

1 An Empirical Study of Perceptions towards Construction and Demolition Waste 2 Recycling and Reuse in China

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18 **Abstract:** This study was designed to investigate the recent movement and current stage of
19 China's construction and demolition (C&D) waste recycling and reuse. Specifically, the
20 research aimed to provide the big picture of recent C&D waste diversion practice in China, as
21 well as to offer insights from Chinese field practitioners' perceptions towards benefits,
22 challenges, and recommendations of C&D recycling and reuse. This research was conducted
23 based on a review of existing practice and a holistic approach by collecting feedback of
24 professionals from multiple disciplines through a questionnaire-based survey. Totally 77 valid
25 responses were received from 592 questionnaires sent. Both quantitative data and qualitative
26 information implied that China was still at the early stage of recycling C&D wastes. Lack of
27 client demands was identified as one of the main difficulties in C&D waste diversion. The
28 study revealed that engineers and consultants had a more positive perception on promoting
29 industrial training in C&D waste recycling, while construction management professionals held
30 more conservative opinion on it. It was also found that gaining experience in C&D waste
31 recycling and reuse would offer professionals more positive perception on the quality of
32 products containing recycled contents. It was further implied that although governmental

33 supervision had a high impact on China's current C&D waste management practice, the
34 economic viability should eventually dominate the C&D waste diversion.

35 **Keywords:** Construction waste; Sustainability; Recycling; Reuse; Policy; Questionnaire
36 survey

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38 **1. Introduction**

39 Construction and demolition (C&D) waste was defined as a mixture of surplus materials
40 generated from construction, renovation, and demolition activities, for example, site clearance,
41 land excavation and roadwork, and demolition (Shen et al., 2004). It accounts for around 40%
42 of total urban waste in mainland China (China Strategic Alliance of Technological Innovation
43 for Construction Waste Recycling Industry or CSATICWRI, 2014), 26% of total solid waste
44 in the U.S. (U.S Environmental Protection Agency, 2009), and 34% of all industrial waste
45 within Europe (Eurostat, 2016). The construction industry in China is continuing its
46 considerable growth, and billions of tonnes of C&D waste have been produced in recent years
47 due to the large-scale urbanization programs (Duan and Li, 2016). The enormous amount of
48 C&D waste generated in China over the past decades has caused severe damage to the
49 environment (Lu and Yuan, 2010; Wu et al., 2016). Duan and Li (2016) used, Shenzhen, one
50 of China's most developed municipalities as the example, showing that 84% of C&D waste
51 were landfilled in recent years far exceeding the local landfill capacity. It was further stated by
52 Duan and Li (2016) that over half of C&D waste in Shenzhen was disposed to unlicensed
53 landfill sites or by dumping. The urgency in reducing C&D waste to decrease the pressure on
54 landfills and to enhance waste diversion has driven the movement towards the environmental
55 sustainability from both government and industry perspectives in mainland China.

56 Wu et al. (2016) found that in China, government played an important role in guiding and
57 promoting contractor's behavior in C&D waste management. Several researchers (e.g., Zhao

58 et al., 2008; Zhao et al., 2010; Wu et al., 2016) proposed that besides governmental policy,
59 economic instruments (e.g., tax and subsidy for fostering the recycling industry), and economic
60 viability in terms of business profitability also influenced C&D recycling practice. Technical
61 issues with recycling C&D wastes such as quality of recycled concrete aggregates and their
62 applications were also evaluated in the studies of Li (2008) and Li (2009). Lu and Yuan (2010)
63 suggested the importance of having the active participation of all stakeholders (e.g.,
64 government, clients, contractors, and suppliers, etc.) in C&D waste management. Nevertheless,
65 lack of communication and coordination among parties was identified by Domingo and Luo
66 (2017) as one of the major barriers. It was further identified by Saez et al. (2013) that limited
67 comprehensive strategies have been studied in effective waste management and individual
68 attitudes towards the C&D waste management evaluation could vary. Whether multiple parties
69 involved in the C&D waste diversion share consistent views on this subject could impact the
70 effectiveness in communication, as the C&D waste management requires team effort in
71 recruiting participants from different disciplines. The other concern was whether the prior
72 project experience would affect professionals' perceptions on C&D waste management.

73 Research gaps could be identified from a review of these existing studies (e.g., Zhao et al.,
74 2010; Saez et al., 2013; Wang et al., 2014; Domingo and Luo, 2017) in that: 1) there is still
75 limited research on investigating the overall experience of recycling and reusing C&D waste
76 crossing regions in China; 2) there has been insufficient feedback on policy and economy
77 related issues from practitioners and stakeholders who are directly involved in the C&D waste
78 treatment; 3) limited studies have addressed the question regarding the influence of
79 professionals' occupation and prior experience on their perceptions, which could further impact
80 their behavior on C&D waste treatment.

81 This study targets on investigating the current movement and practice of C&D waste
82 recycling and reuse in China. The objectives of this empirical study are: 1) to gain the overall

83 picture of more recent changes in China's governmental policy and industry practice towards
84 sustainable treatments of C&D waste; 2) to study benefits and difficulties related to C&D waste
85 recycling and reuse from the perspectives of professionals within relevant fields; 3) to explore
86 whether practitioners' perceptions towards C&D waste management related items would be
87 dependent on their occupations or prior experience; and) to provide suggestions on enhancing
88 the existing practice of C&D waste diversion based on the responses received from the
89 questionnaire survey. Survey participants from this study consisted of practitioners or
90 researchers from multiple relevant fields (e.g., material supplier, construction management,
91 and engineering consultants). The following sections of this paper include: 1) background
92 information regarding benefits, barriers, and recommendations in C&D waste recycling and
93 reuse in Section 2; 2) a description of research methodology in Section 3 involving a review of
94 China's C&D waste diversion practice in terms of both quantitative data summary and
95 qualitative policy change, as well as a questionnaire-based survey to collect insights from
96 professionals involved in C&D waste treatment; 3) results and discussion in Section 4 with
97 subgroup tests conducted to determine whether the perceptions on C&D waste recycling and
98 reuse would be affected by survey participants' occupations or their prior experience.; 4)
99 summary from findings in Section 5 providing information on whether stakeholders and
100 practitioners from various disciplines, either with or without relevant experience, would share
101 the consistent views on C&D waste management related issues.; and 5) conclusion in Section
102 6. The findings from this study serve as insights to stakeholders including governmental
103 authorities, especially those from developing countries, on the current practice and trend of
104 C&D waste management in China, as well as provide directions on sustainable treatment of
105 C&D waste in developing or populous regions.

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108 **2. Background**

109 **2.1. Benefits of Recycling and Reusing C&D Waste**

110 Numerous studies (e.g., Li, 2008; Marzouk and Azab, 2013; Vieira and Pereira, 2015)
111 have recognized several benefits of recycling and reusing C&D waste. These benefits are
112 summarized below:

- 113 • Reusing of materials on-site and saving natural resources (Poon and Chan, 2007; Rao et
114 al., 2007; Tam, 2008^a; Zhao et al., 2010; Sabai et al., 2012; Duan et al., 2013; Huang et
115 al., 2013; Vieira and Pereira, 2015);
- 116 • Decreasing the needs on landfill spaces (Hsiao et al., 2002; Poon and Chan, 2007;
117 Marzouk and Azab, 2013);
- 118 • Saving energy and reducing greenhouse gas emissions (Huang et al., 2013; Marzouk and
119 Azab, 2013);
- 120 • Reducing health-related risks associated with landfilled C&D wastes (Marzouk and Azab,
121 2013);
- 122 • Coping with governmental strategy or industry standard to achieve environmental
123 sustainability (Fatta et al., 2003; Li, 2008).

124 It can be indicated that the recycling and reuse of C&D wastes could generate
125 environmental, social, and economic benefits. For example, recycling programs can save
126 landfill charge and build the social sustainability image (Doan and Chinda, 2016), and
127 construction companies could benefit from reduced waste by lower costs to purchase virgin
128 materials (Bossink and Brouwers, 1996).

129 **2.2. Difficulties and Challenges in Recycling and Reusing**

130 Despite the widely recognized benefits, the sustainable management of C&D waste are
131 facing these difficulties and challenges, including:

- 132 • Lack of waste-processing facilities or companies (Melo et al., 2011; Domingo and Luo,
133 2017; Jia et al., 2017);
- 134 • Insufficient relevant policies, regulations, and acts (Chung and Lo, 2003; Fatta et al., 2003;
135 Rao et al., 2007; Domingo and Luo, 2017);
- 136 • Poor communication and coordination among parties involved (Domingo and Luo, 2017);
- 137 • Lack of economic feasibility and viability in recycling and reusing C&D wastes, for
138 example, when the cost of recycling and reuse exceeding the recycled waste value, or when
139 landfilling tipping charge was lower for direct disposal (Zhao et al., 2008; Zhao et al., 2010);
- 140 • Poor qualities of recycled products and their limited applications (Rao et al., 2007; Li, 2009;
141 Zhao et al., 2010; Sabai et al., 2012; Duan and Poon, 2014);
- 142 • Reluctance or cultural resistance to implement C&D waste diversion (Saez et al., 2013; Esa
143 et al., 2016), for example, illegal dumping still occurring worldwide (Poon et al., 2001;
144 Conceição Leite et al., 2011; Melo et al., 2011).

145 It should be noticed that some benefits verse challenges within C&D waste diversion
146 remain inconsistent among different studies. For example, Zhao et al. (2008) and Zhao et al.
147 (2010) were backed by Gull (2011)'s study that incurred labor cost when extracting waste
148 materials and the cost of using extra admixture in the recycled product could downplay the
149 economic benefit of recycling and reusing C&D wastes. In contrast, Tam (2008^b)'s case study
150 showed that reusing recycled C&D materials could be more cost effective compared to
151 landfilling them. Therefore, further studies might be needed to determine the effects of multiple
152 parameters (e.g., desired quality of recycled products) in the economic viability of C&D waste
153 diversion.

154 **2.3.Recommendations on Improving C&D Waste Recycling and Reusing**

155 Existing studies have provided recommendations in enhancing the effective C&D waste
156 management; these strategies and suggestions include:

157 • Applying economic instruments, such as tax incentive, penalty and subsidy mechanism
158 (Zhao et al., 2008; Zhao et al., 2010; Marzouk and Azab, 2013; Wang et al., 2014; Jia et
159 al., 2017);

160 • Governmental initiatives to increase C&D waste diversion activities, for example, a landfill
161 ban for unsorted wastes, policies towards more judicious management of C&D wastes, and
162 standards for recycled materials aiming to establish the recycling market (Zhao et al., 2010;
163 Melo et al., 2011; Marzouk and Azab, 2013; Duan and Li, 2016; Esa et al., 2017);

164 • Innovations in construction technology and management such as fewer design
165 modifications, modular design, on-site sorting out waste categories, and technical
166 regulations of using recycled materials in construction (Lu and Yuan, 2010; Wang et al.,
167 2010; Saez et al., 2013; Wang et al., 2014; Esa et al., 2017; Marrero et al., 2017);

168 • Investment, research (e.g., economic feasibility), and development in waste reduction,
169 recycling, and reuse (Lu and Wang, 2010; Sabai et al., 2012; Wang et al., 2014);

170 Training in C&D waste management (Lu and Wang, 2010). It is worth noticing that these
171 suggestions for promoting C&D waste management came from different studies crossing
172 countries. The effects of implementing these recommendations may vary in different countries
173 or regions, and the industry practitioners may hold varied views on the recommendations. For
174 example, the HongKong's Waste Management Disposal Charging Scheme, although with
175 financial incentives to C&D waste generators, did not significantly reduce waste diversion
176 according to Poon et al. (2013). Tam (2009)'s empirical study of waste concrete recycling
177 practice in Australia and Japan also identified several inconsistent perceptions towards relevant
178 recommended methods in enhancing recycling from practitioners between these two countries.
179 It is hence important to investigate the effectiveness and practitioners' perceptions within the
180 context of the targeted country or region such as China in this study.

182 2.4. *Review of C&D waste diversion in China*

183 Unlike developed countries such as Japan, where the recycling industry and market have
184 been well established, most C&D waste currently in China is still directly transported to
185 landfills instead of being reused effectively. According to CSATICWRI (2014), there were
186 only around twenty professional corporations in China's C&D waste reuse and recycling
187 market, mainly producing masonry bricks containing recycled contents but with lower quality
188 and limited applications. In comparison, South Korea, with annual C&D waste generation at
189 about 60 million tonnes, has 373 construction C&D waste treatment corporations
190 (CSATICWRI, 2014).

191 Nevertheless, governmental policies and guidelines are being developed to encourage the
192 C&D waste diversion in China. In April 2015, State Council of China announced *Suggestions*
193 *on Accelerating Ecological Civilization Development* demanding on the reuse of C&D waste.
194 In the provincial level, the newly enacted *Zhejiang Green Building Regulation* that has taken
195 effect since May 2016 encourages recycled building materials to be applied in building
196 foundation work, retaining walls, road base and subgrade, as well as parking lots. In the
197 municipal level, Chengdu government announced the policy in October 2016 that for all
198 government-funded projects, the percentage of recycled contents should be more than 15% for
199 infrastructure projects and above 5% for building projects. Some other municipal governments,
200 such as Sanya in southern China, has been planning the financial incentive to encourage C&D
201 waste diversion.

202

203 **3. Research Methodology**

204 A holistic approach was adopted in this study. It was built upon a constructivist knowledge
205 claim with an inclination towards pragmatist paradigm as opposed to a pure positivist approach.
206 It used a mixed method approach where a combination of secondary data analysis with the

207 outcome of a questionnaire survey were used to elaborate on participants' expert opinions' on
208 C&D waste diversion related issues..

209 The study investigated the current status of C&D waste recycling and reuse in China.
210 Initially existing data (e.g., these related to C&D waste generation) were retrieved from
211 relevant literature sources. This would also enable cross-country comparison of C&D waste
212 diversion practice between China and some developed countries or region (e.g., Japan, U.S.,
213 and Europe). Relevant policy changes in China's C&D waste management were reviewed and
214 summarized to provide a big picture of the transitional change towards waste diversion.

215 A questionnaire-based approach was later adopted to collect professionals' perceptions on
216 C&D waste in terms of benefits, difficulties, and suggestions in waste recycling and reuse.
217 Survey questions, provided in the appendix, were divided into two portions. The first portion
218 aimed to collect the survey population's background information on recycling and reusing of
219 C&D waste. Survey participants were identified based on their occupation and involvement in
220 C&D waste management, for instance, material supplier, contractor, and consultants, etc. They
221 were also asked whether they have relevant prior experience. The second portion adopted
222 Likert-scale questions, which were divided into three categories within C&D waste recycling
223 and reuse, namely benefits, difficulties, and suggestions. There were multiple items under each
224 category, and survey participants were asked to choose the numerical scale from "1" to "5",
225 where "1" indicated "least important" of the described item or "strongly disagree" with it, "3"
226 meant a neutral attitude, and "5" conveyed the option of "strongly agree" or the perception of
227 "very important". Survey participants were also given the extra option of "N/A" if unsure of
228 the given item. At the end of each category, an open-ended question was prepared to capture
229 additional information of survey participants' perception towards the given category in C&D
230 waste diversion.

231 The questionnaire was developed from January to May of 2016 within the research team
232 of the University of Nottingham Ningbo China and peer reviewed technically in the pilot study.
233 The content of the questionnaire was finalized at the end of May 2016. The questionnaire-based
234 research was approved by the institutional Research Ethics Office before it reached survey
235 participants. Potential survey sample was identified from the professional network of
236 Construction Material Research & Practice Group and Construction Waste Management
237 Forum within mainland China. These professional groups consisted of practitioners and
238 researchers within the field of C&D waste management and material sustainability. The
239 questionnaire was set electronically and sent to potential participants through SOJUMP, a
240 Chinese on-line survey tool (www.sojump.com) to collect responses.

241 Multiple statistical methods were adopted in the data analysis of survey responses,
242 including Relative Important Index (*RII*) to rank these multiple items under each category
243 related to C&D waste recycling and reuse (i.e., benefits, difficulties, and recommendations),
244 Cronbach's alpha value to quantify the internal consistency of items within each category, and
245 Analysis of Variance (ANOVA) to test whether participants' perceptions would depend on
246 their occupations or prior experience.

247 The *RII* value of each given Likert-scale item was calculated according to Eq.1, which had
248 been adopted in some other empirical studies (e.g., Tam et al., 2000; Tam et al., 2009; Eadie et
249 al., 2013; and Jin et al., 2017) in the field of construction engineering and management.

$$250 \quad RII = \frac{\sum w}{A \times N} \quad \text{Eq.1.}$$

251 where w denotes the numerical score chosen by each survey participant in a given item, A
252 is the possibly highest score in the Likert-scale item, which is 5 in this study. The parameter N
253 denotes the total number of responses. The *RII* value ranges from 0 to 1, and a higher value of
254 *RII* means a more positive attitude or higher perception of the survey population towards the
255 target item.

256 Cronbach's alpha value, ranging from 0 to 1, its higher value would indicate a higher
 257 consistency among the items within the category, meaning that a survey participant who has
 258 chosen a Likert value for one item is prone to select a similar numerical value to other items.
 259 According to Nunnally and Bernstein (1994) and DeVellis (2003), Cronbach's alpha value from
 260 0.70 to 0.95 indicates a high internal consistency among all items. Otherwise, a lower
 261 Cronbach's alpha would display a poorer inter-relatedness among items (Tavakol and Dennick,
 262 2011).

263 The survey population in this study was divided into subgroups according to their
 264 occupation and prior experience in C&D waste management. ANOVA was applied to test the
 265 statistical consistency among subgroups in their perceptions towards items within each category
 266 using the null hypothesis that there was no significantly different mean values among subgroups
 267 towards the given Likert-scale item based on the 5% level of significance.

268

269 **4. Results and Discussion**

270 The results of this study are divided into two major sections: the review of current status of
 271 C&D waste recycling and reuse in China, and the data analysis of questionnaire-based survey.

272 **4.1. Review of Current Stage of C&D Waste Management in China**

273 Quantitative data related to C&D waste generation and recovery were acquired from
 274 multiple existing sources across different countries or region (see Table 1).

275 Table 1. Comparison of C&D waste management related information within selected
 276 municipalities, countries, and region.

City, Country or region	Population density (number of people per km ² of land)	Annual generation of C&D waste (million tonnes)	Generation of C&D waste per unit land area (tonne/km ²)	Generation of C&D waste per capita (kg/person daily)	Average tipping fee for solid waste (\$/tonne) ¹	C&D waste recovery (%)
Japan	337	76	201	1.63	359	80
Australia	3.3	18	2.34	2.13	68	57
Europe	73	870	85.5	3.22	102	75
U.S.	33	485	49.3	4.17	60	82
China	143	1,550 to 2,400	162 to 250	3.14 to 4.86	11	5

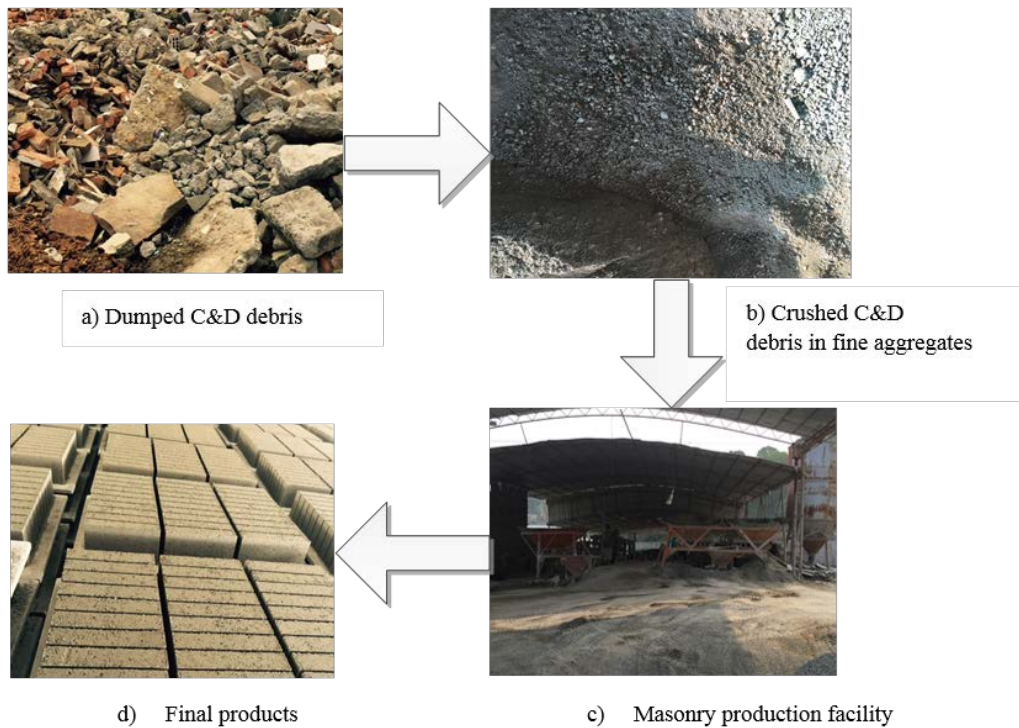
Table 1. Cont.						
Shanghai	3,809	100 to 144	15,773 to 22,713	11.34 to 16.33	N/A ²	N/A ²
Beijing	1,322	35 to 40	2,133 to 2,438	4.42 to 5.05	N/A ²	N/A ²

277 ¹ The average tipping fee has been adjusted to the 2015 U.S. dollar value per tonne of solid waste
278 Note: The data in Table 1 are summarized from multiple sources including BDA Group (2009), Railey and
279 Greenberg (2009), Japan Environmental Sanitation Center (JESC, 2012), European Environment Agency (2013),
280 Ministry of the Environment (2014), Randell Environmental Consulting (2014), CSATICWRI (2014), Shin (2014),
281 U.S. EPA (2014), EU-Japan Centre for Industrial Cooperation (2015), and Eurostat Press Office (2015), Eurostat
282 (2016), U.S. EPA (2016), and Bureau of Transportation Statistics (2017).
283 ² The average tipping fee and C&D recovery rate in Shanghai and Beijing are not available.

284 The annual C&D waste generated in China is much higher than any other countries or
285 region listed in Table 1. When evaluated from the average generation of C&D waste based on
286 unit land area or per capita, China still topped the countries or region listed in Table 1. It is
287 noticed that the average tipping fee for landfilling solid wastes in China is significantly lower
288 than that of any other developed countries or region. Jin and Chen (2017) identified that the
289 tipping fee would have strongly negative relationship with landfilling rate. This might partially
290 explain the low recovery rate (i.e., 5%) of C&D waste in China, while the same rate in
291 developed countries or region would be close to or over 60%. It is also worth noticing that there
292 are regional differences in C&D waste generation within China. More populous or developed
293 regions, such as eastern coast, may generate more C&D waste than the less populous west
294 inland part of China. Two major metropolitan municipalities (i.e., Shanghai and Beijing) are
295 also listed in Table 1 as examples of how more developed regions in China would differ from
296 the national average in C&D waste generation. It can be found that population density in
297 Shanghai and Beijing are both close to or higher than 10 times of the national average. The
298 C&D generation per unit land area in Shanghai and Beijing are approximately 100 and 10 times
299 of the national average value. The C&D generation per capita in Shanghai is also significantly
300 higher than China's average value.

301 It can be indicated that guidelines and regulations from authorities could drive the industry
302 practice towards C&D waste recycling and reuse, an example being the “green” concrete
303 masonry blocks made from recycled C&D debris. Fig.1 displays one of the researchers' field

304 investigations focusing on reusing crushed C&D waste in a plant production of masonry bricks
305 in China.



306
307 Fig.1. Workflow of masonry brick production using C&D wastes in China

308
309 Though similar masonry products containing recycled contents described in Fig.1 are
310 available in certain regions of China such as Zhejiang (a southeastern province near Shanghai)
311 and Beijing, these “green” products are still limited in their applications, such as in non-load
312 bearing partition walls. Some technical problems remain to be solved when utilizing recycled
313 materials, for example, the high water absorption rate in recycled aggregates may cause
314 durability problems in wall products. The recycling market would determine the long-term
315 business of “green” building materials. Besides the commercial “green” masonry production
316 plant shown in Fig.1, some PPP (i.e., public-private-partnership) projects of C&D waste
317 treatment plants have been planned in metropolitan areas including Xi’an and Sanya. These
318 plants would have annual treatment capacity between 0.5 and 2 million tonnes.

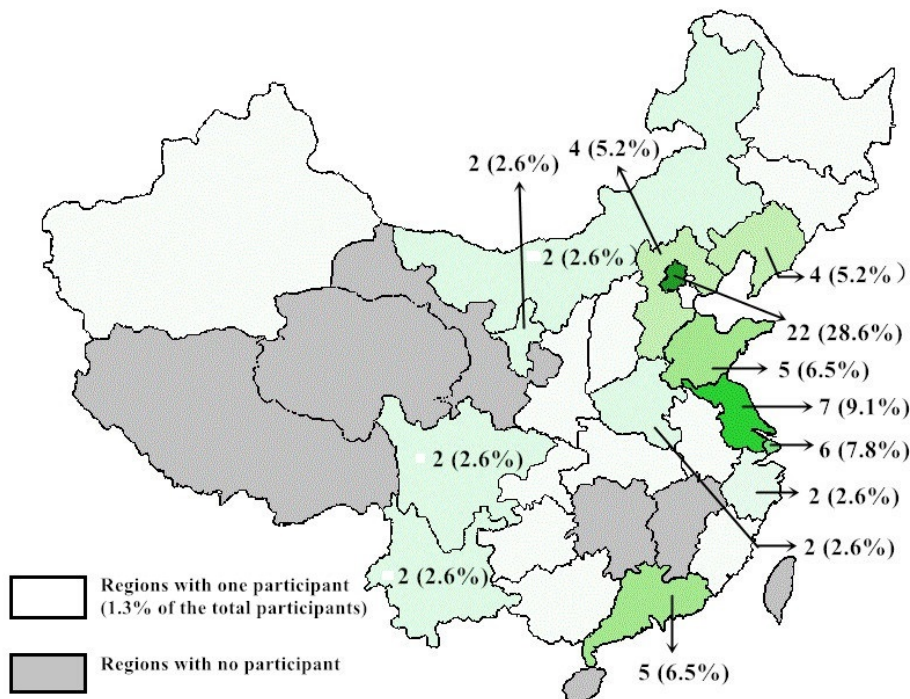
319

320 **4.2.Questionnaire Survey Results**

321 Among totally 592 on-line questionnaires sent during June and August of 2016, 77 valid
322 responses were received, representing the response rate of 13.0%, which is acceptable
323 compared to previous questionnaire survey-based studies within architecture, engineering, and
324 construction (AEC) industries (e.g., 7.4% in Abdul-Rahman et al., 2006). All these 77
325 respondents claimed that they had either participated in C&D waste diversion related projects
326 in the past three years or planned to be involved in C&D waste diversion in the near future due
327 to their work needs.

328 *4.2.1. Background Information of Survey Participants*

329 The respondents came from various regions of China. Fig.2 displays the numbers and
330 percentages of responses by provinces or municipalities in the map of mainland China.

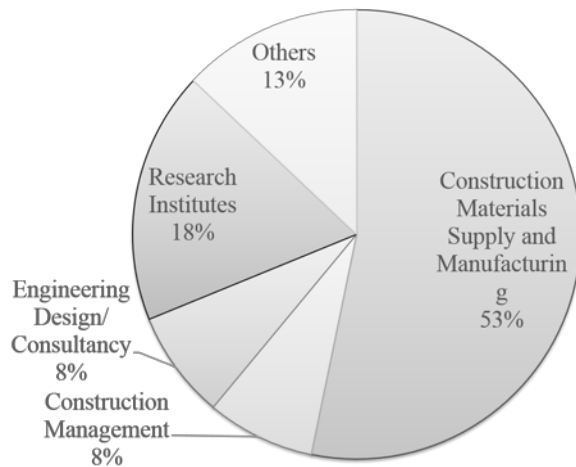


331 Fig.2. Working location of survey respondents (N=77)
332

333 Note: besides the two identified types of regions either with only one respondent or no in Fig.2, the remaining
334 regions have been highlighted in different colors, with each individual region shown the number of respondents
335 and the percentage accounted to the whole survey respondent sample.

336
337 The professions of respondents mainly included supply or manufacturing of construction
338 materials, construction management, engineering design or consultancy, research institutes

339 involving C&D waste management, and others (e.g., authority of environmental protection and
340 business development). The percentages of survey participants according to their professions
341 are summarized in Fig.3.



342

343 Fig.3. Distribution of Survey Participants' Profession (N=77)

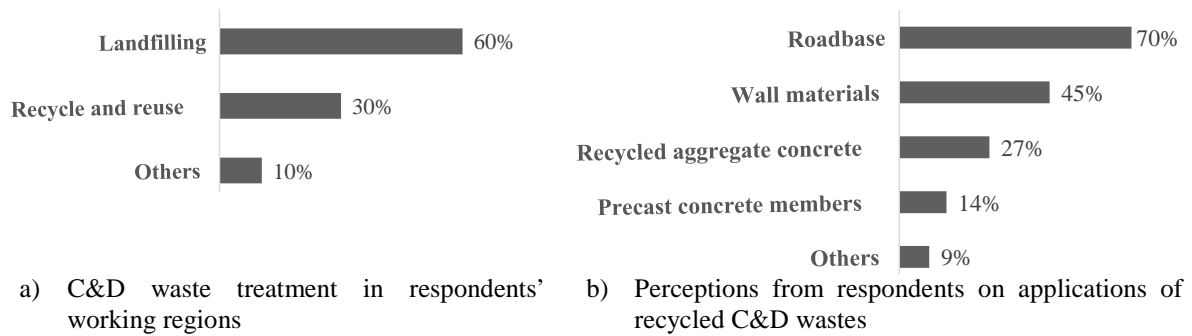
344 Note: Other professions in Fig.3 include environmental protection agency and stakeholders, business
345 developers in environmental protection, inspection authority, and heavy equipment manufacturer for cementitious
346 materials.

347

348 It can be found from Fig.3 that over half of the respondents from this survey came from the
349 construction materials industry. Around 42% of them confirmed that they had worked in
350 projects involving C&D waste recycling and reuse in the past three years, and the rest 58%
351 stated that they did not have direct experience working in a specific project incorporating
352 recycling or reuse of C&D wastes. However, all the rest 58% claimed that they would be
353 involved in C&D waste diversion in the near future. Survey participants were further asked
354 about the treatment of C&D waste in the region where they worked and the existing
355 applications of recycled C&D wastes. The bar charts in Fig.4 display the percentages of each
356 option selected by respondents in the multi-choice questions.

357

358



359 Fig.4. Summary of C&D waste treatment and reuse from survey participants (N=77)

360 It can be seen from Fig.4 that landfilling remained the major treatment approach for C&D
 361 waste in China according to the responses received. Only 30% of survey respondents claimed
 362 that C&D waste had been widely recycled and reused in their work regions. The majority of
 363 the remaining 10% who chose “others” further specified that C&D wastes were mainly applied
 364 in road base or backfill. Somewhat similar to the study of Wilburn and Goonan (1998) who
 365 identified that 85% of recycled concrete debris was used as road base in the U.S., in this survey,
 366 70% of respondents perceived that recycled C&D waste had been reused in road base. In
 367 comparison, recycled aggregate concrete and precast concrete members were not widely
 368 identified by respondents. Those who selected “others” provided details that recycled C&D
 369 wastes had also been applied in materials for cement manufacturing and site backfill.

370 *4.2.2. Benefits of C&D Waste Recycling and Reuse*

371 In this subsection, participants were asked of their perceptions towards benefits related to
 372 C&D waste recycling and reuse. Table 2 lists the seven major Likert-scale items, namely B1
 373 to B7, which are ranked according to their *RII* values. The overall Cronbach’s alpha over 0.750
 374 in this category showed generally high internal consistency of these seven benefit-related items,
 375 indicating that a survey participant who chose a numerical option to one item in Table 2 would
 376 be likely to select a similar option to other items.

377

378

379 Table 2. Data analysis of the overall survey sample regarding benefits of C&D waste
 380 recycling and reuse (Cronbach's alpha = 0.7878)

Item	Percentage of selecting each Likert-scale option (%)					N*	RII	Item-total correlation	Cronbach's Alpha
	1	2	3	4	5				
B1: Complying with relevant governmental policies	0	0	8	44	48	64	0.881	0.6860	0.7348
B2: Saving space from landfills, reducing the demand for new waste landfills	2	3	3	45	47	66	0.867	0.3672	0.7866
B3: Saving natural materials	0	3	7	48	42	69	0.858	0.6909	0.7303
B4: Motivating the entrepreneurships	0	0	9	59	32	66	0.845	0.3655	0.7853
B5: Increasing business opportunities for AEC companies	1	3	14	51	30	70	0.811	0.4858	0.7664
B6: Saving the transportation cost between construction sites and landfills and saving the disposal cost	3	6	15	46	30	71	0.789	0.5805	0.7488
B7: Lowering project budget by using recycled materials	3	10	17	44	26	70	0.760	0.5204	0.7664

381 *: The total number of responses received in Table 2 excluded those who chose "N/A" indicating unsure to the given item.
 382 The same rule applies to Table 4 and Table 6.
 383
 384

385 The individual Cronbach's Alpha values in Table 2 display the changed value if the given
 386 item is removed from this category. Each individual Cronbach's Alpha value turned out lower
 387 than the overall value, indicating that each item in Table 2 positively contributed to the internal
 388 consistency. Item-total correlation in Table 2 displays the correlation between the given item
 389 and the remaining items. B2 and B4, the two items with higher individual Cronbach's Alpha
 390 values, had correspondingly lower item-total correlations, meaning that survey participants
 391 were more likely to assign inconsistent scores on B2 and B4, while their perceptions on other
 392 items tended to be more internally correlated.

393 The top ranked item within this category was compliant with governmental policies in
 394 terms of green building and environmental protection. Waste minimization and sustainable
 395 waste management were identified by Fatta et al. (2003) as basic principles of environmental
 396 authorities. Lu et al. (2016) inferred that public policies impacted construction waste
 397 management performance in both public and private sectors. Most respondents in this survey
 398 also highly emphasized the conformance of C&D waste management to certain governmental
 399 requirements or guides. Other highly positively perceived benefits included reducing the

400 demand on landfill spaces and saving natural materials, consistent to the findings of Tam (2009)
401 in the study of concrete recycling practice in Japan and Australia. The cost-related items in
402 Table 2 ranked relatively low in their *RII* values, which conveyed the information that lowering
403 cost by reusing the recycling C&D wastes might still be uncertain compared to other benefit-
404 related items.

405 An open-ended question was asked in order to gain more perceptions of survey
406 participants on extra benefits not listed in Table 2. The open responses received can be
407 summarized from financial, social, and environmental perspectives:

- 408 • In the financial aspect, some respondents specified the tax incentive by recycling and
409 reusing C&D wastes.
- 410 • Survey participants also mentioned that recycling C&D waste would reduce the safety-
411 related risks caused by landfilling wastes.
- 412 • It was also mentioned by survey participants that C&D wastes had been placed illegally
413 somewhere when local landfill space was full or unavailable. Recycling and reuse of C&D
414 wastes could also reduce the illegal waste placement.
- 415 • Respondents also perceived that recycling and reusing C&D wastes could promote the
416 environmental friendliness by reducing pollutions, enabling the benchmarked “green”
417 procedure of recycling and reusing wastes, and turning wastes into useful resources.

418 The overall survey sample was further divided into subgroups according to participant
419 occupations, shown earlier in Fig.3, and prior experience in C&D waste treatment. Table 3
420 displays the ANOVA conducted to test the subgroup differences in each of the seven benefit-
421 related items.

422

423

424

425 Table 3. Subgroup analysis of survey participants' perception towards benefits in recycling and
 426 reusing C&D wastes
 427

Item	Overall Mean	Standard deviation	ANOVA analysis for subgroups according to occupations		ANOVA analysis for subgroups with and without prior experience	
			F value	p value	F value	p value
B1	4.406	0.635	0.02	0.999	0.55	0.462
B2	4.333	0.810	0.66	0.625	0.67	0.417
B3	4.290	0.730	0.71	0.589	1.72	0.194
B4	4.227	0.602	1.24	0.304	1.19	0.279
B5	4.057	0.832	0.19	0.943	0.01	0.921
B6	3.944	0.969	0.52	0.723	2.57	0.113
B7	3.800	1.030	2.35	0.064	1.09	0.301

428

429 Subgroups from different professions were found without significant differences in their
 430 perceptions, according to the low *F* statistics and corresponding *p* values all higher than 0.05
 431 in Table 3. Similar results were found in subgroup analysis for survey participants with and
 432 without prior experience in C&D waste reuse and recycling. It is therefore inferred that survey
 433 participants from different professions shared consistent views on benefits related to C&D
 434 waste recycling and reuse, and their perception was not affected by whether they had relevant
 435 previous experience or not.

436 *4.2.3. Difficulties encountered in C&D waste recycling and reuse*

437 Survey participants were asked of their opinions on difficulties or barriers encountered
 438 during C&D waste recycling and reuse. In total 20 Likert-scale items were provided in this
 439 category. They were listed in Table 4 following their *RII* values calculated. The overall
 440 Cronbach's alpha value at 0.9275 indicated very high internal consistency of the 20 items
 441 within this difficulty-related category.

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447 Table 4. Data analysis of the overall survey sample regarding difficulties in C&D waste
 448 recycling and reuse (Cronbach's alpha = 0.9275)

Item	Percentage of selecting each Likert-scale option (%)					N*	RII	Item-total correlation	Cronbach's Alpha
	1	2	3	4	5				
D1: Lack of demand from the client on C&D waste recycling and reuse	1	3	4	54	38	69	0.846	0.6722	0.9234
D2: Lack of supervision and regulations in C&D waste recycle and reuse	2	3	8	52	36	66	0.836	0.5795	0.9246
D3(1)*: Lack of industry standards in C&D waste recycling and reuse	1	7	4	51	36	69	0.826	0.7143	0.9222
D3(2)*: Lack of industrial awareness and support for C&D waste recycling	1	4	9	51	35	69	0.826	0.4635	0.9267
D5: Lack of governmental support	1	7	11	39	42	72	0.825	0.4870	0.9264
D6: High cost and labor-intensiveness in separating industrial wastes	0	4	12	52	32	73	0.822	0.6392	0.9233
D7: Lack of sufficient C&D waste recycling practitioners	0	8	10	48	34	71	0.814	0.5872	0.9243
D8: Insufficient AEC companies' support in developments of technology, resource, training and human resource	0	3	17	51	29	69	0.812	0.5786	0.9245
D9: Lack of participation and training of employees in C&D waste recycling and reuse	3	6	7	57	28	72	0.803	0.7141	0.9225
D10: High cost for transportation between jobsites and waste diversion facilities	0	5	16	51	27	74	0.800	0.6135	0.9238
D11: Lack of balance between demand and supply in the recycling and reuse market	1	4	17	50	27	70	0.794	0.7256	0.9218
D12: The cost for waste diversion is higher than traditional landfilling	1	10	13	43	33	70	0.791	0.7455	0.9207
D13: Insufficient investments in the scientific research of C&D waste diversion	0	6	19	53	23	70	0.786	0.5222	0.9255
D14: Increased work load such as recording and supervising C&D waste diversion	5	5	14	53	23	74	0.765	0.6663	0.9227
D15: Difficult to install and maintain recycling and reuse machines (e.g. crushers) on jobsites	3	10	16	46	25	69	0.759	0.5793	0.9251
D16: Increased maintenance and management cost spent in C&D waste diversion	4	7	24	38	27	74	0.754	0.5693	0.9251
D17: Difficult to establish a waste recycling plan for an individual project	1	14	14	46	23	69	0.751	0.6047	0.9240
D18: Causing changes in companies' existing management policy and working mechanisms	3	15	13	49	21	72	0.739	0.6447	0.9231
D19: Inferior quality of products containing recycled contents	3	10	24	43	19	67	0.731	0.5274	0.9255
D20: Limited applications for recycled products	3	15	15	49	18	72	0.728	0.5615	0.9249

449 *: Two items within this category received the same RII value at 0.826 and ranked 3rd among all items. Therefore, they were
 450 denoted as D3(1) and D3(2).
 451
 452

453 All individual Cronbach's alpha values in Table 4 lower than the overall value showed
 454 that each item contributed positively to the consistency. Among these items, D3(1), D9, D11,
 455 and D12 turned out with higher contribution to the internal consistency according to their lower
 456 individual Cronbach's alpha values and higher item-total correlations (i.e., over 0.7000). In
 457 other words, survey participants' perceptions towards difficulties related to lack of industry

458 standards, insufficient participation and training, unbalanced between supply and demands, as
459 well as higher cost were highly correlated to the rest of difficulty-related items. In contrast,
460 survey participants' opinions on D3(2) (i.e., lack of industrial awareness and support for C&D
461 waste recycling and D5 (i.e., lack of governmental support) tended to be more independent
462 with what they viewed on the other items in Table 4. It could be inferred that respondents
463 generally had a higher recognition on these two items and their perceptions were not affected
464 by other difficulty-related items.

465 It is seen in Table 4 that the first ten items had *RII* values equal to or over 0.800, which
466 was corresponding to a mean Likert score value at 4.00, which meant that survey participants
467 tended to have a higher recognition of these difficulties, among which the top ranked item was
468 the lack of client demands on C&D waste. It was stated by Lu et al. (2016) that clients play the
469 leading role in environmental protection and closely monitor contractors' construction waste
470 practices, and hence making a significant difference to contractors' waste management
471 performance. Besides the insufficient client requirements, lack of regulations, industry
472 standards, and industry awareness were also perceived as major barriers in recycling and
473 reusing C&D wastes. These high-ranked items in Table 4 conveyed the information that there
474 could be potentially better-established technical guidelines and standards in mainland China to
475 drive the C&D diversion movement. Similar challenges in terms of lack of governmental
476 legislatives and public practices had been identified in other developing countries' C&D waste
477 diversion, such as that in Vietnam (Lockrey et al., 2016).

478 Survey participants were further asked about other difficulties or challenges encountered
479 in recycling and reusing C&D wastes. The findings could be summarized in terms of cultural,
480 economic, and other aspects.

- 481 • The most frequently mentioned barriers turned to be cultural resistance to products or
 482 projects using C&D wastes. Specifically, end-users and public currently had doubt or
 483 uncertainty of living or working in a building containing recycled C&D waste streams.
- 484 • Economic issue was another barrier in implementing C&D waste diversion, according to
 485 open-ended responses received. Survey participants revealed that: 1) the cost of treating
 486 C&D wastes other than directly landfilling them was high without financial aids; 2) the
 487 return on investment in diverting C&D wastes were low and AEC companies could not see
 488 the best economic benefits; 3) it was also costly to categorize different C&D wastes; 4)
 489 contractors were unwilling to spend extra budget on C&D waste diversion.
- 490 • Some other difficulties included lack of locally qualified companies in dealing with C&D
 491 wastes, hard to collect C&D wastes discreetly distributed across different locations, and
 492 some individual projects did not generate large amount of C&D wastes and hence not worth
 493 the cost of recycling.

494 Subgroup analysis was also conducted and summarized in Table 5. The overall sample was
 495 divided according to their occupations and prior experience in C&D waste recycling and reuse.

496
 497 Table 5. Subgroup analysis of survey participants' perception towards barriers in recycling and
 498 reusing C&D wastes
 499

Item	Overall Mean	Standard deviation	ANOVA analysis for subgroups according to occupations		ANOVA analysis for subgroups with and without prior experience	
			F value	p value	F value	p value
D1	4.232	0.789	1.14	0.347	0.60	0.440
D2	4.182	0.821	0.54	0.705	1.42	0.239
D3(1)	4.130	0.906	0.52	0.724	0.04	0.835
D3(2)	4.130	0.856	0.74	0.569	0.00	0.951
D5	4.125	0.963	0.85	0.500	1.71	0.195
D6	4.110	0.774	1.60	0.186	0.13	0.719
D7	4.070	0.884	2.16	0.084	1.29	0.260
D8	4.058	0.765	0.43	0.786	2.87	0.095
D9	4.014	0.911	0.25	0.908	0.17	0.681
D10	4.000	0.811	1.22	0.312	0.76	0.387
D11	3.971	0.868	1.61	0.183	1.31	0.257
D12	3.957	0.999	1.16	0.337	1.98	0.164
D13	3.929	0.804	1.14	0.345	1.65	0.203
D14	3.824	1.025	0.50	0.733	1.64	0.204
D15	3.797	1.023	3.89	0.007*	1.07	0.304
D16	3.770	1.054	0.93	0.454	1.19	0.278
D17	3.754	1.020	1.43	0.235	0.05	0.831

Table 5 cont.						
D18	3.694	1.057	1.80	0.139	0.32	0.573
D19	3.657	1.008	1.43	0.236	5.20	0.026*
D20	3.639	1.039	2.54	0.048*	2.48	0.120

*: *p* value lower than 0.05 indicates significantly different perceptions among subgroups towards the given item

501 While generally all subgroups shared consistent views on items related to difficulties
502 encountered in C&D waste management, there were a few significantly different perceptions
503 among subgroups in D15, D19, and D20:

504 • Material suppliers and construction managers tended to perceive more difficulties in
505 installing and maintaining recycling and reuse facilities on jobsites, with average Likert
506 score at 4.111 and 4.000 respectively. In comparison, the average Likert scores in
507 subgroups of engineers & consultants and others reached 3.600 and 3.778 respectively,
508 indicating that these two subgroups had the perception between “agree” and “neutral”
509 towards D15. In contrast, respondents from research institutions had the perception below
510 “neutral”, with average score at 2.923. It could be inferred that material suppliers and
511 construction managers, who had more jobsite experience, would consider more difficulties
512 on placing recycling facilities, compared to those professions with less site exposure, such
513 as researchers.

514 • All those professionals directly involved in C&D recycling and reuse were prone to have
515 an attitude between “agree” and “neutral” regarding the limited applications of recycled
516 products, with average Likert scores at 3.763, 3.000, 3.200, and 3.286 respectively for
517 material suppliers, construction managers, engineers & consultants, and researchers.
518 However, other professions (e.g., environmental protection agency, authorities, and
519 entrepreneurs) perceived more difficulties on the applications of recycled C&D wastes,
520 with the average score at 4.333. This differed perception from other professions could be
521 due to the fact that they tended to view the difficulty at the macro level from social and
522 economic perspectives and hence might see more barriers in marketing products containing
523 recycled streams. In comparison, the remaining professionals were mostly direct

524 practitioners within C&D waste management field, they might view the applications of
 525 recycled products more from the technical perspective.

- 526 • Survey participants with and without prior experience in C&D waste diversion held
 527 significantly different views on the quality issue of products containing recycled materials.
 528 Those without previous project experience in C&D wastes tended to perceive it more a
 529 problem of qualities in recycled products, with an average Likert score at 3.895, while those
 530 with prior experience would consider it less a problem in quality issues (average Likert
 531 score at 3.345). This could be due to the fact that gaining project experience in C&D waste
 532 diversion will provide more confidence to professionals on quality of recycled products.

533
 534 *4.2.4. Suggestions to improve C&D waste recycling and reuse*

535 This category focuses on suggestions to improve C&D waste recycling and reuse. Survey
 536 participants were asked of their perceptions on the importance of nine Likert-scale items, which
 537 are listed in Table 6 in the order according to their overall *RII* values.

538 Table 6. Data analysis of the overall survey sample regarding suggestions in enhancing
 539 C&D waste recycling and reuse (Cronbach's alpha = 0.8537)
 540

Item	Percentage of selecting each Likert-scale option (%)					N*	RII	Item-total correlation	Cronbach's Alpha
	1	2	3	4	5				
S1: Mandatory requirement or financial incentives from governmental authorities	0	0	6	40	54	63	0.895	0.5910	0.8372
S2: Categorizing recyclable wastes according to the application of recycled products	0	1	3	52	43	69	0.875	0.6204	0.8340
S3: Including C&D waste recycling and reuse in the early project stages	0	1	7	44	47	68	0.874	0.5714	0.8389
S4: Effective communication among clients, engineers, contractors and consultants	0	1	4	51	43	68	0.871	0.7467	0.8208
S5: A comprehensive and accurate evaluation on the return on investment	0	1	9	49	41	69	0.858	0.5098	0.8456
S6: Enhancing C&D waste recycling technologies	0	0	11	51	38	65	0.855	0.6475	0.8311
S7: Promoting training of C&D waste recycling in the industry	1	0	6	59	34	70	0.849	0.6896	0.8289
S8: Enhancing trainings and management of C&D waste recycling within AEC companies	1	3	3	62	31	71	0.837	0.5459	0.8412
S9: Increasing the tipping fee for landfilling C&D wastes	0	3	16	48	33	67	0.821	0.3409	0.8657

541

542 The Cronbach's alpha value at 0.8537 indicated high internal consistency among the nine
543 items. However, S9 (i.e., increasing the tipping fee for landfilling C&D wastes) had its
544 individual Cronbach's alpha value higher than the overall value, indicating that S9 was the only
545 item that did not contribute to the internal consistency. The item-total correlation of S9 also
546 appeared low at 0.3409, which means that respondents tended to have an independent view on
547 it compared to what they did to other eight items.

548 Excluding those responses claiming unsure to the given item, it can be found from Table 6
549 that the majority of survey participants chose "4" or "5" in all these Likert-scale items,
550 indicating they would positively suggest or strongly recommend these methods in improving
551 C&D waste diversion. It is seen in Table 6 that all nine suggestions were received with positive
552 perceptions among survey participants, with *RII* values higher than 0.800, or corresponding
553 average Likert scores over 4.000. Similarly to two other categories, the governmental influence
554 was considered one of the top driving factors in moving forward C&D waste recycling and
555 reuse. Governmental support, either mandatory requirement or financial incentives, was ranked
556 as the top recommendation in enhancing C&D waste diversion. Other suggestions perceived
557 highly positive included S2 (i.e., categorizing C&D wastes according to their applications), S3
558 (i.e., earlier project delivery stage involving C&D waste management plan), and S4 (i.e., multi-
559 party communications on C&D waste diversion).

560 The open-ended question was asked to collect more insights from participants on extra
561 suggestions in driving C&D waste diversion. The governmental requirement and monitoring
562 was still the most frequently mentioned suggestion. Some other suggestions were also provided
563 from the survey sample and could be summarized below.

- 564 • The state-of-the-art practices could be demonstrated in C&D waste recycling and reuse at
565 certain provincial and municipal levels. This could potentially lead to knowledge transfer
566 in the relevant field.

- 567 • Public guidelines and effective monitoring to sustainability practice from the authority were
 568 important to continuously implement C&D waste diversion.
- 569 • Public or government-funded projects should consider it a priority using products
 570 containing C&D wastes as the way to show the public the government attitude and effort
 571 in promoting C&D waste recycling and reuse.

572 Survey participants were tested of subgroup perceptions towards the nine given suggestions.
 573 The survey sample was divided into subgroups based on their occupations and prior experience
 574 in C&D waste management. Table 7 displays the ANOVA results.

575 Table 7. Subgroup analysis of survey participants' perception towards suggestions in
 576 improving practices of recycling and reusing C&D wastes
 577

Item	Overall Mean	Standard deviation	ANOVA analysis for subgroups according to occupations		ANOVA analysis for subgroups with and without prior experience	
			F value	p value	F value	p value
S1	4.476	0.618	0.81	0.526	2.29	0.135
S2	4.377	0.621	0.65	0.629	0.32	0.571
S3	4.368	0.689	0.55	0.699	0.55	0.460
S4	4.353	0.641	0.06	0.993	3.08	0.084
S5	4.290	0.688	2.04	0.099	0.84	0.364
S6	4.277	0.650	0.75	0.560	2.24	0.140
S7	4.243	0.690	2.56	0.047*	0.00	0.988
S8	4.183	0.743	1.07	0.377	1.99	0.163
S9	4.104	0.781	4.07	0.005*	1.58	0.213

578 *: p value lower than 0.05 indicates significantly different perceptions among subgroups towards the given item

579
 580 There were generally consistent views on items listed in Table 7 among subgroups,
 581 especially for subgroups with and without previous experience, except that:

- 582 • Compared to participants from other occupations who would strongly suggest promoting
 583 the industry-wide training on C&D waste recycling, with the average Likert score ranging
 584 from 4.111 to 4.600, the subgroup of construction management showed less positive view
 585 on the same suggestion with Likert score at 3.500. This could be due to the fact that
 586 construction management is the profession that has most exposure and direct experience in
 587 C&D waste treatment, and it could be in their perception that relevant training was not the
 588 most critical factor compared to other factors in enhancing waste recycling and reuse.

589 • Professionals from other occupations including material supplier, construction
590 management, research, and others were highly positive on the suggestion to increase the
591 tipping fee for landfilling wastes, with average Likert score ranging from 4.000 to 4.263.
592 In contrast, engineers & consultants had a low recognition on this item, with the average
593 Likert score at 2.750 indicating their perception between “unimportant” and “neutral”.

594

595 **5. Discussion**

596 This study aimed to investigate the current stage of C&D waste recycling and reuse practice
597 in China. It started from describing the big picture of China’s C&D waste diversion movement
598 in terms of governmental policy changes and industry practice. The questionnaire-based
599 approach was later adopted to study perceptions of participants, specifically focusing on the
600 three major categories (i.e., benefits, difficulties, and suggestions) in China’s C&D waste
601 recycling and reuse.

602 **5.1. The overview of China’s C&D waste management practice**

603 China generates a tremendous amount of C&D waste annually compared to some
604 developed countries or regions (e.g., U.S and Europe), and the average generation rate of C&D
605 waste measured by unit land area or per capita is also comparatively high. Compared to
606 developed countries, the landfilling charge in China is significantly lower, which could be one
607 cause of low C&D waste recovery rate in China. It is worth noticing that the average values of
608 C&D waste in China does not reflect the regional status, especially those more developed or
609 populous regions such as Shanghai and Beijing, where the C&D generation per km^2 or per
610 person daily is significantly higher than China’s national average value. It is implied that
611 diversion of C&D wastes within these metropolitan regions are more urgent, as C&D wastes,
612 if not properly treated, could further occupy the limited land sources. Recent movements of
613 C&D waste diversion from both governmental regulations and industry implementation in

614 China has indicated the ongoing trends of technical standard development for waste diversion.
615 It should be realized that although there have been changes in policy and guideline to promote
616 the sustainable treatment of C&D waste from all the three governmental levels (i.e., state,
617 provincial, and municipal) in China, the current C&D waste recycling and reuse in China is
618 still at the early development stage compared to developed countries or region (e.g., Japan). A
619 long-term effort towards the higher recovery of C&D waste could be expected in China starting
620 from these few metropolitan areas (e.g., Chengdu) where the municipal governmental
621 guidelines have been announced.

622 **5.2. Benefits and difficulties within C&D waste recycling and reuse**

623 Practitioners had a high awareness of governmental policies in C&D waste management.
624 All governmental policies, guides, or support related items were ranked as the most important
625 or key issues in each of the three categories with this questionnaire survey. Besides complying
626 with governmental policies, other main benefits of recycling and reusing C&D wastes received
627 with highly positive perceptions included lowering the demands on landfilling space and saving
628 natural resources, which were also considered top benefits of concrete recycling in the study
629 conducted in U.S (Jin et al., 2015) and Australia and Japan (Tam, 2009).

630 Governmental supportive policies in terms of mandatory requirements or financial
631 incentives, guidelines, and effort in monitoring the industrial behavior of recycling and reusing
632 C&D wastes were perceived as playing a significantly important role in promoting the C&D
633 waste diversion practice. However, it was also mentioned by survey participants that the lack
634 of governmental support and insufficient awareness or effort from the government side would
635 become one of the major barriers. It should be noticed that although policies from the state
636 government and certain provincial authorities have been established in encouraging the
637 sustainable C&D waste treatment, the implementation at local or municipal level could vary
638 significantly depending on some factors such as the local governmental guideline and recycling

639 facilities of local AEC companies. The availability of well-established regulations and
640 standards was also identified as one major concern in treating C&D wastes. In comparison,
641 other potential problems associated with implementing C&D waste diversion, such as
642 increased work load and management cost, the extra cost of recycling wastes, as well as limited
643 applications and lower qualities of recycled products were not perceived as top challenges.
644 Responses from open-ended questions revealed another barrier of applying recycled products
645 due to the public cultural resistance.

646 Generally, the cross-country comparison revealed that developing countries, such as
647 China in this study and Vietnam in the study of Lockrey et al. (2016), would be more likely to
648 claim governmental support and legislation with top importance in enhancing C&D waste
649 recycling and reuse. In contrast, investigations conducted in developed countries, such as U.S
650 (Jin and Chen, 2015) and Australia and Japan (Tam, 2009) would find governmental
651 restrictions on waste generation with less impact on C&D waste diversion. Economic
652 feasibilities and governmental supervisions were identified as two key factors affecting China's
653 C&D waste management (Zhao et al., 2010; Wu et al., 2016), and this study further implied
654 that survey participants perceived more influence from governmental policy than economic
655 motivations. This could be due to the fact that China is still at the beginning stage of
656 implementing C&D waste recycling and reuse nationwide, and governmental guide would play
657 a more significant role in influencing industry behaviors. Nevertheless, as the recycling market
658 is growing and developing its own economic mechanism, eventually the economic viability
659 would be a determining factor in C&D waste management, as what is now seen in the market
660 of some developed countries such as Japan, where recyclers are more capable to make ends
661 meet without governmental aid.

662

663

664 **5.3.Subgroup perceptions towards C&D waste diversion**

665 Although the perceptions of the survey population towards the three major categories
666 within C&D waste diversion were mostly consistent crossing different occupations and
667 generally unaffected by their prior experience, certain significant subgroup differences were
668 identified on survey sample's perceptions. For example, professionals from engineering design
669 and consulting firms had the most positive view on promoting industrial training on C&D waste
670 recycling, but with significantly lower recognitions on increasing the tipping charge of
671 landfilling wastes. Differing from engineers and consultants, construction management
672 professionals held more conservative opinion on promoting the industrial training on C&D
673 waste diversion. Those with prior experience in C&D waste recycling or reuse would hold
674 more positive view on the qualities of recycled products, and those with more direct exposure
675 to C&D waste management were more likely to be more optimistic on the applications of
676 recycled C&D wastes.

677 **5.4.Suggestions to promoting C&D waste management in China**

678 All suggestions listed in this study in improving C&D waste management were positively
679 perceived by the survey sample. Based on the responses collected from the review of existing
680 practice and questionnaire survey, several recommendations to improve China's C&D waste
681 recycling and reuse are provided:

- 682 • Continuous work on establishing regulations and standards in sustainable treatment of
683 C&D wastes, especially those related to categorizing C&D wastes according to their
684 applications, and certain policies (e.g., incentives for recycling C&D wastes);
- 685 • Enhancements of clients sophistication aiming to increase the demand on recycling and
686 reusing wastes through possible approaches such as demonstration and knowledge transfer
687 starting from public sector projects involving C&D waste diversion;

- 688 • Government or authority work in both provincial and municipal levels to be further
689 implemented, including but not limited to specified requirements on site waste recycling
690 and reuse, incentives to encourage waste diversion, and promoting industry-wide trainings
691 in relevant fields;
- 692 • Communicating and specifying C&D waste management work in the early project design
693 or procurement stage by involving multiple project parties (e.g., engineers, contractors, and
694 consultants);
- 695 • Continuing development of technologies to improve the quality of recycled products and
696 exploring potential applications of products containing recycled streams;
- 697 • Further investigation of economic feasibility and governmental supervision strategies
698 aiming to nurture the local recycling markets.

699

700 6. **Conclusions**

701 This study adopted a holistic approach in investigating the current status of C&D waste
702 recycling and reuse in China. Quantitative data including China's C&D waste generation were
703 provided and discussed in comparison with some developed countries or region (i.e., Australia,
704 Europe, Japan and U.S). The urgency of diverging C&D wastes in metropolitan and
705 surrounding regions (e.g., Shanghai and Beijing) was addressed. Some governmental policies
706 and guides from state, provincial, and municipal levels on enhancing diversion of C&D wastes
707 were reviewed together with the existing applications of recycled products (e.g., masonry
708 bricks). It could be foreseen that China is moving towards the sustainable treatment of wastes,
709 although the long-term work in C&D waste diversion can be expected. The second part of the
710 study adopted a questionnaire-based survey by recruiting professionals from multiple
711 occupations involved in C&D waste management. Perceptions of the survey sample towards
712 benefits, difficulties, and suggestions related to C&D waste recycling and reuse were analyzed.

713 Governmental policies, guidelines, and strategies were perceived as one key driving factor in
714 implementing C&D waste diversion in China. Other key issues identified in impacting C&D
715 waste diversion included clients' demands on waste treatment, availability of relevant industry
716 standards, classifying C&D wastes, and multi-party communication of C&D waste
717 management in the early project stage. Responses collected from open-ended questions also
718 provided insights on suggestions in enhancing C&D waste management practice, for example,
719 demonstrating sustainable use of C&D wastes from government-funded projects, which could
720 be one strategy in handling the public cultural resistance to products with recycled contents.

721 This empirical study serves as the extension from previous research on C&D waste
722 management by combining review of state-of-the-art implementation and questionnaire-based
723 approach which provides information on whether professionals' occupation or prior experience
724 would affect their perceptions. The findings obtained from this study could provide insights to
725 relevant stakeholders in studying the strategies or making decisions of implementing C&D
726 waste diversion. Critical factors in implementing C&D waste management could be applicable
727 crossing countries, such as governmental influence, cultural acceptance to recycled products,
728 and multi-party communications. It is implied that though a C&D diversion market (e.g.,
729 mainland China) at the initial stage might view governmental supervision as a key impact factor
730 in its own development, the economic viability would ultimately become the dominating factor
731 in C&D waste diversion business.

732 The survey sample in this questionnaire-based study mostly came from more populous or
733 developed regions along the eastern coast of China (e.g., Beijing, Shanghai, Guangdong,
734 Jiangsu, and Shandong), with limited size of sample from less developed or populous inland
735 regions. Although the survey results would be more applicable to these populous regions with
736 more urgent needs of C&D waste diversion, it could be implied that as China is undergoing the
737 continuous urbanization with more C&D wastes generated, other less developed regions could

738 also learn from the experience in these studied populous counterparts in the future. Future
739 research could focus on the follow-up evaluation of C&D waste diversion performance
740 according to relevant benchmarked criteria or governmental regulations, estimating the return
741 on investment of recycling and reusing C&D wastes through case studies, the effects of project
742 delivery method (e.g., integrated project delivery) on enhancing C&D waste diversion in the
743 early project stage, and the application of digital technologies (e.g., building information
744 modeling) in C&D waste management.

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937 **Appendix: Questionnaire Survey on Recycling and Reuse of Construction and Demolition**
938 **Waste**

939

940 *Background and Experience on Recycling and Reuse of Construction Waste*

- 941 1. Have you participated in any projects involving C&D diversion in the past three years? A. Yes B. No
942 2. Based on your work needs, do you plan to be involved in projects related to recycling and reuse of C&D
943 waste in the near future?
944 A. Yes B. No C. Unsure
945 3. Your working location. _____
946 4. Your career field. A. Construction materials B. Construction Industry C. Engineering design or
947 consulting D. Academics E. Others (Please specify).
948 5. What is the major way of disposing construction waste in the region where you work? A. Landfilling B.
949 Recycling and reuse C. Others (Please specify).
950 6. According to your experience, what are the main applications of the construction and demolition waste
951 recycling and reuse in your region? Multi choice. A. Wall materials (e.g. bricks and blocks) B. Recycled
952 aggregate concrete C. Precast concrete members D. Roadbase E. Others (Please specify).
953

954

955 *Perceptions on Recycling and Reuse of Construction and Demolition Waste*

956 **Please answer the benefits, difficulties and suggestions in construction waste recycling area. For the**
957 **following questions, the choices are 1-6 (1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5.**
958 **Strongly agree 6. Not sure)**

959

- 960 7. The benefit of construction and demolition waste recycling and reuse
961 • Saving space from landfills, reducing the demand for new waste landfills
962 • Saving natural materials
963 • Lowering project budget by using recycled materials
964 • Saving the transportation cost between construction site and landfills and saving the disposal cost
965 • Complying with the governmental policies of green building and environmental protection
966 • Enhancing the competitiveness and increasing business opportunities for AEC companies
967 • Motivating the entrepreneurs in the field of construction waste recycling and reuse
968 • Others, please explain _____
969
- 970 8. The difficulties of construction and demolition waste recycling and reuse
971 • High cost and labor-intensiveness in separating C&D wastes
972 • High cost for transportation between jobsites and waste diversion facilities
973 • Difficult to install and maintain recycling & reuse machines (e.g. crushers) on jobsites
974 • The cost for waste diversion is higher than traditional landfilling
975 • Increased maintenance and management cost spent in C&D waste diversion
976 • Difficult to establish a recycling plan for an individual project
977 • Increased work load such as recording and supervising C&D waste diversion related activities
978 • Causing changes in companies' existing management policy and working mechanisms
979 • Lack of participation and training of employees in C&D waste recycling and reuse
980 • Inferior quality of products containing recycled contents (e.g. strength reduction in recycled aggregate
981 concrete)
982 • Limited applications for recycled products
983 • Lack of balance between demand and supply in the recycling and reuse market
984 • Lack of investment in the scientific research of C&D waste diversion
985 • Not enough AEC companies' support in developments of technology, resource, training and human
986 resource in C&D waste recycling
987 • Lack of demand from the owner or investor side on C&D waste recycling and reuse
988 • Not enough construction waste recycle practitioners
989 • Lack of awareness and support for C&D waste recycling in the industry
990 • Lack of support from government
991 • Lack of supervision and regulations in C&D waste recycling and reuse
992 • Lack of industry standard in C&D waste recycling and reuse
993 • Others, please explain _____
994

995 **For the following questions, the choices are 1-6 (1. Least important 2. Unimportant 3. Neutral 4.**
996 **Important 5. Very important 6. Do not know)**

997

998 9. Suggestions in construction and demolition waste recycling and reuse

999 • A comprehensive and accurate evaluation on the return on investment of C&D waste recycling and reuse

1000 • Defining the categories of recyclable C&D wastes according to the application of the recycled product (e.g.
1001 red bricks, old concrete, mud and etc.)

1002 • Enhancing C&D waste recycle technologies

1003 • Including C&D waste recycling and reuse in the early project stages

1004 • Enhancing trainings and management of C&D waste recycling within AEC companies

1005 • Promoting training of C&D waste recycle in the industry

1006 • Effective communication among clients, engineers, contractors and consultants on C&D waste recycling
1007 and reuse

1008 • Mandatory requirement or financial incentives from governmental authorities for waste recycling on
1009 construction sites

1010 • Increasing the tipping fee for landfilling C&D wastes

1011 • Others, please explain _____

1012