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

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A B S T R A C T

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 decoration 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 [3,4,63]. 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
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 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 3 Recycled solid waste in Australia [7].

<table>
<thead>
<tr>
<th>State/Territory</th>
<th>Recycled waste (tons)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Municipal</td>
<td>Commercial and industrial</td>
<td>Construction and demolition</td>
</tr>
<tr>
<td>New South Wales</td>
<td>1,156,000</td>
<td>1,365,000</td>
<td>3,309,000</td>
</tr>
<tr>
<td>Victoria</td>
<td>744,000</td>
<td>1,740,000</td>
<td>1,945,000</td>
</tr>
<tr>
<td>Queensland</td>
<td>445,000</td>
<td>212,000</td>
<td>488,000</td>
</tr>
<tr>
<td>Western Australia</td>
<td>92,000</td>
<td>324,000</td>
<td>410,000</td>
</tr>
<tr>
<td>South Australia</td>
<td>235,000</td>
<td>460,000</td>
<td>1,452,000</td>
</tr>
<tr>
<td>Australian Capital</td>
<td>29,000</td>
<td>52,000</td>
<td>223,000</td>
</tr>
<tr>
<td>Total</td>
<td>2,701,000</td>
<td>4,162,000</td>
<td>7,827,000</td>
</tr>
</tbody>
</table>

Fig. 1. Recycling and disposal rate of construction and demolition materials in Australia [7].
than 80 m²; ii) construction or enlargement work with a total floor area larger than 500 m²; 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$50,000). 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.

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 I” (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]:

\[ RII = \sum \frac{w_i}{AN} \]  

(1)

![Fig. 2. Construction waste recycling rate in Japan [8].](image-url)
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 \( \text{RII} \) 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

<table>
<thead>
<tr>
<th>State/Territory</th>
<th>Legislation</th>
<th>Waste minimization strategies and targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commonwealth</td>
<td>Natural Heritage Trust of Australia Act 1997</td>
<td>The National Waste Minimization and Recycling Strategy (NWMSRS)</td>
</tr>
<tr>
<td></td>
<td>Environmental Protection and Biodiversity Conservation Act 1999</td>
<td></td>
</tr>
<tr>
<td>Australian Capital</td>
<td>Environment Protection Act 1997</td>
<td>No Waste By 2010</td>
</tr>
<tr>
<td>Territory</td>
<td>Waste Minimization Act 2001</td>
<td>Waste Pricing Strategy for the ACT</td>
</tr>
<tr>
<td></td>
<td>Litter Act 2004</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waste Avoidance and Resource Recovery Act 2001</td>
<td></td>
</tr>
<tr>
<td>Queensland</td>
<td>Environmental Protection Act 1994</td>
<td>Waste Reduction and Purchasing Policy</td>
</tr>
<tr>
<td>South Australia</td>
<td>Environmental Protection Act 1993</td>
<td>Used Packaging Materials Industry</td>
</tr>
<tr>
<td></td>
<td>Environmental Protection and Pollution Control Act 1994</td>
<td>Litter Abatement and Resource Recovery Strategy 2003</td>
</tr>
<tr>
<td></td>
<td>Environmental Protection Act 1970</td>
<td></td>
</tr>
<tr>
<td>Western Australia</td>
<td>Environment Protection Act 1986</td>
<td>No Waste By 2010</td>
</tr>
</tbody>
</table>

Note: Violation of registration is penalized.

Note: Violation of order is penalized.

Fig. 3. System of 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.
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.

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],
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>
<thead>
<tr>
<th>Table 8</th>
<th>Types of recycled aggregate concrete and suggested uses in civil and building work [27].</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Civil works applications</strong></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Coarse aggregate</td>
</tr>
<tr>
<td>CI</td>
<td>Recycled coarse aggregate type C1</td>
</tr>
<tr>
<td>CII</td>
<td>Recycled coarse aggregate type C2</td>
</tr>
<tr>
<td>CIII</td>
<td>Recycled coarse aggregate type C3</td>
</tr>
<tr>
<td><strong>Building works applications</strong></td>
<td></td>
</tr>
<tr>
<td>BI</td>
<td>Recycled coarse aggregate type C1</td>
</tr>
<tr>
<td>BII</td>
<td>Recycled coarse aggregate type C2</td>
</tr>
<tr>
<td>BIII</td>
<td>Recycled coarse aggregate type C2</td>
</tr>
<tr>
<td>BIV</td>
<td>Recycled coarse aggregate type C3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 9</th>
<th>Requirements of recycled aggregate and suggested concrete applications for classes H, L and M in Japan [28,29].</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class of recycled aggregate</td>
<td>Requirements of recycled aggregate</td>
</tr>
<tr>
<td>Class H</td>
<td>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.</td>
</tr>
<tr>
<td>Class L</td>
<td>Recycled aggregate which crushed and manufactured concrete waste which arises when a concrete structure object is mainly demolished by the machines for heating and crushing and which has not performed advanced wastewater treatment.</td>
</tr>
<tr>
<td>Class M</td>
<td>Recycled aggregate which is processed by demolition, grinding down by friction and classification.</td>
</tr>
</tbody>
</table>
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 plans”, “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>
<thead>
<tr>
<th>Group Description</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 Contractor</td>
<td>37 60 102</td>
<td>68.5 75.0 76.0</td>
</tr>
<tr>
<td>G2 Consultant</td>
<td>7 6 13</td>
<td>13.0 7.5 9.6</td>
</tr>
<tr>
<td>G3 Recycling company</td>
<td>6 8 14</td>
<td>11.1 10.0 10.2</td>
</tr>
<tr>
<td>G4 Governmental department and developer</td>
<td>4 6 10</td>
<td>7.4 7.5 4.2</td>
</tr>
<tr>
<td>Total</td>
<td>54 80 134</td>
<td>100.0 100.0 100.0</td>
</tr>
</tbody>
</table>

Table 10
Distribution of respondents.

<table>
<thead>
<tr>
<th>Awareness in concrete recycling</th>
<th>Result (in %)</th>
<th>Australia</th>
<th>Japan</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company has any used concrete recycling policies, objectives and procedures</td>
<td>48 52</td>
<td>68 32</td>
<td>60 40</td>
<td></td>
</tr>
<tr>
<td>Company implemented concrete recycling methods to achieve the stated policy</td>
<td>63 37</td>
<td>81 19</td>
<td>74 26</td>
<td></td>
</tr>
<tr>
<td>Company has division(s)/department(s) for implementing concrete recycling</td>
<td>52 48</td>
<td>61 39</td>
<td>57 43</td>
<td></td>
</tr>
<tr>
<td>Company concerns on the importance of concrete recycling</td>
<td>80 20</td>
<td>72 28</td>
<td>75 25</td>
<td></td>
</tr>
<tr>
<td>Employee participates in training or program(s) in concrete recycling</td>
<td>41 59</td>
<td>64 36</td>
<td>54 46</td>
<td></td>
</tr>
<tr>
<td>Company is planning to invest more resources in the implementation of concrete recycling</td>
<td>44 56</td>
<td>35 65</td>
<td>39 61</td>
<td></td>
</tr>
<tr>
<td>Concrete has been handling as recyclable material in projects</td>
<td>70 30</td>
<td>80 20</td>
<td>76 24</td>
<td></td>
</tr>
<tr>
<td>Natural concrete materials may be insufficient in the coming future</td>
<td>65 35</td>
<td>75 25</td>
<td>71 29</td>
<td></td>
</tr>
</tbody>
</table>

Table 11
Survey results on awareness in concrete recycling.
Saving the cost in transportation between sites to recycling plants when recycling machines are located on-site

0.612 5 0.559 4 0.414 3

Saving the cost in transportation between sites to recycling plants when recycling machines are located on-site

0.630 4 0.622 4 0.447 3

Stimulating continuous improvement in concrete recycling

0.562 7 0.706 3 0.491 3

Rising concrete recycling awareness, such as selecting suitable resources, techniques and training and compliance with regulations

0.586 6 0.706 3 0.491 3

Increasing overall business competitiveness and strategic business opportunities

0.586 6 0.602 7 0.420 7

Stimulating continuous improvement in concrete recycling

0.562 7 0.615 3 0.420 7

Rising concrete recycling awareness, such as selecting suitable resources, techniques and training and compliance with regulations

0.586 6 0.615 3 0.420 7

Increasing overall business competitiveness and strategic business opportunities

0.586 6 0.602 7 0.420 7

Improving management and employee’s communication on concrete recycling information and commitment

0.562 7 0.602 7 0.420 7

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

Table 13

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Australia</th>
<th>Japan</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RII</td>
<td>Ranking</td>
<td>RII</td>
</tr>
<tr>
<td>Reducing the need for new landfills</td>
<td>0.748</td>
<td>1</td>
<td>0.729</td>
</tr>
<tr>
<td>Saving natural materials</td>
<td>0.752</td>
<td>2</td>
<td>0.782</td>
</tr>
<tr>
<td>Reducing project costs by using recycled materials</td>
<td>0.612</td>
<td>5</td>
<td>0.559</td>
</tr>
<tr>
<td>Saving the cost in transportation between sites to recycling plants when recycling machines are located on-site</td>
<td>0.630</td>
<td>4</td>
<td>0.622</td>
</tr>
<tr>
<td>Stimulating continuous improvement in concrete recycling</td>
<td>0.562</td>
<td>7</td>
<td>0.606</td>
</tr>
<tr>
<td>Rising concrete recycling awareness, such as selecting suitable resources, techniques and training and compliance with regulations</td>
<td>0.662</td>
<td>3</td>
<td>0.706</td>
</tr>
<tr>
<td>Increasing overall business competitiveness and strategic business opportunities</td>
<td>0.586</td>
<td>6</td>
<td>0.602</td>
</tr>
<tr>
<td>Improving management and employee’s communication on concrete recycling information and commitment</td>
<td>0.562</td>
<td>7</td>
<td>0.640</td>
</tr>
</tbody>
</table>
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 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
The lack of certain regulatory requirements and restrictions is an issue.

- Different attitudes in the construction industry and the government about concrete recycling.
- The number of concrete recycling companies is not enough.
- Lack of government financial support.
- Lack of clients' support.
- Lack of technologies support, such as resources, training, competent staff and expertise.
- Unbalanced supply and demand of recycled products.
- Limited applications of using recycled concrete products such as pavement.
- Recycled product is of poor quality.
- The prices of recycled products are costly.
- Lack of experience on recycled products.
- Lack of staff participation in concrete recycling.
- Change of existing practice of company structure and policy.
- Increase in documentation workload, such as working documents, procedures and tools.
- Increase in management cost.

In addition to the above issues, the unbalanced supply and demand of recycled products is also a significant problem. The prices of recycled products are often higher than those of new products, which makes it difficult for recycling companies to grow.

The survey also highlights the importance of training and education. Providing in-house training about concrete recycling is perceived as an effective measure in encouraging the implementation of concrete recycling. In the interview discussions, an Australian main contractor argued that they lack experience in recycling concrete for projects. 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 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.

For 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 3.13 in “Providing in-house training about concrete recycling” is higher than that for Australia 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...
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>
<thead>
<tr>
<th>Table 16</th>
<th>F-statistics on the survey of recommended methods in concrete recycling.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended methods</td>
<td>Overall average value</td>
</tr>
<tr>
<td></td>
<td>Mean value</td>
</tr>
<tr>
<td>Defining clear legal evaluation of concrete recycling</td>
<td>3.30</td>
</tr>
<tr>
<td>Defining more details on classification about recycled products such as recycled aggregate</td>
<td>3.72</td>
</tr>
<tr>
<td>Inclusion of concrete recycling management evaluation in tender appraisal</td>
<td>2.81</td>
</tr>
<tr>
<td>Continuous efforts in improving concrete recycling management in your organization</td>
<td>3.17</td>
</tr>
<tr>
<td>Providing in-house training on concrete recycling</td>
<td>2.93</td>
</tr>
<tr>
<td>Effective communications on concrete recycling issues among all parties</td>
<td>3.23</td>
</tr>
<tr>
<td>Exhaustive control of concrete waste volume generated on site from the government</td>
<td>3.40</td>
</tr>
<tr>
<td>Government financial support for companies</td>
<td>3.49</td>
</tr>
<tr>
<td>High landfill charge for disposing waste</td>
<td>2.72</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 17</th>
<th>Relative important index on the survey of recommended methods in concrete recycling.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended methods</td>
<td>Australia</td>
</tr>
<tr>
<td></td>
<td>RI</td>
</tr>
<tr>
<td>Defining clear legal evaluation of concrete recycling</td>
<td>0.618</td>
</tr>
<tr>
<td>Defining more details on classification about recycled products such as recycled aggregate</td>
<td>0.718</td>
</tr>
<tr>
<td>Inclusion of concrete recycling management evaluation in tender appraisal</td>
<td>0.552</td>
</tr>
<tr>
<td>Continuous efforts in improving concrete recycling management in your organization</td>
<td>0.640</td>
</tr>
<tr>
<td>Providing in-house training on concrete recycling</td>
<td>0.626</td>
</tr>
<tr>
<td>Effective communications on concrete recycling issues among all parties</td>
<td>0.634</td>
</tr>
<tr>
<td>Exhaustive control of concrete waste volume generated on site from the government</td>
<td>0.582</td>
</tr>
<tr>
<td>Government financial support for companies</td>
<td>0.738</td>
</tr>
<tr>
<td>High landfill charge for disposing waste</td>
<td>0.540</td>
</tr>
</tbody>
</table>
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 reuse 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

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