Journal of Cleaner Production 17 (2009) 688–702

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Comparing the implementation of concrete recycling in the Australian and Japanese construction industries

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ARTICLE INFO

Article history:
Available online 4 January 2009

Keywords:
Concrete recycling
Benefit
Difficulties
Recommendation
Construction
Australia
Japan

ABSTRACT

Environmental problems have been considered to be serious in the construction industry. Waste management pressures are pressing very hard with alarming industrial warming signals. Among the different types of construction and demolition wastes, concrete is about 81 percent of the volume of construction and demolition waste in Australia. To minimize the concrete waste generated from construction activities, recycling of concrete waste is one of the best methods to improve the environment. However, situations of concrete recycling in different countries vary considerably. Japan is a leading country in recycling concrete waste, with 100 percent recycling of the wastes that are used for new structural applications. This paper investigates the current concrete recycling situations in Australian and Japanese construction industries. A questionnaire survey and structured interviews were conducted. In comparing the current concrete recycling situations between Australia and Japan, it should be noted that major difficulties found from Australian and Japanese construction industries are on different phases of the transition to recycling of construction wastes. Therefore, it is suggested that the Australian construction industry should be: i) developing a unified policy in concrete recycling; ii) providing financial governmental support; iii) developing clear technical specifications or standards on the use of recycled aggregate for structural applications.

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1. Introduction

The promotion of environmental management and the mission of sustainable development have exerted pressure on the adoption of proper methods to protect the environment across all industries, including construction. Extensive extraction of natural resources for building construction jeopardizes the principle of sustainability and has received increasing objections from environmentalists. Construction by nature is not necessarily an environmental-friendly activity. The comprehensive building development and redevelopment plans in different countries have aggravated construction problems pertaining to building demolition. To optimize the use of natural resources and particularly concrete demolition waste, there is a need to develop long-term action plans on the use of materials and to coordinate various interests among stakeholders and companies in the construction industry [1]. The hierarchy of disposal options can be categorized into six environmental impact levels, from low to high; namely, reduce, reuse, recycle, compost, incinerate and landfill [2]. Three main waste minimization strategies of reuse, recycle and reduction are collectively called the "3Rs". To reduce construction waste generated on site, coordination among all those involved in the design and construction processes is essential.

Sustainable construction is a set of processes by which a profitable and competitive industry delivers built assets [3,4]: i) to enhance the quality of life and to provide customer satisfaction; ii) to offer flexibility and the potential to help to anticipate and respond to anticipated future, user demands; iii) to provide and support desirable natural and social environments; and iv) to maximize the efficient use of resources. A potential contributor for sustainable performance can include recycling of construction waste.

The best way to deal with material wastes is not to create them in the first place [34,63]. Table 1 summarizes the problems of the current practices and highlights some of the recommended measures for reducing the generation of construction wastes by improved management and operational improvements. Four management measures are highlighted including: i) policy; ii) training; iii) audit; and iv) feedback and two operational measures on design and construction stages are also considered.

Recycling, being one of the strategies in waste minimization, offers three major benefits [5]: i) to reduce the demand upon new resources; ii) to cut down transport and production energy costs; and iii) to use waste which would otherwise be transferred to

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doi:10.1016/j.jclepro.2008.11.015

Table 1
Problems and recommended measures for controlling construction waste by previous researchers [14–16,34,50,54,56,57,59–78].

	Management level				Operational level	
	Policy	Training	Audit	Feedback	Design	Construction
Aim	Enhance environmental awareness and company culture	Provide benchmarking measures in understanding the weaknesses		Achieve continuous improvement	Have an early planning for the environmental issues	Ensure all construction wastage had been minimized by all means
Problems	Waste management as a low priority in a project	Insufficient training provided and lack of knowledge on waste minimization technology	Normally no benchmarking tool provided in an organization	No encouragement to provide feedback	Lack of consideration of environmental issues in the design stage	Waste generation is increasing
Measures	Set up environmental policy Demonstrate greater commitment to waste management Implement waste management plan Consider reduction of construction waste and awareness of environmental protection as basic requirements in building management	Provide training programme to all levels of employees	Provide bench-marking measures for understanding the problems of the current measure and provide some improvements Incentive reward scheme	Provide feedback loop from the public and in-house employees Improve building construction technology by research or adoption	Use long-life construction materials, such as steel Consider dimensional coordination construction Minimize variations Flexible design Purchasing quantity of materials just required Consider site selection Provision of adequate information on maintenance Clear specification Use environmental-friendly construction method and modular design, such as prefabrication Avoid buying poor quality materials Coordinate with designer and specification writer to use recyclable materials	Reuse, recycle and reduction Good site planning Separation of construction materials Well-organized site and proper storage facilities Use of secondary materials Avoid complex and labour intensive works Labeling of construction materials Effective logistics Agreements with sub-contractors Avoid overloading limited storage space on site Avoid unnecessary handling Less packaging or reusable packaging Adopt just-in-time ordering Avoid damage while unpacking on site Order appropriate material sizes to minimize cutting, and order appropriate quantities to avoid excess Designate central areas for cutting and storage so reusable pieces can easily be located Review waste management periodically to identify additional waste reduction alternatives Employ competent sub-contractors and skill labourers

landfill sites. Construction and demolition waste including demolished concrete, bricks and masonry, wood, glass, insulation, roofing, wire, pipe, rock and soil [6] constitutes a significant component in the total waste.

Among various types of construction and demolition waste, concrete constitutes the major proportions of the total waste of about 81 percent in Australia [7]. The situation of surrounding concrete recycling is varied in different countries. Japan is a leading country in concrete recycling, in which about 98 percent of concrete waste is recycled [8]. Most demolished concrete structures are reused for road-base materials and backfill materials, some can even be used it for structural applications [9,10]. Although concrete recycling is recommended in the Australian construction industry, it is still not clear on concrete recycling procedures and the lack of experience in conducting these [11]. This limits the concrete recycling rate in Australia to only about 40 percent which is mainly used for low-grade applications [12].

2. Research objectives

This paper aims to achieve the following objectives:

- to study waste generation in the Australian and Japanese construction industries;
- to examine their regulatory requirements on waste minimization and concrete recycling procedures;
- to investigate their current concrete recycling methods;

- to examine their existing standards on the use of recycled concrete;
- to examine and to compare benefits gained and difficulties encountered from concrete recycling in the Australian and Japanese construction industries; and
- to recommend some measures to improve the current concrete recycling situations in Australia based on lessons learned from Japan.

3. Construction waste problems

Waste is defined as by-product material of human and industrial activities that have no residual values [13]. From Table 2, about 32.4 million tons of solid waste are generated in Australia annually [7], of which about 42 percent is from the construction and demolition sectors. From that, about 7.8 million tons of material corresponding to about 57 percent of construction and demolition waste is recycled (see Table 3).

Among different types of construction and demolition wastes, concrete waste constitutes about 81.8 percent of the total waste [7]. From that, 54 percent of the concrete waste is recycled (see Fig. 1). Moreover, the metal recycling rate is the highest at about 82 percent. The industry is highly motivated to recycle metal waste because it is profitable. Some demolition projects may even take risk in estimating the amount of metal waste to be collected on site and thereby lowering the contract sum during tendering to improve their competitiveness.

In Japan, wastes generated from construction and demolition activities are only about 16 percent of the total waste, with about 0.75 million tons of waste generated annually [8] (see Table 4). The recycling rate of various types of construction and demolition waste from 1995, 2000 and 2003 are improving (see Fig. 2). In 2003, concrete and asphalt recycling rates are about 98 percent and 98.5 percent respectively.

4. Regulatory requirements on concrete recycling

One of the major factors to effectively handle waste recycling in the construction industry is the top management support [14]. However, the implementation of waste management requires a large amount of investment such as facilities and equipment, which is the main burden to the industry. To coordinate various construction stakeholders in implementing waste management, it is necessary that long-term policies and strategies should be developed and implement [15,16].

Australia has three governmental hierarchical levels: i) the Commonwealth government which represents the whole country; ii) state and territory governments; and iii) local governments and councils. All three levels of government have various responsibilities in the areas of environment, waste minimization and recycling.

Table 2
Solid waste generation in Australia [7].

State/Territory	Waste generated (tons)			
	Municipal	Commercial and industrial	Construction and demolition	Total
New South Wales	3,326,000	4,196,000	4,649,000	12,171,000
Victoria	2,291,000	2,743,000	3,575,000	8,609,000
Queensland	1,742,000	959,000	1,166,000	3,973,000
Western Australia	833,000	744,000	1,945,000	3,522,000
South Australia	600,000	677,000	2,156,000	3,433,000
Australian Capital Territory	111,000	150,000	250,000	674,000
Total	8,903,000	9,469,000	13,741,000	32,382,000

Table 3
Recycled solid waste in Australia [7].

State/Territory	Recycled waste (tons)			
	Municipal	Commercial and industrial	Construction and demolition	Total
New South Wales	1,156,000	1,365,000	3,309,000	5,830,000
Victoria	744,000	1,740,000	1,945,000	4,429,000
Queensland	445,000	212,000	488,000	1,251,000
Western Australia	92,000	324,000	410,000	826,000
South Australia	235,000	469,000	1,452,000	2,156,000
Australian Capital Territory	29,000	52,000	223,000	467,000
Total	2,701,000	4,162,000	7,827,000	14,959,000

Table 5 summarizes legislation, and waste management strategies and targets from the Commonwealth government and various states/territories. The Commonwealth government, as a member of the Australian and New Zealand Environment Conservation Council (ANZACC), has been committed to achieve a target of 50 percent waste reduction. The Commonwealth Environment Protection Agency is also responsible for many issues regarding waste management and pollution but does not directly address issues related to demolition waste. Although various Australian states/territories have enacted and amended legislation to pursue waste minimization objectives and to adopt new waste minimization strategies including “zero waste” or “towards zero waste” goals, landfill levies in most states are low and cannot encourage the implementation of waste reduction schemes in the industry. Four major issues on the limitations of implementing waste minimization can be summarized: i) absence of a uniform national approach to waste minimization; ii) lack of information on the extent, types and sources of waste; iii) landfill levies are too low to be an incentive to reduce waste generation and waste deposition; and iv) insufficient education in the private sectors in investing waste management technologies.

In Japan, construction material recycling law was enacted in 2000 [8], which was aimed at increasing the recycling and reusing of construction materials in view of ensuring efficient use of natural resources. The construction material recycling law requires contractors to sort out and recycle waste generated in building & demolition work. Specified construction materials (such as concrete, asphalt and wood) must be reused from demolition projects. In addition, requirements of using the specified construction materials for new construction work are regulated, including: i) demolition building work with a total floor area larger

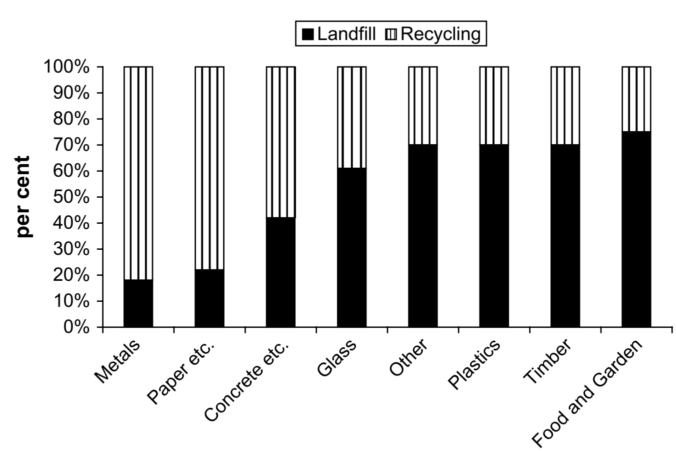

Fig. 1. Recycling and disposal rate of construction and demolition materials in Australia [7].

Table 4
Solid waste generation in Japan [8].

Industry	Amount of waste (million tons)	Percentage of waste
Electricity, gas, heat supply and water service	0.92	20%
Agriculture	0.91	20%
Construction and demolition	0.75	16%
Pulp paper factory	0.37	8%
Steel	0.31	7%
Chemical	0.19	4%
General waste	0.52	11%
Others	0.67	14%
Total	4.64	100%

than 80 m^2; ii) construction or enlargement work with a total floor area larger than 500 m^2; iii) repair work or remodeling with a contract sum exceeding 100 million yen (or AU$1.1 million); and iv) demolition or construction work other than building with a contract sum exceeding five million yen (or AU$550,000). A detailed system of responsibilities of clients, main contractors and sub-contractors in the construction material recycling law are shown in Figs. 3 and 4 respectively. It should be noted that this system requires high technical skills from construction and demolition contractors because they need to submit detailed procedures before starting construction and demolition activities. Along with this law, the Japanese government also targets the recycling rate of the specified construction materials to reach about 95 percent in 2010 [8].

5. Current concrete recycling methods

Basic equipment used to process virgin aggregate is similar to that used for crashing, sizing and stockpiling recycled aggregate. A recycling plant usually is comprised of crushers incorporating sieves, sorting devices and screens. The main recycling processes are crushing, sorting and screening to produce aggregate for use in civil engineering work, landscaping and as a substitute for gravel in concrete products [17].

Although the current concrete recycling method is used in many countries to produce recycled aggregate, the quality of the produced recycled aggregate is low, which limits its use to applications for low-grade activities such as road work, pavement and drainage [18–22]. Japan is now using advanced technologies to improve the quality of recycled aggregate, so that it can be used for high-grade concrete applications [9,10,23]. Some advanced technological methods to improve the quality of recycled aggregate are listed in Table 6.

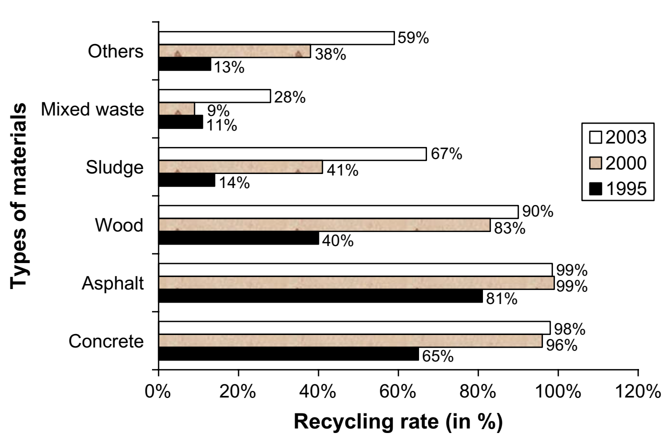

Fig. 2. Construction waste recycling rate in Japan [8].

6. Existing standards on the use of recycled concrete

The construction industry and concrete manufacturers realize that they need to use available aggregate rather than search for the perfect aggregate to make an ideal concrete suitable for all concrete applications [24]. The importance of concrete recycling has been recognized by the industry, in which hundreds of tons of recycled aggregate concrete have been recycled and used for specific purposes such as road-base and pavement [11].

In Australia, the Commonwealth Scientific and Industrial Research Organization (CSIRO) initiates one of the most significant steps in promoting the use of recycled aggregate in new concrete. “Guidance on the preparation of non-structural concrete made from recycled concrete aggregate” and “Guide to the use of recycled concrete and masonry materials” (Ref: H155-2002) were issued in 1998 and 2002 respectively [25,26]. These guidelines recommend two classes of recycled aggregate (Class 1 and Class 2) for non-structural concrete applications (see Table 7). Although there are current technical specifications for the use of recycled aggregate as a sub-base material in road construction, there is an urgent need to establish technical and performance standards for recycled aggregate for new concrete production [25,26].

In Japan, three types of recycled coarse aggregate (C1, C2 and C3) and two types of recycled fine aggregate (F1 and F2) are employed for non-structural applications (see Table 8) [27]. To optimize the use of recycled aggregate, the Japanese Industrial Standards (JIS) issued two standards on the use of recycled aggregate and recycled aggregate concrete for high-grade concrete applications. “Recycled aggregate for concrete class H” (Ref: JIS A 5021) and “Recycled concrete using recycled aggregate class L” (Ref: JIS A 5023) was enacted in 2005 and 2006 respectively [28,29]. “Recycled aggregate for concrete class M” (Ref: TR A 0006) has also been drafted and expected to be enacted by 2007. Details of the requirements of recycled aggregate and suggested concrete applications for classes H, L and M are shown in Table 9.

7. Research methodology

To examine the effectiveness of concrete recycling in the Australian and Japanese construction industries, a questionnaire survey was conducted. Four main sections are divided in the questionnaire. The first section seeks for awareness about concrete recycling, such as policy and participation of concrete recycling in their companies. The second section examines benefits gained from implementing concrete recycling. The third section investigates difficulties encountered in the implementation of concrete recycling. The fourth section studies effective methods for implementation of concrete recycling.

The survey was sent to 423 parties including contractors, consultants, recycling companies, governmental departments and developers. To date, 134 were received with a response rate of about 32 percent. The respondents can be classified into four categories, G1–G4. Table 10 shows the details of G1–G4 and distribution of respondents in each group from Australia and Japan.

Data collected from questionnaires were analyzed using the Statistical Package for Social Sciences (SPSS) Version 14.0 for Windows. The mean values of the four groups were derived first. Then the values were tested for concordance between groups and the *F*-test was performed with a demarcation level of significance at 0.05. The test is used to assess any similarity of opinion between groups in implementing concrete recycling.

To determine relative ranking of factors, the scores were transformed to important indices based on Equation (1) [30]:

$$\mathrm{RII} = \frac{\sum w}{AN} \quad (1)$$

Table 5
Legislation, and waste minimization strategies and targets of waste recycling in Australia [7].

State/Territory	Legislation	Waste minimization strategies and targets
Commonwealth	Natural Heritage Trust of Australia Act 1997 National Environment Protection Measures(Implementation) Act 1998 Environmental Protection and Biodiversity Conservation Act1999	The National Waste Minimization and Recycling Strategy (NWMRS) The National Kerbside Recycling Strategy (NKRS).
Australian Capital Territory	Environment Protection Act 1997 Waste Minimization Act 2001 Litter Act 2004	No Waste By 2010 Waste Pricing Strategy for the ACT
New South Wales	Protection of the Environment Operations Act 1997 Waste Avoidance and Resource Recovery Act 2001	Waste Avoidance and Resource Recovery Strategy 2003 Waste Reduction and Purchasing Policy Used Packaging Materials Industry Waste Reduction Plans
Northern Territory	Waste Management and Pollution Control Act 1995	Litter Abatement and Resource Recovery Strategy 2003
Queensland	Environmental Protection Act 1994 The Environment Protection (Waste Management) Policy 2000	Waste Management Strategy for Queensland 1996
South Australia	Environmental Protection Act 1993Zero Waste SA Act 2004	South Australia's Waste Strategy 2005–2010
Tasmania	Environmental Protection and Pollution Control Act 1994Litter Act 1973	Guide to Industrial Waste Management
Victoria	Environment Protection Act 1970	Towards Zero Waste Strategy 2005Environmental Sustainability Framework2005
Western Australia	Environment Protection Act 1986Environment Protection (Landfill Levy) Act 1998	Statement of Strategic Direction for Waste Management in Western Australia 2004

where w is the weighting given to each factor by the respondent, ranging from 1 to 5 in which '1' is the least important and '5' the most important; A is the highest weight, in this study $A = 5$; N the total number of samples; and RII the relative important index, $0 \leq \text{RII} \leq 1$.

After receiving the questionnaire responses, individual structured interviews were arranged with eight respondents, selected from different business sectors: one from a government department, one from a building developer, one from a consultant, two

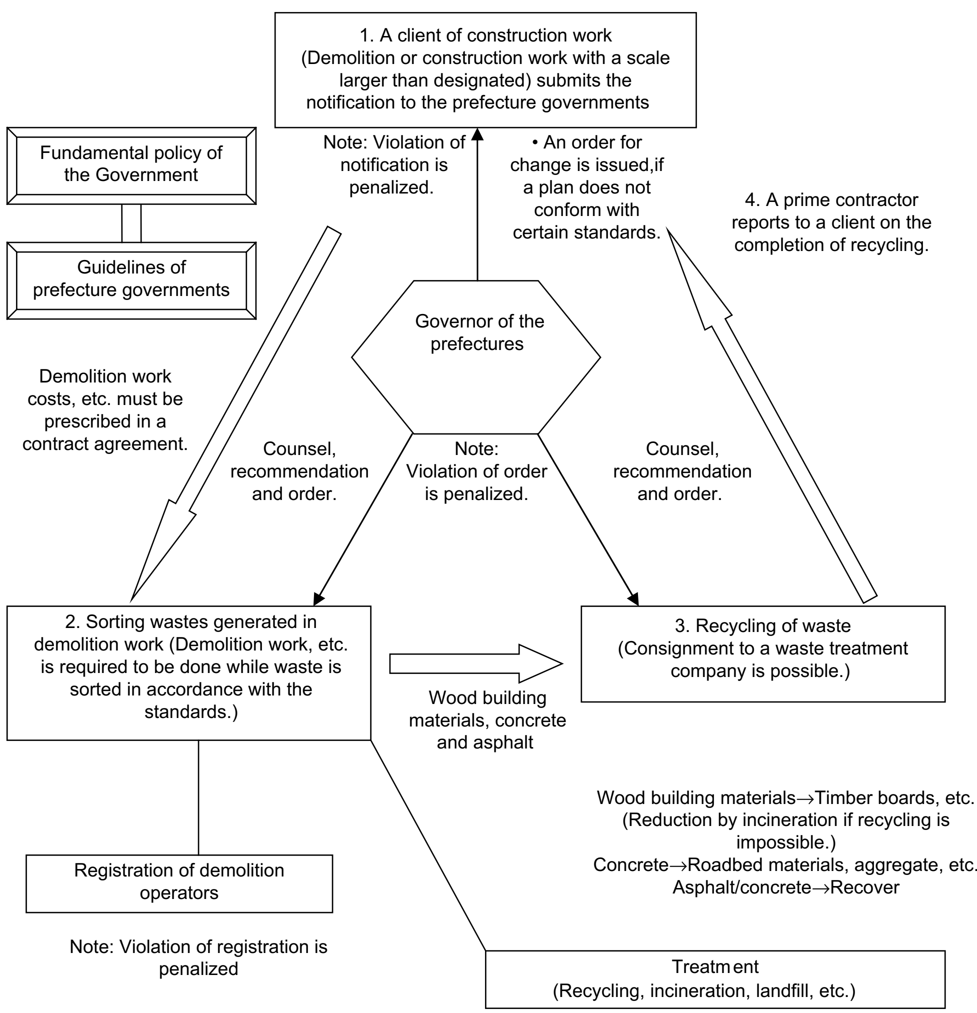

Fig. 3. System of construction material recycling law in Japan [8].

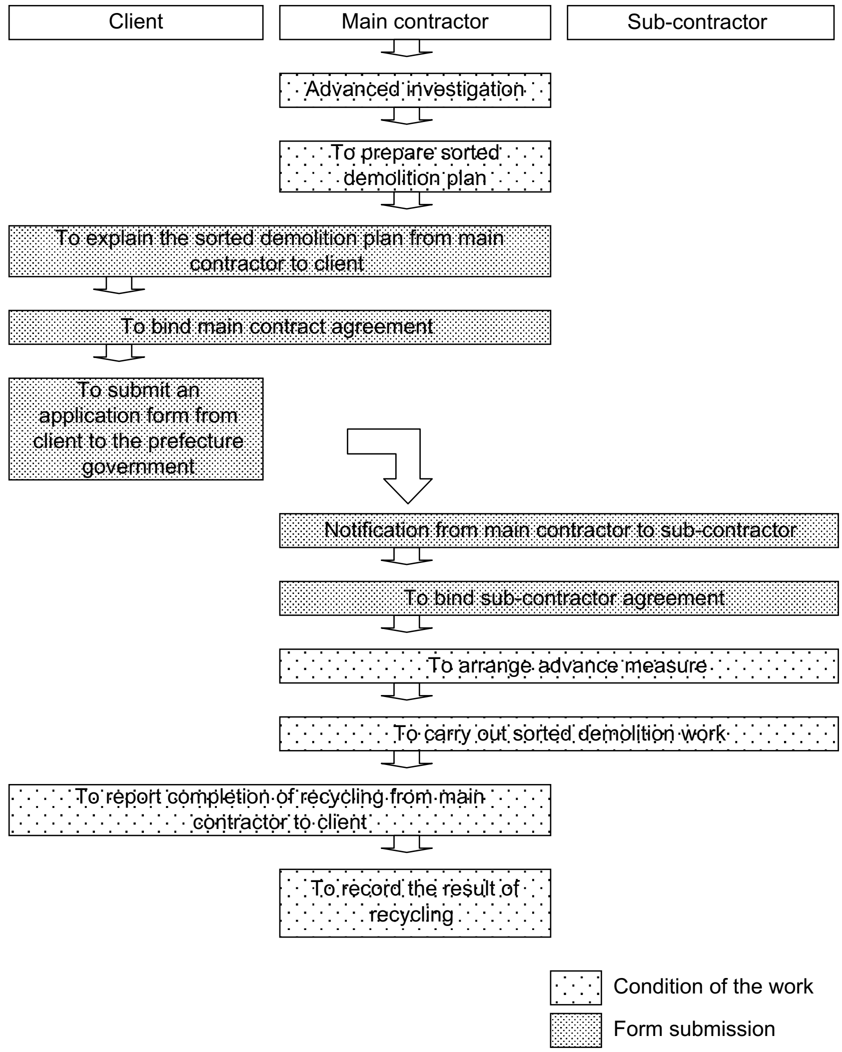

Fig. 4. Responsibilities among client, main contractor and sub-contractor in construction material recycling law in Japan [8].

from main contractors, two from sub-contractors and one from a recycling company. The interviews were used to gather further comments, elaborations and interpretations on the results obtained from the questionnaire and to reduce the limitation of low response rates from G2, G3 and G4.

8. Results and discussions

8.1. Awareness of concrete recycling

From the results shown in Table 11, it should be noted that awareness towards concrete recycling is quite high in both the Australian and Japanese construction industries, with more than half of the respondents being positive. In comparing the awareness between the two countries, it can be clearly shown that about 68 percent of the Japanese construction companies have used concrete recycling policies, objectives and procedures, which are higher than in Australia of about 48 percent. These Japanese construction companies not only have a higher percentage in using their concrete recycling policies, objectives and procedures, they also have a higher percentage in having a specific division/department to implement concrete recycling and concrete recycling methods of about 61 percent and 81 percent respectively, whereas Australia's responses are about 52 percent and 63 percent respectively. From the interview discussions with one of the Japanese main contractors, he explained that concrete is one of the specified construction materials in the construction material recycling law enacted by the Japanese government. The construction material recycling law requires every contractor to submit a detailed material recycling plan for designated projects before their commencement. Therefore, it is necessary for construction organizations to have clear concrete recycling policies and to also have specific departments to satisfactorily implement concrete recycling.

Although the Japanese government regulates the use of recyclable materials in construction and demolition projects, many construction organizations are not planning to invest resources to implement concrete recycling and increase the number of staff in training programs. The results show that only about 39 percent and 54 percent of the respondents were planning to invest in concrete recycling resources and joining training programs respectively. From the interview discussions, one of the Australian contractors claimed that awareness towards concrete recycling between the public and private organizations is limited and cooperation is very different. One of the main reasons is that the implementation of concrete recycling requires a high investment at the initial stage, while the private sector is mainly concerned with short-term returns, rather than long-term benefits.

Table 6
Methods on advanced technologies to improve the quality of recycled aggregate.

Method	Details of the method
Heating and grinding method	The heating and grinding method makes the hardened cement paste which adheres to concrete waste soften by heating concrete waste to about 300 degrees [79]. After that parts of the hardened cement paste adhered to original aggregate in the concrete mass can then be separated by a grind process resulting in clean original aggregate from the concrete waste.
Screw grinding method	The screw grinding method uses a shaft screw consisting of an intermediate part and an exhaust part with a warping cone to remove mortar adhered to the aggregate's surface [80].
Mechanical grinding method	The mechanical grinding method uses a drum body which finely separates partition boards with same-sized holes. The steel balls can move horizontally and vertically by rolling the drum. The quality of aggregate can then be improved in narrowing the inside space by using the partition boards [81].
Gravity concentration method	After processing with a jaw crusher, an impact crusher and an improvement rod mill, aggregate of over 8 mm are divided into recycled coarse aggregate and mortar particles. Aggregate with sizes under 8 mm are divided into two types: recycled fine aggregate of sizes 5 mm and 5-8 mm [82]. The wet gravity concentration machine is used to move: i) light weight things such as mortar particle and wood waste upward; and ii) heavy-weight things such as aggregate grain downward.

8.2. Benefits gained from concrete recycling

Using demolished concrete waste is an effective and economical option to recycle waste materials. This option provides waste minimization benefits by avoiding the use of landfill space and reducing consumption of natural resources [31]. The recycling of waste can greatly reduce environmental damages caused by incorrect disposal, extend the useful life of landfills and can also preserve precious natural resources [32]. The advantages of recycling demolition concrete are that substances are reused which would otherwise be classed as waste. Recycling of concrete demolition waste can also provide opportunities for saving resources, energy and time. Furthermore, recycling and controlled management of concrete demolition waste can save use of land and create better opportunities for handling other kinds of waste. The economic and environmental benefits to be gained from concrete waste minimization and recycling are enormous [33], since it will benefit both the environment and the construction firms in terms of cost reduction. The economic benefits of concrete waste minimization and recycling include the possibilities of selling specific recycled products and the removal from site of other waste at no charge or reduced cost, with a subsequent reduction in materials going to landfill at a higher cost [34]. Therefore, it can increase contractors' competitiveness through lower production costs and a better public image. Previous studies have identified a number of benefits in implementing concrete recycling for construction [14,31–36], which are summarized into the following eight factors and form the major areas of inquiry in the questionnaire:

- reducing the need for new landfills;
- saving natural materials;
- reducing project costs by using recycled materials;
- saving the cost in transportation between sites to recycling plants when recycling machines are located on-site;
- stimulating continuous improvement in concrete recycling;
- rising concrete recycling awareness, such as selecting suitable resources, techniques and training and compliance with regulations;
- increasing overall business competitiveness and strategic business opportunities; and
- improving management and employee's communication on concrete recycling information and commitment.

Table 7
Classification of recycled aggregate in Australia [25,26].

Class	Sub-class	Definition
Class 1	Class 1A	Uniformly graded coarse aggregate (4–32 mm), produced by crushing waste concrete with total contaminant levels lower than 1 percent of the bulk mass
	Class 1B	Class 1A recycled aggregate blended with no more than 30 percent crushed brick
	Grade 1	Plain unreinforced and reinforced concrete made with a maximum of 30 percent uniform quality of Class 1A recycled aggregate with characteristic strength up to and including N40 grade, i.e., 40 MPa
	Grade 2	Plain unreinforced and reinforced concrete made with up to 100 percent uniform quality of Class 1(A or B) recycled aggregate having characteristic strength up to and including N25 grade, i.e., 25 Mpa, concrete for use in non-structural concrete applications
Class 2	Class 2A1	Suitable for use on roads with a traffic loading of greater than 1×10^6 ESA as either base course or sub-base
	Class 2A2	Suitable for use on roads with a traffic loading of less than or equal to 1×10^6 ESA as either base course or sub-base
	Class 2B	For use as a base layer for pavers in pedestrian areas, car parks and shopping malls
	Class 2C	General filling behind kerbs and gutters, retaining walls or beneath grassed areas
	Class 2D	Bulk filling for urban and rural development or for construction of embankments
	Class 2E	Backfilling for subsoil drains and stormwater pipes

From the *F*-statistics result shown in Table 12, it is clear that "Reducing project costs by using recycled materials" and "Improving management and employee's communication on concrete recycling information and commitment" are significant; this means that there is a significantly different viewpoint among different groups. The respondents from the governmental department and developer group (G4) on "Reducing project costs by using recycled materials" clearly exhibit a higher mean value in comparison with those of G1, G2 and G3. In the interview discussions, one of the governmental staff members explained that long-term benefits gained from concrete recycling in reducing project costs is very significant for the project. However, the construction industry is mainly concerned with high, short-term initial investment costs, which limit the implementation of investment in waste recycling equipment.

From the responses of various groups in "Improving management and employee's communication on concrete recycling information and commitment", recycling companies (G3) have a higher mean value than other groups. An interviewed recycling company representative explained that there is a severe lack of information on current construction or demolition projects; therefore, they adopt a "*wait and see*" attitude for the recycling activities from construction sites. A main contractor also highlighted that communication among contractors and recyclers is very weak. He suggested including recyclers as one of the project parties in receiving and recycling the construction and demolition materials; thereby, according to him the total waste generation would be significantly reduced.

To unveil the ranking and the relative importance of benefits gained in implementing concrete recycling, the relative important index for Australia and Japan are shown in Table 13.

The survey result shows that "Saving natural materials" and "Reducing the need for new landfills" are recognized as the greatest benefits in recycling concrete. These two reasons ranked at the top in the survey results. It is clear that recycling concrete waste, which is the major proportion of construction and demolition waste [7],

Table 8
Types of recycled aggregate concrete and suggested uses in civil and building work [27].

Type	Coarse aggregate	Fine aggregate	Suggested design strength (MPa)	Suggested use of recycle aggregate concrete
Civil works applications				
CI	Recycled coarse aggregate type C1	Normal fine aggregate	18–24	Reinforced or plain concrete; lower structure of bridges, tunnel lining, retaining walls, etc.
CII	Recycled coarse aggregate type C2	Normal or recycled fine aggregate type F1	16–18	Plain concrete; masonry units, bases for road attachment, gutters, gravity type retaining walls, etc.
CIII	Recycled coarse aggregate type C3	Recycled fine aggregate type F2	Less than 16	Subslab concrete, back filling concrete, leveling concrete, etc.
Building works applications				
BI	Recycled coarse aggregate type C1	Normal fine aggregate	18 or more	Ordinary reinforced concrete buildings
BII	Recycled coarse aggregate type C2	Normal fine aggregate	18 or more	Concrete attached to ground; foundation, cast-in-place concrete piles, concrete slabs on steel decks, etc.
BIII	Recycled coarse aggregate type C2	Recycled fine aggregate type F1	18 or more	Foundation slabs, earthen floor slabs, subslab concrete, back filling concrete, leveling concrete, etc.
BIV	Recycled coarse aggregate type C3	Recycled fine aggregate type F2	18 or more	Subslab concrete, back filling concrete, leveling concrete, etc.

can significantly reduce the total waste generation on site. In the interview discussions, a recycler explained that recycled aggregate is the most common way to recycle concrete waste. Recycled aggregate, crushed from the demolished concrete waste can be mixed with other natural materials for applications in pavement and road-base construction.

In comparing the survey responses from Australia and Japan, there are different viewpoints on the benefits of "Reducing project costs by using recycled materials" and "Improving management and employee's communication on concrete recycling information and commitments". The Japanese responses consider the former benefit having a higher ranking than the latter; but it is the opposite in the Australian responses. In an interview with one of the main Australian contractors, he underscored that the main concern in implementing concrete recycling is to reduce material's costs. Lowering project cost ranks as the first priority for the project. An interviewed Japanese contractor explained that recycling concrete from construction and demolition sites has been implemented due to the construction material recycling law in Japan since 2000. The Japanese construction industry can achieve long-term cost savings for the project in concrete recycling by using the demolished concrete waste for other concrete applications. However, improved communications with various project parties is essential to gain the benefits such a cost saving for the projects. An interviewed recycling company representative claimed that the industry should first improve the management and communication with various project stakeholders, then project's cost savings will be more easily achieved.

8.3. *Difficulties encountered with concrete recycling*

Although recycling concrete brings benefits to the industry and the environment, there are a number of difficulties during its implementation. There are inadequate regulations which specify and control the use of recyclable materials [37]. Without uniform enforcement of specific codes, specifications, standards and guidelines for use of virgin and reused aggregate in making cement, contractors will not invest in the equipment that is needed to increase the use of recycled materials [37,38]. Another major barrier in concrete recycling is the lack of experience in using new materials and construction methods to ensure safety on site.

Apart from the management aspects, there are a number of technical problems in implementing concrete recycling such as weaknesses in demolished concrete waste. In concrete, the interfacial zone between cement paste and aggregate plays a critical role in determining its mechanical performance and thus its strength. A weak transition zone exhibits a different mineralogy and microstructure between virgin aggregate and aggregate prepared from concrete waste [20,22,39–43]; this influences the ultimate behavior of the new concrete. In addition, aggregate is more porous and thus less resistant to mechanical actions in comparison with virgin aggregate [44–46]. It should be remembered that the major problem arises from the fact that the quality of recycled aggregate is lower than virgin aggregate [27]. This is the reason why concrete users have not used recycled aggregate and they fear that virgin aggregate might be mixed with recycled aggregate to make lower-quality natural concrete. Furthermore, the quality of demolished concrete varies from site to site and the quantity from each site is normally small. These facts widen the variations in the quality of recycled materials from centralized recycling plants [37].

Based on previous work [14,22,31–37,47–50], four main categories of difficulties are highlighted: i) high cost investment; ii) limited management skills; iii) lack of experience with usage of recycled products; and iv) lack of support. Under these four categories, twenty one difficulties were highlighted and used in the

Table 9
Requirements of recycled aggregate and suggested concrete applications for classes H, L and M in Japan [28,29].

Class of recycled aggregate	Requirements of recycled aggregate	Suggested concrete applications
Class H	Recycled aggregate which performs advanced processing of a separation, grinding down by friction and classification from the concrete mass generated by demolition of the structures.	It can be used in the main structure part of a concrete structure object on a par with natural river gravel and sand, and the macadam and crushed sand.
Class L	Recycled aggregate which crushed and manufactured concrete waste which arises when a concrete structure object is mainly demolished by the machines for beating and crushing and which has not performed advanced wastewater treatment.	It can be used on concrete without applying energy and costs. Three types of concrete are suggested: a stock item, a salt regulation article, and a technical specification order article.
Class M	Recycled aggregate which is processed by demolition, grinding down by friction and classification.	It can be used for components which cannot be easily influenced by drying shrinkage or freezing and thawing such as a stake, withstanding-pressure version, a footing beam and steel-tubing in filled concrete.

Table 10
Distribution of respondents.

Group	Description	Frequency			Percentage		
		Australia	Japan	Total	Australia	Japan	Total
G1	Contractor	37	60	102	68.5	75.0	76.0
G2	Consultant	7	6	13	13.0	7.5	9.6
G3	Recycling company	6	8	14	11.1	10.0	10.2
G4	Governmental department and developer	4	6	10	7.4	7.5	4.2
Total		54	80	134	100.0	100.0	100.0

questionnaires. Details of the twenty-one difficulties and their *F*-statistics results in implementing concrete recycling are shown in Table 14a and b.

There are a number of significant difficulties in the *F*-statistics shown in Table 14a and b. In the category of high cost investment, "Difficult to place recycling machines on-site" is significant among various groups and there are also differences between Australia and Japan. The mean score of 3.39 for Australia is lower than Japan of about 3.80. It should be clear that the population to land ratio in Japan is higher than Australia. In addition, the Japanese construction sites are smaller than those in Australia. One of the interviewed Japanese contractors argued that it is very hard for them to implement waste management and to sort different types of waste on-site. They explained that they can only implement waste management at the later stages of the project, which have been cleared for use of the demolition wastes. In comparing among different groups in the survey, the mean score for consultants (G2) is lower than for other groups. In discussions, a consultant explained that the industry found it difficult to implement waste management processes and to locate recycling machines on site. Therefore, construction organizations normally transfer their waste to recycling companies, which can reduce their burden on the congested site and can increase the construction and demolition activities. However, the interviewed consultant argued that a good management practice with a clear procedure on waste management can significantly reduce waste and reduce the construction period. Construction organization's personnel should be encouraged to attend training programs provided by consultation companies, which can also provide practical examples of ways to effectively implement waste management on site.

In the category of management skill, "Difficult to form concrete recycling team and to prepare scopes, goals, objectives and overall concrete recycling plants", "Increase in management cost" and "Time consuming" are significant in the *F*-statistics between Australia and Japan. In the interviews, a Japanese contractor explained that the construction material recycling law regulates the use of specified construction materials including concrete for projects; this can force the construction organizations to implement a comprehensive waste management procedure to reduce waste and to recycle construction and demolition materials. Therefore, most Japanese construction organizations already have an in-house waste management team and a concrete recycling team to plan and to implement waste management for projects, which reduce their "Difficult to form concrete recycling team and to prepare scopes, goals, objective and overall concrete recycling plans". Although the Japanese construction industry gains experience in implementing waste management for projects, implementing concrete waste recycling on site can still lengthen project duration particular on congested site conditions. An interviewed main contractor argued that construction duration and contract sum can increase up to 100 percent more if they sort different types of material on-site and recycle it. Therefore, the Japanese construction industry found difficulties in "Time consuming" and "Increase in management cost" in implementing concrete recycling.

"Lack of staff participation in concrete recycling" is found to be significant in the *F*-statistics among various groups. The mean score of recycling companies (G3) is lower than the other groups. As explained earlier, recyclers do not usually belong to project parties. Therefore, they are not involved in the recycling process of projects. It is highly encouraged that recyclers should be a project member, which can provide more practical experience in recycling different types of construction and demolition waste on site, and they can actively help to reduce the burden at congested sites.

In the category of lack of experience on recycled products, "The prices of recycled products are costly", "Poor quality of recyclable products", "Limited applications in using recycled concrete products" and "Unbalance of supply and demand for recycled products" are significant in the *F*-statistics among various groups. The mean values of recycling companies (G3) are higher for the first three difficulties and lower for the last difficulty than the other groups. In the interview discussions, a recycler argued that most recycling companies provide a competitive price for recycled materials with natural resources and try to use various methods to improve the quality of recycled materials to widen their applications. The interviewed recycler explained that one of the main reasons for limited use of recycled materials in the industry is the lack of experience. In fact it is not guaranteed that the use of recycled materials can provide the same or similar quality and performance as virgin resources. Therefore, on the one hand, recyclers keep producing recycled materials from the huge generation of construction and demolition waste, on the other hand, the industry lacks the experience in using the recycled materials which forms a very serious problem in balancing between supply and demand of recycled products.

In the category of lack of support, "Not enough concrete recycling companies," there are significant differences in the *F*-statistics between Australia and Japan. The mean score for Japan is 2.74 is lower than that from Australia where was found to be 3.33. An interviewed Japanese recycler explained that there are sufficient concrete recycling companies. Most of the recycling companies are

Table 11
Survey results on awareness in concrete recycling.

Awareness in concrete recycling	Result (in %)					
	Australia		Japan		Total	
	Yes	No	Yes	No	Yes	No
Company has any used concrete recycling policies, objectives and procedures	48	52	68	32	60	40
Company implemented concrete recycling methods to achieve the stated policy	63	37	81	19	74	26
Company has division(s)/department(s) for implementing concrete recycling	52	48	61	39	57	43
Company concerns on the importance of concrete recycling	80	20	72	28	75	25
Employee participates in training or program(s) in concrete recycling	41	59	64	36	54	46
Company is planning to invest more resources in the implementation of concrete recycling	44	56	35	65	39	61
Concrete has been handling as recyclable material in projects	70	30	80	20	76	24
Natural concrete materials may be insufficient in the coming future	65	35	75	25	71	29

Table 12
F-statistics on the survey of benefits gained in concrete recycling.

Benefit	Overall average value	Standard deviation	Difference between Australia and Japan				Difference between G1–G4					
			Mean value		*F* value	Significant *p*	Mean values				*F* value	Significant *p*
			Australia	Japan			G1	G2	G3	G4		
Reducing the need for new landfills	3.65	0.95	3.74	3.60	0.71	0.403	3.53	3.85	4.07	4.10	2.48	0.064
Saving natural materials	3.85	0.91	3.76	3.91	0.91	0.343	3.86	3.85	3.50	4.30	1.51	0.214
Reducing project costs by using recycled materials	2.90	1.04	3.06	2.79	2.15	0.145	2.75	2.92	3.07	4.00	4.88	0.003
Saving the cost in transportation between sites to recycling plants when recycling machines are located on-site	3.13	1.01	3.15	3.11	0.04	0.842	3.10	2.92	3.29	3.40	0.55	0.648
Stimulating continuous improvement in concrete recycling	2.94	0.92	2.81	3.03	1.71	0.194	2.91	3.15	2.71	3.30	1.08	0.361
Rising concrete recycling awareness, such as selecting suitable resources, techniques and training and compliance with regulations	3.44	1.02	3.31	3.53	1.39	0.241	3.48	2.92	3.50	3.60	1.29	0.279
Increasing overall business competitiveness and strategic business opportunities	2.98	1.09	2.93	3.01	0.20	0.655	2.91	2.85	3.43	3.20	1.13	0.339
Improving management and employee's communication on concrete recycling information and commitment	3.05	0.95	2.81	3.20	5.49	0.021	2.83	3.00	3.79	3.20	3.64	0.015

privately run; this shows that the recycling industry is profitable in Japan, due in part to the construction material recycling law. Although construction organizations are required to recycle waste and to use recycled products, most contractors lack experience in recycling waste and lack space on site to store recyclable materials.

Table 15 shows the difficulties ranked by the relative important index for Australia and Japan.

"Limited applications in using recycled concrete products" and "Difficult to form concrete recycling team and to prepare scopes, goals, objectives and overall concrete recycling plans" are considered as the major difficulties, ranked the 1st and the 3rd respectively in implementing concrete recycling in Australia with RII's of about 0.744 and 0.712 respectively, and only ranked as the 6th and the 19th respectively in Japan with RII's of about 0.672 and 0.588 respectively. In an interview with an Australian construction organization leader, he explained that the use of recycled concrete is limited to low-grade applications. Although Australian technical specifications have also focused on the use of recycled material for road work; many local councils are not allowed to use recycled aggregate for concrete applications. Therefore, the most common way to use recycled aggregate is drainage filling in Australia. An interviewed Australian contractor explained that they can only use recycled aggregate for a concrete application, which is not controlled by specification, such as for drainage. It should be noted that there are no clear specifications on recycled concrete and its use as new concrete from the Australian government and local councils. In contrast, Japan is now a leading country in using recycled aggregate for concrete applications, due in part to the fact that technical specifications have enacted for recycled concrete for low-grade and high-grade applications depending on the quality of aggregate and are based upon clearly defined standards. Furthermore, the construction material recycling law helps the industry to gain experience by participating in using recycled materials in concrete in diverse projects. Therefore, the Japanese industry did not rank "Limited applications of using recycled concrete products" and "Difficult to form concrete recycling team and to prepare scopes, goals, objectives and overall concrete recycling plans" as major difficulties in implementing concrete recycling.

"The charge of sending concrete waste to recycling companies is high" and "Difficult to place recycling machines on-site" are ranked as the major difficulties in implementing concrete recycling with RII's of about 0.802 and 0.760 in Japan and ranked as the 13th and 8th in Australia. As explained earlier, the construction material recycling law regulates the use of specified construction materials for construction projects and also controlled the material recycling rate for demolition projects. However, based on the congested site conditions in Japan, construction organizations found "Difficult to place recycling machines on-site". If organizations wish to place recycling machines on-site, it is necessary to obtain permission for intermediate treatment from the Japanese government for every project. Management time and cost used in obtaining such permits increases significantly, which increases their burden on the use of the on-site recycling machines. Thus, organizations commonly send materials to recycling companies. However, "The charge of sending concrete waste to recycling companies is high" which is one of the major difficulties in implementing concrete recycling. It should be noted that the charges for sending materials to recycling companies are higher than sending them to landfills.

"Poor quality of recyclable products" is found as one of the major difficulties in implementing concrete recycling in Australia,

Table 13
Relative important index on the survey of benefits gained in concrete recycling.

Benefit	Australia		Japan		Combined	
	RII	Ranking	RII	Ranking	RII	Ranking
Reducing the need for new landfills	0.748	1	0.720	2	0.521	2
Saving natural materials	0.752	2	0.782	1	0.550	1
Reducing project costs by using recycled materials	0.612	5	0.558	8	0.414	8
Saving the cost in transportation between sites to recycling plants when recycling machines are located on-site	0.630	4	0.622	5	0.447	4
Stimulating continuous improvement in concrete recycling	0.562	7	0.606	6	0.420	7
Rising concrete recycling awareness, such as selecting suitable resources, techniques and training and compliance with regulations	0.662	3	0.706	3	0.491	3
Increasing overall business competitiveness and strategic business opportunities	0.586	6	0.602	7	0.426	6
Improving management and employee's communication on concrete recycling information and commitment	0.562	7	0.640	4	0.436	5

Table 14a
F-statistics on the survey of difficulties encountered in concrete recycling.

Difficulties	Overall average value	Standard deviation	Difference between Australia and Japan				Difference between G1–G4					
			Mean value		*F* value	Significant *p*	Mean values				*F* value	Significant *p*
			Australia	Japan			G1	G2	G3	G4		
High cost investment												
The industrial waste sorting procedure is costly	3.04	1.07	3.06	3.03	0.03	0.872	3.00	3.62	2.57	3.30	2.46	0.066
Transportation from site to recycling plant is costly	3.28	0.97	3.31	3.26	0.09	0.761	3.22	3.46	3.71	3.10	1.35	0.261
Difficult to place recycling machines on-site	3.63	0.13	3.39	3.80	4.40	0.038	3.77	2.85	3.43	3.60	2.88	0.038
The charge of sending concrete waste to recycling company is high	3.66	3.65	3.15	4.01	1.82	0.180	3.85	3.15	3.21	3.20	0.28	0.837
Management skill												
Difficult to form concrete recycling team and to prepare scopes, goals, objectives and overall concrete recycling plans	3.19	1.04	3.56	2.94	12.31	0.001	3.23	3.00	3.00	3.30	0.371	0.774
Increase in management cost	3.06	1.09	2.67	3.33	12.85	0.000	2.97	3.46	3.29	3.10	1.02	0.385
Time consuming	2.88	1.00	2.63	3.05	5.86	0.017	2.96	2.54	2.64	2.90	0.96	0.413
Increase in documentation workload, such as working documents, procedures and tools	3.07	1.01	2.91	3.19	2.52	0.115	3.07	3.38	2.79	3.10	0.79	0.501
Change of existing practice of company structure and policy	2.87	0.90	2.80	2.91	0.65	0.421	2.86	2.62	3.07	3.10	0.79	0.499
Lack of staff participation in concrete recycling	3.16	1.00	3.26	3.09	0.95	0.333	3.20	3.00	2.57	3.80	3.28	0.023

which is ranked the 5th in the survey; however in Japan, it is only ranked the 13th. Japan developed various concrete recycling technologies as stated in Section 5 to improve the quality of recycled aggregate to make it as competitive as virgin aggregate. The Japanese standards allow recycled aggregate to be used for structural applications, which evidence a significant improvement in its concrete recycling industry, and have resulted in it taking a leading position in concrete recycling technology. It should be noted that quality improvement for recycled materials has made remarkable progress in recent years.

The survey results show that "Unbalance of supply and demand of recycled products" is ranked the 6th as one of the major difficulties in implementing concrete recycling in Japan, and ranked the 15th in Australia. It should be considered that concrete waste is a reusable and recyclable material for road work and pavement and even structural elements. However, the demand and supply of concrete products is unstable in Japan. An interviewed recycler encouraged the government should require recyclers to be project members so that they can provide a more constant supply of high quality recyclable materials and receive demolished concrete waste on site.

8.4. Recommendation for the implementation of concrete recycling

Although there are many construction projects using recycled concrete, they are limited to low-grade applications [20,51–53]. Recycled concrete cannot achieve designed requirements as normal concrete. Properties of concrete with recycled aggregate at high porosity, less density and high absorption, tend to be worse in strength and in resistance to freezing and thawing than those with ordinary aggregates. Some recommendations are proposed to encourage the adoption of recycled aggregate [14,22,23,27,37,48,54,55]: i) price of recycled materials should be competitive with natural materials so to encourage the use of recycled concrete in replacing gravel in concrete; ii) recommendations and specifications for concrete recycling should be provided for promoting its use. A detailed requirement should be

Table 14b
F-statistics on the survey of difficulties encountered in concrete recycling.

Difficulties	Overall average value	Standard deviation	Difference between Australia and Japan				Difference between G1–G4					
			Mean value		*F* value	Significant *p*	Mean values				*F* value	Significant *p*
			Australia	Japan			G1	G2	G3	G4		
Lack of experiences on recycled product												
The prices of recycled products are costly	3.70	1.06	3.70	3.70	0.00	0.984	3.92	3.54	2.50	3.50	8.87	0.000
Poor quality of recyclable product	3.34	1.09	3.52	3.21	2.57	0.111	3.45	3.38	2.57	3.20	2.85	0.040
Limited applications in using recycled concrete products	3.51	1.07	3.72	3.36	3.74	0.055	3.53	3.92	2.79	3.80	3.20	0.025
Unbalance of supply and demand on recycled products	3.26	1.03	3.11	3.36	1.92	0.168	3.15	3.08	3.93	3.60	2.91	0.037
Insufficient research investment on concrete recycling products	3.43	0.92	3.44	3.43	0.01	0.905	3.39	3.46	3.64	3.50	0.32	0.808
Lack of support												
Lack of technologies support, such as resources, training, competent staff and expertise	3.10	1.10	3.07	3.13	0.07	0.794	3.13	3.00	2.71	3.50	1.09	0.358
Lack of clients' support	3.42	1.09	3.56	3.33	1.46	0.229	3.42	3.77	3.07	3.40	0.93	0.428
Lack of government financial support	3.27	0.99	3.13	3.36	1.77	0.186	3.28	3.31	3.00	3.50	0.52	0.668
Not enough concrete recycling companies	2.98	1.13	3.33	2.74	9.47	0.003	3.04	2.85	2.36	3.40	2.07	0.107
Different attitude between construction industry and the government on concrete recycling	3.01	1.04	3.20	3.26	0.01	0.905	3.03	2.77	3.07	3.10	2.14	0.099
Lack of certain regulatory requirements and restrictions	3.48	0.96	3.48	3.48	0.00	0.969	3.60	3.62	2.86	3.00	0.28	0.839

Table 15
Relative important index on the survey of difficulties in concrete recycling.

Difficulties	Australia		Japan		Combined	
	RII	Ranking	RII	Ranking	RII	Ranking
High cost investment						
The industrial waste sorting procedure is costly	0.612	17	0.606	18	0.608	17
Transportation is costly from site to recycling plant	0.662	10	0.652	11	0.656	9
Difficult to place recycling machines on-site	0.678	8	0.760	2	0.726	3
The charge of sending concrete waste to recycling company is high	0.630	13	0.802	1	0.732	2
Management skill						
Difficulty for forming concrete recycling team and preparing the scopes, goals, objectives and overall concrete recycling plans	0.712	3	0.588	19	0.638	12
Increase in management cost	0.534	20	0.666	9	0.612	16
Time consuming for the concrete recycling in the project term	0.526	21	0.610	17	0.576	20
Increase in documentation workload, such as working documents, procedures and tools	0.582	18	0.638	14	0.614	15
Change of existing practice of company structure and policy	0.560	19	0.582	20	0.574	21
Lack of staff participation in concrete recycling	0.652	11	0.618	16	0.632	13
Lack of experience on recycled product						
The prices of recycled products are costly	0.740	2	0.740	3	0.740	1
Recycled product is poor quality	0.704	5	0.642	13	0.668	8
Limited applications of using recycled concrete products such as pavement	0.744	1	0.672	6	0.702	4
Unbalance of supply and demand of recycled products	0.622	15	0.672	6	0.652	11
Insufficient research investment for concrete recycling products	0.688	7	0.686	5	0.686	6
Lack of support						
Lack of technologies support, such as resources, training, competent staff and expertise	0.614	16	0.626	15	0.620	14
Lack of clients' support	0.712	3	0.666	9	0.684	7
Lack of government financial support	0.626	14	0.672	6	0.654	10
The number of concrete recycling companies is not enough	0.666	9	0.548	21	0.596	19
Different attitude in between construction industry and the government about concrete recycling	0.640	12	0.652	11	0.602	18
Lack of certain regulatory requirements and restrictions	0.696	6	0.696	4	0.696	5

provided; iii) since the variety of supply sources cause variations of quality, stricter quality control of concrete recycling is required. An authorized party should be responsible for controlling the quality before adopting these materials; iv) other than setting up recycling plants and quality specifications or standards, an information network should be the link between them. An information network needs to be built up to disseminate the experiences in the concrete recycling; v) methods should be adopted to standardise different types of recycled aggregate, all over the world. A standard classification system should be developed and used; and vi) limited applications of recycled concrete are attributable to their poor qualities. To solve the problems of concrete recycling, some techniques need to be developed to improve the quality of recycled concrete, such as to minimize the cement portions adhering to recycled aggregate or to separate aggregate from cement paste as much as possible to attain quality comparable to original aggregate. Based on the findings from previous researchers [14,15,20–22,27,37,48,50–53,55–58], the following nine tools for encouraging the implementation of concrete recycling have been identified, which form part of the questions in the questionnaire:

- defining clear legal evaluation of concrete recycling;
- defining more details on classification about recycled products such as recycled aggregate;
- inclusion of concrete recycling management evaluation in tender appraisal;
- continuous efforts in improving concrete recycling management in your organization;
- providing in-house training on concrete recycling;
- effective communications on concrete recycling issues among all parties;
- exhaustive control of concrete waste volume generated on site from the government;
- government financial support for companies; and
- high landfill charge for disposing waste.

The *F*-statistics results of the survey are shown in Table 16.

From Table 16, it shows that "Defining clear legal evaluation of concrete recycling", "Providing in-house training about concrete recycling" and "Exhaustive control of concrete waste volume generated on site by government" are significant in the *F*-statistics between Australia and Japan. In addition, "Providing in-house training about concrete recycling", "Effective communication on concrete recycling issue between all parties" and "Exhaustive control of concrete waste volume generated on site by government" are significant in the *F*-statistics among various groups.

The mean score for Japan of about 3.44 of "Defining clear legal evaluation of concrete recycling" is higher than that for Australia of about 3.09 in encouraging the implementation of concrete recycling. In the interview discussions, a Japanese government employee highlighted that implementing mandatory regulations are more effective than voluntary approaches, particular in implementing high initial cost investment activities and requiring detailed planned procedures such as concrete recycling. He argued that the recycling rate of concrete increased significantly after the enactment of the construction material recycling law, from about 65 percent in 1995 to about 96 percent in 2000 [8]. It should be noted that mandatory regulations can provide an initial push to the industry to implement concrete recycling and can result in benefits to the environment.

The mean score for Australia of about 3.13 in "Providing in-house training about concrete recycling" is higher than Japan of about 2.79 in the survey. In the interview discussions, an Australian main contractor argued that they lack experience in recycling concrete for projects. It should be noted that concrete recycling is a new issue in Australia, which starts implementation since 2002. The industry does not have enough experience to predict the results of using recyclable materials. Therefore, Australian responses found "Providing in-house training about concrete recycling" as an effective measure in encouraging the implementation of concrete recycling. In addition, the mean score of governmental department (G4) of about 3.90 of "Providing in-house training about concrete recycling" is higher than

Table 16
F-statistics on the survey of recommended methods in concrete recycling.

Recommended methods	Overall average value	Standard deviation	Difference between Australia and Japan				Difference between G1–G4					
			Mean value		*F* value	Significant *p*	Mean values				*F* value	Significant *p*
			Australia	Japan			G1	G2	G3	G4		
Defining clear legal evaluation of concrete recycling	3.30	0.98	3.09	3.44	4.08	0.046	3.24	3.23	3.29	4.00	1.89	0.135
Defining more details on classification about recycled products such as recycled aggregate	3.72	0.84	3.59	3.81	2.21	0.140	3.64	3.77	4.07	4.00	1.50	0.217
Inclusion of concrete recycling management evaluation in tender appraisal	2.81	0.99	2.76	2.85	0.27	0.607	2.78	2.54	2.71	3.60	2.57	0.057
Continuous efforts in improving concrete recycling management in your organization	3.17	1.02	3.20	3.15	0.09	0.767	3.12	3.38	3.21	3.30	0.32	0.815
Providing in-house training on concrete recycling	2.93	0.95	3.13	2.79	4.31	0.040	2.87	2.85	2.71	3.90	4.20	0.007
Effective communications on concrete recycling issues among all parties	3.23	0.96	3.17	3.28	0.41	0.522	3.11	3.15	3.64	3.90	3.16	0.027
Exhaustive control of concrete waste volume generated on site from the government	3.40	0.99	2.91	3.74	26.65	0.000	3.44	3.77	3.43	2.50	3.58	0.016
Government financial support for companies	3.49	1.04	3.69	3.36	3.16	0.078	3.56	3.54	3.36	3.00	0.96	0.414
High landfill charge for disposing waste	2.72	0.99	2.70	2.74	0.04	0.847	2.74	2.69	2.71	2.60	0.07	0.978

that of the other groups. An interviewed governmental department staff highlighted that one of the best ways to gain experience in a new issue is by education. To gain the most benefits by education, it is highly encouraged to have a senior technical staff to attend training sessions provided by some environmental consultant and the senior staff then used the experience to provide an in-house, tailor made training program to other staff members for improving the whole recycling process.

Governmental departments (G4) provide a higher mean value of about 3.90 in "Effective communications on concrete recycling issue between all parties" than the other groups in the survey. In the interviews, a developer argued that a clear, procedure in waste minimization before project start can only be achieved with effective communication among all relevant parties. It should be noted that clear responsibility for each project party in defining their role in concrete recycling is important for helping to increase concrete recycling.

The mean score for Australia in "Exhaustive control of concrete waste volume generated on site by government" is lower than that in Japan in the survey and also the mean score for governmental departments and developers (G4) is also lower than that for the other groups. In the interview discussions, a Japanese construction organization highlighted that an initial push from the government to regulate the use of recyclable materials is necessary to improve the recycling rate of construction and demolition materials. This construction organization leader argued that most of the construction and demolition contractors would not implement recycling activities on-site if the Japanese government did not enact the construction material recycling law in 2000. One of the main difficulties for contractors is the high initial investment cost and the lack of experience in recycling activities. However, an interviewed developer argued that voluntary approaches in implementing concrete recycling should be the long-term focus after the initial governmental regulatory push. It should be noted that the long-term results gained from voluntary approaches are better than mandatory approaches, in which the industry will not only focus on the minimum requirements.

Using the relative index, Table 17 ranks the priority of these measures for Australia and Japan.

"Government financial support for companies" is considered as the major recommended method to encourage the implementation of concrete recycling for Australia; however, Japan only ranked it as the 4th in the survey. An interviewed Australian contractor explained that the initial implementation of recycling activities requires a high investment cost, including building an in-house recycling team, attending training programs to gain experience and installing environmentally friendly facilities and equipment. This can reduce their burden and can increase the overall environmental performance in the construction industry but the initial costs can be too high for many companies.

In the recommended method of "Exhaustive control of concrete waste volume generated on site by government", respondents from Japan ranked it as the 2nd, in which those from Australia only ranked it as the 7th in the survey. As explained earlier, the initial control of recycling activities should be managed by the government to improve awareness in the industry.

9. Recommendations to the Australian construction industry – lessons learned from japan

After collecting information from the questionnaire survey in the implementation of concrete recycling in the Australian and

Table 17
Relative important index on the survey of recommended methods in concrete recycling.

Recommended methods	Australia		Japan		The combined	
	RII	Ranking	RII	Ranking	RII	Ranking
Defining clear legal evaluation of concrete recycling	0.618	6	0.688	3	0.471	4
Defining more details on classification about recycled products such as recycled aggregate	0.718	2	0.762	1	0.531	1
Inclusion of concrete recycling management evaluation in tender appraisal	0.552	8	0.570	7	0.401	8
Continuous efforts in improving concrete recycling management in your organization	0.640	3	0.630	6	0.453	6
Providing in-house training on concrete recycling	0.626	5	0.558	8	0.419	7
Effective communications on concrete recycling issues among all parties	0.634	4	0.656	5	0.461	5
Exhaustive control of concrete waste volume generated on site from the government	0.582	7	0.748	2	0.486	3
Government financial support for companies	0.738	1	0.672	4	0.499	2
High landfill charge for disposing waste	0.540	9	0.548	9	0.389	9

Japanese construction industries, it should be noted that the Australian concrete recycling practice is running behind Japan. Japan acts as a leading country in concrete recycling around the world. To improve concrete recycling in Australia, the following recommendations are suggested:

a) Although some states in Australia have been implementing concrete recycling very well, the overall recycling rate in Australia is still not high. The main reason is unstandardized policies and classification systems for concrete waste. Unified policies in concrete recycling in Australia are needed.
b) Financial support from the government is required to reduce the initial high investment costs for using managing and using waste concrete materials.
c) In Australia, there are current technical specifications for recycled aggregate which is mainly employed as sub-base materials and road construction. However, because of the large generation of concrete waste, there is an urgent need to establish technical and performance standards to use recycled aggregate for structural applications.

10. Conclusions

The large generation of concrete waste causes a serious problem to the environment. Many countries are presently directing efforts towards measures to promote waste minimization and waste reuse. However, the situation surrounding concrete recycling in each country varies tremendously. This paper compared the cement waste recycling practices in Australia and Japan. From the questionnaire survey results, it is clear that awareness about concrete recycling is quite high in the Australian and Japanese construction industries. In implementation of concrete recycling, "Reducing the need for new landfills" and "Saving use of natural materials" are considered as the major benefits in Australia and Japan. However, "The prices of recycled products are costly" and "Limited applications for using recycled concrete products" were found to be the major difficulties encountered in practice. To encourage the use of recycled materials, "Defining more details on classification of recycled products such as recycled aggregate" was suggested. From the experience gained from Japan, the Australian construction industry should be: i) develop a unified policy in concrete recycling; ii) provide financial support from government; and iii) develop a clear technical specification or standard on the use of recycled aggregate for structural applications.

Acknowledgement

The author would like to thank Mr. Kazunobu Takagi for his help in conducting the survey.

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