STUDY OF RESOURCE SUSTAINABILITY ASSESSMENT FOR BUILDING
Part 3. Environmental Assessments for Demolition and Waste Treatment Processes

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Summary

Construction waste management is an important social issue due to the large quantities of waste generated and the trace elements that it contains. While recycling helps reduce landfill needs, it requires additional energy and resources and releases trace elements into the environment. General contractors affect the waste flow by their choice of methods for separating and collecting the waste, and of treatment sites, but they receive little feedback on the results of their decisions. To control waste flows, the environmental loads must be assessed comprehensively.

The assessment tool described in this paper is designed to calculate various indices, such as the final disposal rate, CO_2 emissions, the quality of the recycled materials, and the likelihood of releasing trace elements. After establishing the waste flow and treating methods, the tool quantitatively calculates the indices using various databases, such as specific landfill rates and specific CO_2 emissions deduced from the operational I/O data surveyed at several treatment sites. The indices are normalized and plotted on a radar chart so that the strengths and weaknesses of the decisions can be relatively understood at a glance. This paper uses case studies to discuss an effective procedure for reducing some of the indices.

1. Introduction and Background

Japan's Construction Waste Recycling Law covers general contracting. Specifically, it covers the on-site separation and collection of waste, and recycling at treatment plants. General contractors of demolition works play an important role in determining the flow of waste when they develop demolition plans, select methods for separating and collecting the waste, and choose treatment plants and methods (Figure 1). Therefore, in terms of EPR (expanded producer responsibility), they are regarded as the most responsible sector of the construction waste recycling industry. However, they are experts in neither materials (as are material producers) nor waste treatment/management, and they cannot understand and evaluate the environmental impacts of their decisions.

Buildings are composed of a variety of materials. In the process of on-site demolition, the flow of waste, including trace elements, depends largely on the thoroughness of the separation, collection, and demolition methods. The next step—waste treatment—also offers diverse choices. The choice of treatment method can affect not only the waste flow but also the quality and quantity of the environmental load. Therefore, it is essential to have an environmental evaluation tool with adequate indices corresponding to important protection goals. General contractors can use this tool to determine appropriate methods for separating, collecting, and treating waste. This paper describes such a tool and the results of a case study.

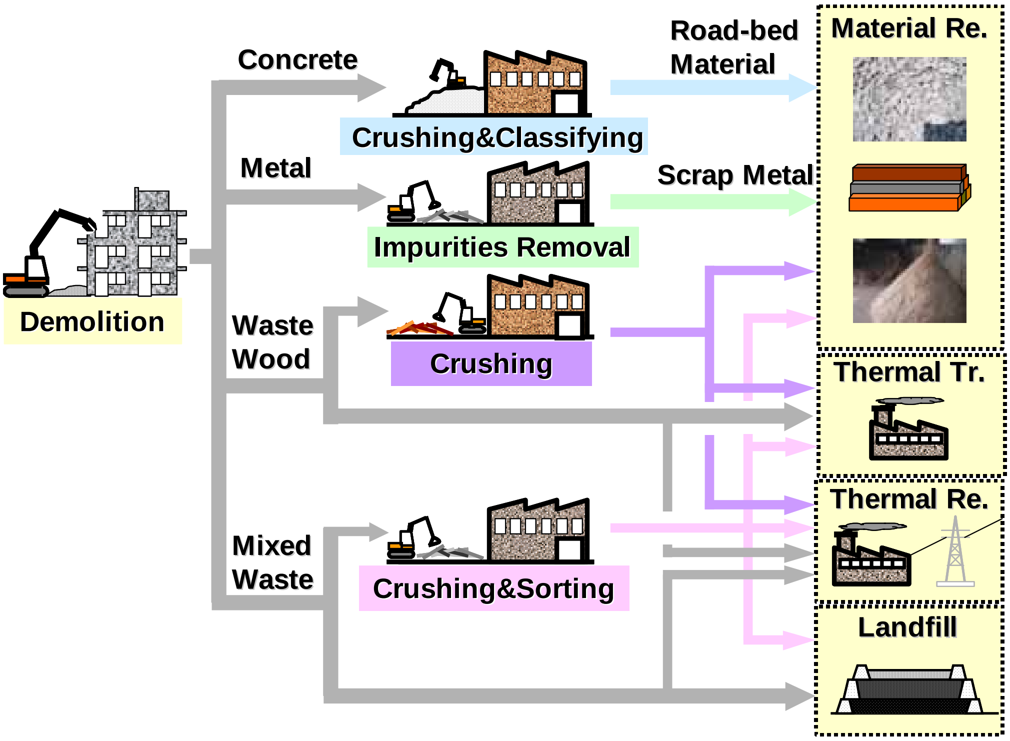

Figure 1 Flow of Construction Waste

2. State-of-the-Art Demolition and Treatment Processes in Japan

2.1 Demolition Processes

Demolition processes are comprised of four steps: 1) removal of harmful materials, including asbestos, CFCs, and PCBs; 2) separation and collection of interior finishing materials and equipment; 3) structure demolition; and 4) removal of metals and impurities from the crushed concrete (Figure 2). Certain types of demolition waste, such as PVC piping and gypsum board, might separately collected and treated, but most of the waste is separated into concrete waste, metal trash, wood waste, and mixed waste, and then transported to treatment plants. The classification of the waste depends not only on the physical properties of the building materials but also on the requirements of the treatment plants. For example, wooden construction panels are generally classified as wood waste, but they might be treated as mixed waste if treatment plants refuse to accept them.

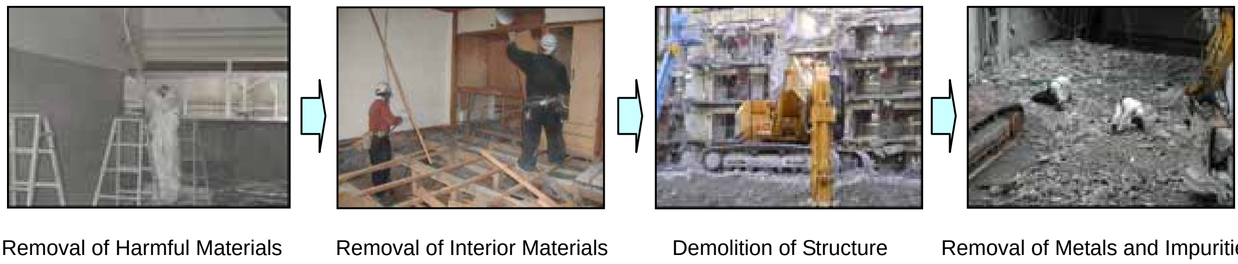

Figure 2 Main Demolition Processes

2.2 Treatment Processes

2.2.1 Crushed Concrete

Crushed concrete is first recycled as banking or filling material at the demolition site. Any remaining concrete is transported as waste to a treatment plant, where it is crushed, classified, and used as roadbed material.

The recycling rate for concrete waste was 65% in FY1995. This rate increased to 96% in FY2000 as a result of the decrease in available landfills. However, recycling as roadbed material is characterized as low-quality down-cycling. The expected demand for roadbed material in the future suggests that high quality up-cycling, such as aggregate recovery from concrete, will be required.

2.2.2 Scrap Metals

An international metals recycling market already exists. After a structure is demolished, iron and nonferrous metals are collected and separated at the demolition work site using magnetic separators. Reinforcing rods, equipment, and other iron items, as well as nonferrous metals such as copper wire, window frames, etc., are purified at treatment plants and then transported to metal production lines in and outside Japan.

2.2.3 Wood Waste

Wood waste from the construction sector generates about 50kg/(a*capita) while the demand for particleboard, which is made from recycled waste wood, is only 12 kg/(a*capita). The demand for wood for consumer durables is quite small and the material recycling potential of wood waste is limited. Therefore, energy recycling is inevitable. In FY2000, the material- and energy-recycling ratio was 38% while the volume reduction ratio—incineration without energy recovery—was 45%. Because of the limited capacity of landfills, incineration plants are used to reduce landfill volume but waste heat recovery engines are expensive and the purchasing price of electricity is too low for energy production from wood waste to be profitable in Japan. Moreover, social support for biomass utilization is too low in Japan to sustain such a system.

2.2.4 Mixed Waste

Mixed waste is composed mainly of bulky materials such as plastics, wallpaper, finishing wood, etc. The recycling ratio (treated ratio), for these materials is about 10%. Most of this waste goes straight into landfills. Mixed waste is either sent to refuse incinerators for use as fuel for power generation, or to sorting plants for materials recovery. In the former case, the incineration ash byproduct is sent to landfills, while in the latter case, the waste that remains after materials recovery, especially the plastic waste generated by the construction sector, cannot be recycled even after separation, collection, and sorting.

3. Evaluation Tool

3.1 Basic Concept

On the one hand, recycling decreases the volume of waste sent to landfills. On the other hand, recycling requires not only additional input of resources and energy but also releases trace elements into the environment that otherwise would be buried in a landfill. The evaluation tool provides comprehensive environmental impact evaluation from the ordinary perspectives of available landfills and CO_2 emissions as well as the new perspectives offered by the recycling ratio considering the quality of recycled materials. By providing a means for planning the separation and collection of waste and determining waste treatment methods, the tool also considers the quality of the waste and the release of trace elements into the environment as a result of demolition work. Chemical analysis of crushed concrete and wood waste has identified trace elements of hexavalent chromium in cement, heavy metals such as copper, zinc, and lead in cables and paint, and THP (total petroleum hydrocarbons) in waterproofing materials. Table 1 lists the six environmental indices contained in the tool.

Table 1 Environmental Evaluation Indices

No.	Index Nomenclature	Comments
1	Landfill volume	Incl. treatment of byproducts
2	CO_2 emissions	From treatment plants
3	Quality of recycling	See Table 5
4	Emissions of Cr^6+	In cement
5	Emissions of heavy metal	In cable, paint and cement
6	Emissions of TPH	In waterproofing materials and wood preservatives

3.2 Schematics of the Tool

The evaluation tool handles the five steps shown in Figure 3. Engineers working at the site first determine the quantity and composition of the waste. Next, they determine the number of fractions obtained when the waste is collected and separated and the thoroughness of the collection and separation. This quantitatively determines the materials flow on the site. The tool then selects a treatment method (and treatment plant) for each fraction and calculates the environmental indices for each fraction along the waste flow corresponding to the input data. Finally, the tool plots the summed indices on a radar chart.

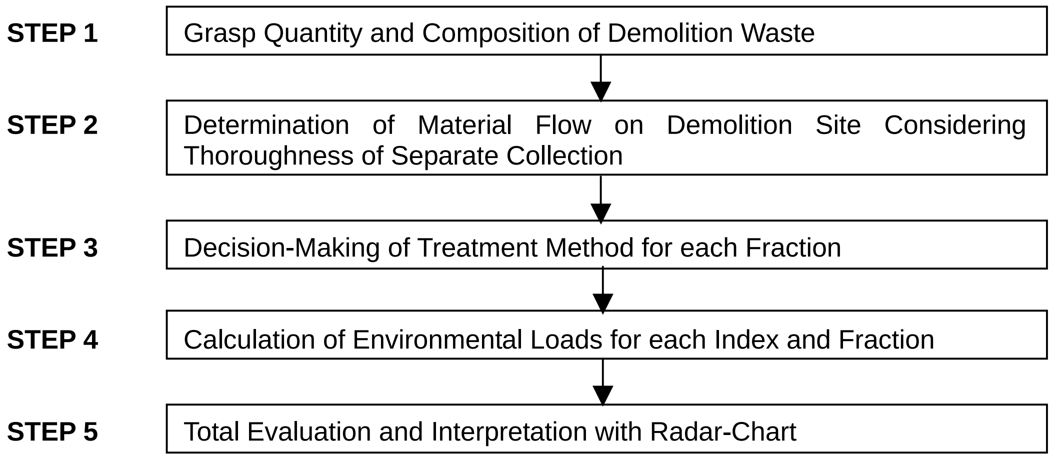

Figure 3 Evaluation Schematics

3.3 Database

3.3.1 Quantity and Composition of Waste

Any of several methods can be used to determine the quantity and composition of building demolition waste. The most detailed quantity and composition profiles can be calculated using LCW Software, which was developed as part of the Sustainable Housing Technology Development Project financed by METI (Ministry of Economy, Trade and Industry) of Japan and is now integrated in the LCA Software developed by the AIJ (Architectural Institute of Japan). LCW can calculate the specific weight [kg/m^2] of each waste material for each building part and each equipment group for which the quality of recycling and treatment is not an issue. By determining the minute waste flow from the LCW data and using the method proposed in this paper, not only a quantitative but also a qualitative environmental assessment of waste treatment can be obtained. LCW is not the only way to determine the quantity and composition of demolition waste, but its demolition site estimates are wholly acceptable.

3.3.2 Impurities Ratio for Each Fraction

The goal is perfect separation and collection at the site. In reality, most concrete is collected and treated as ‘crushed concrete,’ but some might be included in the ‘mixed waste’. The waste flow matrix representing actual conditions (Table 2) is indispensable to the tool’s environmental evaluations. The relationship between the input building materials and the waste fractions is simplified and shown in matrix form in Table 2. The components are determined by the part of the building from which the materials came, the composition of the waste brought to the treatment plants, and the quality or thoroughness of the on-site separation and collection processes. In this evaluation, two matrices were generated in order to compare ‘general’ separation and collection with ‘thorough’ separation and collection.

3.3.3 Specific Emissions

The waste fractions do not have unique waste treatment methods. Every method requires additional input of resources and energy, and produces byproducts that are further treated, sent to a landfill, or released into the environment as a fluid. Table 3 lists the landfill rate, specific CO_2 emission due to energy and resources input for important treatment methods for various fractions, including further treatment of the byproducts. These were calculated using the operation data—the actual input and output data—of about 30 treatment plants in Japan. In the case of incineration, the contribution of energy recovery is counted as part of the specific CO_2 emissions.

Table 2 Waste Flow Matrix According to the Level of Separation and Collection (Example)

Material	Waste Generation kg/m^2	Fraction				
		Separation and Collection	Crushed Concrete	Wood Waste	Scrap Metal	Mixed Waste
Concrete	1648.7		1632.2			16.5
ALC	31.1		30.8			0.3
Tile Carpet	0.2	0.2				
Reinforcing Rod	134.9		13.4		121.4	
Plywood	16.3		0.2	14.7		1.5
Others			92.4	19.1	226.7	7.8

Table 3 Specific Emissions According to Plant Investigation

Fraction	Treatment Method	Specific Emission	
		Landfill Rate [Weight-%]	Specific CO_2 Emission [kg-CO_2/Mg-Waste]
Crushed Concrete	Crushing and classifying	0.1	3
Wood Waste	Crushing and incineration	7.5	140
	With power generation	7.5	-10
Mixed Waste	Sorting and further treatment	25.0	140
	Sorting, further treatment, and power generation	25.0	10
Conbustible	Incineration	27.5	200
Mixed Waste	With power generation	27.5	-20
Landfill	Damping and leachate treatment		10

3.3.4 Trace Elements

The concentrations of trace elements in crushed concrete, wood waste and mixed waste are listed in Table 4. The concentrations for crushed concrete and wood waste were determined from environmental reports issued by cement makers and from original chemical analyses. There is no published data for trace elements in mixed construction waste, so these were deduced from the assumption that mixed waste is 70% crushed concrete and 15%wood waste. The Total Petroleum Hydrocarbons (TPH) in wood waste were not taken into account due to a lack of data.

Table 4 Trace Elements in Crushed Concrete and Wood Waste

Trace Element		Unit	Crushed Concrete	Wood Waste	Mixed Waste
Cr^{6+}	Hexavalent Chromium	mg/kg	3.2		2.2
Cu	Copper	mg/kg	50	17.5	37.5
Pb	Lead	mg/kg	25	37.5	23
Zn	Zinc	mg/kg	170		119
TPH	Total Petroleum Hydrocarbons	mg/kg	325		228

3.4 Weight Factor

3.4.1 Quality of Recycling

The recycling ratio for crushed concrete was about 96% in FY 2000. While this seems sufficient, recycling as roadbed material is considered down-cycling, which does not solve the fundamental problem of waste. One of the ultimate objectives must be the recycling of crushed concrete into new concrete, which cannot be evaluated using the ordinary recycling ratio. Therefore, weight factors must be introduced to take into account the quality of the recycling. These weight factors are listed in Table 5 and are multiplied by the quantity of waste before the evaluation.

Table 5 Weight Factors for Quality of Recycling

Division		Weight Factor	Crushed Concrete	Wood Waste
Material	Reuse	1	Pile	Reuse of finishing materials
Recycling	Up-cycling	2	Aggregate for concrete	Methanol
			Cement material (powder)	Ethanol
	Recycling	3	Aggregate for concrete	Paper material
			Admixture (powder)	
	Down-cycling	4	Roadbed or filling material	Particle board, activated coal
	Final Disposal	5	Dumped in landfill	Dumped in landfill
Thermal	Power Generation	2.5		RDF power generation
Recycling	Heat recovery	4		RDF
	Incineration	5		Volume reduction

3.4.2 Environmental Risks

Trace elements in recycled materials that otherwise would be buried in a landfill might result in being released into the environment. Emission paths are diverse in general, but the three indices for trace elements are fully backed by data. The weight factors listed in Table 6 take into account the potential for exposure to human beings. The weight factors are 5.0 when the trace elements are directly released into the environment, and 1.0 when they are detoxified or decontaminated. For example, the quantity of TPH is multiplied by 1.0 when it is decontaminated using thermal treatment.

Table 6 Weight Factors for Environmental Risks

Destination of Trace Elements	Weight Factor	Destination of Trace Elements	Weight Factor
Environment	5	Sub-environment	4
Products (heavy exposure)	4	Products (light exposure)	3
Isolation in landfill site	2	Detoxification, decontamination	1

4. Case Study

4.1 Calculation Conditions

An environmental evaluation was carried out using the RC multiunit residential apartment building (ordinary model) described in the previous report (Part 2). The building had a total floor area of 25,600 m^2 and generated 2,180 kg/m^2 of waste. Various conditions are listed in Table 7. These include both ordinary and thorough separation and collection, and special treatment cases for each fraction. The calculated values are linearly transformed so that the most desirable value is one and the least desirable value is five.

Table 7 Conditions

No.	Separate Collection	Crushed Concrete	Wood Waste	Mixed Waste
1	Ordinary	Roadbed material	Volume reduction	Landfill
2	**Thorough**	Roadbed material	Volume reduction	Landfill
3	Ordinary	**Aggregate** **Cement material**	Volume reduction	Landfill
4	Ordinary	**Aggregate** **Soil stabilization**	Volume reduction	Landfill
5	Ordinary	Roadbed material	**Particle board**	Landfill
6	Ordinary	Roadbed material	**Power generation**	Landfill
7	Ordinary	Roadbed material	Volume reduction	**Rough sorting and incineration**
8	Ordinary	Roadbed material	Volume reduction	**Thorough sorting and further treatments**

4.2 Results

The results are listed in Table 8 and Figure 4. The RC building is mostly concrete by weight, and selection of the treatment method has a lot to do with the results and contributions of the different countermeasures to each environmental index (summarized below).

1. Thorough separation and collection at the demolition site reduces the quantity dumped in landfills.
2. Aggregate recovery from crushed concrete increases both the quality of recycling and the volume of CO_2 emissions. The powder byproduct should be treated in a cement kiln to reduce the amount of trace elements released into the environment.
3. Wood waste incineration for power generation helps reduce CO_2 emissions to some degree.
4. Sorting and recycling of mixed construction waste reduce the quantity dumped in landfills.

This environmental evaluation tool promotes quantitative and comprehensive understanding of the impacts of separation, collection, and treatment method on the environment. Construction engineers who need to make on-site decisions can also use it for cost-benefit analyses.

Table 8 Results of Case Study

No.	Landfill Ratio	CO_2 Emission	Recycling Quality	Cr^{6+} Emission	Heavy Metal Emission	TPH Emission
1	5.00	1.14	5.00	4.98	4.94	4.96
2	2.42	1.00	4.79	5.00	2.22	4.93
3	4.54	5.00	1.00	1.00	1.00	1.00
4	5.00	5.00	2.82	4.98	4.94	4.96
5	2.85	1.17	4.97	4.98	4.97	4.96
6	3.15	1.42	4.93	4.98	4.94	4.96
7	3.95	1.65	4.99	4.98	4.94	4.95
8	1.00	1.14	4.94	4.95	5.00	5.00

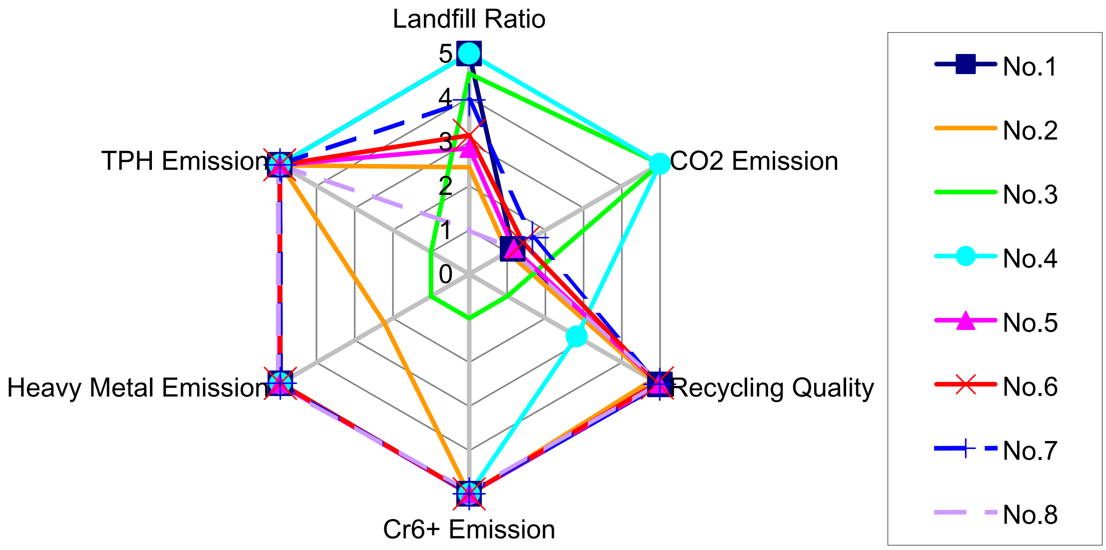

Figure 4 Total Evaluation plotted on Radar Chart

5. Summary

This paper introduces a framework for a comprehensive environmental evaluation method for separating, collecting, and treating building demolition waste, and discusses the results of a case study. The variety of construction waste characteristics, treatment methods, and evaluation indices mean that a lot of problems remain to be tackled, including appropriate system boundaries, applicability to the various specific emissions, the lack of original data, etc.

Acknowledgement

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