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ORIGINAL ARTICLE

ANALYSIS OF THE COSTS OF CONSTRUCTION WASTE IN RESIDENTIAL BUILDING WORKS IN CITIES IN THE NORTHEAST OF BRAZIL

Análise dos custos de resíduos da construção em obras de edifícios residenciais em cidades do nordeste do Brasil

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Resumo
Este artigo apresenta um levantamento das vertentes econômicas, decorrentes do modo de gestão dos Resíduos da Construção (RCC) em canteiros de obras de cinco cidades do Nordeste brasileiro, ocasionando despesas na produção e rentabilidade das edificações. A partir da coleta de dados de oitenta e quatro empreendimentos, quanto à gestão de resíduos, foram obtidas informações sobre: custo unitário para destinação, classificação do material, área construída e etapa de construção. Verificou-se que os RCC são predominantemente de Classe A, podendo ser reaproveitados como agregado, porém, não é feita uma segregação correta na obra, acarretando em um acréscimo de valores. Além disso, percebeu-se que não há uma relação proporcional entre a área construída e o resíduo gerado. Por fim, foi observada a ineficiência dos sistemas de gestão, devido ao desrespeito de algumas práticas, embora a maioria das construções sejam certificadas por programas de gestão da qualidade (ISO 9001). Deste modo, uma das formas mais simplificadas de mitigar custos pode ser através da aplicação de uma gestão eficiente, associada ao aperfeiçoamento dos profissionais da área, trazendo consciência sobre o produto utilizado.

Palavras–chave: Resíduos de Construção Civil, Custos, Gestão de Resíduos, Gestão da Qualidade.

Abstract
This article presents a survey of the economic aspects of managing Civil Construction Waste (CCW) on construction sites in five cities in Northeast Brazil, causing expenses in the production and profitability of buildings. From collecting data from eighty-four projects relating to waste management, information was obtained on unit cost for disposal, classification of materials, built area and construction stage. It was found that CCW is predominantly Class A and can be reused as aggregate. However, correct segregation is not carried out on-site, resulting in increased values. Furthermore, it was noticed that there is no proportional relationship between the built area and the waste generated. Finally, the inefficiency of management systems was observed due to the disregard of some practices, although most buildings are certified by quality management programs (ISO 9001). Therefore, one of the simplest ways to mitigate costs can be through the application of efficient management, which is associated with the improvement of professionals in the area and raising awareness of the product used.

Keywords: Civil Construction Waste, Costs, Waste Management, Quality Management.

1. INTRODUCTION

The construction industry plays an important role in the country's economic scenario, as the sector has proved very productive (Silva *et al.*, 2023). This has been due to people's interest in seeking safe and lasting investments and financing alternatives that make real estate more accessible.

However, the lack of planning has led to the use of a large quantity and variety of building materials, which, more often than not, are wasted and turned into waste. Quaglio and Arana (2020) explain that the generation of CCW can result from these planning shortcomings since construction sites have had to adapt and bring forward the completion of construction activities. This lack of definition of stages and activities led to losses and waste.

Cost control in implementing construction systems is important, as its measurement benefits the process. This control is the basis for analysing the management of the constructions and is fundamental for the indexes that will be used to draw up new spreadsheets for future projects. (Souto Filho *et al.*, 2022).

Based on this scenario, it can be seen that to increase the productivity of buildings and the profitability of companies, a waste management system can be indispensable, especially in the development of ~~u~~ncontrolled tools.

The purpose of this study ~~is~~ to present a survey of economic costs resulting from the CCW management on construction sites in five cities in Northeast Brazil (Fortaleza-CE,

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Natal-RN, Recife-PE, Maceió-AL and Salvador-BA) and the impacts of these costs on the production and profitability of buildings.

2. MATERIALS AND METHODS

Initially, the waste generated was identified, the site was characterised, the built area was determined, and other requirements such as the company's certification and the project's completion date were checked. The volume generated was also monitored by analysing the CCW control sheets and the construction budget.

It should be noted that the cost adopted as the basis for the economic analysis of CCW was disposal, as this type of expense can be identified more easily on construction sites since current legislation stipulates that large generators need to control their residues and dispose of them in suitable locations. Another relevant aspect would be the significant value of this disposal since the volumes of waste are constant throughout the construction process.

To calculate the total costs of detritus generation, the unit costs were identified from the budgets for the upbuilding analysed, which were provided by the technicians responsible for the construction company. In this case, the values were denominated according to Equation 1:

$$C = Q \times U \qquad \text{Equation 1}$$

Where:

C = Cost analysed;

Q = Quantity of waste analysed per work (ton);

U = Unit waste cost (R$/ton).

The survey was carried out on 84 (eighty-four) construction sites belonging to two ISO 9001 certified construction companies located in five capital cities in the Northeast region of Brazil (Fortaleza-CE, Natal-RN, Recife-PE, Maceió-AL and Salvador-BA). Notably, they all meet a pre-established standard: vertical residential buildings that have recently been completed or are in progress.

As the buildings included have different built-up area values, they were identified in built-up area intervals, determined by identifying the value of the highest and lowest built-

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up. Subsequently, the intervals were drawn up so that there was a balanced distribution between the number of buildings included in each one.

Due to the particular characteristics of construction on each site, where the CCW is very heterogeneous, it was necessary to conduct a detailed analysis to determine its composition. Graphs were therefore drawn up to analyse the cost according to the waste classification.

To determine the representativeness of the data, statistical analyses were carried out by identifying the margin of error present in the confidence interval method for the mean of a normal distribution with known variance, based on Montgomery (2006), described in Equation 2. It is worth noting that this method was used because it is a technique already applied in engineering.

$$E = z \frac{\sigma}{\sqrt{n}}$$

Equation 2

Where:

Z = Deviation from the mean value that we accept to reach the desired confidence level;

σ = Standard deviation;

n = Sample Size;

E = margin of error or estimation error.

By determining the estimation error or margin of error, it is possible to assess whether the samples analysed are satisfactory from a statistical point of view. To do this, the values found in the samples must have an estimation error close to 5% (or 0.05), considering that for better representativeness, a probability of success (confidence level) close to 95% has been accepted.

3. RESULTS

Data was collected on the contracts with the processing plants of eighty-four (84) construction sites. The contracts included the unit values for disposing of CCW and some observations on the variation in costs in relation to the degree of contamination for receiving class A waste. Data was obtained from two companies to compose the unit cost spreadsheet described in Table 1.

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Table 1: CCW allocation unit costs spreadsheet.

Construction Company	Destination Type	Description	Unit Price (R$/t)	Degree of Contamination
Company 1	Beneficiation Plant	Debris/concrete (Class A)	27,50	Up to 10%
		Excavated Material (Class A)	30,00	Up to 10%
		Debris (Class A)	35,00	10% - 40%
		Paper and Plastic (Class B)	55,00	-
		Wood (Class B)	70,00	-
	Landfill	Waste	50,00	Above 40%
Company 2	Beneficiation Plant	Waste Class A	18,75	Up to10%
		Plaster, Paper and Plastic (Class B)	55,00	-
		Wood (Class B)	70,00	-
	Landfill	Waste	50,00	Above 10%

Source: Authors
Legend: t = tons

Table 1 shows the total costs of the destination of CCW at company 1, obtained from three-unit costs (R$ 27.50; R$ 30.00; and R$ 35.00), which varied according to the degree of contamination of the Class A. It should be emphasised that the costs of the waste of gypsum (R$ 55.00) and wood (R$ 70.00) do not differ in terms of contamination in their fixed unit values, which is why they were considered the same for all cases.

The data shown in Table 4.1 served as the basis for all the analyses. An important point is that the unit value with the highest contamination percentage (between 10% and 40%) was adopted for class A waste, which is the closest to what is found on construction sites since the value was matched to the amounts of waste generated reported by those responsible for the project sites during the unstructured interview.

From determining the unit costs of CCW, the total waste costs were elaborated, thus helping to determine the losses throughout the construction process.

3.1. Cost analysis by built-up area

In this analysis, all the buildings provided data on their built-up area. They were separated into around 7,500 m², 10,000 m², 12,000 m², 17,000 m², 20,000 m², 30,000 m² and over 30,000 m², a diagram of which is shown in Figures 1 and 2.

Initially, the analysis found that construction sites of up to 7,500 m², except for sites 1, 8 and 10, which cost more than R$ 40,000.00 (Forty thousand reais), were around R$

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20,000.00 (Twenty thousand reais), which could characterise a certain regularity in the generation of waste in construction sites with building areas close to 7,500m² (Figure 1).

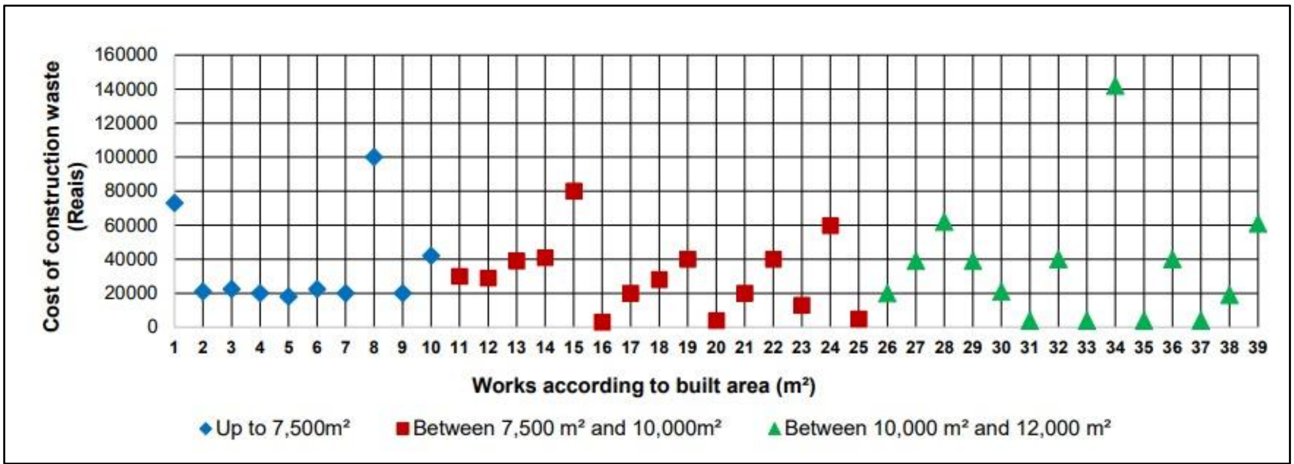

Figure 1 – Cost of CCW on construction sites with a built-up area (up to 12,000m²).
Source: Author (2019).

If the projects are related to the total time to be built, it can be seen that the building that presented the lowest cost (work nº 5) was one of the projects that provided the longest lead time (35 months). If this analysis includes the other works, it will also be observed that the works with the shortest execution time have higher costs in generating CCW. As a result, it is understood that, with the shorter time frame, the work tends to speed up services without efficient monitoring, which leads to an increase in waste rates.

On sites with a built-up area between 7,500 m² and 10,000 m², very different amounts were found, ranging from R$80,325.00 (development n° 15) to R$1,172.00 (building n° 20). This shows that the increase in floor space is starting to positively or negatively influence waste management.

In this list of costs, it can be seen that, for projects with this range of built area, a longer execution time does not guarantee more effective management of CCW. Building nº 15 had the highest cost (R$80,000.00), with an execution time of 42 months. In addition, the construction sites have some specific features that help to reduce this cost, such as using ceramic blocks masonry, which generally does not cause an increase in waste because they are more resistant than conventional ceramic bricks.

Regarding RCC costs on sites with built areas between 10,000 m² and 12,000 m², it can be seen that project nº 34 had the highest cost (R$144,112.50), with an execution time of 42 months. In addition, the building sites have some specific aspects that help reduce costs, such as using ceramic masonry blocks, which generally do not cause an increase in waste because they are more resistant than conventional ceramic bricks.

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Figure 2 shows information on construction sites with a built-up area over 12.000m². There is still some variation in the values for these buildings, reinforcing the failure to manage CCW as the built-up area increases, mainly due to the lack of technical monitoring of projects during production. According to Gomes and Almeida (2021), the project is the basis for defining all the details for monitoring the development.

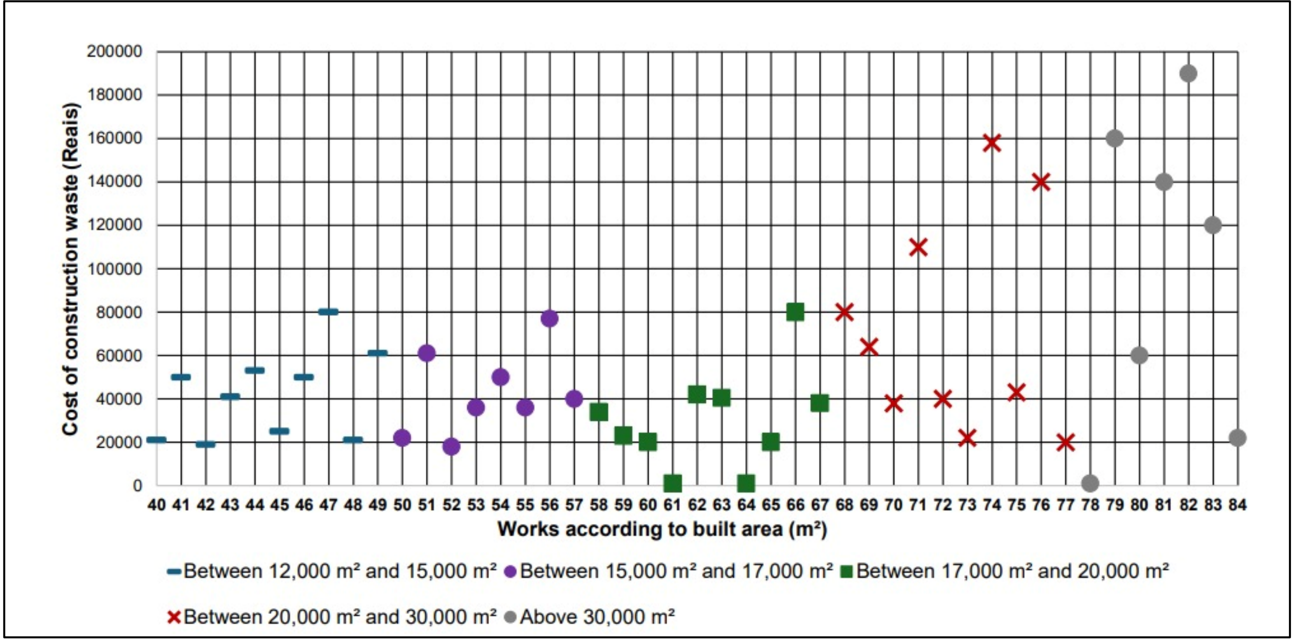

Figure 2 – Cost of CCW on construction sites with built-up area (above 12.000m²).
Source: Authors.

Between 12,000 m² and 15,000 m², there was a need to analyse possible cost variations. The main evidence was errors in making projects compatible with the final services. These developments took around four years to complete, and the finishing phase corresponded to the highest cost of all the buildings, proving that in this range of built area, projects tend to be more difficult to complete.

As for the 15,000 m² and 17,000 m² projects, the costs varied between R$20,000.00 and R$50,000.00 in 80% of the building sites. Project nº 56 is slightly higher than the other constructions (R$72,633.00), mainly due to the renovations close to the delivery period, which led to the accumulation of waste and poor final quality. However, this is a contradiction since all the projects analysed have ISO 9001, and one of its guidelines is that, according to Okudan and Budayan (2021), internal organisations use their resources efficiently.

In general, the costs shown in this scenario can also be justified by the lack of equipment, as well as techniques more suited to the aspects of each site (GOMIDE; PEREIRA, 2018), such as the use of concrete mixers, which in some cases increase the

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amount of waste generated. If the equipment is suitable for the job and, on the other hand, the workforce does not have the necessary training, waste costs can still be high.

The building sites with a built area between 17,000 m² and 20,000 m² had values below R$ 40,000.00 (except for project nº 66), which can be explained by the growth in the hiring of professionals, who were duly qualified and carried out the procedures as recommended by the administration.

However, in the case of construction sites between 20,000 m² and 30,000 m², the waste costs were very different between the projects (costs between R$ 20,000.00 and R$ 170,000.00), which may indicate a change in the way waste management is valued; buildings with built areas between 20,000 and 30,000 m² are considered medium to large-sized. Nevertheless, Ferronato *et al.* (2023) describe that the practice of integrated waste management benefits cost reduction regardless of the size of the construction site.

High expenditure on RCC (over R$100,000.00) was identified in 60% of construction projects with a built area of over 30,000 m². This is due to the absence of a (business) culture of reusing waste, as large investments operate with more specific and sectorised systems, which can lead to easily solvable issues not being resolved.

On building sites with significant built-up areas, most services need to be outsourced (Figure 3), making it difficult to manage construction waste due to bureaucratic issues that, in a way, interfere with good management practices.

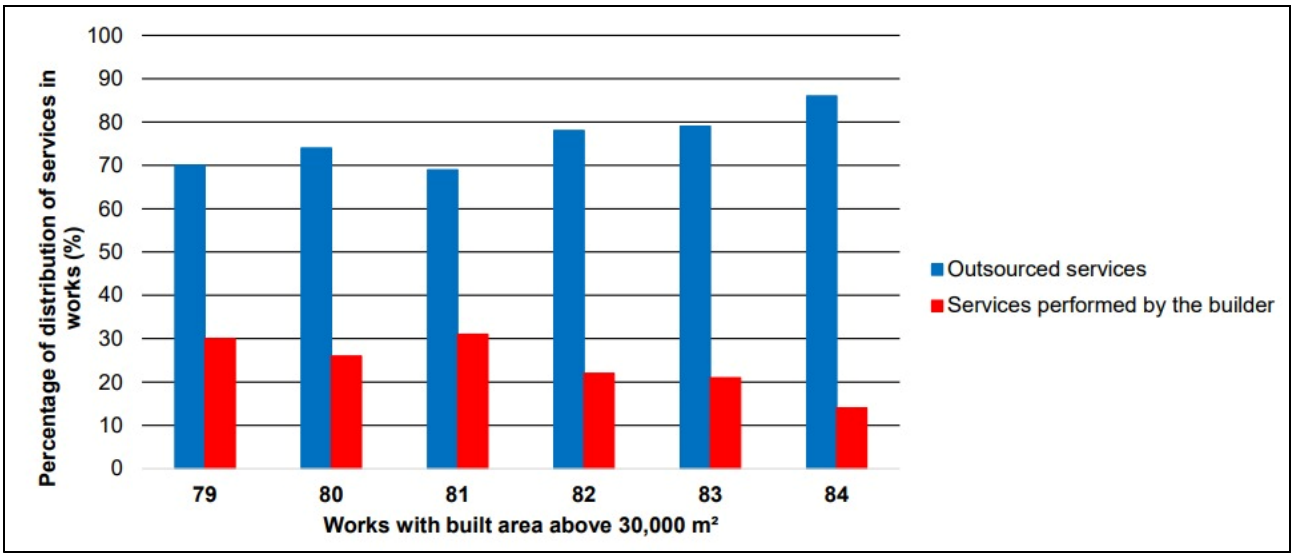

Figure 3 – Analysis of the works concerning the outsourcing systems.
Source: Authors.

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Project nº 84 has the largest built area (99.092m²) and one of the lowest values, around R$ 20,000, demonstrating more efficient construction planning than the others with this type of built area.

3.2. Cost analysis by construction stages

In the generation scenario concerning its construction stage, the corresponding values for each building site and the values for the foundation, structure and finishing. Of the eighty-four (84) works, twenty-seven (23) were initially used because they had data on waste generated in the three stages shown in Figure 4.

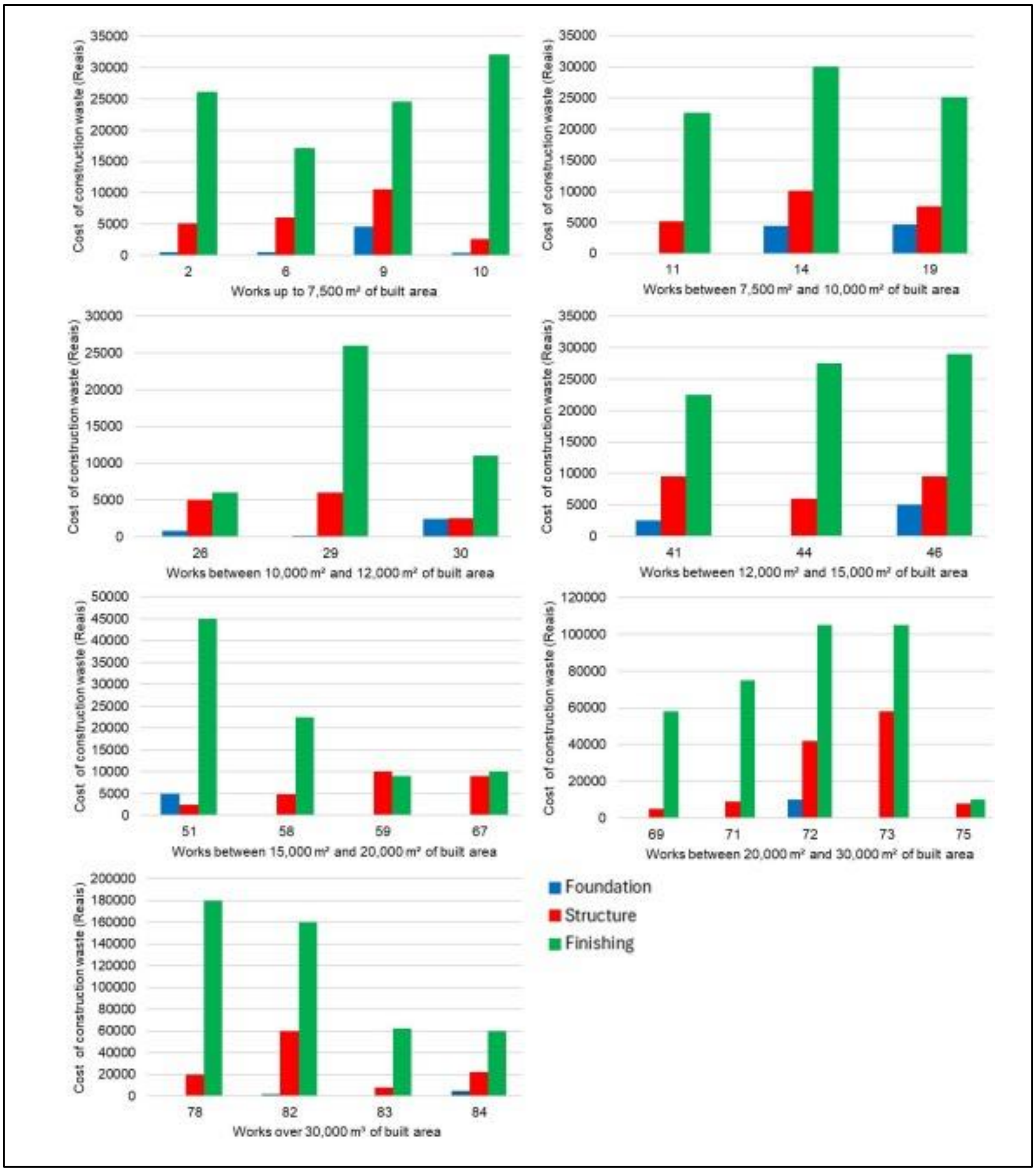

Figure 4 – Analysis of the building sites regarding the construction stage.
Source: Authors.

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With the exception of project nº 59, Figure 4 shows that all building sites had the highest cost in the finishing phase, as it is the stage with the greatest detail in the construction process. Four of them (nº 72, nº 73, nº 78 and nº 82) cost more than R$ 100,000.00 (one hundred thousand reais) due to the technology used in finishing, which in turn can lead to increased debris, as well as problems in the execution of services that are usually identified in this phase.

It is important to note that the types of cladding used on construction sites may undergo possible changes during the building process; that is, concrete blocks may replace ceramic bricks and textured paints can be replaced by ceramic tiles, generating an even more variable cost in the generation of CCW.

It can, therefore, be seen that when finishing, extreme care must be taken when quantifying and planning the services related to this phase, and it is necessary to continuously monitor the real possibility of utilising the waste generated.

In the foundation stage, although the cost was in the finishing process, only 37% of the projects spent less than R$ 1,000.00 (one thousand reais). Building nº 72 costs R$ 11,396.00 (eleven thousand three hundred and ninety-six reais), the highest cost in this construction stage, which is approximately six times the amount spent on the projects nº 41 and nº 67, and the lowest cost R$ 192.50 (one hundred and ninety-two reais and fifty cents).

Constructions nº 41 and nº 67 had low costs, but no records were kept during the execution of the foundation, which indicates that the real cost of generating CCW was much higher. The value of site nº 72 can be justified by the variation in the built area given that it has an area of 27218.45m², while the other sites with lower values have less than 20,000m² dimensions.

As far as the structure is concerned, most of the works had average costs. Hence, the amounts were neither higher than the costs of finishing nor lower than the costs of the foundation, given that more than 90% of the projects use reinforced concrete as the solution for this stage, which is simpler to execute and favours a reduction in waste generation.

However, the three sites had different results. The CCW generation found at building nº 59 in the structure phase is higher than that spent in the finishing phase. Project nº 51, on the other hand, has lower costs than the foundation, showing that even though it is the basic technology, it is subject to failures, often caused by the lack of supervision of concreting, linked to poor execution.

In the works with high levels of CCW, the main focus is on the execution of the parts since the most commonly used structure is reinforced concrete. Its application requires formwork and the bending of the steel bars, which requires a greater number of employees and/or longer execution time, so concern about the costs that can be generated by waste at this stage becomes secondary.

3.3. Cost analysis by waste classification

Of the construction sites analysed, only six presented cost data according to waste classification (Figure 5). For the others, the quantitative information was generalised and not identified by class, with only class A recorded.

Class A waste includes the following materials: soil from earthworks, ceramic components (bricks, blocks, tiles, cladding slabs), mortar and concrete. Notably, 90% of works have records of this type of detritus, confirming the predominance of Class A, as described in Leite's research (2018).

It can be seen that 33% of the building sites spend more than R$ 20,000.00 (twenty thousand reais) on generation class A, possibly because this type contains materials such as mortar, sand, ceramics, concrete, stones and bricks. Therefore, this category is more likely to be wasted during its execution, as evidenced by Silva (2017) when he characterises the errors in applying mortar, ceramic blocks and concrete.

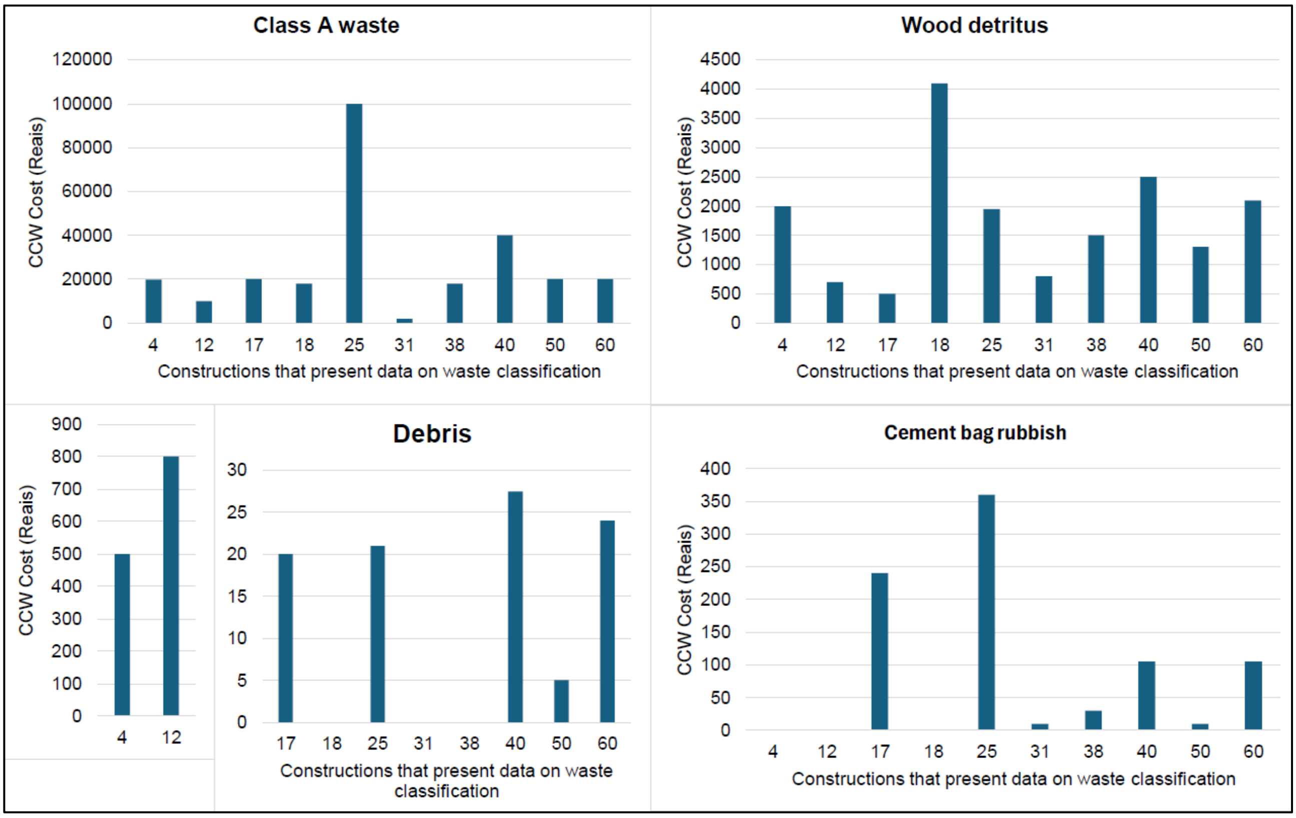

Figure 5 – Class A debris cost in the construction sites.
Source: Authors.

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The works that had values below R$ 20,000.00 (twenty thousand reais) may indicate more careful planning concerning the projects in their preparation and execution, making it possible to reduce the generation of detritus.

Expenses on wood refuse were also related, as they are present in reinforced concrete structures moulded into shapes composed of pieces of lumber in the form of beams, rafters, planks and boards (Geraldo Filho *et al.*, 2022).

Building nº 12 had a value of over four thousand reais for wood debris, which indicates inefficiency in its utilisation for this type. About 40% of the construction sites had values above R$ 2,000.00 (two thousand reais), while the rest had values below R$ 1,500.00 (one thousand five hundred reais), which may indicate the reuse of wood.

Another aspect that can be evidence of the low value of wood detritus is that it is often contaminated with nails, staples, screws, hinges, cement, and mortar and is almost always disposed of as rubbish. The technologies involved in removing contaminants are relatively simple to separate, but applying the techniques takes time and labour, making this practice unattractive for construction.

The costs obtained for the quantification of waste are also identified in Figure 5, which also shows significant values in project nº 12, which may be an indication of the lack of application regarding the segregation of detritus, which consequently increases the cost of disposal since the recycling process is more expensive than processing class A, or even the recycling of a segregated material (Liu and Teng, 2023).

It should be noted that if there is no effective supervision of the debris management process, the figures will consequently be higher and higher since disposing of debris in landfills is more expensive and shows the lack of supervision even of products that already have a collection system the manufacturer, such as cement, which would minimise unnecessary expenditure.

The relative costs of cement bags were identified in nine building sites that do not carry out the practice of collection with the supplier, even though they are ISO 9001 certified.

Variable costs were common when evaluating the detritus according to its classification. Construction nº 11 and nº 34 had values above R$ 200.00 (two hundred reais), which may reveal a certain segregation of debris, given that they had low values. Buildings nº 15 and nº 25 had values below R$ 50.00 (fifty reais) because they were at the beginning of their construction process.

The costs found for cement bag rubbish were low compared to the other types of CCW, but this expense could not be considered because the supplier is responsible for collecting the waste, which would not generate costs for the work. Another aspect would be that this type of CCW cannot be recycled, as it is contaminated and must be sent to landfill sites.

3.4. Statistical Analysis

By determining the estimation error, it was found that the analyses of the costs relating to the built-up area and construction stage showed a percentage of 20.22%, which is high concerning the accepted value (5%). Figure 6 shows the distribution for the built-up area scenario.

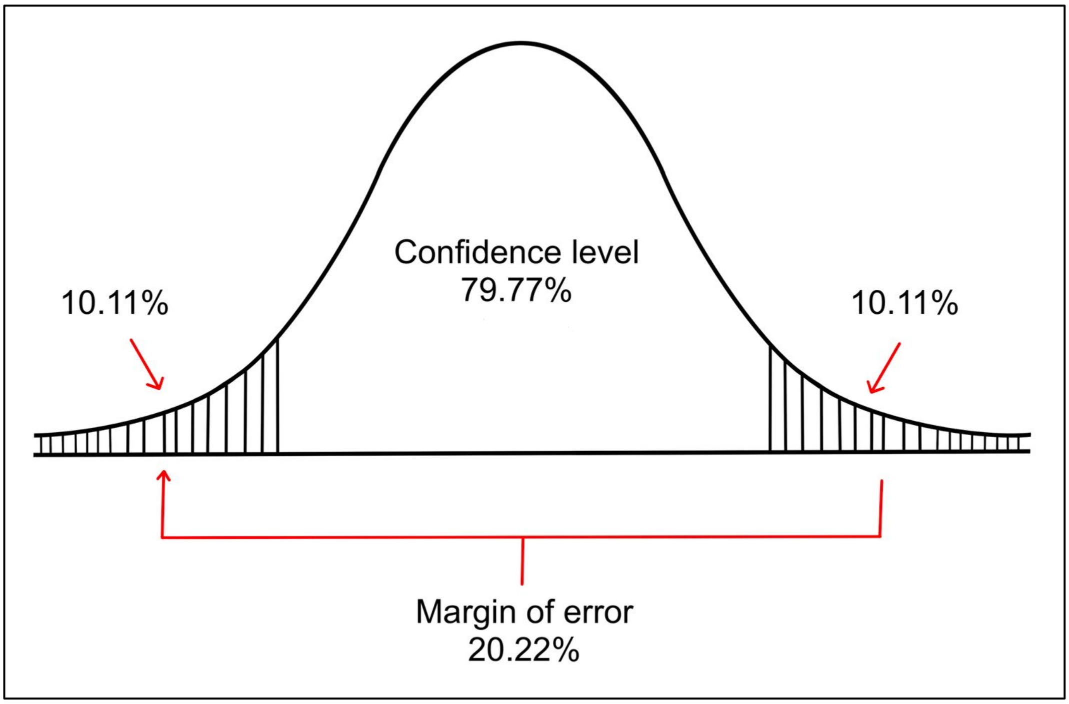

Figure 6 – Distribution of the built-up area
Source: Authors

However, when compared to the total number of sites, the value was not very relevant, indicating that the content of the sample is representative since if the analyses were carried out with random samples, similar values would be found from a statistical point of view in 80% of the cases. When analysing spending on the construction stage, the margin of error was 2,66%, with a confidence level of 97,34% (Figure 7).

Figure 7 shows an even more relevant confidence level, considering that the confidence index used was 95% probability. It is worth emphasising that the lower the standard error, the stronger the sampling content. To analyse the samples that inform the cost of classifying the CCW, figure 8 presents the histogram developed with the data from this scenario.

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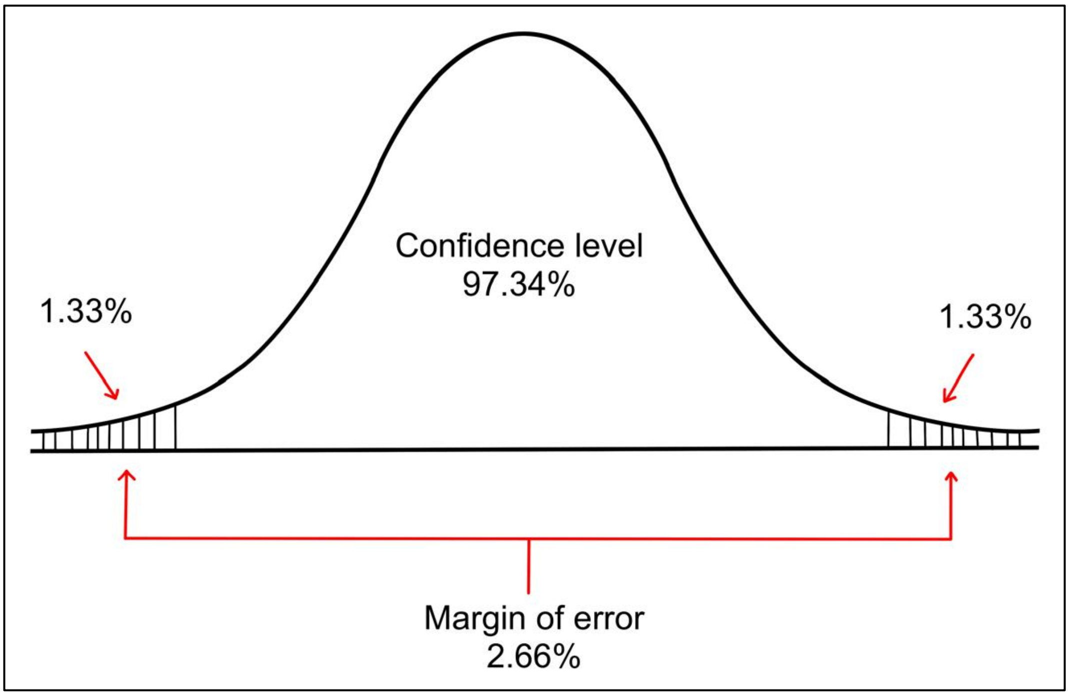

Figure 7 – Distribution regarding the constructive stage.
Source: Authors.

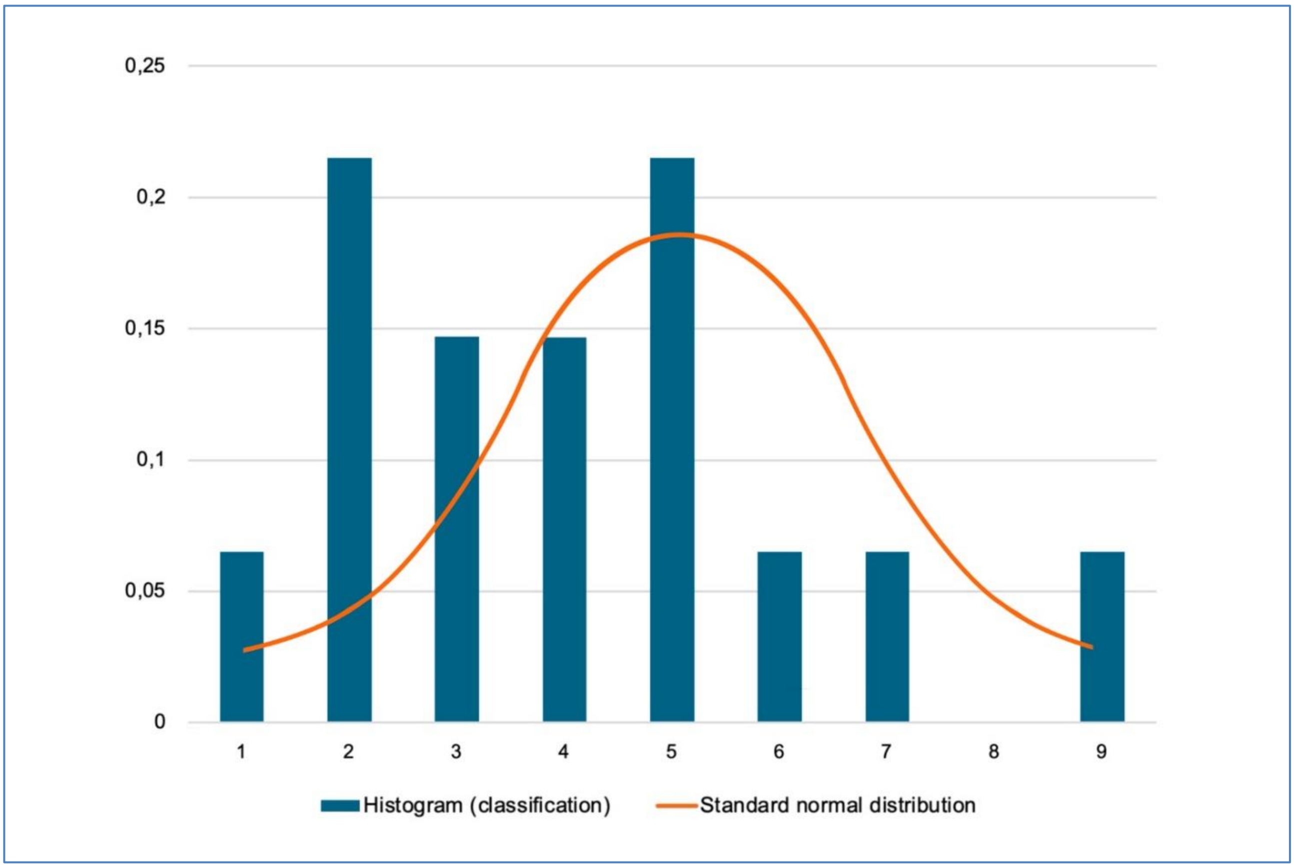

Figure 8 – Histogram of CCW samples regarding classification.
Source: Authors.

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As shown in Figure 8, the evaluation of the data referring to the CCW classification revealed that the histogram of the probability distribution did not resemble the normal distribution, making it impossible to carry out a representativeness analysis using the methods used in the two previous cases.

However, the analysis is significant, given the lack of studies relating to the classification of CCW with these characteristics. The result presented can serve as a parameter for future research that addresses this scenario.

As for the classification waste of the residual, the sample size is less than 30, which makes it impossible to determine them directly by margin of error. Therefore, to assess its representativeness, it was only analysed whether the shape of a histogram established by its sample data is similar to the standard normal distribution curve.

In cases where the sample size is greater than 30, the probability distribution of the event is close to the normal distribution. It will, therefore, be satisfactory, regardless of the shape of the sample, conforming to the central limit theorem (Montgomery, 2006).

4. CONCLUSIONS

The focus of large construction companies is still on meeting construction site deadlines, often neglecting management policies that could transform the reality of the waste generated. It was found that even though the fifty construction sites presenting ISO 9001 have quality management systems, they are inefficient in their application, as the certifications, for most companies, only represent a commercial purpose, leaving aside the management system that quality proposes.

It was observed that construction companies see the legislation instituted around rubble as an obligation, and they do not realise the power that policies linked to CCW can have in transforming buildings as an indicator of their performance and the quality of the services carried out.

Other important aspects are the data on the degree of contamination of basic types of debris, such as class A, which indicates a lack of care in correct segregation, leading to increased costs.

The lack of implementation of rubble management was a relevant factor in classification, as it was identified that the majority of construction sites had class A outliers and detritus with a significant degree of contamination. Wood refuse, which could be reused or even sold without generating expenses for the developments, was found to be an expense for some buildings.

The same goes for cement bags, for which the supplier is responsible. The significant percentage of remains on the sites confirms the poor application of policies relating to CCW.

Expenses on fragments of building materials concerning the built area indicated that there is no proportionality, so the amount of detritus generation does not always increase concerning the built area. The application of management, the type of technology used, and employee training, among others, are the main causes of the remnants generated.

It is important to note that, for large construction sites (over 30,000 m² of built-up area), the sectorisation system leads to the bureaucratisation of CCW management. Since its objectives are not always clear or identifiable, it is also difficult to measure and justify the costs and benefits because of the long duration, leading to uncertainties that jeopardise the effectiveness of planning, implementation, budgeting and management.

Although the costs of detritus are analysed differently between construction companies due to their differing policies, the high amounts generated by CCW were noted throughout the study, highlighting the ineffectiveness of the plans established by the construction companies and the failure of inspections and supervision in the service phases.

One way of finding solutions to mitigate these high figures would be to promote quality training for construction site employees. Professional development accelerates their ability to raise awareness of the product they use in relation to its application in their work environment. Managing large projects requires agility to anticipate and circumvent problems, so the easier it is to manage a project, the lower the risk of failure.

Another point to take into consideration would be more efficient action by those responsible for construction sites, as they are the ones who encourage the practice of quality management, as well as construction rubble management. It is well known that policies such as these are instigated by those responsible for the project.

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