction processes. To ensure that maximum benefit from good waste and best practices are realised and shared, it is therefore imperative for the client, the main contractor and the recycle specialist to work together. The paper advocate that on-site waste practices ought be effectively manage by introducing innovative tool-box workshops and sessions for all construction workers and demolition specialists, provide education on waste management to recyclers, project and site managers, develop innovative container types, segregate container and signage, accurate on-line reporting system.

To complement the rate of waste recovery process on construction sites there is a need to commendably consider the 3R's principle as a key guidance. A positive feedback from one of the participant interviewed reveals that concrete waste can be effective minimised if construction activities involving concrete work are greatly prefabricated units/panels. Significantly, the merits of reducing, reusing, recycling C&DW are emphasized, however the economic and environment impact are important to be considered in aspect of life-cycle assessments of construction waste materials. Although, satisfactory environmental awareness cannot be achieved in planned management support, however the legislative restrictions preventing construction and demolition waste stream from diversion to landfill still remains a bigger challenge globally.

V. Conclusion

The success of C&DW recovery operations remains a key challenge as many municipals around the world. This process has great impact on the environment and the cost benefits within this process remain a positive outcome to all recyclers, demolition contractors, site managers and project managers. Construction activities remain a grand challenge as a result of consistent civil works, site clearing, demolition, and excavation. The properly functioning waste recovery operations process must earn much of its income from tipping fees and the sales of fully developed secondary materials. Sadly, the economics of recycling operations are not very favourable in most cases, waste recovery process is a complex process in the industry depending on materials to be reused, recycled and recovered. Recycling serves more to maintain positive outcomes on construction sites with diminished capacity to land.

Despite the extent of waste problem in construction, the available waste options such as reducing, reuse, recycle has swept the entire industry. Yet, the hurdles to meet global target to reduce unnecessary landfill of valuable materials that can be recovered and redeployed remain a grand challenge.

This paper investigated the costs and benefits in using secondary materials and focus on investigating reuse and recycling process for five major types of construction materials: concrete, metal, wood, cardboard/paper and plasterboard. It was found that 'concrete, metal and wood' have shown a high recovery rate. However, the costs and benefits for recovery these three materials are dependent on experience of end users. The content of this paper seems to be beneficial for different construction groups namely, demolition contractors, recyclers, on-site waste producers', aggregate users and other researchers.

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