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Critical success factors for the effective management of construction waste: a study in Brazil

Fatores críticos de sucesso para o gerenciamento eficaz de resíduos da construção civil: um estudo no Brasil

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ABSTRACT

Construction is a major contributor to the development of growing countries. However, it produces negative environmental impacts, such as the significant consumption of natural resources, and is the sector that generates the most waste in the world. Some authors argue that this can be minimized with the implementation of effective construction waste management (CWM) practices at construction sites, and a good strategy to define these practices is the application of the critical success factors (CSF) method, as this method helps to reduce the complexity of management tasks. In this way, this research aims to identify the CSFs for improving CWM on the construction sites of the municipality of Natal/RN (Brazil). The method was applied in five stages, including the literature review, questionnaire application, calculation of the questionnaire results, definition of CSF, and CSF interpretation with the help of interviews. Altogether, based on the 19 success factors selected in the review, 13 CSFs were defined based on quantitative analysis. The first three factors were as follows: CSF1—To develop and apply the Construction Waste Management Plan (CWMP) at the construction site; CSF2—To encourage the reduction of construction waste; and CSF3—To dispose of the construction waste generated at legally authorized sites or recyclers/cooperatives. Stakeholders of the sector in the city investigated in this study have mechanisms for effectively implanting the CWM practices at their construction sites, which, through measures aimed at the management of CW, will contribute to the minimization of waste generation in Natal/RN.

Keywords: construction; environmental impact; sustainable practices; waste management.

RESUMO

A construção civil é um dos principais contribuidores para o desenvolvimento de países em crescimento. No entanto, produz impactos ambientais negativos, como o consumo significativo de recursos naturais e é o setor que mais gera resíduos no mundo. Alguns autores argumentam que isso pode ser minimizado com a implementação de práticas eficazes de gerenciamento de resíduos da construção civil (GRCC) nos canteiros de obras, e uma boa estratégia para definir essas práticas é a aplicação do método dos fatores críticos de sucesso (FCS), pois este método ajuda a reduzir a complexidade das tarefas de gestão. Dessa forma, esta pesquisa teve como objetivo identificar os FCS para aprimorar a GRCC nos canteiros de obras do município de Natal/RN (Brasil). O método foi aplicado em cinco etapas, incluindo a revisão da literatura, a aplicação do questionário, o cálculo dos resultados do questionário, a definição do FCS e a interpretação do FCS com a ajuda de entrevistas. No total, com base nos 19 fatores de sucesso selecionados na revisão, 13 FCS foram definidos com base na análise quantitativa. Os três primeiros fatores foram os seguintes: FCS1 — Desenvolver e aplicar o Plano de Gerenciamento de Resíduos de Construção no local da construção; FCS2 — Incentivar a redução de resíduos de construção; e FCS3 — Descartar os resíduos de construção gerados em locais legalmente autorizados ou recicladores/cooperativas. As partes interessadas do setor na cidade investigada neste estudo dispõem de mecanismos para implantar efetivamente as práticas de GRCC em seus canteiros de obras, que, por meio de medidas voltadas para a gestão de GRCC, contribuirão para a minimização da geração de resíduos em Natal/RN.

Palavras-chave: construção; impacto ambiental; práticas sustentáveis; gestão de resíduos.

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Introduction

The construction sector plays an important role in the growth of developing countries (Hasmori et al., 2020; Al-Mhdawi et al., 2024). However, it has a strong negative environmental impact, harmful to ecosystems, consuming significant amounts of natural resources, modifying landscapes, generating large amounts of waste, and promoting the final disposal of wasted materials (Lu and Yuan, 2010; Nagapan et al., 2013; Dräger and Letmathe, 2022).

Compared to other economic sectors, the construction sector is the largest waste generator in the world (Osmani and Villoria-Sáez, 2019; Alsheyab, 2022). However, this large amount of construction waste (CW) can be predicted, avoided, and reduced (Mohammed et al., 2021). Thus, environmental degradation needs to be avoided through proper treatment of CW (Vidyasekar and Selvan, 2019; Liu et al., 2020).

For this, it is suggested that promoting effective construction waste management (CWM) practices is the best way to achieve sustainability in the sector with the prevention and recovery of CW (Gangolells et al., 2014; Saad et al., 2022; Cheng et al., 2023). Managing CW effectively is becoming increasingly important, considering the era of scarcity of natural resources and the high costs of waste disposal, as well as the limitation of landfill areas in metropolitan regions (Siregar and Kustiani, 2019; Nanda and Berruti, 2021).

Advances in research on CW have increased in recent decades due to the growing involvement and awareness of the industrial sector and researchers worldwide. However, further investigation of the specific context of each region is needed to be able to have effective applicability. The effectively applied CWM contributes to obtaining economic, social, and environmental benefits (Hao et al., 2019; Jin et al., 2019; Kabirifar et al., 2020).

The critical success factors (CSFs) can be a good alternative for research in Brazil on CWM practices, with the purpose of reducing the negative impacts of the construction sector on the environment (Chen et al., 2022). CSFs are parameters for setting goals that make the sector or institution visualize whether it will be successful or the things that work and are efficient. It helps to reduce the complex nature of management (Wang et al., 2010).

The CSF technique has been popular in construction management research (Banihashemi et al., 2017; Gunduz and Almuajebh, 2020; Badraddin et al., 2022; Alawag et al., 2023; Ali et al., 2023; Koc et al., 2023; Yüregir and Ekşici, 2024) and, specifically, CWM (Lu and Yuan, 2010; Wang et al., 2010; Silva et al., 2020). It is possible to build strategies to develop waste management at the construction site effectively by identifying the CSFs as a reference for the public authorities, construction companies, professionals, and investors in the area (Lu and Yuan, 2010; Wang et al., 2010).

Thus, of the many factors that affect the effectiveness of waste management, such as regulations and technologies (Lu and Yuan, 2010), this research identified CSFs for the effective management of CW in the municipality of Natal/RN (Brazil).

Research methodology

This research is of an applied nature, using the inductive scientific method with a quantitative-qualitative approach, as the objectives of the study are exploratory, with technical procedures adopted in bibliographic research in the area, and descriptive, with the use of surveys to question the research participants (Prodanov and Freitas, 2013). This research was submitted and approved by the research ethics committee of Brazilian legislation, CEP no. 4.663.478.

To this end, this research used the CSF method, conducting the work in five steps:

1. Survey the selected success factors (SSFs) specific to the activity to be achieved;
2. Research the importance of each SSF related to an objective;
3. Perform a quantitative analysis of the importance of each factor based on the survey;
4. Extract the CSFs based on the most relevant SSFs according to the quantitative analysis;
5. Interpret qualitatively the importance of each CSF for the specific activity to be successful (Lu and Yuan, 2010).

Each step will be detailed in the following subtopics.

Survey the SSFs for successful CWM

Strategies for CW minimization or successful CWM practices on the construction site were researched through a narrative literature review of 23 publications (see the search in Table 1), found in the ScienceDirect and Scopus databases (1998–2020). This review resulted in 19 strategies that were defined as SSFs, as listed in Table 2.

So, he SSFs were evaluated below, related to the local context of the CWM in the construction works of the municipality of Natal/RN.

Research on the importance of each factor

The methods used in the step on the importance of each SSF for successful CWM were carried out using a questionnaire and applying interviews conducted remotely to assist in the interpretation of the results (Lu and Yuan, 2010; Wang et al., 2010). Data collection tools were employed with professionals, entrepreneurs, and academic researchers of the construction management or CW sector in the region.

Questionnaire

The questionnaire was developed by the Google Docs forms platform, and was divided into five sections.

In the first section, there was a presentation with information about the research and whether the participant agreed with the informed consent record, as established in Resolution 510/2016 of the National Health Council (Brazil, 2016).

In the second section, information was requested related to the participant's function/position, the economic sector in which he/she works, the main activity he/she performs in the construction sector, and the length of experience with construction management and/or CW in Natal/RN.

Table 1 – SSF survey for a successful CWM.

SSF	Survey																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Σ
SSF1			x	x	x	x	x	x	x					x	x					x	x			11
SSF2		x					x	x	x										x		x			6
SSF3		x	x	x	x	x	x		x		x		x	x	x				x					12
SSF4			x	x										x	x		x							5
SSF5			x	x		x	x		x						x	x			x					8
SSF6			x	x	x	x	x		x	x	x	x	x			x	x			x	x			14
SSF7			x	x		x	x		x								x							6
SSF8	x	x		x	x	x		x	x	x		x	x	x		x		x	x		x	x		16
SSF9			x			x	x	x				x	x		x	x			x	x	x			11
SSF10	x	x	x			x	x			x		x			x		x		x					10
SSF11	x	x	x	x			x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	19
SSF12	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	x	20
SSF13		x	x	x	x		x	x			x	x	x		x		x		x	x		x	x	15
SSF14			x	x	x	x	x			x							x		x			x		9
SSF15			x	x		x	x			x	x	x						x		x		x		10
SSF16			x	x	x											x		x	x					6
SSF17	x							x		x					x		x			x				7
SSF18	x			x				x		x			x				x	x					x	8
SSF19	x			x				x		x			x				x	x					x	8
Σ	7	7	14	15	7	11	13	10	9	10	6	7	9	6	9	7	11	7	11	8	5	6	5	

X:Identified; Survey: 1: (Ajayi et al., 2008), 2: (Begum et al., 2007), 3: (Gálvez-Martos et al., 2018), 4: (Gálvez-Martos and Istrate, 2020), 5: (Gangolells et al., 2014), 6: (Hasmori et al., 2020), 7: (Kelly and Dowd, 2017), 8: (Lu and Yuan, 2010), 9: (Magalhães et al., 2017), 10: (Mahayuddin and Pereira, 2014), 11: (Marinelli et al., 2014), 12: (Mcdonald and Smithers, 1998), 13: (Nagapan et al., 2013), 14: (Narcis et al., 2019), 15: (Osmani, 2012), 16: (Ouda et al., 2017), 17: (Paschoalin Filho et al., 2017), 18: (Rodríguez et al., 2007), 19: (Tam, 2008), 20: (Tischer et al., 2013), 21: (Udawatta et al., 2015), 22: (Yu et al., 2013), 23: (Yuan, 2017).

Table 2 – List of SSFs for successful CWM.

SSF	Description
SSF1	Improve communication between project participants
SSF2	Adopt construction processes with low waste (e.g., prefabricated)
SSF3	Manage the procurement of materials according to demand (e.g., just in time)
SSF4	Get Green Seals (LEED, AQUA, BREEAM, etc.)
SSF5	Predict the materials on the construction site with potential for generation, reuse, recovery, and recycling
SSF6	Develop and implement the Construction Waste Management Plan (CWMP) on-site
SSF7	Set targets and incentives related to waste management on the construction site
SSF8	Sensitize the entire team on the site about environmental education and construction waste management
SSF9	Implement a monitoring and supervision system on the construction site related to pre-established practices in the CWMP
SSF10	Encouraging the reduction of CW
SSF11	Encouraging the reuse of CW
SSF12	Encouraging the recycling of CW
SSF13	Improve CW collection and screening techniques at the generation source
SSF14	Dedicate a space for the storage and sorting of CWs on site
SSF15	Make specific collectors available for each type of CW
SSF16	Controlling and storing hazardous waste
SSF17	Quantify the CW generated
SSF18	Control the transport of waste through a document (CWT, for example)
SSF19	Allocate the CW generated to legally authorized sites or recyclers/cooperatives

In the third section, the participants' opinion was requested for each factor. The evaluation was required through a level of agreement measured on a five-point Likert scale, where 5 denotes "completely agrees"; 4, "partially agrees"; 3, "neutral"; 2, "partially disagrees"; and 1, "completely disagrees" (Lu and Yuan, 2010; Wang et al., 2010). In this way, it was possible to measure the degree of importance of each factor and thereby define the CSFs.

The fourth and fifth sections indicated the opportunity for participants to volunteer for the interview phase, confirming their acceptance and leaving contact information.

The complete research was then conducted in the municipality of Natal/RN during the period from 23 April to 11 May 2021. The sampling applied to the study population was 75 participants according to the quantitative method established also by Lu and Yuan (2010) and Wang et al. (2010). Invitations were sent by email, Instagram, and/or WhatsApp. Reminders were sent to participants after 7 and 15 days from the first contact to ensure a quick and good return rate.

The response rate of the questionnaires was 77.3% (58 volunteers), a value above the response rate of 68%, considered satisfactory by Moser and Kalton (1971). It was observed that participants had considerable experience in construction management in Natal/RN (96.6% above 1 year, 62.1% above 5 years, and 39.7% above 10 years) and more recent contact with CW in Natal/RN (87.9% above 1 year, 48.2% above 5 years, and 24.1% above 10 years), making them qualified to answer the questionnaire. Of these, 39.7% worked exclusively in the public sector, 39.7% exclusively in the private sector, and 20.7% in both sectors. The majority (46.6%) worked in construction, renovation, and demolition activities. Another 24.1% worked as teachers, 25.9% in other activities (projects, consultancy, service provision, etc.), and 3.4% in the infrastructure sector.

Quantitative analysis of the importance of each factor

To analyze the 19 SSFs evaluated by the participants of the questionnaire, Equation 1 below was used, with the objective of quantifying the importance of each factor:

$$VSSFi = \sum_{j=i}^{5} MijSj \,/ \sum_{j=i}^{5} Mij \; (i = 1, 2, \dots, 19; j = 1, 2, \dots, 5) \qquad (1)$$

Where:

VSSFi: degree of importance for the SSF in the CWM;

Sj: rating received by the factor evaluated (*S1*=1, ..., *S5*=5);

Mij: number of respondents who chose j for the defined rating (*S*) for the *i* of the factors.

This equation was sufficient to carry out the survey of the importance among the variables, calculated through their importance index (Tam, 2008; Lu and Yuan, 2010; Wang et al., 2010).

The results were inserted in IBM SPSS Statistics 20.0, and the mean and standard deviation for each factor were calculated. The SSFs were classified according to their mean values, considering the standard deviation (the lower the value, the better placed) as a tiebreaker criterion (Lu and Yuan, 2010; Wang et al., 2010).

Extraction of the most relevant results on the basis of quantitative analysis

The results of the analysis of the factors can be visualized in Table 3. SSFs with degrees of importance greater than the total mean of factors (4.678) are determined as CSFs. Thus, there are 13 factors appropriate for this criterion: SSF6, SSF10, SSF19, SSF9, SSF5, SSF7, SSF8, SSF16, SSF18, SSF15, SSF13, SSF14, and SSF12.

Qualitative interpretation of factors

The CSFs were interpreted in the analysis of the results with the support of the literature investigated and the interviews with the participants.

Interview

In order to clarify the results found in the questionnaire survey, interviews were held with 14 volunteers who had volunteered in the previous stage (Lu and Yuan, 2010; Wang et al., 2010).

This stage was previously scheduled according to the data made available in the questionnaire phase, conducted remotely, semi-structured, and with an average duration of 20–30 min. The interviews were developed during the month of May 2021. During the interview, participants were not informed of the results of the questionnaire to keep their answers without any specific direction or bias (Lu and Yuan, 2010; Wang et al., 2010).

Analysis of Results

The number of factors found in Table 3 is twice that reported in Lu and Yuan (2010) and Wang et al. (2010). The results show, then, that the study of factors is specific for each region. The 13 factors detected in this study will be discussed as follows.

CSF1: Develop and implement the CWMP on site

The CWMP is an effective measure to improve the performance of CWM, being a successful basis for the implementation of its practices at the construction site (Nagapan et al., 2013; Gálvez-Martos et al., 2018). Moreover, the plan is the main management tool for the reduction or even elimination of the generation of CW throughout the construction cycle (Kelly and Dowd, 2017; Narcis et al., 2019).

A good plan should be specific to each development and contain the management actions for each type of CW; the estimated amount generated; the management options; the resources used in the process; the identification of materials that can be recovered, reused, or recycled; the cost reduction to be achieved; and the responsibilities of each participant involved (Gangolells et al., 2014; Gálvez-Martos et al., 2018).

Table 3 – Classification of SSFs according to the degree of importance.

factor	*VSSFi*	standard deviation	Rank	CSF
SSF6	4.810	0.760	1st	CSF1
SSF10	4.776	0.773	2nd	CSF2
SSF19	4.759	0.802	3rd	CSF3
SSF9	4.759	0.802	4th	CSF4
SSF5	4.741	0.785	5th	CSF5
SSF7	4.724	0.790	6th	CSF6
SSF8	4.724	0.812	7th	CSF7
SSF16	4.724	0.833	8th	CSF8
SSF18	4.724	0.833	9th	CSF9
SSF15	4.724	0.913	10th	CSF10
SSF13	4.707	0.795	11th	CSF11
SSF14	4.707	0.817	12th	CSF12
SSF12	4.690	0.922	13th	CSF13
SSF17	4.621	0.834	14th	
SSF2	4.621	0.875	15th	
SSF11	4.621	0.933	16th	
SSF4	4.534	0.977	17th	
SSF1	4.517	0.903	18th	
SSF3	4.483	1.064	19th	

The interviewees reported that, in Natal/RN, the document is often only for the purpose of legal regularization of the enterprise and granting of environmental licenses. For them, besides being mandatory, the plan is essential to have a vision of the necessary practices that need to be applied to seek effectiveness in the management. However, in practice, it is not implemented, monitored, or controlled at the construction sites, leaving most of the construction sites to develop the most basic practices of collection, transportation, and disposal of CW, without any separation treatment at the source and greater reuse or recycling of waste.

Without the plan, the management is applied only as a correction of what is being generated or by the disorganization of the construction site (Lu and Yuan, 2010).

CSF2: Encouraging the reduction of CW

The studies by Begum et al. (2007), Tam (2008) and Hasmori et al. (2020) assert that to minimize the CW generated at the construction site, it is necessary to adhere to waste reduction practices during the execution of the construction work services.

The interviewees of the research emphasized that reducing or encouraging this practice demonstrates to the construction team how important it is to use the maximum capacity of the materials applied, besides signifying the relevance of the other waste management practices also developed in the management. To this end, they pointed out that this factor must be performed at the generation source or in the planning processes with the choice of more updated construction techniques that generate less waste of materials, such as industrialized or prefabricated executive systems.

As described by Poon (2007), the reduction of CW can be achieved by changing the design ideas, by changing the material used, or by changing the executive procedure. He also alerts that this practice must be established for all the agents involved in the construction.

CSF3: Allocate the CW generated to legally authorized sites or recyclers/cooperatives

It is of utmost importance to destine the CW at legally authorized sites because the CW can promote a large environmental liability for the region where it is allocated (Paschoalin Filho et al., 2017). In addition, it is guaranteed that the waste can be reused, recovered, or recycled for other purposes, avoiding public lands being used indiscriminately as a dumping area, which may create danger to the health of the population and the environmental balance (Ajayi et al., 2008).

For the interviewees, there is no point in following all the necessary procedures to manage CW if it is not properly disposed of. Interviewee 8 mentioned that, in the city of Natal/RN, there is still a lack of awareness, in the great majority of the work managers, regarding the certainty that the waste generated by the construction site reaches the place scheduled to receive it, with care being neglected at this stage. The big problem in question is whether the generator will be exempt from liability if there is an inappropriate disposal.

Therefore, this factor is important to ensure the reuse and recycling of CW. However, it must be carefully observed that it is being done safely and responsibly, being the responsibility of the companies that transport and receive the waste, but mainly, the generator itself.

CSF4: Implement a monitoring and supervision system at the construction site related to pre-established practices in the CWMP

The activities of CWM should be supervised with clear information, considering the training of the whole organization chart of the construction site and the construction company, so that it is possible to implement the management effectively and improve the behavior of the agents involved regarding the care of the CW (Udawatta et al., 2015).

In the opinion of Interviewee 2, this system is a pillar for the functioning of the proposals established by the plan to establish the management measures at the construction site, because, without it, it is very difficult to coordinate the planned tasks "*it has to have.*" Other interviewees pointed out the importance of monitoring to make it possible to apply the practices of the CWMP so that it is not just a document shelved on site, and thus ensure the organization and implementation of the CWM.

As for the cost of implementing this system, there are advantages, especially the cost-benefit of effective CWM practices. For Gálvez-Martos et al. (2018), CWM represents 0.10% of the total budget of the construction site.

CSF5: Predict the materials at the construction site with potential for generation, reuse, recovery, and recycling

Of all the waste generated at the construction site, over 80% has great potential for future reuse or recycling (Islam et al., 2019). During the production of the CWMP, through the investigation of the executive procedures that may admit secondary materials, it is possible to identify the CW generation flow, the minimization procedures, the possibilities of reuse and recycling, and their potential application in each stage of the work, making the use of virgin material partially reduced (Gálvez-Martos et al., 2018).

In the interviewees' opinion, developing the materials and construction stages with potential for CW generation, which can return to the production cycle, is very important to estimate the amount of waste generated, reduce waste, predict management costs, and contribute to the quality of segregation by type of CW. Therefore, this step is important, and it must be included in the initial planning processes of the work or before the execution of each specific service to be more effective.

CSF6: Set targets and incentives related to waste management at the construction site

For Gálvez-Martos and Istrate (2020), the goals or objectives must be clear and attainable, such as the amount of CW directed to recycling, the amount of waste to be segregated, and the reduction in the number of incidents involving waste, for example.

For the interviewees, the goals and incentives established to ensure the management of waste at the construction site are important links to guide the management activities of the waste at the construction site and provide reflection and understanding, in addition to the purpose to be achieved by the entire team, from the highest administration to the operational sector, bringing awareness of the action of the CWM and increasing the performance of those involved.

Once the strategies and procedures are established, the construction manager or manager responsible for the implementation of waste management at the construction site is responsible for disseminating the ideas of the CWMP to the agents involved through awareness practices (Gálvez-Martos et al., 2018).

CSF7: Sensitize the entire team on the site about environmental education and CW management

To raise this awareness, it is necessary that the site apply training on the CWM, the saving of resources, and the protection of the environment with all stakeholders. This should be developed in a simple and objective way, presenting the importance of segregation of CW, management practices, goals, and procedures to be achieved and other important issues foreseen in the CWMP (Gangolells et al., 2014; Gálvez-Martos et al., 2018; Hasmori et al., 2020).

The study by Udawatta et al. (2015) identified environmental training and education as the main solution for successful waste management at the site. Begum et al. (2007) reinforce that, in addition to helping in the implementation of the CWM, it further reduces the waste of material in the work.

It was highlighted by the participants that awareness should be strengthened for both classes: the workers, in order to bring further clarification about the processes and, above all, to educate those with low schooling, explaining effectively with an accessible language; and the business class, also involving the administrative sector of the construction site, in order to see the CWM as something important for the overall management of the construction work, not only for environmental return, but also for the reduction of costs, better use of resources, and social return, as highlighted by Paschoalin Filho et al. (2017), with generation of work in recycling services.

Therefore, the training should be developed regularly with the new hires, renewed in planned periods with the former employees, and documented with the date and theme addressed in each training (Gálvez-Martos et al., 2018).

CSF8: Controlling and storing hazardous waste

The authors Rodríguez et al. (2007) clarify those different processes in the management of hazardous waste that should be adopted in the work, compared with the care provided with other types of solid waste or inert waste. For them, it is necessary to verify the legal and normative requirements for these residues to take the necessary measures in the management of each type.

Hazardous waste must be collected separately from the other waste, and its packaging made in sealed collectors, protected from weathering, and isolated from surfaces (Gálvez-Martos et al., 2018; Gálvez-Martos and Istrate, 2020).

For interviewee 2, this practice is important to contain the environmental liabilities that hazardous waste scans can promote, considering that this type of CW (even with low generation) has the greatest potential for impact. However, the statement is that many construction companies are not prepared for the management of hazardous waste, especially those that work in the construction and demolition sector in Natal/RN. Some of the interviewees also pointed to the importance of judicious segregation and storage of this type of waste at the work site because, when mixed with others, it contaminates them and makes them unfeasible for subsequent processes of reuse or recycling.

CSF9: Control the transport of waste through a document (CWT, for example)

The control of waste transport (CWT) has been suggested in Brazil since 2004 by ABNT NBR 15113. The CWT is a document filled out at the construction site every time the waste leaves the work, recording the type of waste, its volume or weight, and the day and time of withdrawal, in addition to the information of the carrier and the owner, and must then be signed by the agents involved (Souza et al., 2008; Paschoalin Filho et al., 2017).

From 2020, this became a legally mandatory factor throughout Brazil with the publication of Ordinance No. 280 of the Ministry of the Environment/Cabinet of the Minister (Brazil, 2020).

The interviewees stated that the issuance of CWT is a way to ensure the transport and environmentally appropriate destination of CWs. If a conveyor improperly allocates waste, it breaks the entire chain and minimizes all work done up to that moment. If this happens, Brazilian law establishes that the responsibility will be not only that of the transport company, but also of the generator, thus the importance of documenting the entire external process. However, it was reported that there is still considerable negligence on the part of the professionals of the construction sector in Natal/RN regarding the responsibility to control and supervise this stage outside the work.

CSF10: Make specific collectors available for each type of CW

Managing, minimizing, and requiring the correct separation of waste by type on the construction site requires the disposal of specific collectors and should be identified and differentiated for each CW. In addition, workers must have access to the packagers at collection points near the place of origin and with capacity proportional to the estimated amount of generation, with the objective of increasing the screening efficiency of the CW (Gálvez-Martos et al., 2018; Gálvez-Martos and Istrate, 2020).

According to Gálvez-Martos and Istrate (2020), the identification of collectors should be illustrative, with images or drawings related to the residue that should be discarded in each container, being then an important measure in the context of segregation within the work.

For the interviewees, it is necessary that the appropriate collectors be made available for the CW and that they are accessible because if they are supplied in the wrong way, this will confuse the worker and, thus, generate problems in the storage of waste.

Collectors should be arranged with proper identification, both in the color itself and in the illustration of images, to avoid difficulty for the production team at the time of temporarily disposing of the CW at the construction site.

CSF11: Improve CW collection and screening techniques at the generation source

Improving the techniques of collecting and sorting CW at the source of generation is effective to reduce waste generation, have greater reuse (reuse or recycling), improve the treatment of materials, and reduce the volume of waste directed to the final disposal.

The authors Gálvez-Martos and Istrate (2020) give examples of how these techniques can be improved, one of which is considering activities that generate a great deal of waste (demolition, ceramic, or mortar coating), because temporary collectors must be very close to performing these activities, and it is possible to already perform the screening at the origin, if space is available. Poon et al. (2001) reinforce the importance of training employees on CWM so that the techniques of collection and screening are effective, as they are the ones who will be on the front line to perform the practice.

For the interviewees, this stage still has difficulty in performing the construction works of Natal/RN. It is much more skillful to send all the waste together than to have the dedication to separate it in the enterprise, they point out. However, if there was action and space within the work, some equipment could be supplied by recyclers and receivers to reduce the volume of CW forwarded, such as the use of a press to compact plastic waste. Consistently, it was highlighted by the interviewees that the residues reach the destination in a mixed way.

Builders need to see that using good techniques for collecting and sorting the CW allows for a reduction in transportation and destination costs and, in some cases, even more revenue from the sale of recyclable waste, as Wang et al. (2010) point out.

CSF12: Dedicate a space for storage and sorting of CWs on site

Associating the selection of a space for storage and screening of CWs on the construction site with the convenient positioning of collectors and their proper identification is a concordant and important strategy to increase the efficiency of the CWM with techniques of collection, sorting, reuse, and recycling of the waste of the construction. For this, it is necessary that the construction site have enough space to allow well-identified storage sites and containers in regions closer to the point of generation, and thus the sorting will be more effective at the origin (Yu et al., 2013; Gálvez-Martos et al., 2018).

Wang et al. (2010) present that it is necessary to plan the layout of the construction site to define where the waste collectors will be located and where the screening activities will be carried out for each type of CW, as this will reduce any management interference in the productive activities.

The interviewees believe that having a space on the construction site only for segregation complements the task that can be best performed within the work that generated the CW and, thus, ensures that the intended material is clean for reuse or recycling. The great difficulty presented is that not all the projects in Natal/RN have the availability of extra space for this activity

The solution for the construction sites of the municipality, at sites with little space, is to carry out as much of the screening as possible at the place where it is generated to reduce the possibility of mixing with CW and avoid a subsequent separation.

CSF13: Encouraging the recycling of CWs

Encouraging the recycling of CWs includes processes at the construction site itself, such as the use of crushers for segregated waste, or off-site, directing waste to destinations where this process is carried out, and acquiring recycled materials.

For Narcis et al. (2019), it is possible to reuse or recycle the following CW: steel, asphalt, plastic, aluminum, wood, brick and block, glass, ceramics, cardboard, concrete, paint, insulation, and plasterboard.

CW recycling is one of the main ways to reduce the environmental impacts caused by the works, eliminating problems such as greenhouse gas emissions, water, soil, and odor contamination. In addition, it reduces landfill costs and saves areas of land and natural resources (Ouda et al., 2017; Paschoalin Filho et al., 2017; Ram et al., 2020; Alsheyab, 2022). Thus, just as reducing was considered a CSF in this study, recycling should also become a priority in the CWM.

The interviewees pointed out that waste recycling generates a cost reduction not only for construction companies, but for society itself. In addition, environmental impacts are minimized by the allocation of smaller amounts of CW and the reduction of virgin material through the reuse of recycled waste. However, the participants warn that there is still resistance to using the material from CW in residential construction works, while in the paving sector, this practice is already more widespread. For them, if there are plenty of natural resources, there will be cultural resistance to this in the works of Natal/RN. Moreover, it was evidenced that the local government does not encourage this practice in the private works of the city.

Germany has a rate of more than 90% recycling of its CW by requiring environmental regulations and having comparative standards of quality of recycled waste (Gálvez-Martos et al., 2018).

Conclusion

Identifying the main processes to manage waste at the construction site is important to be able to implement the ideas set out in the CWMP. The CSFs are precise in selecting the main tasks to obtain an effective performance in any type of management and, thus, simplify the actions for the managers responsible for a sector.

This research identified 13 CSFs for the efficient management of CW at construction sites in Natal/RN by means of various analytical procedures.

With the survey of these factors, the construction companies and professionals of the studied city have the possibility to reduce unnecessary efforts at the construction site to carry out the measures of CWM and to focus on the practices that will bring high benefit in the efficiency of the management. Other researchers can also benefit from this study because it provides a method of easy application, which presents objective results and can be adapted to various regions of Brazil or other countries, considering that each location has different economic, cultural, environmental, and social aspects.

Moreover, it is important to highlight the minimization of waste generation that can be achieved with the dissemination of these results, because with the application of management practices, there is an incentive to reduce the generation of CW, the reuse of leftovers, recycling, treatment, and, finally, disposal. That is, a part of the CW returns to the productive chain before it occupies space in inert landfills or is inadequately disposed of.

Therefore, the factors found herein are applied only to Natal/RN. However, considering regional adaptations, this methodology can be used in other municipalities that need to reduce the negative environmental impact of the construction sector as well as improve CWM practices.

It is therefore hoped that this study will enlighten local public and private initiatives about the needs required by the construction sector to increasingly encourage waste management at construction sites classified as large generators to reduce waste generation and improper disposal, thus minimizing costs for city management, costs for construction site management, and the environmental impacts of the sector.

Authors' Contributions

Silva, J.D.S.S.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review and editing. **Lopes**, R.L.: Conceptualization, Formal analysis, Methodology, Project administration, Supervision, Validation, Writing – review and editing.

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