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Main Challenges to Concrete Recycling in Practice

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Abstract: While concrete recycling is crucial to protecting the environment, its implementation in practice is low in many countries. This study aims to highlight challenges to concrete recycling. To achieve that aim, the study objectives are (1) to identify the main challenges to concrete recycling in construction projects; (2) to compare the main challenges between small–medium enterprises (SMEs) and large enterprises (LEs); and (3) to determine the underlying groups among the main challenges. Potential challenges were identified through a systematic literature review of journal articles and semi-structured interviews with fifteen industry practitioners. Then, the identified challenges were inserted into a questionnaire survey and distributed to industry practitioners. Eighty-nine valid responses were collected and analyzed using the mean score ranking, normalization, agreement analysis, and factor analysis techniques. The analyses show thirteen main challenges to concrete recycling. The main challenges include increased project duration, lack of national programs, lack of comprehensive rules and regulations, increased project cost, low demand for recycled concrete, low cost-effectiveness of concrete recycling, and increased transportation cost. However, there is no consensus on the criticality between SMEs and LEs. For example, increased project cost is the main challenge for SMEs but is only middlingly ranked for LEs. Finally, the main challenges can be categorized into three interrelated groups: people and technical, legal and environmental, and economic challenges. This study contributes to the literature by analyzing challenges that hinder concrete recycling in practice. The findings allow researchers and practitioners to develop strategies to reduce concrete recycling rejection.

Keywords: sustainable development; sustainable construction; waste management; construction and demolition waste; concrete recycling; challenges

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1. Introduction

The construction sector is crucial to any country's socioeconomic progress [1]. The construction sector is experiencing rapid growth due to rising living standards, increased demand for infrastructure projects, shifting shopping habits, and natural population growth. As a result of this advancement, concrete output has increased significantly during the construction and demolition stages [2]. Consequently, concrete waste has evolved into a global environmental hazard that necessitates a rapid response. Concrete waste that is not properly disposed of can be harmful to the environment. As a result, concrete waste is a source of pollution that, if not managed properly, can become a major problem in any country [3]. Since concrete waste is seen as having little or no value, contractors may opt to dispose of it in landfills rather than recycling facilities. Furthermore, contractors and project owners may suffer additional costs as a result of managing concrete waste. In this context, treating concrete waste is no longer an option; rather, it is required.

Concrete recycling, which involves transforming concrete waste into recycled aggregates, is one of the most successful methods of managing concrete waste [4]. Moreover, concrete recycling is a must-do practice for reducing concrete waste's environmental impact [2]. In other words, concrete recycling has immense potential [5]. As a result of the numerous advantages of concrete recycling, several governments, particularly in developed nations, have begun to mandate it. In comparison, our global concrete recycling rate remains low at approximately 5% [5]. Specifically, this rate is common in developing countries [6]. One probable explanation is that countries with abundant natural resources and many landfill areas are unwilling to use recycled materials. Furthermore, the dynamism of construction operations impacts the efficiency of concrete recycling in construction projects [7]. Therefore, to encourage concrete recycling, it is important to understand the challenges that prevent it from successfully implementing in construction projects.

This study aims to highlight challenges to concrete recycling in construction projects. To achieve that aim, the study objectives are (1) to identify the main challenges to concrete recycling in construction projects; (2) to compare the main challenges between organization sizes; and (3) to determine the underlying relationships among the main challenges. Achieving these objectives allows the study to provide several novel outputs, including a list of main challenges to concrete recycling. Additionally, any significant difference in the criticality between organization sizes is provided. Finally, the study illustrates the root cause of concrete recycling. These outputs contribute to the construction and environmental management body of knowledge by providing a better understanding of the main challenges that hinder concrete recycling in practice.

2. Literature Review

Researchers and practitioners are investigating a wide range of issues related to construction waste recycling. Prior works have highlighted essential factors influencing construction waste recycling implementation. For example, in Kuwait, four factors influence the recycling of construction waste: the purity of the recycled material; the cost of collection and transportation; the cost of sorting, transformation into reusable material, and disposal costs of any residual material to landfills or incineration; and the requirement that recycled materials meet the relevant specifications and standards [8]. Similarly, data collected from various sources and questionnaire surveys with cement manufacturers, contractors, and project managers in Thailand reveal that the most important factors influencing the Thai industrial sector are cement quality, the source of law and regulations, standardization, price, and confidence [9]. According to the data, the most crucial aspect in deciding whether to recycle construction and demolition waste is market and site activity. It is the most essential of the three elements and has the most sway. Furthermore, the limited number of available recycled markets and fierce competition within the business are important sources of concern [10]. Although earlier works have provided insights into the aspects that drive construction and demolition waste recycling, the results have also indicated that many factors may be involved. As a result, these factors must be investigated.

Clients and developers are increasingly attempting to set construction and demolition waste management requirements [11]. Udawatta et al. argued that clients and other construction and demolition project participants have fewer positive attitudes toward construction and demolition waste management practices [12]. Different reasons contribute to the difficulty of construction and demolition waste management practice in practice. Some of the reasons are the inability to predict the production environment, unique project characteristics, time pressure, and cost limitations [11]. Additionally, construction and demolition processes can produce waste due to improper handling and less management attention. For instance, main project team members provide more attention to construction materials than waste management. Construction and demolition waste management activities were considered unimportant to contractors [12]. Such negative thinking regarding construction and demolition waste has hindered the implementation of innovations that target its reduction [11].

Training and incentives for waste management operators to improve their knowledge and participate in less wasteful activities can help to promote a good attitude and viewpoint of construction and demolition waste management operations [11]. Researchers have emphasized the fundamental challenge to waste reduction in developing countries [11,13]. According to one of the issues, uncertainty about the leadership commitment and support for construction and demolition waste reduction has influenced the attitudes of project team members, contributing to a lack of resources, workforce, and time available for construction and demolition waste management activities. The second cause of the difficulty is the lack of construction and demolition waste management performance criteria. The third hindrance to advancement is the construction industry's unwillingness to adapt its established work routines. Furthermore, the fourth point is that waste reduction activities are primarily motivated by financial gain. Finally, one of the difficulties with construction and demolition waste recycling in Canada is that the waste is bulky, difficult to compress, and takes up more space in the recycling process [14].

3. Method

A questionnaire survey is a systematic method for collecting quantitative data using a random sample [15]. This data collection approach has been extensively used in construction management research to solicit professional opinions. Surveys can come in various forms, such as electronic or postal mail. Usually, surveys are self-completed or self-administered, which means that respondents answer and complete the survey by themselves [16]. In construction management research, surveys are very similar to structured interviews. The clear difference is that self-completed surveys have respondents read the survey themselves. In addition, self-completed surveys have strengths compared to structured interviews: surveys are cheaper and quicker to administer, flexible to the interviewer's absence, have no interviewer variability, and are convenient for respondents [16]. In contrast, the disadvantages of self-completed surveys include the following: interviewers cannot guide respondents in completing the survey or request respondents for further elaboration as necessary. Due to these advantages, the study uses self-completed electronic surveys to examine the underlying relationship between the main challenges to concrete recycling in construction projects.

3.1. Developing the Survey

This study uses the systematic literature review (SLR) approach to conduct a thorough review of a list of potential challenges to concrete recycling in construction projects in the existing literature. The initial stage of the review involved a search using Scopus' 'title/abstract/keyword' features. Scopus was chosen as the search engine because it has a larger database than other search engines and is frequently used to review the literature [17]. The keywords used were recycl* AND concrete AND construction AND project*. To narrow the scope to the construction engineering and management body of knowledge, this search filters the papers to subject areas of 'engineering,' 'material science,' 'environmental science,' 'business, management, and accounting,' 'economics, econometrics, and finance,' 'social science,' and 'decision science.' The search was conducted on 5 January 2020, yielding 193 results. The latter stage involves a visual examination of the title, abstract, and conclusion to select appropriate papers for the systematic review. Finally, 21 articles were retrieved and analyzed. The full search string was:

TITLE-ABS-KEY (recycl*) AND (concrete) AND (construction) AND (project)) AND (LIMIT-TO (SRCTYPE "j")) AND (LIMIT-TO (PUBSTAGE "final")) AND (LIMIT-TO (SUBJAREA "ENGI") OR LIMIT-TO (SUBJAREA "MATE") OR LIMIT-TO (SUBJAREA "ENVI") OR LIMIT-TO (SUBJAREA "BUSI") OR LIMIT-TO (SUBJAREA "SOCI") OR LIMIT-TO (SUBJAREA "ECON") OR LIMIT-TO (SUBJAREA "DECI") AND (LIMIT-TO (LAGE AND "ECON")

Along with the SLR, the survey development process entails a two-step procedure to ensure the survey's appropriateness and rationality. First, semi-structured interviews with fifteen industry practitioners were conducted to elicit missing challenges to concrete recycling from the existing body of knowledge. The interviews involve construction managers because these individuals have more experience than most personnel at construction sites. Then, a survey was developed using data from the SLR and interviews. Challenges with the same semantic content were combined, resulting in seventeen potential challenges to concrete recycling in construction projects (as listed in Appendix A). Second, the survey was reviewed by five project managers with more than ten years of experience in managing construction projects to ensure no ambiguous expressions or inappropriate terms in the survey. Additionally, the survey was pilot tested with four industry practitioners with several years of experience in the construction industry to discover additional or remove irrelevant challenges. Based on these procedures, the survey was finalized.

The finalized survey has two main sections. The first section elicits individual background data to determine the respondents' suitability before using the associated data for further analysis. The second section involves respondents evaluating the criticality of the 17 challenges using a 5-point Likert scale (1 = not critical, 2 = slightly critical, 3 = moderately critical, 4 = critical, and 5 = very critical). This scale was adopted because of its relative brevity [18]. Spaces were provided at the end of the seventeenth challenge for respondents to list and evaluate additional challenges to concrete recycling in construction projects. This approach ensures that all potential challenges were considered.

3.2. Collecting Survey Data

The target population comprises industry practitioners from construction organizations, including clients, consultants, and contractors. Additionally, the respondents should be from SMEs and LEs as per the local government's definition: SMEs are organizations with 5 to 50 full-time employees or annual sales turnover between USD 50,000 and USD 1.25 million, and LEs are organizations with more than 50 full-time employees or annual sales turnover more than USD 1.25 million.

The data collection starts by approaching industry practitioners who are directly involved in managing construction projects. Then, the initial respondents were requested to forward the survey to others. Finally, 89 valid responses were collected, as classified in Table 1. While the sample size is on the lower side, scholars generally agree that a minimum sample size of 30 is sufficient for statistical data analysis and drawing meaningful conclusions [19]. In addition, this number of responses is higher than the previous response rates of similar types of surveys [20]. Additionally, this study sought to emphasize the relative importance of the challenge rather than present the population's overall perception of the variables. This objective is consistent with other published work, such as identifying main factors for design–build implementation in public projects [21,22] and digital construction adoption in post-conflict low-income nations [23]. Therefore, the sample size is deemed sufficient.

3.3. Analyzing Survey Data

3.3.1. Reliability Test

The internal consistency of the seventeen challenges was tested using the Cronbach alpha method. The Cronbach alpha coefficient has a range of values between 0 and 1. A high alpha value suggests that a group of factors on a scale has a high degree of internal consistency and reliability. According to the results, the seventeen challenges have internal consistency and reliability coefficients of 0.897, indicating that they are internally consistent and reliable.

3.3.2. Mean Score Ranking Analysis

Statistical procedures such as descriptive means and standardization, rank agreement analysis, and factor analysis were used to analyze the data. Previous research used the mean score ranking analysis and normalization techniques to estimate the cost-effectiveness of optimization techniques for rehabilitating water distribution networks (Farouk et al., 2021). Similarly, the mean scores of the seventeen challenges were first computed and then utilized to generate the normalized values. Only variables with a normalized value of 0.50 or higher were deemed essential [24].

Table 1. Respondent profile.

Characteristics	Frequency	Percent	Years of Experience			
Organization size			<2	2–5	6–9	>10
Large enterprises	53	59.55%	4	18	24	7
Small–medium enterprises	36	40.45%	9	17	9	1
Subtotal	89	100.00%	13	35	33	8
% by year	-	-	14.61%	39.33%	37.08%	8.99%
Organization type						
Client	10	11.24%	3	5	2	0
Consultant	9	10.11%	1	7	0	1
Contractor	70	78.65%	9	23	31	7
Subtotal	89	100.00%	13	35	33	8
% by year	-	-	14.61%	39.33%	37.08%	8.99%
Number of projects involved						
1 to 5 projects	52	58.43%	13	28	9	2
6 to 10 projects	31	34.83%	0	5	22	4
More than 10 projects	6	6.74%	0	2	2	2
Subtotal	89	100.00%	13	35	33	8
% by year	-	-	14.61%	39.33%	37.08%	8.99%

3.3.3. Agreement Analysis

Afterwards, the mean and normalization values for all responder categories, including SMEs and LEs, were determined. It is worth assessing the level of agreement among organization sizes to identify consensus or inconsistencies and their potential implications for concrete recycling in construction projects. One method for quantitatively assessing agreements between respondent groups is the rank agreement factor (RAF) technique [25]. The RAF technique can assess the average absolute difference in the ranking of factors between two groups. In this study, respondents from LEs and SMEs can be grouped into groups one (R_{i1}) and two (R_{i2}), N is the number of items (seventeen challenges), and k is the number of judgments. The null hypothesis is "there is no good agreement in the ranking of challenges between LEs and SMEs." Therefore, the alternate hypothesis is "there is good agreement in the ranking of challenges between both groups." To test the null hypothesis, the percentage agreement was calculated using Equations (1) to (5).

The mean value of the total ranks (R) is given by

$$R = \frac{1}{N}\sum_{1=1}^{k}\left(R_{ij}\right) a. \tag{1}$$

The RAF is defined as

$$RAF = \frac{\sum_{i=1}^{N}\left|R_{i^1} - R_{i^2}\right|}{N}. \tag{2}$$

The maximum rank agreement factor (RAFmax) is given by

$$RAFmax = \frac{\sum_{i=1}^{N}\left|R_{i^1} - R_{j^2}\right|}{N}. \tag{3}$$

The percentage disagreement (PD) is given by

$$PD = \frac{\sum_{i=1}^{N}\left|R_{i^1} - R_{i^2}\right|}{\sum_{i=1}^{N}\left|R_{i^1} - R_{j^2}\right|} \times 10. \tag{4}$$

The percentage agreement (PA) is given by

$$PA = 100 - PD. \quad (5)$$

3.3.4. Factor Analysis

Factor analysis can uncover the underlying variables that explain the same association pattern when many variables are evaluated. To evaluate whether the data were suitable for factor analysis, the study used the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity. The KMO determines sample adequacy by measuring the size of partial correlation coefficients. In contrast, Bartlett's test of sphericity examines the relationship between an array of distinct variables. If Bartlett's test was significant ($p < 0.05$) and the KMO value was more than 0.50, the data were eligible for factor analysis [26]. To uncover relevant variables, factor extraction was required before completing the factor analysis. The eigenvalue is a numerical measure of how much a variable contributes to the groupings. This method was used to determine the importance of a variable, which was then used as a criterion. In most circumstances, it is advisable to keep variables with eigenvalues greater than one.

4. Results

4.1. Results for Mean Score Ranking Analysis

Table 2 shows the mean, standard deviation, and normalization values for each potential challenge to concrete recycling in construction projects. The results show that thirteen challenges have normalization values ≥0.50 and are therefore deemed the main challenges. 'Increased project duration' is the main challenge with the highest mean scores. The other main challenges are 'lack of national programs on concrete recycling,' 'lack of comprehensive rules and regulations on concrete recycling,' 'increased project cost,' 'low demand for recycled concrete,' 'low cost-effectiveness of concrete recycling,' 'increased transportation cost,' 'lack of technical knowledge in concrete recycling,' 'lack of knowledge on the value of concrete recycling,' 'tight timeframes between project activities,' 'lack of cooperation between project team members on concrete recycling,' 'lack of guidelines for concrete recycling,' and 'current practice in treating concrete waste.'

Table 2. Ranking of challenges to concrete recycling.

Code	Challenge	Mean	SD	NV [a]	Rank
CH15	Increased project duration	3.922	0.770	1.00 [b]	1
CH17	Lack of national programs on concrete recycling	3.887	0.810	0.93 [b]	2
CH06	Lack of comprehensive rules and regulations on concrete recycling	3.853	0.737	0.88 [b]	3
CH16	Increased project cost	3.793	0.774	0.79 [b]	4
CH07	Low demand for recycled concrete	3.767	0.848	0.74 [b]	5
CH02	Low cost-effectiveness of concrete recycling	3.724	0.840	0.68 [b]	6
CH04	Increased transportation cost	3.724	0.752	0.68 [b]	7
CH08	Lack of technical knowledge in concrete recycling	3.706	0.854	0.65 [b]	8
CH09	Lack of knowledge on the value of concrete recycling	3.698	0.804	0.63 [b]	9
CH14	Tight timeframes between project activities	3.672	0.862	0.60 [b]	10
CH05	Lack of cooperation between project team members on concrete recycling	3.655	0.895	0.58 [b]	11
CH12	Lack of guidelines for concrete recycling	3.637	0.858	0.53 [b]	12
CH11	Current practice in treating concrete waste	3.612	0.821	0.50 [b]	13
CH01	Lack of knowledge in using concrete recycling technologies	3.594	0.823	0.47	14
CH10	Insufficient space on-site to concrete recycling	3.569	0.896	0.45	15
CH03	Lack of support to concrete recycling	3.551	0.858	0.41	16
CH13	Insufficient time to develop plans for concrete recycling	3.293	1.095	0.00	17

Note: SD = Standard deviation; [a] NV = Normalized value = (mean − minimum mean)/(maximum mean − minimum mean); [b] Indicates the challenge is a main challenge (normalized value ≥0.50).

4.2. Results for Agreement Analysis

Table 3 presents the agreement analysis results between organization sizes (SMEs and LEs) on the thirteen main challenges to concrete recycling in construction projects. The percentage of agreement for the thirteen main challenges is 49%. In other words, there is no good agreement between LEs and SMEs on the main challenges. It is worth noting that eleven out of the thirteen main challenges have different rankings between organization sizes. Additionally, while 'increased project cost' is highly ranked for SMEs, this challenge is middlingly ranked for LEs. Furthermore, 'lack of technical knowledge in concrete recycling' and 'increased transportation cost' have large discrepancies between rankings (middlingly ranked for SMEs and lowly ranked for LEs). These discrepancies could be the main reason for the low level of agreement in ranking the thirteen main challenges between SMEs and LEs.

Table 3. Agreement analysis on the ranking of main challenges to concrete recycling.

Code	SMEs			LEs			Agreement Analysis		
	Mean	SD	Rank	Mean	SD	Rank	R_i	$\lvert R_{i1} - R_{i2} \rvert$	$\lvert R_i - R \rvert$
CH16	3.976	0.780	1	3.689	0.757	7	8	6	6
CH15	3.928	0.808	2	3.918	0.754	2	4	0	10
CH17	3.887	0.810	3	3.937	0.790	1	4	2	10
CH06	3.904	0.790	4	3.824	0.709	3	7	1	7
CH08	3.857	0.718	5	3.621	0.917	12	17	7	3
CH02	3.761	0.759	6	3.702	0.887	5	11	1	3
CH14	3.761	0.849	7	3.621	0.871	13	20	6	6
CH04	3.761	0.726	8	3.702	0.771	6	14	2	0
CH07	3.714	0.891	9	3.797	0.827	4	13	5	1
CH09	3.714	0.834	10	3.689	0.792	8	18	2	4
CH05	3.690	0.923	11	3.635	0.884	11	22	0	8
CH12	3.619	0.961	12	3.648	0.801	10	22	2	8
CH11	3.547	0.802	13	3.648	0.834	9	22	4	8
	Sum						182	38	74

4.3. Results for Factor Analysis

The obtained KMO value for the thirteen key challenges is 0.877, which is greater than the required minimum of 0.50. Furthermore, Bartlett's test of sphericity is 643.521 with a significance level of 0.00, demonstrating that the correlation matrix is not an identity matrix. Considering this, the data are appropriate for factor analysis. Finally, varimax rotation was applied to the thirteen key challenges, yielding three underlying groups that account for 61.64% of the overall variance (as shown in Table 4).

Table 4. Results of the factor analysis.

Code	Challenges to Concrete Recycling	Groupings		
		1	2	3
	Component 1: People and technical challenges			
CH12	Lack of guidelines for concrete recycling	0.731	–	–
CH08	Lack of technical knowledge in concrete recycling	0.725	–	–
CH11	Current practice in treating concrete waste	0.665	–	–
CH14	Tight timeframes between project activities	0.661	–	–
CH05	Lack of cooperation between project team members on concrete recycling	0.504	–	–
	Component 2: Legal and environmental challenges			
CH09	Lack of knowledge on the value of concrete recycling	–	0.780	–
CH17	Lack of national programs on concrete recycling	–	0.770	–
CH15	Increased project duration	–	0.730	–

Table 4. *Cont.*

Code	Challenges to Concrete Recycling	Groupings		
		1	2	3
CH06	Lack of comprehensive rules and regulations on concrete recycling	–	0.684	–
	Component 3: Economic challenges			
CH02	Low cost-effectiveness of concrete recycling	–	–	0.737
CH16	Increased project cost	–	–	0.666
CH07	Low demand for recycled concrete	–	–	0.630
CH04	Increased transportation cost	–	–	0.543
	Variance (%)	23.994	23.164	14.639
	Cumulative variance (%)	23.994	47.108	61.747

5. Discussion

5.1. Group 1: People and Technical Challenges

Group 1 consists of five main challenges: 'lack of guidelines for concrete recycling,' 'lack of technical knowledge in concrete recycling,' 'current practice in treating concrete waste,' 'tight timeframes between project activities,' and 'lack of cooperation between project team members on concrete recycling.' Therefore, this group is named 'people and technical challenges'.

5.1.1. Lack of Guidelines for Concrete Recycling

Companies with a concrete recycling culture recruit concrete recycling personnel, purchase concrete recycling equipment and machinery, and train employees. Other technical incentives include concrete recycling site space, concrete recycling technology, recycled material service competence, and the development of criteria and recommendations for using recycled materials [2]. Issues with concrete recycling worksite design include a lack of space for extra rubbish containers and record keeping for concrete removed from the site [27]. Deconstruction planning and management emphasize the importance of project planning. Creating a site plan for where worksite items will be processed, tracking construction components taken from the project, defining material recovery goals, and preparing how particular materials will be managed following removal are just a few examples.

5.1.2. Lack of Technical Knowledge in Concrete Recycling

The recycling of concrete is impeded by a lack of understanding of technical features and standards. Prescriptive project guidelines and procedures currently confine this new concept to designers and builders. Cases that deviate from the norm lack specified norms and precedence. Unique connecting methods may be necessary to maintain structural integrity due to the fast decommissioning of structural components. Professional builders must deconstruct safely. Uncertainty about construction materials leads to construction uncertainty. It is difficult to discern what structural materials are constructed. Therefore, pre-demolition inspections are needed. However, these inspections rarely contain material qualities. Additionally, waste materials necessitate difficult-to-separate chemical adhesives, complicating recycling even further. These materials should be avoided until safe disassembly techniques are identified.

5.1.3. Current Practice in Treating Concrete Recycling

Concrete structures are crushed, steel reinforcement and interior finishes are removed, and combined material is dumped indiscriminately into landfills. This demolition method is dangerous and time consuming, especially if the concrete is physically removed. Concrete waste is rarely recyclable. A slew of economic issues makes it difficult to market recovered aggregates from concrete waste [28]. Waste treatment plants can remove concretereinforcing steels. However, the presence of pollutant residues also necessitates cleaning, processing, inspection, and storage. Separation and treatment might be as expensive as raw aggregates [27]. To be economically recycled into aggregates, concrete waste must be processed on site, and recovered aggregates must be transported directly to the destination.

5.1.4. Tight Timeframes between Project Activities

Regarding demolition, deconstruction contractors frequently take the quickest path feasible. Contractors do not take the time to separate structural components methodically [29]. Abandoned structures are entirely demolished if it is determined that a new project will be erected on the site [30]. The passage of time is a clear and commonly acknowledged argument concerning careless demolition.

5.1.5. Lack of Cooperation of all Parties

Owners, contractors, subcontractors, waste haulers, architects, and designers are all examples of construction workers. Any interested parties that do not understand the construction project thoroughly can sabotage the entire process. Every project participant frequently lacks a clear understanding of the project objectives and a well-developed strategy, both of which must be communicated and monitored [27]. For example, assume that recycled aggregate must be stored and transported in some way. In this instance, even though it necessitates greater transportation costs, using virgin gravel is typically less expensive. Unfortunately, a prevalent misperception about recycled aggregate is that it is insufficient for new road construction compared to virgin material.

5.2. Group 2: Legal and Environmental Challenges

Group 2 consists of four main challenges: 'lack of knowledge on the value of concrete recycling,' 'increased project duration,' 'lack of comprehensive rules and regulations on concrete recycling,' and 'lack of national programs on concrete recycling.' Therefore, this group is named 'legal and environmental challenges.'

5.2.1. Lack of Knowledge on the Value of Concrete Recycling

Construction research, both private and academic, has been minimal. Despite the number of resources and retailers' and builders' global distribution, the public is uninformed about the possibility of reuse and the worth of existing materials. According to industry experts, most individuals are unaware that materials can be reused in their original state [29]. Modern structures are primarily comprised of prefabricated components that can be installed but not deinstalled. The government is hesitant to accept new criteria to promote material reuse in construction. The market should now recognize the benefits of planning and develop new economic models [31].

5.2.2. Increased Project Duration

Development will also be delayed by a modest increase in the time required to dismantle structures and reclaim the materials used in their construction. Structural component disassembly and salvage will take significantly longer than standard demolition methods. This is due to the care that must be taken to preserve and maintain the condition of the materials for repurposing. This means that prior agreement between the developers and the project team, including demolition contractors, is essential to complete project deliverables on time. Developers would be expected to specify the project criteria in the contract documents, including a realistic completion date [31].

5.2.3. Lack of Comprehensive Rules and Regulations on Concrete Recycling

Due to a lack of standards and approvals, reusing components is difficult. Most governments are hesitant about recycled components or outright prohibit them for structural or energy-efficient reasons. Construction and demolition waste minimization are addressed by several legislations, programs, and goals. Individuals would benefit from a comprehensive document that included all relevant environmental construction policies. The materials and construction methods utilized in a structure are occasionally unknown, impacting technical and economic feasibility. Material swaps and changes, on the other hand, are common. The only simple and effective solution is for a skilled professional to undertake a comprehensive pre-demolition survey. Additionally, comparing archival documents could assist the situation.

5.2.4. Lack of National Programs on Concrete Recycling

One of the greatest impediments for an effective recycling program is inadequate regulation and standards. Governments should implement legislation, policies, and long-term goals. For example, recycling in Japan is accomplished through retailer trade-in, barter system activities, and community-based methods. On the other hand, Germany governs deposit systems, waste disposal taxes, and recycling [32]. Municipal waste recycling is a relatively recent concept. Efforts to decrease waste through recycling or waste reduction must be planned. That is not to say that it is necessary to switch to more expensive and complex technologies simply because they are superior. Recycling programs should include the government, municipalities, households, and nongovernmental organizations [32].

5.3. Group 3: Economic Challenges

Group 3 consists of four main challenges: 'low cost-effectiveness of concrete recycling,' 'increased project cost,' 'low demand for recycled concrete,' and 'increased transportation cost.' All these factors are closely related to cost.

5.3.1. Low Cost-Effectiveness of Concrete Recycling

Since most concrete construction is cast-in-place, it is unique to the structure in which it is erected. This construction innovation presents dimension concerns, and the high shipping costs of concrete components make reuse impractical compared to new concrete [28]. Other financial incentives could include tax reductions for recycling-related projects or enterprises. Another option is to publicize construction and demolition projects so that material salvagers can take as much as possible ahead of time. Concrete structures are frequently constructed using a variety of methods, including cast-in-place or precast concrete members. Although it is common to remove concrete and use the debris as aggregates, deconstructing concrete or masonry is not cost-effective. The most significant constraint is the extra time required for the contractor to demolish the structure selectively.

5.3.2. Increased Project Cost

According to several industry practitioners, the construction approach, as opposed to traditional demolition and landfilling procedures, will result in higher overall project costs than the traditional demolition and landfilling technique [29]. Two specific impediments prevent the real estate development industry from making greater use of concrete waste: low demolition waste disposal costs, which commonly result in the absence of any financial penalty; and uncertain cost difficulties for existing construction, preventing the property development business from utilizing more concrete debris in its operations.

5.3.3. Low Demand for Recycled Concrete

Increasing the market for recyclables, the architectural salvage industry is growing. Structures and their components are rarely built to last. The construction industry acquires high-profit items. Unpopular items will not sell and will not be carried by retailers. These unpopular items include construction materials made from recycled resources. The market for structural components is underserved. Repurposing structural components to produce "new" items is difficult. Therefore, researchers are exploring approaches to repurpose recycled concrete including as construction materials e.g., [33–35], and geotechnical applications e.g., [36–38]. However, consumers may be hesitant to use these materials and applications because the minimum specifications have not been met. If there is no salvage market, there will be no construction. Inadequate market development jeopardizes construction. The resource recovery industry is divided into two distinct sectors: architectural specialty and antique parts, which appear to have existing or developing markets. This type of recycling is common throughout the country. The demand is huge, but the supply is limited. Salvaged construction equipment is commonly sold. For example, concrete is a relatively tiny substance.

5.3.4. Increased Transportation Cost

Transportation expenses are a large factor in the surge in concrete recycling prices in the United States. The most frequent kind of transportation is vehicle transportation, such as cars and trucks. As a result, gasoline is required, and the amount of waste transported by a single automobile or truck is highly constrained. Driving or driving a truck, as opposed to other kinds of transportation such as railways or other modes of transportation, allows us to pick up and drop off items at a precise location. Concrete construction and demolition debris must be disposed of at landfills, since recycling facilities are not readily available near construction and demolition sites. Some recycling services charge a fee for the processing of construction and demolition waste. As a result, the cost of delivering waste has decreased.

5.4. Implications

Many countries have waste management regulations but no guidelines to put them into effect. Thus, the government cannot enforce these regulations. Companies, on the other hand, are underinformed of environmental standards and criteria. In terms of sustainability, construction firms are following the lead of their competitors. These firms realized that introducing efficient material management systems might boost their reputation and market share. The construction industry is dedicated to raising environmental awareness. The industry can provide useful information about new equipment and materials. Clients looking for long-term solutions would put pressure on large practitioners to adjust.

In contrast, recycled concrete is not affiliated with respectable organizations, making it impossible to use or certify as a high-quality construction material. The unfavorable perception of recycled concrete in the construction industry substantially negatively impacts the sector's confidence in and approval of recycled concrete for construction work, especially for large-scale projects requiring strict quality control procedures. Recycled concrete in low-quality applications such as reclamation and subbase construction are becoming more common in the construction industry as a cost-cutting technique. Instead of asserting that recycled concrete is widely available, many professionals are concerned about the material's quality and durability.

There are numerous rules, programs, and targets in place to reduce construction and demolition waste. It is advised that a comprehensive paper be made available to the public. Furthermore, the lack of guidelines and testing for recovered construction materials makes recycling difficult. To avoid confusion, national standards should be set. There are two markets for resource recovery: unique or historic architectural components and repurposed resources such as concrete. There are many small businesses in the architecture industry. Material reuse companies only collect material from large cities due to transportation and economics.

Despite current interest in recycled materials, the main impediment of recycled concrete use is project finances, which vary depending on location. Contractors have stated that avoiding landfill tipping costs has resulted in a financial benefit in larger industrial regions. Setting recycling limits may encourage recycling in small areas where raw materials are less expensive than recycled materials and modest landfill expenses. To overcome this impediment, it is suggested that local governments work together on a regional level to manage concrete waste. Another alternative would be to urge local communities to be creative in discovering new uses for concrete refuse.

6. Conclusions

This study aims to highlight the challenges to concrete recycling in construction projects. To achieve that aim, the study (1) identified the main challenges to concrete recycling in construction projects; (2) compared the main challenges between organization sizes; and (3) determined the underlying groups among the main challenges. To accomplish these objectives, the study collected semi-structured interview data with fifteen industry practitioners and systematically reviewed the existing literature associated with concrete recycling, identifying 17 potential challenges. Then, the criticality of the potential challenges was evaluated by 89 industry practitioners through questionnaire surveys. Finally, the survey data were analyzed using mean ranking analysis, normalization, agreement analysis, and factor analysis techniques.

The analyses show thirteen main challenges to concrete recycling out of the seventeen potential challenges. The main challenges include increased project duration, lack of national programs for concrete recycling, lack of comprehensive rules and regulations for concrete recycling, increased project cost, and low demand for recycled concrete. However, there is no consensus on the criticality between SMEs and LEs. For example, increased project cost is the main challenge for SMEs but is only middlingly ranked for LEs. The main challenges can be grouped into three interrelated groups: people and technical; legal and environmental; and economic challenges.

The findings can shed light on the challenges that hinder concrete recycling. In addition to providing new insights into concrete recycling, the current study will help both scholars and practitioners, thereby increasing progress in concrete recycling. As a result, this research will increase the chances of concrete recycling becoming a success. This study's most significant theoretical contribution is that it better elaborates the constraints prohibiting concrete recycling from developing. Finally, contractors in all construction industries should recycle concrete and provide workers sufficient training on the benefits of this practice. Concrete recycling will aid in the prevention of loss in the construction industry, as the amount of concrete waste generated equals the amount of money lost by the construction company.

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Appendix A

Table A1. List of potential challenges to concrete recycling in construction projects.

Code	Challenges	Ref.
CH01	Lack of knowledge in using concrete recycling technologies	[7,39–41]
CH02	Low cost-effectiveness of concrete recycling	[2,7,42–44]
CH03	Lack of support for concrete recycling	[40,45,46]
CH04	Increased transportation cost	[2,7,40,41,45,47]
CH05	Lack of cooperation between project team members on concrete recycling	[2,40,46]
CH06	Lack of comprehensive rules and regulations on concrete recycling	[5,40,47–49]
CH07	Low demand for recycled concrete	[31,40,44,50,51]
CH08	Lack of technical knowledge in concrete recycling	[4,49,51,52]
CH09	Lack of knowledge on the value of concrete recycling	[2,7,40,46]
CH10	Insufficient space on-site to concrete recycling	[2,41,47]
CH11	Current practice in treating concrete waste	[7,40]
CH12	Lack of guidelines for concrete recycling	[2,42,45,48,49]
CH13	Insufficient time to develop plans for concrete recycling	[2,5,53,54]
CH14	Tight timeframes between project activities	[39]
CH15	Increased project duration	[2,37]
CH16	Increased project cost	[7,40,41,52]
CH17	Lack of national programs on concrete recycling	[40,46–49,54]

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