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Investigation of concrete recycling in the U.S. construction industry

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Abstract

The emerging sustainable development movement in the construction industry requires the recycling of waste materials to reduce the negative environmental impact of construction activities. In many countries, old concrete, a major waste stream generated from the demolition of obsolete buildings/structures, is being recycled. However, for various reasons, progress toward concrete recycling varies from country to country. This paper discusses the current status of concrete recycling in the U.S. construction industry based on results from a two-part questionnaire survey. The first part of the survey collects information on the recycling practices of surveyed concrete companies. The second part adapts questions from a study conducted in Australia and Japan to examine the awareness, benefits, difficulties, and recommended methods related to concrete recycling. The findings showed that although recycling old concrete is common in the U.S., its application is mostly limited to backfill and pavement base; using waste concrete in new concrete production is not widely applied. There are also similarities and differences in the perceptions of concrete recycling between U.S. concrete companies and their counterparts in Australia and Japan.

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Keywords: Waste Concrete; Concrete Recycling; Demolition; United States; Australia; Japan

1. Introduction

The wide use of concrete in construction has raised multiple environmental concerns due to its high usage of raw materials, the high energy consumption of cement manufacturing, transportation, and the creation of large volumes of old concrete from demolition wastes [1]. It was estimated that the concrete industry uses approximately 10 billion

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tons of sand and natural rock worldwide, and simultaneously over 11 billion tons of construction and demolition (C&D) waste are produced annually [2], in which concrete waste accounts for about 50-70% [3,4]. On the other hand, cement manufacturing is very energy-intensive. It was estimated that at least 3.79 million Btus of energy is needed to produce each ton of cement. This level of consumption leads to high greenhouse gas emissions (e.g., accounting for 7% of CO_2 emissions globally) by the cement industry [5].

In recent years, environmental consciousness, protection of natural resources, and sustainable development have become significant factors in modern requirements for the construction industry worldwide [1]. Recycling of old concrete is one of the main approaches to meeting these requirements. However, concrete recycling faces various difficulties such as the inferior quality of recycled aggregates and increased labor cost [1,6]. At present, not much direct assistance is given to practitioners to help them address these challenges, except for a few scattered efforts, e.g., Limbachiya et al. [7]. In general, there lacks comprehensive understanding on the current status of concrete recycling and related barriers, based on which effective coping strategies could be developed.

This study aims to explore the current status of concrete recycling in the U.S. construction industry through a two-part questionnaire survey. The first part of the survey collects information regarding the current practices of concrete recycling in the U.S. The second part adapts questions about the awareness, benefits, difficulties, and recommended methods related to concrete recycling from a similar study performed in Australia and Japan by Tam [8]. This enables an international comparison of the current concrete recycling practices. The similarities and differences in the perceptions of concrete recycling between the U.S. and the other two countries are also discussed.

2. Literature review of concrete recycling

2.1. Benefits to recycling waste concrete

Concrete is the most widely used building material in the world [9]. Consequently, concrete waste is one of the major waste streams in C&D debris. Recycling and reapplying waste concrete has apparent environmental benefits, as well as many other advantages. First, recycling concrete wastes as aggregates reduces the amount of wastes and preserves natural resources [10]. This can reduce the growing pressure on landfill capacity as waste concrete amounts from construction and demolition increase [11]. Second, using recycled concrete aggregate (RCA) reduces greenhouse gas emissions associated with concrete production using virgin aggregates [12]. The use of RCA also carries economic advantages and aids in regulatory compliance. Manufactured RCA has become more economical than virgin aggregate in terms of transportation costs and the increased cost of landfilling C&D debris [13]. In addition, government authorities in Europe, Japan and the U.S. have begun to encourage the usage of RCA either through direct demands or indirectly (e.g., increasing tipping fees for landfilling concrete wastes).

2.2. Progresses in concrete recycling

Old concrete can be recycled into aggregates and used in many civil engineering applications, including road pavement materials, sub-basements, soil stabilization, and production of new concrete [1]. However, progress toward concrete recycling varies in different countries for various reasons. These include the availability of technical specifications, recycling technologies, and the level of government support. Wilburn and Goonan [14] revealed that up to 1998, more than half of cement concrete debris generated in the U.S. ended up in landfills. Of all recycled cement concrete debris, 85% was used as roadbase although RCA was being increasingly used to replace natural aggregate in such road construction applications as concrete mix and top-course asphalt. According to Gilpin et al. [15], the lower transportation cost of processed waste concrete aggregates might have been the incentive that promoted the use of RCA in the U.S. However, most of the waste aggregates were only suitable as backfill or construction base.

2.3. Difficulties encountered in concrete recycling

Cost and energy consumption are two of the key issues in concrete recycling. A case study conducted in Australia compared cost and benefits between 1) dumping waste concrete in a landfill and producing natural materials for new concrete and 2) recycling old concrete as aggregates for new concrete [3]. The latter approach was found to be cost-effective while also protecting the environment and achieving construction sustainability. However, Gull [6] was concerned about the labor cost incurred in the extraction of waste aggregates from demolished buildings and the cost of using admixture to increase the strength of concrete containing waste aggregates. Another concern lies in the quality of products made of RCA since the source of old concrete was usually unknown and the properties of RCA were different compared to virgin aggregates [1,7,13]. In Lauritzen [16], the key concerns about concrete recycling were summarized as economy, policies and strategies, certification of recycled materials, planning of demolition projects, and most importantly, education and information.

3. Research Methodology

This study has three specific objectives: (1) To obtain background information on U.S. concrete recycling practices; (2) To acquire industry's perceptions of current concrete recycling practices in terms of awareness, benefits, difficulties, and potential strategies; and (3) To compare the results of this study with a previous study that investigated concrete recycling in other countries, including the leading country—Japan. A questionnaire was developed for face-to-face interviews and online surveys. Concrete companies in Central Ohio were identified for face-to-face interviews through the 2012 Membership Directory of Builders Exchange of Central Ohio and the 2012 Directory of Ohio Ready Mixed Concrete Association (ORMCA). Participants for online surveys were found from ORMCA and the C&D facility list from the California Department of Resources Recycling and Recovery. Companies were asked to have their most knowledgeable/experienced people take the survey, if possible.

The questionnaire consists of two parts: Part One was designed to collect background information of survey participants. Part Two was adapted from Tam's study [8] that investigated and compared concrete recycling practices in Australian and Japanese. This part of the questionnaire contains four sections: Awareness, Benefits, Difficulties, and Recommended Methods for Concrete Recycling. In the "Awareness" section, multiple-choice questions were used, which featured three options: "Yes," "No," or "Have no idea." Questions in the other three sections were all based on the Likert scale format. Specifically, five options from "1" to "5" were available for each given statement, with "1" denoting "least important" or "strongly disagree," "3" indicating "neutral," and "5" meaning "most important" or "strongly agree." "N/A" (not applicable) was also provided for cases where the survey participants were not sure about a given statement. The responses of "Have no idea" or "N/A" were excluded in the final data analysis. The developed questionnaire was expert reviewed by two representatives: one from the Builders Exchange of Central Ohio and the other from ORMCA. The finalized questionnaire and survey/interview procedures were reviewed and approved by the University Institutional Review Board. The survey was conducted between July and October, 2012. To protect the confidentiality of survey participants and their companies, no identifiable information was recorded.

In this study, eight local concrete companies were interviewed. Of 155 survey invitations sent out through emails, 17 companies responded and completed the online survey, representing a response rate of 11%. The questionnaires collected through face-to-face interviews and online surveys were combined for data analysis. In addition to summarizing background information obtained, statistical methods were adopted to analyze the information collected through Part Two. The results were then compared to the findings from Tam [8]. First, a two-tailed statistical analysis concerning two proportions [17] was used to analyze the awareness questions, for which a paired comparison was made on the percentage of positive answers to each question between this U.S. survey and the earlier surveys in Australia and Japan. The null hypothesis was that no significant difference existed in the given question between the compared groups, based on the 5% level of significance. A p value of less than 0.05 would disprove the null hypothesis and lead to an alternative hypothesis that significant difference existed between the two compared groups, and the group with a higher percentage of positive answers would have a greater awareness for that given question. The two-tailed statistical test concerning the difference between two means [17] was used to analyze the Likert scale questions.

4. Results and discussions

4.1. Background of survey participants

The background information collected included: 1) companies' specific roles in the concrete construction industry, 2) companies' years in business, 3) surveyed individuals' years of experience, 4) company size, 5) construction industry sectors involved, 6) whether a company has received inquiries about concrete recycling, and 7) how a company handles concrete waste in its projects. According to the survey, the participating companies had their experience in the concrete industry ranging from 3 to 83 years, with an average of 22 years. More than half of the companies (57%) had been involved in the concrete recycling business for over 20 years. Individuals who completed the survey had relevant industry experience ranging from 2 to 30 years, with a mean value of 16 years. The total percentage of individuals having more than 10 years of experience was approximately 80%, indicating that the information and feedback provided by them should be relatively accurate and representative. Most companies (62%) taking the survey had less than 50 employees.

Fig. 1a shows the distribution of companies' roles and sectors they served. When responding to these questions, survey participants were allowed to select more than one option that applied. It was found that more than half of the surveyed companies identified themselves as a recycler/hauler. Other roles mentioned were building materials, construction waste management consultant, etc. The survey results also showed that the same percentage (50%) of survey participants served in the building and roadway/bridge sectors. Some other sectors mentioned included recycling, demolishing, sorting procedure in landfills, and aggregates only.

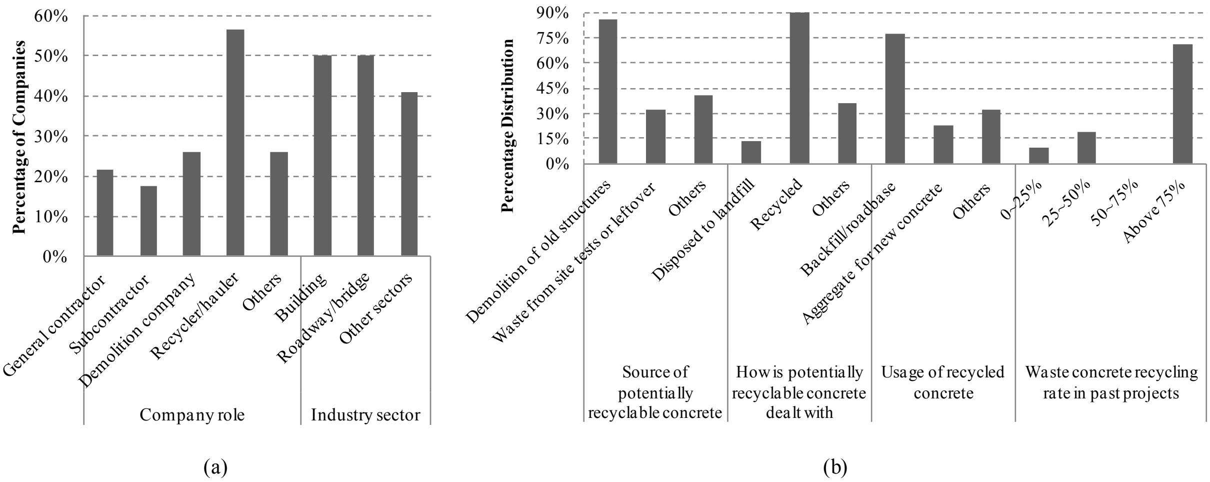

Fig. 1. (a) Company type distribution of survey participants; (b) Past and current practice in concrete recycling of surveyed companies

Survey participants were asked general questions about their current and past practices in concrete recycling. The results are illustrated in Fig. 1b. In terms of the source for potentially recyclable concrete, demolition of old structures was selected by 86% of survey participants, followed by 32% choosing "waste from site tests or leftover from pumping, over-order, and design change." Other waste concrete (mentioned by 40% of respondents) came from infrastructure work, such as concrete roadways, bridges, airports, curbs, sidewalks, barriers, parking lots, and dams. When asked how their companies dealt with waste concrete that could potentially be recycled, 91% of respondents selected "recycled" while only 14% selected "disposed to landfill." Respondents who selected "others" for this question specified that they reused the waste concrete as aggregate in roadbase or for resale. This should also be considered one form of concrete recycling. Therefore, the survey results indicated a high concrete recycling rate among surveyed companies. Noticeably, some respondents chose both recycling and disposing as their ways to handle potentially recyclable concrete, indicating that they only recycled portions of the waste concrete materials and sent the rest to landfill.

Survey participants were asked the typical range of concrete waste that was recycled in their previous projects. The given options were 0-25%, 25-50%, 50-75%, above 75%, or other percentage to be specified. While two and four respondents picked 0-25% and 25-50%, respectively, the majority (71% or 15 out of 21 respondents) selected "above 75%." Of these 15 respondents, four specifically stated that they had 100% waste concrete recycled. The combined recycling rate seems slightly higher than the estimated 50-60% in Wilburn and Goonan [14] and Turley [18]. This could be due to the trend of increased concrete recycling rate in recent years. The survey also found that up to 90% of respondents had received inquiries about concrete recycling, showing the increased awareness among their clients.

When asked what recycled concrete was used for, the majority of respondents (77%) selected "backfill/roadbase." Only 23% selected "aggregate for producing new concrete." Other selected applications included aggregate filling, sub-base, roadway and building pads, base rock, drain rock, sand, etc. One local respondent mentioned the use of RCA for non-structural walls and driveways in residential buildings. Survey participants were also asked to estimate the percentage of each application. The backfill/roadbase usage ranged from 20 to 100% with an average value of 70%. The percentage applied to the production of new concrete varied from 5 to 95%, with an average value of 30%. The survey results from the first part of the questionnaire concluded that most waste concrete in the U.S. was recycled and the most common application was backfill or roadbase.

4.2. Awareness of concrete recycling

The "Awareness" section in Part Two of the questionnaire consists of six questions. Table 1 displays the survey results and the comparison between the results of this study and Tam's study [8] based on the two-tailed statistical analysis concerning two proportions. It can be seen that the 23 U.S. companies surveyed had high awareness in four items, with positive answers ranging from 74 to 95%. These items were: A1) Having concrete recycling policies, goals, and procedures, A2) Having implemented one or more concrete recycling methods, A5) Planning to invest more resources in concrete recycling, and A6) Having handled waste concrete as recyclable material. Compared to their Australian counterparts, statistically higher percentages of U.S. survey participants had answered "Yes" to these four awareness questions. Item A4) Employees participate in training or program(s) regarding concrete recycling received the lowest percentages of positive answers for both U.S. and Australian survey participants.

Table 1. Comparison of awareness survey results between the U.S., Australia, and Japan

		U.S. (U) (N=23)		Australia (A) (N=54)		Japan (J) (N=80)	
		Yes	No	Yes	No	Yes	No
A1. Company has policies, goals and procedures for concrete recycling.	%	85%	15%	48%	52%	68%	32%
	z	2.86(U/A[a])		2.32(A/J[a])		1.50(U/J[a])	
	p	0.005[b]		0.022[b]		0.136	
A2. Company has implemented one or more concrete recycling methods to achieve the stated policy or other requirements (e.g., LEED).	%	90%	10%	63%	37%	81%	19%
	z	2.26		2.32		0.95	
	p	0.027[b]		0.022[b]		0.342	
A3. Company has a specific division/department for concrete recycling.	%	50%	50%	52%	48%	61%	39%
	z	0.51		1.03		0.93	
	p	0.875		0.303		0.356	
A4. Employees participate in training or program(s) regarding concrete recycling.	%	33%	67%	41%	59%	64%	36%
	z	0.61		2.62		2.53	
	p	0.543		0.010[b]		0.013[b]	
A5. Company is planning to invest more resources in concrete recycling.	%	74%	26%	44%	56%	35%	65%
	z	2.23		1.05		3.07	
	p	0.029[b]		0.296		0.003[b]	
A6. Waste concrete in past projects has been handled as recyclable materials.	%	95%	5%	70%	30%	80%	20%
	z	3.26		2.87		1.72	
	p	0.002[b]		0.005[b]		0.088	

[a]The statistical test compares the survey results between two selected countries. Specifically, "U/A," "A/J," and "U/J" denote comparisons between the U.S. and Australia, Australia and Japan, and the U.S. and Japan, respectively.
[b]Denotes a statistically significant difference between the two countries compared.

These comparison results could be attributable to the problems identified in Tam [8]: In Australia, the following elements were lacking: 1) standardized policies and classification systems for concrete recycling, 2) financial support from the government to reduce the cost of recycling, and 3) technical specifications to expand the application of recycled concrete to producing new concrete. Although the U.S. may not be significantly better than Australia in these aspects, the researchers did find some related standards and specifications in the U.S. for recycling concrete waste, e.g., ODOT Supplement 1117.

Compared to their Japanese counterparts, a significantly lower percentage of U.S. survey participants (33% versus 64%) had employees participating in training or programs regarding concrete recycling. However, a significantly higher percentage of these companies (74% versus 35%) were planning to invest more resources in concrete recycling. This could be explained by the fact that Japan may have already invested a lot of resources in this area, resulting in well-developed technologies, equipment, and training programs. This assumption could be further supported by Japan's 100% concrete recycling rate, as observed by Tam [8]. In contrast, the U.S. companies might be still on their way to developing more advanced technologies, equipping contractors with proper equipment, and training more employees. All of these require additional resources.

4.3. Benefits gained in concrete recycling

Eight Likert scale questions were designed to learn survey participants' perception of the benefits of concrete recycling. The two-tailed statistical test concerning the difference between two means was used to compare the results between this study and Tam [8]. Due to the limited data in Tam [8], the comparison was only made between the U.S. and a sample combining Australia and Japan. The results are shown in Table 2.

Table 2. Comparison of perceived benefits to concrete recycling between the U.S., Australia, and Japan.

	U.S. (N=23)		Australia & Japan (N=134)		Statistical test	
Benefits	Mean	Std.	Mean	Std.	z	*p*
B1. Conserving landfill space and reducing the need for new landfills	4.32	1.21	3.65	0.95	1.92	0.057
B2. Saving natural materials	4.32	1.25	3.85	0.91	1.69	0.094
B3. Reducing project costs by using recycled materials	4.32	1.21	2.90	1.04	5.19	0.000[a]
B4. Reducing the cost of transportation (from sites to landfills) and tipping fees	3.91	1.38	3.13	1.01	2.54	0.012[a]
B5. Stimulating continuous improvement in concrete recycling	3.86	1.08	2.94	0.92	3.79	0.000[a]
B6. Raising concrete recycling awareness	4.09	1.15	3.44	1.02	2.50	0.014[a]
B7. Increasing overall business competitiveness and strategic business opportunities	3.90	1.18	2.98	1.09	3.37	0.001[a]
B8. Improving management and communication on concrete recycling information and commitment[b]	3.71	1.10	3.05	0.95	2.61	0.010[a]

[a]Denotes *p* values lower than 0.05, indicating the existence of significant differences between the compared countries.
[b]Denotes items that had significant differences between Japanese and Australian survey participants in Tam [8].

Table 2 shows the high mean values (ranging from 3.71 to 4.32) of the benefits questions from the U.S. survey, indicating that these respondents had very positive views of the benefits from concrete recycling. These mean values are constantly higher than those from the combined Australian and Japanese surveys. Among eight items, B1) Conserving landfill space, B2) Saving natural materials, and B3) Reducing project costs were perceived most positively by U.S. survey participants. The Australian and Japanese survey participants had slightly different views. While they perceived B1) and B2) most positively, they deemed B6) Raising concrete recycling awareness as the third most positively perceived benefit, rather than B3. It seemed that the concrete recycling option was not very cost-effective in Australia and Japan for some reason. Statistical analysis confirmed that the U.S. survey respondents had significantly more positive views of items B3, B4, B5, B6 and B7 compared to the combined sample group. However, for item B8) Improving management and communication, it was not clear which country had the most positive view since a significant difference existed between Australian and Japanese survey respondents.

4.4. Difficulties in concrete recycling

In total, 19 Likert scale questions were asked regarding the difficulties in concrete recycling. These questions were divided into four subcategories: high cost investment, management skills, issues related to recycled concrete products, and lack of support. The survey questions, results, and international comparison results are displayed in Table 3. In the U.S. survey, 10 out of 19 items had mean values lower than 3. These average values falling between scales 2 "disagree" and 3 "neutral" showed the disagreement of survey participants in perceiving these difficulties. In other words, the U.S. survey participants did not regard these items as barriers. In contrast, only 2 out of the total 19 items in the Australian and Japanese surveys had average values below 3, and the majority of these 19 items were considered true difficulties faced in concrete recycling.

Significant differences were found in the survey results between this study and Tam [8]. Firstly, compared to the survey respondents in the U.S., the Australian and Japanese survey participants were more concerned about the higher cost of removing concrete waste. This was consistent with the early finding in Table 3 where B3) Reducing project costs by using recycled materials was ranked low by Australian and Japanese survey participants (5th and 8th, respectively) in the benefits of recycling concrete. Comparatively, the cost of recycling concrete seemed to be more affordable in the U.S. than in the other two countries. Secondly, both Australian and Japanese survey participants perceived more difficulties in recycling concrete. These difficulties lay in the quality issues and limited applications of recycled concrete products. Thirdly, the U.S. survey participants were more concerned about the lack of government awareness and support toward concrete recycling than their counterparts in Australia and Japan.

Table 3. Survey results of perceptions on difficulties in concrete recycling.

	U.S.		Australia & Japan		Statistical test	
Difficulties	Mean	Std	Mean	Std	z	*p*
High cost investment						
D1. The industrial waste sorting procedure is costly	3.26	0.87	3.04	1.07	1.00	0.319
D2. Transportation is costly from sites to recycling plants	3.20	1.01	3.28	0.97	0.33	0.740
D3. Placing recycling machines (e.g., crushers) onsite is difficult [b]	3.32	0.89	3.63	0.13	1.52	0.132
D4. The cost of waste removal (haul away) of recyclable concrete is higher than that of normal concrete removal	2.68	1.42	3.66	3.65	2.16	0.032[a]
D5. Recycling concrete increases labor and management costs[b]	2.58	1.26	3.06	1.09	1.58	0.116
Management skills						
D6. It is difficult to create a plan of action for recycling concrete on a specific project[b]	2.40	1.35	3.19	1.04	2.51	0.013[a]
D7. Recycling of concrete increases workload, e.g., documentation, supervision, etc.	2.65	1.27	3.07	1.01	1.41	0.159
D8. Recycling of concrete changes the existing practice of company structure and policy	2.70	1.03	2.87	0.90	0.70	0.485
D9. There is a lack of staff participation and training in concrete recycling	2.76	0.94	3.16	1.00	1.80	0.074
Issues related to recycled concrete products						
D10. Recycled products are of poor quality (e.g., reduced compressive strength)	2.23	1.13	3.34	1.09	4.12	0.000[a]
D11. There are limited applications in using recycled concrete products	2.61	1.19	3.51	1.07	3.33	0.001[a]
D12. There is an imbalance of supply and demand on recycled products	3.25	1.45	3.26	1.03	0.03	0.975
D13. There is insufficient research invested in concrete recycling products	3.13	1.12	3.43	0.92	1.14	0.255
Lack of support						
D14. There is a lack of support in technologies, resources, training, competent staff regarding recycling concrete	3.17	1.24	3.10	1.10	0.24	0.807
D15. Our clients do not ask for the use of recycled concrete	3.14	1.28	3.42	1.09	0.95	0.344
D16. There are not enough concrete recycling companies[b]	2.90	1.45	2.98	1.13	0.24	0.814
D17. There is a lack of industry awareness and support toward concrete recycling	3.05	1.17	N/A	N/A	N/A	N/A
D18. There is a lack of governmental awareness and support toward concrete recycling	3.82	1.22	3.27	0.99	2.01	0.046[a]
D19. There is a lack of certain regulatory standards regarding concrete recycling	2.95	1.32	3.48	0.96	1.73	0.086

[a]Denotes items with significant differences between Japanese and Australian survey participants in [8].

4.5. Recommended methods in concrete recycling

In total, nine items were included in the section of recommended methods in concrete recycling. The survey questions, results, and statistical comparisons are displayed in Table 4.

Table 4. Survey results of recommended methods in concrete recycling.

	U.S.		Australia & Japan		Statistical test	
Recommended methods	Mean	Std	Mean	Std	z	*p*
R1. Comprehensive and accurate evaluation of concrete recycling[b]	3.39	1.14	3.30	0.98	0.32	0.750
R2. Identifying and classifying various uses of recycled wastes	4.15	0.93	3.72	0.84	1.95	0.053
R3. Developing techniques and best management practices for recycling concrete*	3.90	0.91	N/A	N/A	N/A	N/A
R4. Considering concrete recycling in design	4.10	0.91	2.81	0.99	5.00	0.000[a]
R5. Improving concrete recycling management in your organization	2.84	1.01	3.17	1.02	1.33	0.185
R6. Providing in-house training on concrete recycling[b]	2.65	0.99	2.93	0.95	1.19	0.237
R7. Effective communication on concrete recycling among all parties	3.68	0.89	3.23	0.96	2.04	0.043[a]
R8. Government restrictions on concrete waste volume generated onsite[b]	3.17	1.38	3.40	0.99	0.68	0.495
R9. High landfill charges for disposing concrete waste	3.67	1.39	2.72	0.99	3.01	0.003[a]
R10. Government financial support for companies**	N/A	N/A	3.49	1.04	N/A	N/A

Note: *Item R3 was not included in Tam [8] but recommended by the expert reviewers of the questionnaire.
**Item R10 was in [8] but removed from this study based on the reviewers' feedback.
[a]Denotes p values lower than 0.05, which indicated significant differences between the compared countries.
[b]Items with significant differences between Japanese and Australian survey participants in Tam [8].

Participants in the U.S. survey gave high scores to R2) Identifying and classifying various uses of recycled wastes, R4) Considering concrete recycling in design, and R3) Developing techniques and the best management practices for recycling concrete. Actually, only two items in this section, R5) Improving concrete recycling management in your organization and R6) Providing in-housing training on concrete recycling, were not recommended by respondents. It seemed that companies cared more about the external measures/support in improving concrete recycling than their internal actions (i.e., organization management and training of employees). The U.S. survey participants deemed methods R4, R7) Effective communication on concrete recycling among all parties, and R9) High landfill charges for disposing concrete waste more effective in improving concrete recycling.

5. Conclusion and recommendations

This study explored the status of concrete recycling in the U.S. by adopting a questionnaire survey approach. It also statistically compared the results between this survey and previous surveys that investigated concrete recycling in Australia and Japan. The survey revealed that in the U.S., waste concrete (mainly from the demolition of old buildings/structures) had been largely recycled into aggregates and widely applied in backfill and roadbase. The use of recycled concrete aggregate (RCA) in new concrete production was still limited. The statistical analysis results showed that the U.S. survey respondents had high perceptions on the items regarding the awareness of concrete recycling and recommended methods. However, most participating companies had neither in-house training programs for their employees nor specific recycling departments/divisions in their organizations. In light of recommended methods for concrete recycling, companies seemed to be in favor of the external influence/support from the government and other parties, as well as techniques to improve concrete recycling.

Based on the literature review and comparisons performed in this study, it could be inferred that the U.S. is ahead of Australia in concrete recycling, but lags behind Japan, especially in using RCA in new concrete production for structural applications. In general, these three countries face different challenges in concrete recycling. Future research will adopt more statistical methods to perform a deeper analysis on concrete recycling practices among these three countries. For example, Relative Importance Index can be used to study the relative ranking of questions within each section. Cronbach's alpha can be used to measure the internal consistency of items within each section.

References

[1] N. D. Oikonomou, Recycled concrete aggregates, Cement Concrete Comp. 2005; 27(2):315-318.
[2] P. K. Mehta, Greening of the concrete industry for sustainable development, Concr. Int. 2002; 24(7):23-28.
[3] V. W. Y. Tam, Economic comparison of concrete recycling: A case study approach, Resour. Conserv. Recy. 2008; 52(5):821-828.
[4] G. D.Kim, T. B. Kim, Development of recycling technology from waste aggregate and dust from waste concrete, J. Ceram. Process. Res. 2007; 8(1):82-86.
[5] C. Meyer, Concrete as a green building material, In Proc., 3rd. Int. Conf. on Constr. Mater.: Performance, Innovations and Structural Implications, Vancouver, Canada, 2005.
[6] I. Gull, Testing of strength of recycled waste concrete and its applicability, J. Constr. Eng. Manage. 2011; 137(1):1-5.
[7] M., Limbachiya, M. S., Meddah, Y. Ouchagour, Performance of Portland/silica fume cement concrete produced with recycled concrete aggregate, ACI Mater. J. 2012; 109(1):91-100.
[8] V.W.Y. Tam, Comparing the implementation of concrete recycling in the Australian and Japanese construction industries, Constr. Manage. Econ. 2009; 17(7):688-702.
[9] B. Mobasher, USA—concrete construction industry—cement based materials and civil infrastructure, CBM-CI Int. Workshop, Karachi, Pakistan, 2008, pp.73-90.
[10] C. J. Zega, A. A. D. Maio, Recycled concrete made with waste ready-mix concrete as coarse aggregate, J. Mater. Civ. Eng. 2011; 23(3):281-286.
[11] T. Y., Hsiao, Y. T., Huang, Y. H., Yu, I. K. Wernick, Modeling materials flow of waste concrete from construction and demolition wastes in Taiwan, Resour. Policy 2002; 28(1):39-47.
[12] U.S. Environmental Protection Agency (USEPA). Asphalt concrete, WARM Version 12, USEPA, Washington, DC, 2012.
[13] C. Meyer, The greening of the concrete industry, Cement Concrete Comp. 2009; 31(8):601-605.
[14] D. Wilburn, T. Goonan, Aggregates from natural and recycled sources: Economic assessments for construction applications—A materials flow analysis, U.S. Geological Survey Circular 1176, U.S. Department of the Interior, Washington, DC, 1998.
[15] R. Gilpin, D. W., Menzie, H. Hyun, Recycling of construction debris as aggregate in the Mid-Atlantic Region, USA, Resour. Conserv. Recy. 2004; 42(3):275–294.
[16] E. K. Lauritzen, Recycling concrete—An overview of development and challenges, In Proc., Conf. on the Use of Recycled Materials in Buildings and Structures, RILEM, Bagneux, France, 2004.
[17] R. A. Johnson, Miller & Freund's Probability and Statistics for Engineers, 7th ed., Pearson Prentice Hall, Upper Saddle River, NJ, 2005.
[18] W. Turley, Personal communication between William Turley, Construction Materials Recycling Association and Philip Groth of ICF Consulting, 2002.