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CURRENT STATE, COMPREHENSIVE ANALYSIS AND PROPOSALS ON THE PRACTICE OF CONSTRUCTION AND DEMOLITION WASTE REUSE AND RECYCLING IN PORTUGAL

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Abstract. The traditional method of construction and demolition waste (CDW) consumes a substantial amount of land resources causing severe environmental and social problems. In Portugal, the low recycling rate, combined with a high use of landfill as a way of managing CDW, has resulted in a negative index of 39% in the waste hierarchy, thus making it impossible for Portugal to be classified as a country that implements waste hierarchy in practice. The main goal of this study is to investigate the benefits of CDW reuse and recycling and the factors that promote or hinder this practice in Portugal. Therefore, a comprehensive approach has been adopted by combining the analysis of secondary data collected through extensive bibliography research with the results of a survey by questionnaire conducted on a group of experts in CDW management. It was concluded that the main method of CDW management consists of its disposal in licensed landfills (47%), and the rate of CDW reuse on site is still low (6%). The results show a high consistency between the respondents' answers, as well as consistency between the opinions of these participants from different areas of professional activity. The respondents do recognize a concern regarding the reduction of carbon emissions, as well as a cultural resistance to materials or buildings that use CDW. These problems are further compounded by the difficulty in installing or supporting recycling equipment for CDW reuse on site. Respondents agree that there should be more investment and support from the government in this area, as well as in the training of construction companies.

Keywords: demolition waste, recycling rate, construction, waste hierarchy, low recycling rate, demolition waste reuse, licensed landfills.

Introduction

In recent years, most companies have started to adopt project management (PM) methodology (Marinho, 2017) to meet market demands and customer satisfaction. The main concept of the PM methodology is to apply knowledge, skills, tools, and techniques in project activities to achieve the desired goals. Consequently, the construction sector, with its own complexity, has not been an exception and several researchers implement PM to optimize construction projects. However, companies that develop projects are increasingly concerned with meeting the requirements that society imposes, particularly on issues related to social responsibility, environmental and financial impact. Therefore, PM must be adapted to the concept of sustainability by integrating some techniques and tools aimed at anticipating issues related to the projects' social and environmental responsibility aspects (Edum-Fotwe & Price, 2009). Some authors consider this symbiosis an important way for long-term growth of companies (Huemann & Silvius, 2017; Mishra et al., 2011). For example, Brent and Labuschagne (2006), and Edum-Fotwe and Price (2009) have developed indicators that allow the assessment of the contribution of sustainability in construction projects by combining the projects' environmental, economic and social requirements, thus allowing the stakeholders to have a more comprehensive and holistic view of sustainable issues in order to achieve a balance between economic growth and social welfare (Dyllick & Hockerts, 2002).

Still, it is necessary to consume less energy and resources, generate less carbon emissions and reduce the sector's ecological footprint (Zhong & Wu, 2015). According to Mavi and Standing (2018), the main factors for PM's sus-

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tainability in the construction sector are essentially waste management (WM), water saving, conservation, and recycling and reuse of materials. Material waste minimization during the construction process through the management of construction and demolition waste (CDW) during the life cycle of the construction project is not only beneficial from the point of view of sustainability (Ajayi & Oyedele, 2018), but can also contribute to reducing the work's total cost and to the success of the project (Mavi & Standing, 2018; Martens & Carvalho, 2017; Ojiako et al., 2014; Wang et al., 2014, 2017).

The main goal of this study is to investigate the factors that promote or hinder the practice of CDW reuse and recycling in Portugal, and it is expected to give important contributions, namely: (i) to assess the general perception regarding CDW reuse and recycling in the construction sector; (ii) to study the benefits and difficulties of CDW reuse and recycling; and (iii) to identify factors that help to promote the adoption of the principle of resource reuse in buildings to improve sustainable performance when promoting circular economy (CE) in the construction sector.

Based on the set of intentions proposed above, it is important to investigate the perceptions of the professionals involved in CDW management in Portugal. The subsequent sections are organized as follows: Section 1 describes the literature research; Section 2 describes the research methodology implemented in this study; Section 3 presents the results achieved; Section 4 discusses the results; and, final section presents the main conclusions of the work carried out under this study.

1. Literature review

CDW issues have gained growing awareness in recent decades from industry and researchers around the world. The strategy to minimize CDW generation in an effective and efficient manner is a dilemma faced by many countries around the world (Kabirifar et al., 2020).

1.1. Construction and demolition waste management hierarchy

In 2016, waste hierarchy was included in the European Union's (EU) action plan for sustainable development up to 2030, with the goal of reducing waste through prevention, reduction, reuse and recycling of CDW (Pires & Martinho, 2019). Because the construction sector is responsible for about 40% of total energy consumption and 36% of carbon emissions, it is important, in addition to selecting low-impact, sustainable and durable materials, to consider CDW reuse and recycling to optimize the use of resources, reduce WM (Atmaca, 2016; de Klijn-Chevalerias & Javed, 2017; Hossain & Ng, 2019; Pal et al., 2017) and thus meet the targets set out in the EU's action plan for a circular economy (CE) (Hossain & Ng, 2019; Vitale et al., 2017) based on waste hierarchy, a concept based on prioritizing waste reduction, their reuse and recycling, rather than investing resources in its treatment (Van Ewijk & Stegemann, 2016).

This is a sustainable development strategy for improving the efficiency of material and energy use by requiring improved assessment and performance techniques for the entire life cycle of buildings (Akanbi et al., 2018). For instance, Tingley et al. (2018) proposed four strategies to meet the CE's principle to reduce environmental impact and resource consumption, namely: materials reuse; materials adaptability; deconstruction and reuse of materials; and reuse in buildings, replacing the "end of life" concept by the concept of materials recovery (Hossain & Ng, 2019; Núñez-Cacho et al., 2018).

Dissimilar views on CDW management have resulted in contradictory waste management ideas, and therefore several efforts have been made to reduce, reuse, or recycle CDW. Each type of waste should be managed based on efficient and proper mechanisms of waste prevention. To achieve this goal, a waste management hierarchy should be followed. According to this hierarchy, generated waste should be recovered based on its appropriateness for being reduced, reused, or recycled earlier than the final stage, which is waste disposal into landfills (Kabirifar et al., 2020). However, the guidelines for selecting and implementing the CE's strategies are not yet properly clarified. For instance, Stephan and Athanassiadis (2018) defend that the CE's analysis should be based, on the one hand, on the building's life cycle analysis and, on the other hand, on the analysis of material flow during the different phases of design, construction and rehabilitation, thus contributing to improving CDW management in buildings, which is one of the foundations of the CE's designs. The EU has a waste hierarchy index between –4% and –9% that measures the level of application of waste hierarchy and which, like the PM system, contributes to the CE. This index can vary from –100% (management options that do not cover either recycling or reuse of CDW) to +100% (management options in which all CDW is geared towards reuse and recycling). In the EU, only 11 countries have a positive index above 10%, namely, in ascending order: Slovenia (+12%), Luxembourg (+14%), Estonia (+16%), Norway (+23%), Denmark (+26%), the Netherlands (+27%), Austria (+29%), Germany (+29%), Sweden (+30%), Belgium (+31%) and Switzerland (+32%). These results are due to the high recycling rates of these countries, all of them above the EU's average of 47.40% (Eurostat, 2020). In Portugal, the low recycling rate and the high use of landfill result in a waste hierarchy index of –39%, with a recycling rate of 30%, which makes it impossible for Portugal to be classified as a country that implements waste hierarchy in practice (Pires & Martinho, 2019).

1.2. Construction and demolition waste management in Portugal

Construction sector related environmental consequences are becoming increasingly evident, with the abundant production of waste being one of the gravest, both in Portugal and in most European Union countries. Besides the considerable quantities of materials used, the waste has other singularities that hinder its management, such as its various sizes, the fractions' heterogeneous constitution and the resulting different hazard levels. Furthermore, the temporary and dispersed location of construction sites makes it difficult to control and supervise environmental performance. Moreover, the adversities of waste quantification, unbalanced disposal and use of inappropriate treatment systems also cause complications to this sector and to waste characterization (Passos et al., 2020).

For these reasons, and given the negative contribution of the sector's practices regarding national and Community environmental performance purposes, specific legislation was prepared to address the flow of CDW. Since a large part of CDW produced in Portugal is deposited in landfills, Decree Law 46/2008 of March 12, as amended by Decree Law 73/2011 of June 17, was published in order to prioritize sorting, recycling and other forms of recovery towards reducing the amount of waste sent to landfills and consequently minimizing their environmental impact. Additionally, the Waste Management Fee (WMF) was created, which provides that waste producers incur higher costs depending on the destination given to the waste, thus contributing to incentivizing material recovery. The regulation establishes that several operations involving CDW are necessary to reduce its environmental impact. These operations include prevention, reuse, transportation, storage, sorting, treatment, recovery, and disposal of part of this waste. The waste that cannot be reused must be subject to sorting, and only after this operation can it be disposed of in landfills or dumps. CDW that is reused as aggregates is called recycled aggregates (RA) (Decree-Law 46/2008, 2008; Decree-Law 73/2011, 2011).

Decree-Law 46/2008 (2008) ensures a chain of responsibility that includes owners, contractors and municipalities. The parties involved in the construction life cycle, from the original product to the waste produced, are responsible for CDW management. Therefore, as soon as the waste is passed on to a licensed operator, it becomes their responsibility to properly proceed to its management. However, if CDW is produced in private works that do not require a license and are not subject to prior notification, the responsibility is assigned to the municipalities. According to article 8 of Decree-Law 46/2008 of March 12, CDW must be sorted on site in order to be forwarded by material flows and lines for recycling or other forms of recovery.

Also, in accordance with this same article, a hierarchy of on-site management is established that prioritizes on-site reuse, followed by on-site sorting of CDW whose production cannot be prevented. If sorting at the site where the waste is produced proves to be unfeasible, sorting may be performed off-site. CDW forwarding to operators licensed for this specific purpose sits at the base of this hierarchy. It should also be noted that article 9 of the above-mentioned Decree-Law also establishes the obligation of sorting prior to CDW disposal in landfills. This binding condition is intended to contribute to increasing recycling or other forms of CDW recovery, and simultaneously to minimizing the amounts deposited in landfills. The APA (the National Waste Authority) ensures CDW planning and management in order to prevent or reduce its production, harmful character and possible adverse impacts. On the other hand, the agency seeks to promote resource efficiency based on the principles of waste hierarchy and circular economy (Foster & Saleh, 2021).

1.3. Construction and demolition waste reuse and recycling

A study conducted by Poon et al. (2004) revealed that in order to reduce waste in building projects it is vital to consider waste management plans during the project development. Therefore, the most significant factors for CDW reduction in construction projects (Kabirifar et al., 2020) include the waste management plan application and monitoring, techniques and machineries, and the collaboration and communication among project teams. Meanwhile, some authors infer that the low rate of recycling in Portugal is due to the quality of the products manufactured from recycled CDW, since their quality is very low, which limits their possible applications and slows down the reuse process to the point that it can even be considered inadequate (Algarvio, 2009; Coelho & de Brito, 2013). However, a recent study showed that recycled aggregates can improve pore distribution and frost resistance of concrete (Wei et al., 2019), and the use of textile fibre waste in concrete, such as polypropylene and nylon, has become a common technology resulting from the changes in technical and environmental conditions (Qin et al., 2019, 2021). Another technique is mobile on-site recycling of CDW because it reduces transport costs by approximately 43% (Zhang et al., 2019). Some authors consider that mobile on-site recycling offers several benefits, such as reduction of land occupation, storage and maintenance costs borne by government, reduction of illegal CDW disposal; and design for construction is also recommended to reduce CDW generation (J. Li & D. Li, 2020; Xia et al., 2020).

Adequate site space for material storage, equipment, and the availability of local infrastructures for recycling and ease of access to them have a significant impact on WM results (Esa et al., 2017a). The traditional method of CDW disposal involves collection by environmental sanitation departments and disposal in open air or in landfills, but this practice consumes a substantial amount of land resources and pollutes the environment, thus causing severe environmental and social problems (Liu et al., 2020; Lu, 2019; Wong et al., 2018).

Therefore, it is central that the main bodies develop effective strategies for CDW reuse and recycling, as regards the benefits of CDW reuse and recycling as suggested by various authors (Table 1).

It is vital to consider all stages of the CDW project management in order to effectively manage CDW, because each stage encompasses specific actions to prevent CDW generation (Kabirifar et al., 2020). Xiao et al. (2016) report that concrete waste and brick waste account for approximately 80% of the total of CDW; recycling and reusing concrete and brick waste resulting from the production process of concrete not only reduce the problem of CDW disposal, but also reduce the overdependence of the construction industry on natural raw materials (He et al., 2021). The factors that hinder the practice of CDW reuse and recycling, as suggested by various authors, are presented in Table 2.

And the factors that promote the practice of CDW reuse and recycling as suggested by various authors are shown in Table 3.

Table 1. The benefits of CDW reuse and recycling

Authors	Factors
Huang et al. (2013); Vieira and Pereira (2015)	Reducing the project's budget by using recycled materials
Guangshe et al. (2008); Huang et al. (2013); Vieira and Pereira (2015); Jin et al. (2017)	Cost savings in transportation between the construction site and the landfill
Doan and Chinda (2016)	Compliance with government policies on green construction and environmental protection
Bossink and Brouwers (1996); Jin et al. (2017)	Promoting increased competitiveness by increasing business opportunities for the sector
Huang et al. (2013); Vieira and Pereira (2015)	Reducing the ecological footprint
Jin et al. (2017)	Protection of natural resources

Table 2. Factors that hinder the practice of CDW reuse and recycling

Authors	Factors
Brasileiro and Matos (2015); Newaz et al. (2020)	High cost and labour intensity in waste separation
Newaz et al., (2020); Saez et al. (2013)	High cost of transportation between the site and the landfills
Jia et al. (2017)	Difficulty in installing and maintaining machinery for reuse and recycling on site (for example, crushers)
Fortunato et al. (2009); Newaz et al. (2020); Sezer and Bosch-Sijtsema (2020)	Increased cost for waste planning and management
Duan and Li (2016); Esa et al. (2017a); Jin et al. (2017); Marrero et al. (2017); Newaz et al. (2020)	Increased workload in the registration and supervision of activities related to the delivery of waste in landfills
Duan and Li (2016); Esa et al. (2017a); Jin et al. (2017); Marrero et al. (2017); Newaz et al. (2020) Sezer and Bosch-Sijtsema (2020)	Change in management policy and work tasks within companies
Almeida et al. (2018); Dhakal et al. (2020); Domingo and Luo (2017)	Lack of employees' participation and training in CDW reuse and recycling
Algarvio (2009); Coelho and de Brito (2013); Duan and Poon (2014)	Lower quality of products or materials with recycled content
Zhao et al. (2010)	Lack of balance between demand and supply in the reuse and recycling market
Algarvio (2009); Coelho and de Brito (2013); Duan and Poon (2014); Sezer and Bosch-Sijtsema (2020)	Lack of investment in scientific research on CDW reuse
Coelho and de Brito (2013); Newaz et al. (2020); Sezer and Bosch-Sijtsema (2020)	Lack of promotion and support from government regarding CDW reuse and recycling
Esa et al. (2017a); Leite et al. (2011); Newaz et al. (2020)	Cultural resistance to products or projects that include CDW

Table 3. Factors that promote the practice of CDW reuse and recycling

Authors	Factors
Algarvio (2009); Coelho and de Brito (2013); Duan and Poon (2014)	A comprehensive and accurate assessment of the return on investment in CDW reuse and recycling
Coelho and de Brito (2013)	Inclusion of CDW reuse and recycling in the first stage of the project
Coelho and de Brito (2013)	Effective communication between all stakeholders on CDW reuse and recycling
Zhao et al. (2010); Coelho and de Brito (2013); Marzouk and Azab (2014); Esa et al. (2017a)	Financial incentives to recycle or reuse CDW
Coelho and de Brito (2013)	Inclusion of training actions to raise awareness of CDW reuse and recycling

To successfully handle CDW, two important parameters should be applied in combination. Firstly, CDW management hierarchy, including reduce, reuse, and recycle policies, and their associated factors should be followed individually. Secondly, effective CDW management contributing factors, including CDW from a sustainability perspective, stakeholders' attitudes, project life cycle, and wast management approaches, particularly the lean principle; circular economy; zero waste approach; green rating system; and site waste management plan should be identified and then be incorporated with the first parameter (Kabirifar et al., 2020).

2. Research methodology

In this study, a comprehensive approach was adopted through the combination of literature review and questionnaire-based research.

The questionnaire (see Appendix) was divided into two sections, the first section aimed to collect information and characterize the sample, namely in terms of the most used methods for CDW management, the percentage of waste that is recycled, and the rate of CDW reuse in the different types of works. In this section, respondents were characterized according to their role and experience in CDW management. In the second section, respondents were asked to assess the importance of the benefits, difficulties and factors that promote CDW reuse and recycling. This section aimed to rank and evaluate the consistency of the results by using a Likert scale, ranked from 1 to 5, where 1 corresponds to "unimportant" and 5 to "very important".

The sample selected for the survey was defined by the technical experts in CDW management registered in the database provided by the IMPIC (the Portuguese Institute for Public Markets, Real Estate and Construction), and the respondents were classified according to the following roles: security technician, construction or production director, construction supervision director and project author.

The questionnaire was structured and e-mailed to the participants using Microsoft Forms to collect their answers. After collecting them, it was adopted the relative importance index (*RII*) determined for each item and defined by the following expression (Eqn (1)):

$$RII = \frac{\sum_{i}^{j} a_i . n_i}{x, j} \times 100, \quad (1)$$

where: x – total number of survey responses (153); j – number of levels defined as valid response options (5 in this case); a_i – constant that expresses the weight assigned to each response option; n_i – variable that expresses the frequency with which response i is selected. The *RII* value ranges from 0 to 1, and so a high *RII* shows a high internal consistency, therefore indicating a good correlation between the respondents' answers.

To evaluate the internal consistency of the questionnaire, an analysis using the Cronbach's alpha value and a one-way analysis of variance (ANOVA) were performed.

Cronbach's alpha value was used to quantify the internal consistency of the items within each question, which can vary between 0 and 1. In other words, the higher the value between the items of the category, the greater the consistency, since this value measures the correlation of the questionnaire answers and presents the average correlation between the questions, calculated both from the variance of the individual items and the variance of the sum of the items of each respondent for all the items of the questionnaire. This means that a participant who has chosen a Likert value for an item is prone to select a similar numerical value for the other items. According to DeVellis (2016), a Cronbach's alpha value between 0.70 and 0.95 indicates a high internal consistency between all items; conversely, a Cronbach's alpha lower than 0.70 indicates a weak interrelationship between the items (Tonglet et al., 2004).

The one-way analysis of variance (ANOVA) compares the averages of the different respondents to check whether the averages are equal or not. That is, ANOVA is used to evaluate whether the respondents' role and experience in CDW management condition the answers they give. This analysis consists in evaluating the null hypothesis (the respondents' averages are the same, i.e., their main area of activity and professional experience are not relevant) and the alternative hypothesis (the respondents' averages are different, i.e., there is inconsistency in their answers). To determine whether any of the differences between the averages are statistically significant, the p-value was compared (the probability of obtaining a test statistic equal to or higher than the one observed in a sample). As a limit, one can reject the respondents' response if the p-value is lower than 5%; that is, one must conclude that not all population averages are equal and, if the p-value is greater than 5%, the differences between some of the averages are not statistically significant.

3. Results

Of the total of 245 questionnaires e-mailed, 153 responses were validated, representing a response rate of 62.45%, which is acceptable in comparison to previous studies based on questionnaire surveys in the construction sector – for example, a response rate of 7.4% (270 questionnaires) in the study by Abdul-Rahman et al. (2006) and 13.0% (210 questionnaires) in the study by Jin et al. (2017).

It should also be noted that the subject under analysis still raises many doubts and uncertainties in the national context, which inevitably makes it difficult to obtain a greater involvement and participation in this type of studies, as well as reflections by the different agents and entities involved in the sector.

3.1. Information about the survey participants

The respondents' main areas of activity are the following: project authors (38%), followed by construction/production directors (28%), construction supervision directors (21%), and safety technicians (13%).

Next, the respondents' experience in CDW management is registered according to the following intervals: under 9 years, 10 to 14 years, and over 15 years (Table 4).

Table 4. Distribution of respondents' experience in CDW management according to their professional activity (n = 153)

Professional activity	Under 9 years	10 to 14 years	Over 15 years
Construction/ production director	20%	27%	53%
Security technician	43%	0%	57%
Construction supervision director	18%	27%	55%
Project author	0%	30%	70%
TOTAL	15%	25%	60%

As can be seen in Table 4, 60% of the respondents have more than 15 years of experience, and all respondents, regardless of their professional activity, have more than 50% experience.

3.2. Data collected from the survey

Firstly, based on their experience, respondents were asked to identify, on a percentage scale, the method of CDW management they use on site, considering the following possibilities: A1 – Licensed landfill; A2 – Recycling; A3 – Reuse on site; and A4 – Other (landfills, construction sites, etc.). For each item, respondents should indicate the interval corresponding to the works carried out, namely: 0%; 0 to 25%; 25 to 50%; 50 to 75%; 75 to 100%.

Table 5 presents the analysis of the collected data, based on the percentage calculated from the responses obtained. According to the data analysis, there is little CDW reuse on site (A3): in particular, 58% of the respondents say they have reused their works' CDW in the interval of 0 to 25%. Equally important, 47% of the respondents said they had never sent their CDW to non-certified landfills (A4), but 34% said they had already sent their CDW to unlicensed landfills, at least in 25% of the works they carried out. It was also observed that only 8% of the respondents had never sent their CDW to a licensed landfill (A1), and 9% never recycled them (A2) in the works they carried out. It was also observed that CDW recycling and/or reusing on site is not yet standard practice, as only 6% of the respondents said they reuse them (A3) in the interval of 75 to 100% in the works they carried out; regarding the issue of recycling (A2), 13% said they recycled CDW in the interval of 75% to 100% in the works carried out during their work experience.

Respondents were then asked to indicate the percentage of waste that is recycled, according to the following possibilities, as shown in Table 6: B1 – Wall materials (e.g., bricks, blocks); B2 – Concrete execution with recycled aggregates; B3 – Materials serving as a base for ground floors; B4 – Other applications, such as drains, foundations and landfills. For each item, the respondents had to indicate the interval corresponding to the works carried out, namely: 0%; 0% to 25%; 25% to 50%; 50% to 75%; 75% to 100%.

As can be seen in Table 6, the most recycled CDW is the one that serves as basis for ground floors (B3), as only 6% of the respondents stated that they had never used CDW in their works. 45% of the respondents used CDW as wall-building materials (B1), with a use between 0 to 25% in the works carried out. Although the truthfulness of the respondents is not something that can be determined properly, the statements concerning the use of recycled aggregates in structural concrete are dubious, to say the very least, for little to no knowledge exists in the industry regarding structural recycled aggregate concrete, and it often comes from ready-mix plants, which still do not produce recycled aggregate concrete. A potential note could be added regarding the respondents' biased answers.

Table 5. Method of CDW management (n = 153)

Method of CDW management	CDW distribution (%)				
	0%	0–25%	25–50%	50–75%	75–100%
A1 – Licensed landfill	8%	34%	21%	19%	19%
A2 – Recycling	9%	32%	36%	9%	13%
A3 – Reuse on site	11%	58%	15%	9%	6%
A4 – Other (landfills, construction sites, etc.)	47%	34%	13%	6%	0%

Table 6. Distribution of CDW reuse on construction site (n = 153)

Method of CDW management	CDW distribution (%)				
	0%	0–25%	25–50%	50–75%	75–100%
B1 – Wall materials (e.g., bricks, blocks)	21%	45%	17%	13%	4%
B2 – Concrete execution with recycled aggregates	21%	38%	26%	9%	6%
B3 – Materials serving as a base for ground floors	6%	26%	34%	26%	8%
B4 – Other applications, such as drains, foundations and landfills	42%	42%	9%	8%	0%

However, regarding item B2, there are very few companies in Portugal that reuse aggregates to use structural concrete; therefore, respondents may use waste for structural concrete in an uncontrolled manner.

There is little recycling, with less than 10% of the respondents recycling between 75% and 100% in the works carried out, irrespective of the type of CDW involved. This indicator also stems from the low rate of recycling by the respondents in the works they carried out.

Given the goal of understanding the panorama of CDW management, the respondents were asked to estimate, based on their own professional experience, the rate of reuse they have adopted for the different types of construction or rehabilitation, considering the following types of works: C1 – Reinforced concrete structure constructions; C2 – Stone masonry constructions; C3 – Metal structure constructions; C4 – Mixed structure constructions; C5 – Wood structure constructions; C6 – Reinforced concrete structure rehabilitations; C7 – Stone masonry rehabilitations; C8 – Metal structure rehabilitations; C9 – Mixed structure constructions; and C10 – Wood structure rehabilitations. For each item, the respondents had to indicate the interval corresponding to the works carried out (Table 7): 0%; 0% to 25%; 25% to 50%; 50% to 75%; 75% to 100%.

According to the results shown in Table 7, the rehabilitation of stone structures (C7) presents the highest rate: 21% of material reuse, with a percentage above 50% of the works (adding the interval of 75% to 100% with the interval of 50% to 75%). And wood structure constructions (C5) present the lowest rate of material reuse, with a percentage below 25% of the works (0% + 0% to 25%), of 74%. Additionally, the respondents did not differentiate between construction and rehabilitation works, because both types of work obtained similar values.

3.3. Benefits of CDW reuse and recycling

In this question, participants were asked about the benefits of CDW reuse and recycling. Table 8 lists the seven benefits (D1 to D7) that were identified in the literature review (Section 1), their general average, standard deviation, and the corresponding RII values. The Cronbach's global alpha resulting from the analysis of the data collected from the general sample corresponds to 0.7898 (above 0.75), which reveals a high internal consistency,

Table 7. Distribution of CDW reuse by type of construction (*n* = 153)

Type of construction	CDW reuse on site (%)				
	0%	0–25%	25–50%	50–75%	75–100%
C1 – Reinforced concrete structure **constructions**	13%	53%	26%	2%	6%
C2 – Stone masonry **constructions**	19%	40%	30%	8%	4%
C3 – Metal structure **constructions**	30%	38%	19%	9%	4%
C4 – Mixed-structure **constructions**	17%	51%	23%	6%	4%
C5 – Wood structure **constructions**	36%	38%	19%	4%	4%
C6 – Reinforced concrete **rehabilitations**	13%	53%	21%	9%	4%
C7 – Stone masonry **rehabilitations**	19%	32%	28%	13%	8%
C8 – Metal structure **rehabilitations**	30%	34%	17%	17%	2%
C9 – Mixed-structure **rehabilitations**	23%	43%	17%	13%	4%
C10 – Wood structure **rehabilitations**	34%	36%	19%	6%	6%
Construction [C1 – C5]	23%	44%	23%	6%	4%
Reconstruction [C6 – C10]	23%	44%	22%	7%	4%

Table 8. Analysis of the general survey sample data regarding the benefits of CDW reuse and recycling (Cronbach's alpha = 0.7898)

Item	General average	Standard deviation	RII	Cronbach's Alpha	ANOVA	
					F-value	p-value
D1 – Saves space in landfills, thus reducing the need for new landfills	4.00	1.01	80%	0.7807	2.54	0.07
D2 – Reduces the project budget by using recycled materials	3.60	1.00	72%	0.7733	0.26	0.6
D3 – Saves the cost of transportation between the construction site and the landfill	3.75	1.01	75%	0.7475	0.11	0.95
D4 – Complies with government policies of green construction and environmental protection	3.91	0.98	78%	0.7658	2.00	0.13
D5 – Promotes increased competitiveness resulting from increased business opportunities for the sector	3.40	1.09	**68%**	0.7300	0.86	0.47
D6 – Decreases the ecological footprint	4.34	0.73	87%	0.7727	0.82	0.49
D7 – Protects natural resources	4.53	0.63	91%	0.7650	0.72	0.55

thus indicating a good correlation between the respondents' statements. And the ANOVA analysis carried out to check whether the respondents' role and professional experience regarding the benefits of CDW reuse and recycling conditioned the answers they gave, as explained in Section 2. The individual values (per item) of Cronbach's alpha indicated in Table 8 suggest that each item contributes positively to internal consistency, as explained in Section 2.

As shown in Table 8, item D5 presents a lower Cronbach's Alpha, which means that respondents are more likely to assign inconsistent scores to that item, while their perceptions of other items tend to be more internally correlated, conveying the idea that promoting increased competitiveness resulting from increased business opportunities for the industry may be uncertain in comparison with other items related to other benefits arising from CDW reuse and recycling. D7 (Protects natural resources) is the best ranked item, with 0.91 *RII*, followed by D6 (Reduces ecological footprint), with 0.87 *RII*.

Also, the results of the respondents' answers do not present significant differences arising from their role and professional experience regarding the benefits of CDW reuse and recycling. As explained in Section 3, the p-value is higher than 0.05, and the value of the statistical factor (F-value) is lower than the value of the critical statistical factor (critical F equal to 2.79). Therefore, it can be inferred that the survey participants share consistent views on the benefits derived from CDW reuse and recycling.

3.4. Factors hindering CDW reuse and recycling

In this question, respondents were inquired about the factors that hinder CDW reuse and recycling. Table 9 lists the fourteen items (E1 to E14) that were identified in the literature review (Section 1), their general average, standard deviation, and the corresponding *RII* values. The global Cronbach's alpha resulting from the analysis of the data collected from the general sample corresponds to 0.8685 (higher than 0.75), which shows a high internal consistency and thus indicates a good correlation between the respondents' statements. The individual values (per item) of Cronbach's alpha indicated in Table 9 suggest that each item contributes positively to internal consistency, as explained in Section 3.

Table 9 shows that items E2, E5 and E8 have a lower *RRI*, which means that the respondents were more likely to assign inconsistent scores to those items, while their perceptions of other items tended to be more internally correlated. Item E14 (Cultural resistance to products or projects using CDW) is the best rated item, with 0.80 RII, followed by E12 (Lack of government support), with 0.78 *RII*. Table 9 also presents the results of an ANOVA analysis carried out to check whether the respondents' role and respective professional experience regarding the factors that hinder CDW reuse and recycling condition the results, as explained in Section 2.

Table 9 shows that the results of the answers do not present significant differences arising from the respondents' role and respective professional experience regarding

Table 9. Analysis of the general survey sample data regarding the factors hindering CDW reuse and recycling (Cronbach's alpha = 0.8685)

Item	General average	Standard deviation	*RII*	Cronbach's alpha	ANOVA	
					F-value	p-value
E1 – High cost and labour intensity in waste separation	3.60	0.81	72%	0.8586	1.70	0.18
E2 – High cost of transport between the work site and landfills	3.36	0.95	**67%**	0.8604	0.65	0.59
E3 – Difficulty in installing and maintaining reuse and recycling machines (e.g., crushers) on site	3.81	0.87	76%	0.8643	0.54	0.66
E4 – Higher cost of work planning and management by incorporating CDW delivery to landfills	3.49	0.9	70%	0.8604	1.09	0.36
E5 – A higher workload in registration and supervision of activities related to CDW delivery to landfills	3.34	0.91	**67%**	**0.8549**	0.05	0.98
E6 – Change in management policy and work mechanism in companies	3.70	0.77	74%	0.8662	0.92	0.44
E7 – Lack of employees' participation and training in CDW reuse and recycling	3.74	0.85	75%	0.8601	2.13	0.11
E8 – Lower quality of products with recycled content	3.06	1.09	**61%**	**0.8556**	1.70	0.18
E9 – Lack of balance between demand and supply in the reuse and recycling market	3.6	0.98	72%	**0.8539**	1.14	0.34
E10 – Lack of investment in scientific research on CDW reuse	3.81	0.89	76%	0.8601	2.72	0.05
E11 – Lack of promotion and support for CDW reuse and recycling	3.72	0.86	74%	**0.8575**	1.83	0.15
E12 – Lack of government support	3.89	0.96	78%	0.8613	2.52	0.07
E13 – Lack of regulation on CDW reuse and recycling	3.49	1.02	70%	0.8605	0.55	0.65
E14 – Cultural resistance to products or projects incorporating CDW	4.02	0.86	**80%**	0.8621	0.26	0.85

the benefits of CDW reuse and recycling. As explained in Section 2, the p-value is higher than 0.05, and the value of the statistical factor (F-value) is lower than the value of the critical statistical factor (F critical equal to 2.79). It can therefore be inferred that the survey participants share consistent views on the benefits derived from CDW reuse and recycling. However, factor E10 (Lack of investment in scientific research on CDW reuse) shows 0.05 p-value, corresponding to the limit, which may give rise to doubts regarding the consistency of responses. Obviously, the respondents have little knowledge on the worldwide advancements made in structural recycled aggregate concrete or on the published material on that subject.

3.5. Factors promoting CDW reuse and recycling

On this point, participants were inquired about the factors that promote CDW reuse and recycling. Table 10 lists the five items (F1 to F5) promoting CDW reuse and recycling that were identified in the literature review (Section 1), their general average, standard deviation, and the corresponding *RII* values. The Cronbach's global alpha resulting from the analysis of the data collected from the general sample corresponds to 0.8214 (higher than 0.75), which shows a high internal consistency and thus indicates a good correlation between the respondents' responses. The individual values (per item) of Cronbach's alpha shown in Table 10 suggest that each item contributes positively to internal consistency, as explained in Section 2, except for item F5 (Financial incentive to CDW reuse or recycling), whose individual Cronbach's alpha value (0.8309) is higher than the overall value (0.8214), thus indicating that this was the only item that did not contribute to internal consistency.

Table 10 shows that items F1 and F4 have a lower correlation, which means that respondents were more likely to assign inconsistent scores to those items, while their perceptions of other items tended to be more internally correlated. Item F2 (Inclusion of waste reuse and recycling in the initial stage of the project) is the best ranked one, with 0.83 *RII*. An ANOVA analysis was carried out to check whether the respondents' role and respective professional experience regarding the benefits of CDW reuse and recycling condition the results of the answers shown in Table 8.

From the analysis, the results of the answers do not present significant differences arising from the respondents' role and respective professional experience regarding the factors that promote CDW reuse and recycling. As explained in Section 2, the p-value is higher than 0.05, and the value of the statistical factor (F-value) is lower than the value of the critical statistical factor (F critical equal to 2.79). Therefore, it can be inferred that the survey participants share consistent opinions on the other factors that promote CDW reuse and recycling.

4. Discussion

This study aimed to investigate the current stage of CDW recycling and reuse practice in Portugal. The results from the analysis of the collected data show that to reduce or minimize CDW, it is important to consider the stakeholders' attitudes and behaviours.

4.1. The perception of CDW reuse and recycling in the construction sector

Portugal generates a high amount of CDW compared to some countries in the EU. According to the data analysis, CDW recycling and/or reusing on site is not yet standard practice: only 6% of the respondents say they reuse CDW in the works they carried out; and only 13% say they recycle CDW. The values are lower in comparison with the study conducted by Coelho and de Brito (2013), whose results showed 11% regarding reuse and 9% regarding CDW recycling, showing a reduction of reuse (–5%) and an increase of recycling (+4%) in Portugal since 2013.

4.2. The benefits of CDW reuse and recycling

The respondents consider that protecting natural resources and decreasing the ecological footprint are the most important benefits of CDW reuse and recycling. It is important to stress that the study conducted by Jin et al. (2017) considered a high awareness of governmental policies to be the most important factor.

Table 10. Analysis of the general survey sample data regarding the factors that promote CDW reuse and recycling (Cronbach's alpha = 0.8214)

Item	General average	Standard deviation	*RII*	Cronbach's alpha	ANOVA	
					F-value	p-value
F1 – A comprehensive and accurate assessment of the return on investment in CDW reuse and recycling	3.94	0.63	**79%**	0.7749	0.32	0.81
F2 – Inclusion of CDW reuse and recycling in the initial stage of the project	4.13	0.65	**83%**	0.7882	0.60	0.62
F3 – Inclusion of training actions to raise awareness of CDW reuse and recycling	4.09	0.81	82%	0.7794	0.39	0.76
F4 – Effective communication between all stakeholders regarding CDW reuse and recycling	3.94	0.76	**79%**	0.7518	0.09	0.96
F5 – Financial incentive for CDW recycling and/or reuse	4.11	0.74	82%	**0.8309**	0.50	0.69

Besides protecting natural resources and decreasing the ecological footprint, another main benefit of CDW reuse and recycling received highly positive perceptions: lowering the demands on landfill space, which were also considered top benefits of concrete recycling in the study conducted in Jin et al. (2015).

4.3. Factors hindering CDW reuse and recycling

The respondents considered that cultural resistance to products or projects using CDW is the best rated item, followed by the lack of government support. Similarly to the study conducted by Jin et al. (2017), governmental supportive policies in terms of mandatory requirements or financial incentives, guidelines, and effort in monitoring the industrial behaviour of recycling and reusing CDW were perceived as playing a significantly important role in promoting the CDW diversion practice. Another study by Lockrey et al. (2016) also claims that governmental support and legislation is highly important in enhancing CDW recycling and reuse.

4.4. Analysis of the survey results in combination with Portugal's national conditions and policies

Portuguese environmental policies have set a 70% target for the reuse and recycling of construction and demolition waste to be met by 2020, and an obligation to use at least 5% recycled materials in construction contracts (Decree-Law 73/2011, 2011).

Based on the survey, only 37% reuse and recycling is verified in at least half of the construction projects carried out by the respondents.

Regarding the use of recycled materials, 18% of CDW is applied in at least 25% of the respondents' construction works, approaching the value set by the Portuguese government. Regarding the distribution of CDW reuse by type of work, there was a value of 10% for new construction and 11% for reconstruction in at least half of the respondents' construction works, reaching the target of 5% of recycled materials in construction contracts.

In the specific case of Portugal, larger quantities of waste are still sent to landfills or incineration plants, but these solutions have demonstrated over time some drawbacks that force society to seek other more environmentally friendly strategies.

Despite mandatory on-site sorting of CDW – and only then deposition in a landfill is allowed – respondents consider waste separation high costs, labor intensity and the lack of government support as factors that hinder CDW recycling and reuse. However, respondents do not consider the cost of transportation between the construction site and landfills to be relevant, nor the workload in registering and supervising the activities related to CDW delivery to landfills.

The main objectives of Portugal's construction and demolition waste management protocol are promoting waste recycling and the use of recycled materials, promoting sustainability by reducing the use of natural resources, and to contribute to the waste recovery targets set at 70%.

Based on the analysis of the survey's results, a set of proposals on the practice of CDW reuse and recycling in Portugal is presented in Table 11, through its importance and level of implementation.

4.5. Factors promoting CDW reuse and recycling

All factors listed in this study for promoting CDW reuse and recycling were positively perceived by the respondents. Based on their responses, the inclusion of waste reuse and recycling in the initial stage of the project is the best ranked factor. The communication and specifying CDW management work in the early project design or procurement stage by involving multiple project parties can promote CDW reuse and recycling. Site waste management plan is becoming popular nowadays as a valuable approach for assisting construction stakeholders to anticipate and officially note the quantity and type of CDW and take appropriate decisions to manage it when necessary (Kabirifar et al., 2020). This plan focuses on the construction project's lifecycle, starting from the planning and designing stage to the demolition stage (Esa et al., 2017b).

Conclusions

The main goal of this study was to survey the current state of the practice of CDW reuse and recycling in Portugal. It started with a description of the overall picture and at a later stage a questionnaire was adopted to study the perception of stakeholders by focusing on three main vectors: advantages, difficulties, and promotion of CDW reuse and

Table 11. Factors that prove the practice of CDW reuse and recycling in Portugal

Item	Importance	Implementation
1. Formation and promotion of products or projects that use CDW via government support, including in the cost of sale	Very important	Easy
2. Investment in scientific research on CDW reuse in new building materials	Very important	Easy
3. Involvement of employees in CDW reuse and recycling via financial incentives	Important	Easy
4. Valuing in public contracting the companies that have management policies and work mechanisms regarding CDW management (for example, by creating a certification for the company that reuses and recycles CDW in their construction sites)	Very important	Difficult
5. Financial incentive to the client towards CDW recycling and/or reuse	Important	Average

recycling. A comprehensive approach was adopted in the research via quantitative data. The sample was considered acceptable in comparison with other studies carried out within the construction sector. The main professional roles/activities referred by the respondents are those of project author, supervision director, safety technician and construction direction, with the majority (60%) having more than 15 years of experience in this area.

After analysing the collected data, it was concluded that the main method/solution adopted for CDW management is delivering it to a licensed landfill (47%), thus indicating insufficient reuse of CDW on site, with only 6% of the respondents stating that they reuse the materials on site, and 13% stating that they recycled CDW. However, this reuse on site is mostly restricted to the manufacturing of floor bases. Respondents did not differentiate the practice of CDW management in new construction or rehabilitation works. But they do consider that new constructions or rehabilitation in metallic structure and new constructions and rehabilitation in stone masonry are the ones with the highest rate of reuse (16%).

Regarding the benefits arising from CDW reuse and recycling, the answers show a high internal consistency, thus indicating a good correlation between the respondents' statements, as well as a consistent sharing of opinions from these participants from different professions, with item D7 (Protects natural resources) being the best ranked benefit, followed by item D6 (Decreased ecological footprint). This shows that the respondents' answers denote environmental awareness and concern with reducing carbon emissions.

Regarding the factors that hinder CDW reuse and recycling, the responses present a high internal consistency, as well as a consistent sharing of views between these participants from different professions. Respondents acknowledge that there is a cultural resistance to products or projects using CDW, combined with the general perception that products with recycled content have lower quality. The difficulty in installing or maintaining recycling equipment for CDW reuse on site is also referred as one among other factors that most hinder the adoption of the practice of CDW reuse and recycling.

It can also be concluded that the respondents share the view that there should be greater investment and support from the government in the training of construction companies.

Future research may focus on integrating project management methodology with the concept of sustainability to create a methodology to support CDW management. The Building Information Modeling (BIM) methodology should also be integrated at an early stage of the construction project to estimate the quantities of CDW generated and assess the types of CDW that can be reused or recycled during the life cycle of the construction project.

References

Abdul-Rahman, H., Berawi, M., Berawi, A., Mohamed, O., Othman, M., & Yahya, I. (2006). Delay mitigation in the Malaysian construction industry. *Journal of Construction Engineering and Management*, *132*, 125–133. https://doi.org/10.1061/(ASCE)0733-9364(2006)132:2(125)

Ajayi, S. O., & Oyedele, L. O. (2018). Waste-efficient materials procurement for construction projects: A structural equation modelling of critical success factors. *Waste Management*, *75*, 60–69. https://doi.org/10.1016/j.wasman.2018.01.025

Akanbi, L. A., Oyedele, L. O., Akinade, O. O., Ajayi, A. O., Delgado, D. M., Bilal, M., & Bello, S. A. (2018). Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator. *Resources*, *Conservation and Recycling*, *129*, 175–186. https://doi.org/10.1016/j.resconrec.2017.10.026

Algarvio, D. (2009). *Construction and demolition waste recycling: contribution for process control*. New University of Lisbon, Portugal.

Almeida, J., Rosa, F. D., Pandolfo, A., Berticelli, R., Brum, E. M., & Martins, M. S. (2018). Estudo de viabilidade econômica do uso do agregado de RCD em pavimentação de vias urbanas. *Revista de Engenharia Civil*, *54*, 16–25.

Atmaca, A. (2016). Life cycle assessment and cost analysis of residential buildings in south east of turkey: Part 1 – review and methodology. *International Journal of Life Cycle Assessment*, *21*, 831–846. https://doi.org/10.1007/s11367-016-1050-8

Bossink, B. A. G., & Brouwers, H. J. H. (1996). Construction waste: Quantification and source evaluation. *Journal of Construction Engineering and Management*, *122*, 55–60. https://doi.org/10.1061/(ASCE)0733-9364(1996)122:1(55)

Brasileiro, L. L., & Matos, J. M. E. (2015). Revisão bibliográfica: reutilização de resíduos da construção e demolição na indústria da construção civil. *Cerâmica*, *61*, 178–189. https://doi.org/10.1590/0366-69132015613581860

Brent, A., & Labuschagne, C. (2006). Social indicators for sustainable project and technology life cycle management in the process industry (13 pp + 4). *The International Journal of Life Cycle Assessment*, *11*, 3–15. https://doi.org/10.1065/lca2006.01.233

Coelho, A., & de Brito, J. (2013). Economic viability analysis of a construction and demolition waste recycling plant in Portugal – part I: Location, materials, technology and economic analysis. *Journal of Cleaner Production*, *39*, 338–352. https://doi.org/10.1016/j.jclepro.2012.08.024

de Klijn-Chevalerias, M., & Javed, S. (2017). The Dutch approach for assessing and reducing environmental impacts of building materials. *Building and Environment*, *111*, 147–159. https://doi.org/10.1016/j.buildenv.2016.11.003

Decree-Law Nr.46/2008, 12 March 2008 (2008). The system of construction and demolition waste management – ministry of environment, spatial planning and regional development. *Republic Journal*, I Series-A – Nr. 51. Lisbon, Portugal.

Decree-Law Nr.73/2011, 17 June 2011 (2011). Establishes the waste management operations regime and aims to clarify waste definitions, prevention, reuse, preparation for reuse, treatment and recycling. *Republic Journal*, I Series-A – Nr. 116. Lisbon, Portugal.

DeVellis, R. (2016). *Scale development: Theory and applications* (4 ed.). Sage Publications.

Dhakal, S., Zhang, L., & Lv, X. (2020). Ontology-based semantic modelling to support knowledge-based document classification on disaster-resilient construction practices. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2020.1765097

Doan, D. T., & Chinda, T. (2016). Modeling construction and demolition waste recycling program in Bangkok: Benefit and cost analysis. *Journal of Construction Engineering and Management*, *142*, 05016015. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001188

Domingo, N., & Luo, H. (2017). Canterbury earthquake construction and demolition waste management: issues and improvement suggestions. *International Journal of Disaster Risk Reduction*, *22*, 130–138. https://doi.org/10.1016/j.ijdrr.2017.03.003

Duan, H., & Li, J. (2016). Construction and demolition waste management: China's lessons. *Waste Management and Research*, *34*, 397–398. https://doi.org/10.1177/0734242X16647603

Duan, Z. H., & Poon, C. S. (2014). Properties of recycled aggregate concrete made with recycled aggregates with different amounts of old adhered mortars. *Materials and Design*, *58*, 19–29. https://doi.org/10.1016/j.matdes.2014.01.044

Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment*, *11*, 130–141. https://doi.org/10.1002/bse.323

Edum-Fotwe, F. T., & Price, A. D. F. (2009). A social ontology for appraising sustainability of construction projects and developments. *International Journal of Project Management*, *27*, 313–322. https://doi.org/10.1016/j.ijproman.2008.04.003

Esa, M. R., Halog, A., & Rigamonti, L. (2017a). Strategies for minimizing construction and demolition wastes in Malaysia. *Resources*, *Conservation and Recycling*, *120*, 219–229. https://doi.org/10.1016/j.resconrec.2016.12.014

Esa, M. R., Halog, A., & Rigamonti, L. (2017b). Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. *Journal of Material Cycles and Waste Management*, *19*, 1144–1154. https://doi.org/10.1007/s10163-016-0516-x

Eurostat. (2020). *Database*. https://ec.europa.eu/eurostat/data/database

Fortunato, E., Lopes, M. L., Curto, P., & Fonseca, A. (2009). *Valorização dos residuos de construção e demolição em obras geotecnicas*. Laboratório Nacional de Engenharia Civil.

Foster, G., & Saleh, R. (2021). The circular city and adaptive reuse of cultural heritage index: Measuring the investment opportunity in Europe. *Resources*, *Conservation and Recycling*, *175*, 105880. https://doi.org/10.1016/j.resconrec.2021.105880

Guangshe, J., Li, C., Jianguo, C., Shuisen, Z., & Jin, W. (2008). Application of organizational project management maturity model (OPM3) to construction in China: An empirical study. In *Proceedings of the International Conference on Information Management*, *Innovation Management and Industrial Engineering* (*ICIII 2008*) (pp. 56–62), Taipei, Taiwan. https://doi.org/10.1109/ICIII.2008.182

He, Z., Shen, A., Wu, H., Wang, W., Wang, L., Yao, C., & Wu, J. (2021). Research progress on recycled clay brick waste as an alternative to cement for sustainable construction materials. *Construction and Building Materials*, *274*, 122113. https://doi.org/10.1016/j.conbuildmat.2020.122113

Hossain, M. U., & Ng, T. S. (2019). Influence of waste materials on buildings' life cycle environmental impacts: Adopting resource recovery principle. *Resources*, *Conservation and Recycling*, *142*, 10–23. https://doi.org/10.1016/j.resconrec.2018.11.010

Huang, T., Shi, F., Tanikawa, H., Fei, J., & Han, J. (2013). Materials demand and environmental impact of buildings construction and demolition in China based on dynamic material flow analysis. *Resources*, *Conservation and Recycling*, *72*, 91–101. https://doi.org/10.1016/j.resconrec.2012.12.013

Huemann, M., & Silvius, G. (2017). Projects to create the future: Managing projects meets sustainable development. *International Journal of Project Management*, *35*, 1066–1070. https://doi.org/10.1016/j.ijproman.2017.04.014

Jia, S., Yan, G., Shen, A., & Zheng, J. (2017). Dynamic simulation analysis of a construction and demolition waste management model under penalty and subsidy mechanisms. *Journal of Cleaner Production*, *147*, 531–545. https://doi.org/10.1016/j.jclepro.2017.01.143

Jin, R., Chen, Q., & Soboyejo, A. (2015). Survey of the current status of sustainable concrete production in the U.S. *Resources*, *Conservation and Recycling*, *105*, 148–159. https://doi.org/10.1016/j.resconrec.2015.10.011

Jin, R., Li, B., Zhou, T., Wanatowski, D., & Piroozfar, P. (2017). An empirical study of perceptions towards construction and demolition waste recycling and reuse in China. R*esources*, *Conservation and Recycling*, *126*, 86–98. https://doi.org/10.1016/j.resconrec.2017.07.034

Kabirifar, K., Mojtahedi, M., Wang, C., & Tam, V. W. Y. (2020). Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. *Journal of Cleaner Production*, *263*, 121265. https://doi.org/10.1016/j.jclepro.2020.121265

Leite, F. da C., Motta, R. dos S., Vasconcelos, K. L., & Bernucci, L. (2011). Laboratory evaluation of recycled construction and demolition waste for pavements. *Construction and Building Materials*, *25*, 2972–2979. https://doi.org/10.1016/j.conbuildmat.2010.11.105

Li, J., & Li, D. (2020). Polyelectrolyte adsorption in single small nanochannel by layer-by-layer method. *Journal of Colloid and Interface Science*, *561*, 1–10. https://doi.org/10.1016/j.jcis.2019.11.116

Liu, Q., Li, B., Xiao, J., & Singh, A. (2020). Utilization potential of aerated concrete block powder and clay brick powder from C&D waste. *Construction and Building Materials*, *238*, 117721. https://doi.org/10.1016/j.conbuildmat.2019.117721

Lockrey, S., Nguyen, H., Crossin, E., & Verghese, K. (2016). Recycling the construction and demolition waste in Vietnam: Opportunities and challenges in practice. *Journal of Cleaner Production*, *133*, 757–766. https://doi.org/10.1016/j.jclepro.2016.05.175

Lu, W. (2019). Big data analytics to identify illegal construction waste dumping: A Hong Kong study. *Resources*, *Conservation and Recycling*, *141*, 264–272. https://doi.org/10.1016/j.resconrec.2018.10.039

Marinho, A. (2017). *A gestão de riscos projetos de construção* [Master thesis]. IPP – Escola Superior de Tecnológia e Gestão, Portugal.

Marrero, M., Puerto, M., Rivero-Camacho, C., Freire-Guerrero, A., & Solís-Guzmán, J. (2017). Assessing the economic impact and ecological footprint of construction and demolition waste during the urbanization of rural land. *Resources*, *Conservation and Recycling*, *117*, 160–174. https://doi.org/10.1016/j.resconrec.2016.10.020

Martens, M. L., & Carvalho, M. M. (2017). Key factors of sustainability in project management context: A survey exploring the project managers' perspective. *International Journal of Project Management*, *35*, 1084–1102. https://doi.org/10.1016/j.ijproman.2016.04.004

Marzouk, M., & Azab, S. (2014). Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics. *Resources*, *Conservation and Recycling*, *82*, 41–49. https://doi.org/10.1016/j.resconrec.2013.10.015

Mavi, K. R., & Standing, C. (2018). Critical success factors of sustainable project management in construction: A fuzzy DEMATEL-ANP approach. *Journal of Cleaner Production*, *194*, 751–765. https://doi.org/10.1016/j.jclepro.2018.05.120

Mishra, P., Dangayach, G. S., & Mittal, M. L. (2011). An ethical approach towards sustainable project success. *Procedia - Social and Behavioral Sciences*, *25*, 338–344. https://doi.org/10.1016/j.sbspro.2011.10.552

Newaz, M. T., Davis, P., Sher, W., & Simon, L. (2020). Factors affecting construction waste management streams in Australia. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2020.1815122

Núñez-Cacho, P., Molina-Moreno, V., Corpas-Iglesias, F. A., & Cortés-García, F. J. (2018). Family businesses transitioning to a circular economy model: The case of 'Mercadona'. *Sustainability*, *10*(2), 538. https://doi.org/10.3390/su10020538

Ojiako, U., Chipulu, M., Gardiner, P., Williams, T., Mota, C., Maguire, S., Shou, Y., & Stamati, T. (2014). Effect of project role, age and gender differences on the formation and revision of project decision judgements. *International Journal of Project Management*, *32*, 556–567. https://doi.org/10.1016/j.ijproman.2013.09.001

Pal, S. K., Takano, A., Alanne, K., Palonen, M., & Siren, K. (2017). A multi-objective life cycle approach for optimal building design: A case study in Finnish context. *Journal of Cleaner Production*, *143*, 1021–1035. https://doi.org/10.1016/j.jclepro.2016.12.018

Passos, J., Alves, O., & Brito, P. (2020). Management of municipal and construction and demolition wastes in Portugal: future perspectives through gasification for energetic valorisation. *International Journal of Environmental Science and Technology*, *17*, 2907–2926. https://doi.org/10.1007/s13762-020-02656-6

Pires, A., & Martinho, G. (2019). Waste hierarchy index for circular economy in waste management. *Waste Management*, *95*, 298–305. https://doi.org/10.1016/j.wasman.2019.06.014

Poon, C. S., Yu, A. T. W., Wong, S. W., & Cheung, E. (2004). Management of construction waste in public housing projects in Hong Kong. *Construction Management and Economics*, *22*, 675–689. https://doi.org/10.1080/0144619042000213292

Qin, Y., Zhang, X., & Chai, J. (2019). Damage performance and compressive behavior of early-age green concrete with recycled nylon fiber fabric under an axial load. *Construction and Building Materials*, *209*, 105–114. https://doi.org/10.1016/j.conbuildmat.2019.03.094

Qin, Y., Li, M., Li, Y., Ma, W., Xu, Z., Chai, J., & Zhou, H. (2021). Effects of nylon fiber and nylon fiber fabric on the permeability of cracked concrete. *Construction and Building Materials*, *274*, 121786. https://doi.org/10.1016/j.conbuildmat.2020.121786

Saez, P. V., Del Río Merino, M., San-Antonio González, A., & Porras-Amores, C. (2013). Best practice measures assessment for construction and demolition waste management in building constructions. *Resources*, *Conservation and Recycling*, *75*, 52–62. https://doi.org/10.1016/j.resconrec.2013.03.009

Sezer, A. A., & Bosch-Sijtsema, P. (2020). Actor-to-actor tensions influencing waste management in building refurbishment projects: A service ecosystem perspective. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2020.1741493

Stephan, A., & Athanassiadis, A. (2018). Towards a more circular construction sector: Estimating and spatialising current and future non-structural material replacement flows to maintain urban building stocks. *Resources*, *Conservation and Recycling*, *129*, 248–262. https://doi.org/10.1016/j.resconrec.2017.09.022

Tingley, D. D., Giesekam, J., & Cooper-Searle, S. (2018). Applying circular economic principles to reduce embodied carbon. In F. Pomponi, C. De Wolf, & A. Moncaster (Eds.), *Embodied carbon in buildings* (pp. 265–285). Springer, Cham. https://doi.org/10.1007/978-3-319-72796-7_12

Tonglet, M., Phillips, P. S., & Read, A. D. (2004). Using the theory of planned behaviour to investigate the determinants of recycling behaviour: A case study from Brixworth, UK. *Resources*, *Conservation and Recycling*, *41*, 191–214. https://doi.org/10.1016/j.resconrec.2003.11.001

Van Ewijk, S., & Stegemann, J. A. (2016). Limitations of the waste hierarchy for achieving absolute reductions in material throughput. *Journal of Cleaner Production*, *132*, 122–128. https://doi.org/10.1016/j.jclepro.2014.11.051

Vieira, C. S., & Pereira, P. M. (2015). Use of recycled construction and demolition materials in geotechnical applications: A review. *Resources*, *Conservation and Recycling*, *103*, 192–204. https://doi.org/10.1016/j.resconrec.2015.07.023

Vitale, P., Arena, N., Di Gregorio, F., & Arena, U. (2017). Life cycle assessment of the end-of-life phase of a residential building. *Waste Management*, *60*, 311–321. https://doi.org/10.1016/j.wasman.2016.10.002

Wang, N., Wei, K., & Sun, H. (2014). Whole life project management approach to sustainability. *Journal of Management in Engineering*, *30*, 246–255. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000185

Wang, N., Yao, S., Wu, G., & Chen, X. (2017). The role of project management in organisational sustainable growth of technology-based firms. *Technology in Society*, *51*, 124–132. https://doi.org/10.1016/j.techsoc.2017.08.004

Wei, Y., Chai, J., Qin, Y., Xu, Z., & Zhang, X. (2019). Performance evaluation of green-concrete pavement material containing selected C&D waste and FA in cold regions. *Journal of Material Cycles and Waste Management*, *21*, 1550–1562. https://doi.org/10.1007/s10163-019-00908-3

Wong, C. L., Mo, K. H., Yap, S. P., Alengaram, U. J., & Ling, T.-C. (2018). Potential use of brick waste as alternate concrete-making materials: A review. *Journal of Cleaner Production*, *195*, 226–239. https://doi.org/10.1016/j.jclepro.2018.05.193

Xia, B., Ding, T., & Xiao, J. (2020). Life cycle assessment of concrete structures with reuse and recycling strategies: A novel framework and case study. *Waste Management*, *105*, 268–278. https://doi.org/10.1016/j.wasman.2020.02.015

Xiao, J., Ma, Z., & Ding, T. (2016). Reclamation chain of waste concrete: A case study of Shanghai. *Waste Management*, *48*, 334–343. https://doi.org/10.1016/j.wasman.2015.09.018

Zhang, C., Hu, M., Dong, L., Gebremariam, A., Mirand-Xicotencatl, B., Di Maio, F., & Tukker, A. (2019). Eco-efficiency assessment of technological innovations in high-grade concrete recycling. *Resources*, *Conservation and Recycling*, *149*, 649–663. https://doi.org/10.1016/j.resconrec.2019.06.023

Zhao, W., Leeftink, R. B., & Rotter, V. S. (2010). Evaluation of the economic feasibility for the recycling of construction and demolition waste in China – The case of Chongqing. *Resources*, *Conservation and Recycling*, *54*, 377–389. https://doi.org/10.1016/j.resconrec.2009.09.003

Zhong, Y., & Wu, P. (2015). Economic sustainability, environmental sustainability and constructability indicators related to concrete- and steel-projects. *Journal of Cleaner Production*, *108*, 748–756. https://doi.org/10.1016/j.jclepro.2015.05.095

APPENDIX

Questionnaire

First section

1. What is your experience in the construction industry?
   ☐ Under 9 years
   ☐ 10 to 14 years
   ☐ Over 15 years

2. What is your area of activity in the company?
   ☐ Construction supervision directors
   ☐ Construction/production directors
   ☐ Safety Technician
   ☐ Project authors

3. Based on your experience, please identify on a percentage scale, the method of CDW management you use on site, considering:

	0%	0–25%	25–50%	50–75%	75–100%
A1 – Licensed landfill	☐	☐	☐	☐	☐
A2 – Recycling	☐	☐	☐	☐	☐
A3 – Reuse on site	☐	☐	☐	☐	☐
A4 – Other (landfills, construction sites, etc.)	☐	☐	☐	☐	☐

4. Based on your experience, please identify the percentage of waste that is recycled, according to the following possibilities:

	0%	0–25%	25–50%	50–75%	75–100%
B1 – Wall materials (e.g., bricks, blocks)	☐	☐	☐	☐	☐
B2 – Concrete execution with recycled aggregates	☐	☐	☐	☐	☐
B3 – Materials serving as a base for ground floors	☐	☐	☐	☐	☐
B4 – Other applications, such as drains, foundations and landfills	☐	☐	☐	☐	☐

5. Based on your experience, please estimate the rate of reuse for the different types of construction or rehabilitation, considering the followings:

	0%	0–25%	25–50%	50–75%	75–100%
C1 – Reinforced concrete structure constructions	☐	☐	☐	☐	☐
C2 – Stone masonry constructions	☐	☐	☐	☐	☐
C3 – Metal structure constructions	☐	☐	☐	☐	☐
C4 – Mixed-structure constructions	☐	☐	☐	☐	☐
C5 – Wood structure constructions	☐	☐	☐	☐	☐
C6 – Reinforced concrete rehabilitations	☐	☐	☐	☐	☐
C7 – Stone masonry rehabilitations	☐	☐	☐	☐	☐
C8 – Metal structure rehabilitations	☐	☐	☐	☐	☐
C9 – Mixed-structure rehabilitations	☐	☐	☐	☐	☐
C10 – Wood structure rehabilitations	☐	☐	☐	☐	☐

Second section

1. Based on your experience, please rank by using a Likert scale, ranked from 1 to 5, where 1 corresponds to "unimportant" and 5 to "very important" the benefits of CDW reuse and recycling

	1 unimportant	2	3	4	5 very important
D1 – Saves space in landfills, thus reducing the need for new landfills	☐	☐	☐	☐	☐
D2 – Reduces the project budget by using recycled materials	☐	☐	☐	☐	☐
D3 – Saves the cost of transportation between the construction site and the landfill	☐	☐	☐	☐	☐
D4 – Complies with government policies of green construction and environmental protection	☐	☐	☐	☐	☐
D5 – Promotes increased competitiveness resulting from increased business opportunities for the sector	☐	☐	☐	☐	☐
D6 – Decreases the ecological footprint	☐	☐	☐	☐	☐
D7 – Protects natural resources	☐	☐	☐	☐	☐

2. Based on your experience, please rank by using a Likert scale, ranked from 1 to 5, where 1 corresponds to "unimportant" and 5 to "very important" the factors that hinder CDW reuse and recycling

	1 unimportant	2	3	4	5 very important
E1 – High cost and labour intensity in waste separation	☐	☐	☐	☐	☐
E2 – High cost of transport between the work site and landfills	☐	☐	☐	☐	☐
E3 – Difficulty in installing and maintaining reuse and recycling machines (e.g., crushers) on site	☐	☐	☐	☐	☐
E4 – Higher cost of work planning and management by incorporating CDW delivery to landfills	☐	☐	☐	☐	☐
E5 – A higher workload in registration and supervision of activities related to CDW delivery to landfills	☐	☐	☐	☐	☐
E6 – Change in management policy and work mechanism in companies	☐	☐	☐	☐	☐
E7 – Lack of employees' participation and training in CDW reuse and recycling	☐	☐	☐	☐	☐
E8 – Lower quality of products with recycled content	☐	☐	☐	☐	☐
E9 – Lack of balance between demand and supply in the reuse and recycling market	☐	☐	☐	☐	☐
E10 – Lack of investment in scientific research on CDW reuse	☐	☐	☐	☐	☐
E11 – Lack of promotion and support for CDW reuse and recycling	☐	☐	☐	☐	☐
E12 – Lack of government support	☐	☐	☐	☐	☐
E13 – Lack of regulation on CDW reuse and recycling	☐	☐	☐	☐	☐
E14 – Cultural resistance to products or projects incorporating CDW	☐	☐	☐	☐	☐

3. Based on your experience, please rank by using a Likert scale, ranked from 1 to 5, where 1 corresponds to "unimportant" and 5 to "very important" the factors that promote CDW reuse and recycling

	1 unimportant	2	3	4	5 very important
F1 – A comprehensive and accurate assessment of the return on investment in CDW reuse and recycling	☐	☐	☐	☐	☐
F2 – Inclusion of CDW reuse and recycling in the initial stage of the project	☐	☐	☐	☐	☐
F3 – Inclusion of training actions to raise awareness of CDW reuse and recycling	☐	☐	☐	☐	☐
F4 – Effective communication between all stakeholders regarding CDW reuse and recycling	☐	☐	☐	☐	☐
F5 – Financial incentive for CDW recycling and/or reuse	☐	☐	☐	☐	☐