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# MANAGEMENT MODEL FOR CONSTRUCTION WASTE PRODUCED IN THE CITY OF RIO DE JANEIRO

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## ABSTRACT

**Background:** A new management model for construction and demolition waste (CDW) was proposed for the city of Rio de Janeiro, hence waste the city planning area estimated generation; the results were compared with the data published by COMLURB and SNIS through the statistics tests was proved that CDW had been dispersed, which support the hypothesis that the current model cause dispersion of the rubble. **Aim:** This study proposes a new management model for CDW to the city, according to regions where occur the higher production of rubble. **Methods:** The estimation of rubble was obtained through the issued licenses from 2006 to 2020 published by SMPU. The quantification of rubble in the city was carried out by adopting the generation indicator from licensed construction activities. The amount of CDW published by COMLURB and SNIS was compared through statistics tests ANOVA and T-Test, the second period from 2006 to 2020 and 2011 to 2020. To measure the area to implant a CDW recycling plant, criteria from production capacity were used. **Results**: ANOVA test to data from 2006 to 2020 and 2011 to 2020, according to a confidence interval of 95%, found the P value 0.589 and 0.022, respectively, it was verified that the significant difference is between data from COMLURB and Estimated. The T-test was applied from the same period in data from SNIS and estimated the P values 0.399 and 0.014. **Discussion:** The data from Estimating between 2006 and 2020 showed the best representation. The *Área de Planejamento – AP* (Planning Area) 4 was where 50.70% of the total rubble, after the AP 3 with 17.66%, the AP 5 was estimated at 16.59%, last of all, AP 2 and AP 1 were calculated the generation of 8.28% and 6.77%, respectively. Therefore, sizing the CDW recycling producing 361,99.00 tons per year demands an area of 32,397.50 m². **Conclusions:** It was concluded that the receipt of CDW in transfer stations managed by COMLURB is not allowed; therefore, the need to create a construction waste recycling plant was presented, to this end, it is necessary to have an available area of approximately 32,397.50 m².

**Keywords**: *construction waste, recycling, quantification*, *waste transfer stations, landfill*

## 1. INTRODUCTION

The high generation of construction and demolition (C&D) waste, associated with the unregulated action of agents, implies the imposition of a significant number of degraded areas on the population in the form of clandestine disposals or irregular disposals. The first arises mainly from the actions of companies dedicated to transporting waste from big constructions that unload in usually inappropriate places and without an environmental license. As for irregular deposits, usually in large numbers, they mostly originate from small works or rehabilitation carried out by the urban population most lacking in resources, often through self-construction processes, as they do not have the financial resources to hire regularized companies that operate in the sector, strongly collaborates for the environmental degradation resulting from irregular dispositions due to the performance of small collection vehicles with low displacement capacity (Pinto & González, 2005).

CDW causes worldwide problems; equally important, the estimated generation of this waste in Brazil is higher than 70 Mt/year, around 500 kg/year per capita, thus representing the largest fraction of municipal solid waste. In recent years, there have been advances in policies concerning responsibility in the disposal and recycling of waste in general; however, currently, only a fraction of CDW is recovered (Contreas, Teixeira *et al*., 2016).

In Rio de Janeiro, three waste disposal centers were operating simultaneously: Gramacho landfill, CTR – Gericinó, and CTR – Rio in Seropédica. Equally important to remember that the Jardim Gramacho Metropolitan landfill was deactivated in June 2012, and CTR – Gericinó, the receipt of urban solid waste, was finished in April 2014 (Rio de Janeiro (Cidade), 2021).

The waste disposal center CTR – Rio, in Seropédica, was inaugurated on April 20, 2011, when it started operating in an area of 220 hectares (Rio de Janeiro (Cidade), 2021).

In its first phase, around nine thousand tons of waste were deposited daily, which initially received rubbish from the Jacarepaguá transfer station, where the garbage truck that serves the neighborhoods of Barra da Tijuca, Recreio, and Jacarepaguá are unloaded (Rio de Janeiro (Cidade), 2011).

When it comes to waste management in the city of Rio de Janeiro, C&D, waste generators of construction waste, which produce more than 2m³ per week, are classified as large generators (Rio de Janeiro (Cidade), 2006).

The collecting and disposing of C&D waste from small generators is the responsibility of the city hall through the Companhia Municipal de Limpeza Urbana - COMLURB (Municipal Urban Cleaning Company). However, for those that exceed this volume, the disposal of such waste becomes the duty of the generator itself, which must hire an accredited company in that institution to dispose of these materials.

COMLURB-accredited companies must comply with requirements related to the accreditation standard concerning the destination of removed waste, such as the § 1° of Art. 17. from Portaria “N” COMLURB N°002, which determines the obligation to dispose of waste from large generators only in places that are part of the urban cleaning system of the city of Rio de Janeiro operated or formally authorized by this corporation (Rio de Janeiro (Cidade), 2022).

Due to the reuse potential of these materials, as well as the high generation, this study consists of developing the estimated generation of construction waste, through formal constructions in the city of Rio de Janeiro, during the period from 2006 to 2020; these values will be compared with the totals of C&D waste published by COMLURB and the Sistema Nacional de Informação Sobre Saneamento - SNIS (National Sanitation Information System). After the analysis, the mapping of authorized site waste disposal in the city will be carried out. The adaptation of waste transfer stations will be proposed to enable the temporary receipt of C&D; the adaptation of those places will follow a priority criterion according to the demand of the regions with the highest generation.

The severity of C&D waste generation does not only depend on the quantity produced but also on its management. In general, the amount and composition of this waste vary between regions, depending on other factors specific to each location, thus influencing its generation, such as population, constructive activity, materials used in construction, and traditions, among others (Villoria Sáez, Porras Amores, & Río Merino, 2020).

As most of the material that we discard and need to be disposed of is not dangerous, it is simply garbage or refuse. Most of the simple constituents of this solid waste are construction and demolition rubble, almost all of which is also reused or eventually buried in the ground. The second largest volume of waste is produced by commercial and industrial sectors, followed by domestic waste from households (Baird & Cann, 2011).

The C&D waste is generated by the loss of materials at construction sites and as a by-product of demolition processes. They are quite heterogeneous, formed by mortar, sand, soil, ceramics, concrete, wood, metals, paper, stone, asphalt, paint, plaster, plastic, rubber, and putrescible materials. The proportion between the materials varies depending on the technology adopted in the construction, as well as the amount produced depends on the greater or lesser heating of the economy in the country (Calijuri & Cunha, 2013).

Anyone who builds or performs makeovers in concrete structures uses cement. Therefore, even if indirectly knowing the cement user, it is possible to establish a profile of the rubble generator (Vilhena, 2018).

As long as cities increase and modernize, there is a growing generation of waste from construction and demolition, whose volume is 30 to 50% of the total urban solid waste produced. They are called C&D waste, which requires specific management due to their characteristics and environmental problems caused by their uncontrolled disposition. A relatively small part of the C&D waste is recyclables, such as plastics, paper, cardboard, wood and others. However, most of it consists of rubble, which can be processed and reused as aggregates in the production of concrete and mortar (Eigenheer & Ferreira, 2011).

The C&D waste generation index is extremely useful for estimating the amount of rubble from a given region or country. However, the values may differ due to the variety of materials used in construction, production, the level of development of the construction industry, and the built environment. According to the analysis of the work, though with a relatively high population density in the city of Shanghai in China, values of waste generation of the order of 724 kg per $capita^{-1}$ $year^{-1}$ and 842 kg per $capita^{-1}$ $year^{-1}$ were recorded in the years 2000 and 2010, respectively. The analysis also indicated that more than 80% of the components of the C&D are composed of concrete, bricks, and blocks, and these materials can be reused if appropriate recycling technologies are applied (Ding & Xiao, 2014).

The index adopted in Spain to estimate the generation of CDW as a function of the built area is used by the Instituto de Tecnología de la Construcción de Cataluña (Institut of Technological Construction in Cataluña), Colegios Profesionales de Arquitectos Técnicos (Professional Associations of Architects' Technicians) and the statistics of the Ministerio de Fomento (Ministry of Public Works), use as a parameter: 120.00 kg/m² for the construction of new buildings, 338.70 kg/m² for rehabilitation, 1,129.00 kg/m² for total demolition and 903.20 kg/m² for partial demolition (Llatas, 2013).

In Brazil, there was an increase in the amount of CDW collected by municipalities between 2010 and 2019, from more than 33 million tons, in 2010, to more than 44.5 million, in 2019. Thus, the amount collected per capita grew from 174.3 kg to 213.5 kg per $capita^{-1}$ $year^{-1}$ (Abrelpe, 2020).

Private construction companies are responsible for the high generation of CDW; for this reason, they have an obligation to develop specific management projects, for example, contemplating screening at construction sites, including the use of registered transporters and licensed areas for handling and recycling. On the other hand, the public authorities must provide an environmentally correct destination for small generators responsible for reforms and self-constructions and cannot implement self-management. In this study, data related to the municipality of Novo Horizonte in the state of São Paulo were presented. The average per capita generation of CDW was around 367 kg per $capita^{-1}$ $year^{-1}$. As the average composition of the CDW was analyzed predominantly those classified as Class A, representing 91% of the total mass, and 9% of Class B, components belonging to Classes C and D were not quantified (Angulo, Teixeira, Castro, & Nogueira, 2011).

In 2015, approximately 612 thousand tons of CDW were collected in the city of Belo Horizonte, representing a total of 42.7% of the quantity of waste destined in the city, generating a value between 0.24 and 0.26 tons of CDW per $capita^{-1}$ $year^{-1}$. This research also presents the data related to the qualitative analysis carried out on the samples collected at the rubble recycling station. As a result, it can be seen that the gravimetric composition of the C&D waste produced in the city is composed mainly of Class A, such as blocks, mortars, and concrete, among others, representing 95.5% of the amount of waste generated, followed by class B waste, such as paper, plastic, glass, and metal, in a smaller proportion (Bessa, Mello, & Lourenço, 2019).

By evaluating the typology of the CDW dumped at the three recycling plants in Belo Horizonte, it was verified that a large part of the waste sent for recycling is based on ceramics and comes from residential rehabilitation works of houses (Carmo, Maia, & César, 2012).

An analysis of the percentages and origin of the CDW from the city of Passo Fundo/RS was carried out and excluded waste from land clearing; the highest collection rates were those from demolition and rehabilitation, which were 51.1% of the collected loads, as well as those from new constructions, that is, residential works and buildings under construction, which together represented 35.6%. Subtracting ground values from excavations, demolitions and rehabilitation represented 58.6%, and the new constructions were 41.4% (Bernardes, Thomé, Prietto, & Abreu, 2008).

In the city of Criciúma/SC, from 2001 to 2010, an estimated daily generation of CDW values between 0.62 and 1.46 kg per capita$^{-1}$ day$^{-1}$ was recorded. The average per capita generation of 0.96 kg day$^{-1}$ emphasizes this value is within the range considered for Brazilian cities. In this same interval, 1,493,212.80 m² of the built area was recorded, representing an average annual waste generation of 22,398.19 tons in this period, corresponding to a daily generation of 93.33 tons, considering only 20 working days in each month. Equally important, the CDW generation values were obtained through an indicator second Pinto (1999), where production of 0.15 ton/m² of the built area is expected. The authors also emphasize that the recycling of CDW is of great importance to regional development since it contributes to the production of recycled aggregate, the conservation of natural reserves of sand and gravel, and the reduction of irregular discard areas. (Cardoso, Galatto, & Guadagnin, 2014).

The impasse over the reuse of CDW is mainly due to the scale of production required for processing the material in crushing plants to be viable and the prohibition of its disposal in sanitary landfills, per the legislation. In a big country like Brazil, with regional differences, it is difficult, if not impossible, for the same legislation to be applied in all municipalities. In practice, many sanitary landfills in the country receive this waste for use in the construction and maintenance of internal roads and, eventually, to cover the waste (Eigenheer & Ferreira, 2011).

A study on the application of recycled aggregates from CDW with cement and hydrated lime developed in Brazil, through the field and laboratory tests, proved that aggregates from CDW can be used as a sub-base material for pavements in places of heavy traffic; however, limited to municipal traffic, where most vehicles consist of single axels, dual/single axes, and dual tandem (Beja, Motta, & Bernucci, 2020).

CDW recycling plants may be economically viable for public authorities depending on market conditions, varying according to the circumstances of each municipality, such as final disposal costs in a sanitary landfill, expenses involved in the transport of waste to the landfill, as well as in the purchase price of natural products. However, viability also depends on the continuous operation and production capacity of recycling centers (Nunes, Mahler, Valle, & Neves, 2007).

The dimensioning of the space needed to install a CDW recycling plant (Jadovski, 2005) conducted technical visits to numerous plants in operation in Brazil, when it was found that the operation of such activity demands areas as stated by the values presented in Table 1.

*Table 1- Area required for recycling plant depending on production capacity*

| Production capacity ton/h | Production capacity ton/year | Required Area m² |
|---|---|---|
| 10 | 21,000 | 5,000 |
| 20 | 42,000 | 6,500 |
| 30 | 63,000 | 8,000 |
| 40 | 84,000 | 10,000 |
| 50 | 105,000 | 12,000 |
| 75 | 158,000 | 16,000 |
| 100 | 210,000 | 20,000 |

Within the scope of the city of Rio de Janeiro, electronic bidding was published to contract technical closure services with the maintenance of the CTR - Gericinó and implementation of a new cell to receive CDW collected by companies accredited by COMLURB, with a minimum capacity of 730,000 ton, over 5 years. Among the justifications, the prohibition of dumped CDW in the transfer stations is recognized, as well as the economic unfeasibility of carrying out the destination of them in the CTR - Rio in Seropédica, due to the great distance from this place to the generation center. It also recognizes that such conditions caused the dispersion of a large amount of rubble in inappropriate places, causing environmental impacts and burdening public coffers. Therefore, the most viable solution was the implementation and operation of a cell to dispose of this waste at the CTR – Gericinó because of the proximity to the west zone, as well as the availability of the area (Rio de Janeiro (Cidade), 2019).

Despite the attempt to contract these services, the Tribunal de Contas do Município do Rio de Janeiro - TCMRJ (Court of Auditors of the Municipality of Rio de Janeiro) suspended the bidding for the electronic bidding n° 382/2019. The rapporteur accepted the complaint against COMLURB. Among the allegations, it was requested the legal basis for the bidding to take place electronically, further clarifications on the closure of the Gericinó landfill due to it has not been in operation since 2014, as well as the legal basis for the provision of contracting a company with experience only in earthworks for the execution of sanitary work, supposedly complex (TCMRJ, 2019).

## 2. CDW QUANTIFICATION, GENERATION DATA PUBLISHED BY AUTHORITIES, APPLICATION OF STATISTICAL TESTS, AND MAPPING OF CDW DISPOSAL SITES

Initially, research was carried out with government agencies to provide information on the topic of interest, such as the Secretaria Municipal de Desenvolvimento Econômico, Inovação e Simplificação - SMDEIS (Municipal Secretary for Economic Development, Innovation, and Simplification), Secretaria Municipal de Planejaento Urbano - SMPU (Municipal Secretary for Urban Planning), COMLURB and SNIS.

### 2.1. Quantification of Construction Waste

Data collection was conducted to estimate the total construction waste produced in Rio de Janeiro, carried out through a survey on the page of the SMPU, and obtained through the tables referring to the issued licenses from 2006 to 2020. This information has been organized according to neighborhoods and city planning areas.

The estimate of CDW generation can be verified through consolidated generation indicators from three information bases, namely: the activities of the built area - services performed and effective losses, the movement of loads by transport companies, and the monitoring of discharges in the places used as the destination of the CDW. This method makes it possible to compose a quantification indicator by aggregating two important parts of urban construction activity: the formal construction of new buildings and the informal execution of rehabilitation and expansions.

The quantification of construction waste generated in the city was carried out by adopting the generation indicator second Pinto (1999), whose estimate is obtained from licensed construction activities, which indicate values of waste products in a formal building through the use of construction waste generation rate in the order of 150 kg/m² built (Pinto, 1999).

### 2.2. Generation Data Published by Authorities

Information from COMLURB was used about the quantity of CDW produced in the municipality of Rio de Janeiro since this company is responsible for the inspection and management of urban solid waste in the city. Another source of information used was the diagnosis of urban solid waste management written by SNIS.

### 2.3. Application Statistical Tests

The results from the quantification of the generation of construction waste second to Pinto's methodology (1999), as well as the survey of the total production of waste published by the agencies COMLURB and SNIS, will be analyzed initially through the ANOVA statistical test, considering two periods, the first from 2006 to 2020 and the second from 2011 to 2020. Furthermore, for statistical analysis between two data groups, the T-test will be used, as this methodology is applied when two data samples are collected, whose sample mean values calculated may differ (Field, Miles, & Field, 2012).

The choice of the generation data, which will be used to calculate the proposed area for the implementation of the construction waste recycling plant, it will be the data group that obtains the best representation following the results from statistical tests, which will be calculated through the software Minitab version 16.

### 2.4. Mapping Locations C&D Waste Destination

Information was obtained from SMDEIS of the city of Rio de Janeiro about the places licensed to carry out waste disposal in the municipality.

The representation of the maps, as well as the proposition of adequacy of the reception locations and creation of the recycling plants of the CDW, will be illustrated through mapping using the QGIS software version 3.16.19. For this representation, the CBERS 04A satellite images will be geoprocessed, whose raster files have a spatial resolution of 2.00 m for the panchromatic spectral band and 8.00 m for the multispectral band. In this process, images of colored composition will be produced through the spectral bands red, green, and blue. Later, the procedure will be pansharpening between the color composition and the raster file of the panchromatic spectral band to obtain an image of spatial resolution of 2.00 m.

The area calculation for choosing the location to propose the installation of a CDW recycling plant will be carried out according to the criteria adopted by (Jadovski, 2005). As a parameter for determining the space, the data presented in Table 1, therefore the verification of those values will be carried out to obtain the Pearson linear correlation coefficient (r), as well as to discover the equation of the fitted line. In addition to this requirement, the availability of vehicle access roads will be verified, and the delimitation outside the permanent preservation areas following the legislation (Brasil, 2012).

## 3. RESULTS AND DISCUSSION

### 3.1. Results

#### *3.1.1. Waste Generation Second City Planning Area*

The quantification of construction waste was done by a survey of the total built area obtained through the licenses concession carried out, according to the information on the SMPU from the city of Rio de Janeiro, between the period from 2006 to 2020. Figure 1 illustrates the total area of occupancy concession as stated by the planning area of the city.

#### *3.1.2. Generation of CDW Released By Authorities*

A survey was carried out about the generation of CDW produced in Rio de Janeiro, published by control authorities from 2006 to 2020. Table 2 presents the data released by COMLURB, while table 3 summarizes information from SNIS through publications on the diagnosis of urban solid waste management.

### 3.2. Discussions

#### *3..2.1 ANOVA Statistical Test Period 2006 to 2020*

The ANOVA statistical test was applied for the period between 2006 and 2020, establishing a confidence interval of 95%; the results of this analysis are shown in table 6.

*Table 6 - Statistical indicators of construction waste generation 2006 to 2020*

| Source | Average (ton) | Standard deviation (ton) |
|---|---|---|
| COMLURB | 303,537.00 | 228,681.00 |
| Estimate | 361,992.00 | 156,001.00 |
| SNIS | 381,440.00 | 247,439.00 |

Source: Authors (2022).

The mean values of the three groups of data are close, and this interpretation can be validated as maintained by the result of the ANOVA test, where a P value equal to 0.589 was obtained, therefore, greater than the significance index, which is 0 .05, thus, hypothesis $H_0$ should not be rejected. Therefore, it can be attested with a significance level of 5% that the average values of CDW generation for the three data groups are the same.

#### *3.2.2 ANOVA Statistical Test Period 2011 to 2020*

The ANOVA statistical test was applied for the period from 2011 to 2020, establishing a confidence interval of 95%, the results of this analysis are shown in table 7.

*Table 7 - Statistical indicators of construction waste generation 2011 to 2020*

| Source | Average (ton) | Standard deviation (ton) |
|---|---|---|
| COMLURB | 170,980.00 | 130,071.00 |
| Estimate | 382,527.00 | 184,419.00 |
| SNIS | 246,119.00 | 166,158.00 |

Source: Authors (2022).

According to the ANOVA statistical test result, the P-value equal to 0.022 was obtained, therefore, lower than the significance index, which is 0.05. Thus, hypothesis $H_0$ must be rejected, and hypothesis $H_1$ must be accepted. Hence, it can be assured with a significance level of 5% that the average values of CDW generation for the three data groups are not the same.

The statistical calculation of the Tukey method was applied, considering the confidence interval of 95%, to determine the probable intervals of the differences and evaluate the practical significance between these discrepancies. The results of the analysis are presented in Figure 2, therefore, according to what can be observed in the lines in the red shade, the significant difference is between the averages from COMLURB and Estimate since the confidence interval for the estimate does not exceed the red line. As a result, there is no significant difference between the averages from COMLURB and SNIS and between the averages from Estimate and SNIS.

### *3.2.3 Application Test T Generation CDW Estimates and Movement of Collecting Companies 2006 to 2020*

As it was verified that there is no significant difference between the average values of the construction waste generation estimate and the data from SNIS, the T-test was applied to the data group related to the estimate and the quantities destined by the collecting companies and self-employed hired by the generator, which was added to the total waste destined by the generator itself, second information presented in columns 3 and 4 of table 3.

As a P value greater than 0.1 was obtained, therefore, higher than the significance index, which is 0.05; hence, the $H_0$ hypothesis should not be rejected. Thus, it can be affirmed with a significance index of 5% that the construction waste generation values from 2006 to 2020, referring to the estimation method, and the data released by the SNIS follow a normal curve. Furthermore, variances related to the two groups of data were also checked. The result verified for the P F test value was 0.228. Therefore, higher than the significance index, which is 0.05, it can be attested with a significance index of 5% that the variances for the two data groups can be considered the same.

As the conditions regarding the obligation for the data to follow a normal distribution were met, as well as the variances to be considered the same, the T-Test was applied, whose result indicated a P value equal to 0.399, thus, higher than the significance index of 0, 05, therefore, should not be rejected $H_0$, so it can be confirmed according to the 5% significance index that the average values of CDW generation for the two data groups are the same.

### *3.2.4 Application Test T Generation CDW Estimates and Movement of Collecting Companies 2011 to 2020*

As it was verified that there is no significant difference between the estimated average quantities for construction waste generation and the average of the data from SNIS, the T-test was applied to the group of estimated and the quantities destined by collecting companies and self-employed hired by the generator, which was added to the total waste destined by the generator itself, second information presented in columns 3 and 4 of table 3, in other words, the amounts of rubble that were destined under the responsibility of the city hall were subtracted.

According to the normality test results, the P value was higher than 0.1, thus, greater than the significance index, which is 0.05, so hypothesis $H_0$ should not be rejected. Thus, it can be attested with a significance index of 5% that the construction waste generation values for the period from 2011 to 2020, referring to the estimation method, as well as the data from SNIS describe a normal curve.

Verifying the variances related to the two data groups was carried out, establishing a 95% index as a confidence interval. The result verified for the P value from the F test was 0.450, therefore, higher than the significance index, which is 0.05, thereby hypothesis $H_0$ should not be rejected, hence can be attested with a significance index of 5% that the variances for the two groups of data can be considered the same.

Finally, the T-Test was calculated, the result of which showed a P-value equal to 0.014, thus, lower than the significance index of 0.05, therefore, $H_0$ must be rejected, and the alternative hypothesis $H_1$ must be accepted, therefore, can be confirmed according to the 5% significance index that the average values of construction waste generation for the two data groups are statistically different.

After applying statistical tests and finding the data that represented the best indicators, it was decided to select the reference for generating construction waste for the period from 2006 to 2020, obtained by estimating second Pinto's methodology (1999), whose average amount of production was 361,992.00 ton year$^{-1}$ and standard deviation of 156,001.00 ton year$^{-1}$, as shown in Table 6.

### *3.2.5. Mapping for C&D Discard*

As stated by Rio de Janeiro (Cidade) (2021), for the adequacy of the final destination of solid waste in the city, a concession contract was signed between COMLURB and the company Ciclus Ambiental do Brasil S.A until 2026, which can be extended for five years, the contractual scope includes the implementation, operation and maintenance of the waste transfer stations, and the landfill in Seropédica. Figure 3 illustrates the logistics for transferring the waste from the ETRs to the CTR – Rio in Seropédica. As can be seen, there are five waste transfer stations in the city, the ETR – Caju in AP1, the ETR – Marechal Hermes in the AP3, the ETR – Jacarepaguá in the AP4, and the ETRs Bangu and Santa Cruz in the AP5.

It should be noted that SMDEIS licenses the transfer stations. However, according to the information presented in table 4, the activity regulated by the environmental agency is for the operation of a solid urban waste transfer station. Hence, it is not described in the activity of ETRs the receipt of CDW. Although the responsible environmental agency regulates the ETRsmoreover the process related to the Jacarepaguá unit was started on February 18, 2011, according to a consultation on the progress of processes at the in Secretaria Municipal de Meio Ambiente (Municipal Environment Department) (SMAC, 2011). At the time, the extension of the operating license for the activity of a recycling and composting plant was required, according to a requirement published on February 12, 2019, issued by the municipal environmental agency, when it was required to submit an application for the operation of a waste transfer station since the activity licensed at the time was not the same (SMAC, 2019).

As for the Seropédica sanitary landfill, this company is regulated by the Instituto Estadual do Ambiente – INEA (State Institute of the Environment), whose information is presented in table 5. According to what can be seen, the activities of the sanitary landfill regulated by the environmental agency include the disposal of Class II waste of residential, commercial, and industrial origin. In this way, the activity of receiving CDW is not considered the object of the license. Although such activity is not described in the object of the sanitary landfill operating license, the charge for disposal of inert solid waste is allowed at CTR-Rio, in Seropédica, as written in Item 4A of the table of values of the special services to be charged and collected by COMLURB, established in § 1º of Art. 1° from the regulation (Rio de Janeiro (Cidade), 2021).

In this way, it can be affirmed that the sanitary landfill receives inert solid waste, which includes construction waste; in this way, in disagreement with the object of the operating license issued by the environmental agency, it must be emphasized that in the "§ 1º of Art. 4º from CONAMA 448 establishes that construction waste cannot be sent to urban solid waste sanitary landfills (Brasil, 2012).

Reaffirming the point of view defended by (Eigenheer & Ferreira, 2011), where they describe that in practice, many sanitary landfills in the country receive construction waste for use in the construction and maintenance of internal roads and, eventually, in the coverage. Because of the above justifications, adopting a new management model for the CDW produced in Rio de Janeiro is necessary. Therefore it is suggested that the ETRs managed by COMLURB be adapted to enable the receipt of this class of waste temporarily for later sending of the CDW to the recycling plant that will be created.

The process of adapting the transfer station should start primarily in the ETR of Jacarepaguá since Planning Area 4 was the region where 50.70% of the total estimated construction waste in the city was generated from 2006 to 2020, as shown in figure 1. In the second order of priority, the ETR of Marechal Hermes must be adequate Planning Area 3 was the region that produced 17.66% of the calculated waste in the municipality of Rio de Janeiro. In the third order of priority, the adaptation of the ETR of Bangu is suggested because, in Planning Area 5, 16.59% of the total rubble originated in the city. Finally, it is recommended to adapt the ETR of Caju, a strategic plan to receive waste from Planning Area 2 and Planning Area 1, regions where it was estimated the generation of 8.28% and 6.77%, respectively, of the number of materials produced in the city of Rio de Janeiro.

In addition to adapting the transfer stations, it will be necessary to build a CDW recycling plant so that this unit to be the destination of the waste sent to ETRs; in this way, it will be possible to recycle the rubble. For the sizing of the CDW recycling, an estimation method was used considering the generation of waste for the period from 2006 to 2020, whose average production value was 361,992.00 tons year$^{-1}$ and a standard deviation of 156,001.00 tons year$^{-1}$, according to data presented in Table 6.

The choice of this reference value was possible after applying the ANOVA statistical test between the generation data from COMLURB, estimated according to the methodology of Pinto (1999), and generation values published by SNIS. As a result, obtained in Section 3..2.1, the construction waste generation data were statistically equal, according to the 95% confidence interval. However, when this test was carried out for the period between 2011 and 2020, as maintained by the same confidence interval, it was proved that the mean values of these three data groups are statistically different, per the results presented in section 3.2.2. After verifying the existence of statistical difference, Tukey's statistical method was applied when it was identified that a significant difference occurred between the generation values published by COMLURB and the estimation metric second Pinto (1999). However, there was no significant difference between the estimate and data from SNIS, according to the results illustrated in Figure 2. For this reason, as there was no significant difference between the average values estimated second Pinto's method (1999) and data published by the SNIS, these two data groups were selected for a more detailed statistical analysis. Therefore, the CDW generation values from COMLURB were eliminated.

As two data groups were used for statistical analysis, the T-test was applied considering two periods, from 2006 to 2020; no difference was identified, in accordance with the results presented in Section 3.2.3. However, for the interval between 2011 and 2020, the existence of a significant difference was proven, according to data shown in Section 3.2.4.

The hypothesis found to justify the existence of a statistically significant difference between the analyzed data is due to the change in the waste management system in the city of Rio de Janeiro; as presented in the introductory section, the CTR – Rio in Seropédica was inaugurated on 20 April 2011 (Rio De Janeiro (Cidade), 2021).

It should be noted that the current urban solid waste management model was gradually regularized. According to information presented in table 4, the beginning of the validity of the municipal operating licenses of the ETRs has a date posterior to the inauguration of the CTR - Seropédica, being on April 16, 2012, to ETR Marechal Hermes, on June 20, 2012, to ETR Santa Cruz, on April 9, 2014, to ETR Caju, on May 9, 2014, to ETR Bangu and on June 17, 2021, to ETR Jacarepaguá.

Regarding the ETR of Jacarepaguá, as presented in the introductory section, this unit was where the waste collected in the city had been dumped since the beginning of the sanitary landfill operation (Rio de Janeiro (Cidade), 2011). However, according to Table 4, the concession of the operating license for the solid urban waste transfer station activity was only completed on July 17, 2021. Because of this, it can be attested that the ETR of Jacarepaguá operated in disagreement with the activity licensed since the beginning of its operation.

As a consequence of the beginning of operation of the CTR – Rio in Seropédica, farther from the urban center of the city of Rio de Janeiro, to the metropolitan landfill of Jardim Gramacho, as well as the CTR Gericinó, disabled in June 2012 and April 2014, respectively. In addition to the legal impossibility of dumping the CDW in the ETRs, this activity is not being described in the objects of the operating licenses resulted in the dispersion of this waste class. This fact was verified through the statistical tests and discussed in this chapter. Therefore, adopting the proposed management model is recommended for the reasons explained.

Because of the above, the criterion for determining the area was used to carry out the sizing of the CDW recycling plant that meets the generation demand of 361,992.00 tons year-1, according to data presented in table 6, under the data disclosed in table 1. However, as the waste production estimate exceeds 210,000.00 tons year$^{-1}$, these values were verified to discover the Pearson (r) linear correlation coefficient and obtain the adjusted straight-line equation, as illustrated in Figure 4.

According to what can be verified, the value of $R^2$ was 0.9987, thus representing a probability of 99.87%. As for the value of Pearson's linear correlation coefficient obtained, it was 0.9993. Thus it is concluded that there is a strong relationship since this result is very close to 1 (one). Because of the above justifications, it can be attested that the equation of the adjusted line is a good representation of data, as a result of applying the equation, a total area of 32,397.50 m² was measured, so it is proposed to adopt an area with this dimension, also selected according to criteria for the availability of access roads for trucks, as well as the delimitation outside the permanent preservation areas, established following the legislation (BRASIL, 2012), as illustrated in the Figures 5 e 6.

Finally, regarding the proposed model for the management of construction waste in Rio de Janeiro, in line with the criteria presented, the adequacy of the ETRs managed by COMLURB is suggested to enable the reception of waste temporarily. Afterward, sending to the recycling plant, the proposition of this mold is illustrated in Figure 7.

## 4. CONCLUSIONS

Achieving the purpose of this study, which consists of proposing a new management model for construction waste in Rio de Janeiro, initially, estimates of construction waste were carried out, second to the city planning area.With regard to statistical tests, it was confirmed by the ANOVA test that there was no statistically significant difference between the generation data published by COMLURB, estimated according to Pinto's methodology, and values published by the SNIS for the period from 2006 to 2020, as maintained by the confidence interval the 95% index. However, when this test was performed for the period from 2011 to 2020, it was verified that the mean values of the three data groups are statistically different,. It was also confirmed, through the Tukey method, that a significant difference occurred between the generation data published by COMLURB and the estimation metric developed by Pinto (1999), .

The values estimated according to Pinto's metric (1999) and data published by the SNIS, were analyzed through the T-test for the period from 2006 to 2020, and no difference was identified. However, from the time between 2011 and 2020, the occurrence of a significant difference was proven.

As for the mapping of authorized sites for the disposal of waste produced in the city of Rio de Janeiro, it was attested that the transfer stations managed by COMLURB, cannot receipt of CDW . It was also found that the ETR of Jacarepaguá operated in disagreement with the activity licensed since the beginning of its operation, due to the granting of the license to operate as a solid urban waste transfer station was concluded only on July 17, 2021.

Regarding the Seropédica sanitary landfill, the charge to dispose of construction waste in the CTR – Rio in Seropédica is allowed, as written in item 4A of the table of values of the special services to be charged and collected by COMLURB, established by § 1º of Art. 1° from regulation N°3-R (Rio De Janeiro (Cidade), 2021). As a result, it can be said that the sanitary landfill receives inert solid wastes, , in disagreement with the object of the operating license issued by the environmental agency, as well as the "§ 1º of Art. 4º from CONAMA 448stablishes that CDW cannot be sent to urban solid waste sanitary landfills (BRASIL, 2012).

For the implementation of the CDW recycling plant, it was found that adaptation of ETRs must start primarily at the ETR of Jacarepaguá since the AP4 corresponded to 50.70% of the total estimated. In the second order of priority, it was recommended to adapt the ETR of Marechal Hermes, how AP3 represented 17.66% of the amount of waste calculated. In the third order of priority, the adjustment of the ETR of Bangu was suggested because the AP5 corresponded to 16.59% of the estimated materials volume. Finally, an adaptation of the ETR of Caju was suggested, as it is a strategic place to receive waste from AP2 and AP1, regions where the generation of 8.28% and 6.77%, respectively, of the total CDW estimated in the city of Rio de Janeiro.

In addition to that, the need to create a construction waste recycling plant was presented, to this end, it is necessary 32,397.50 m² of area available, access roads for trucks, as well as delimitation outside the permanent preservation areas. In conclusion, a new model was proposed for the management of construction waste in the city of Rio de Janeiro.

Finally, it is recommended to revoke the § 1° of Art. 17 from regulation "N" COMLURB N°002 of February 3, 2022, since it is proven that the site has an operating license compatible with the activity, there is no technical justification for prohibiting the disposal of waste from large generators, in companies regularized by other inspection and control institutions.

## 5. DECLARATIONS

### 5.1. Study Limitations

No limitations were known at the time of the study.


### 5.2. Acknowledgements

Not applicable.

### 5.3. Funding source

This research was funded by the authors.


### 5.4. Competing Interests

No conflict of interest exists in this publication.

### 5.5. Open Access



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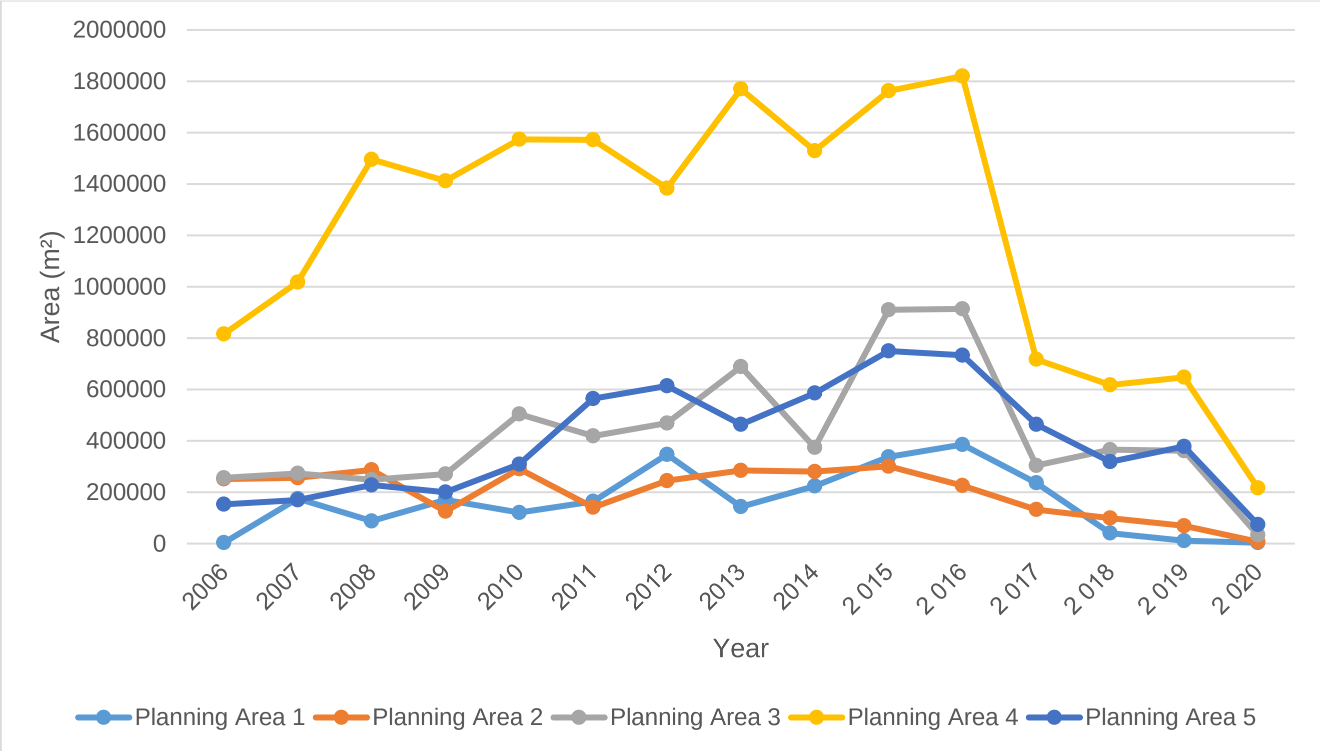


*Figure 1 - Total area of occupancy concession according to the Planning Area*

*Source: Authors based on SMPU data (2006 - 2020).*

*Table 2 - Amount CDW generated in the city of Rio de Janeiro according to COMLURB*

| Year | Total weight (ton) |
|---|---|
| 2006 | 678,258.00 |
| 2007 | 514,475.00 |
| 2008 | 640,559.00 |
| 2009 | 615,647.00 |
| 2010 | 394,324.00 |
| 2011 | 419,225.00 |
| 2012 | 316,295.00 |
| 2013 | 212,687.00 |
| 2014 | 229,202.00 |
| 2015 | 217,079.00 |
| 2016 | 104,285.00 |
| 2017 | 76,883.00 |
| 2018 | 66,209.00 |
| 2019 | 19,036.00 |
| 2020 | 19,037.00 |

Source: COMLURB (2021).

*Table 3 - Amount CDW generated in the city of Rio de Janeiro according to SNIS*

| Year | City Hall or collected by it (ton) | Companies and self-employed hired by the constructor (ton) | constructor (ton) | Total weight (ton) |
|---|---|---|---|---|
| 2006 | 105,410.10 | 388,788.60 | 54,555.40 | 548,754.10 |
| 2007 | 78,501.00 | 377,350.00 | 58,623.00 | 514,474.00 |
| 2008 | 123,998.33 | 688,119.39 | 0.00 | 812,117.72 |
| 2009 | 112,221.90 | 559,840.60 | 0.00 | 672,062.50 |
| 2010 | 124,005.70 | 588,996.00 | 0.00 | 713,001.70 |
| 2011 | 102,576.00 | 489,391.00 | 0.00 | 591,967.00 |
| 2012 | 91,292.00 | 321,100.00 | 0.00 | 412,392.00 |
| 2013 | 86,392.00 | 212,687.00 | 0.00 | 299,079.00 |
| 2014 | 70,549.00 | 229,202.00 | 0.00 | 299,751.00 |
| 2015 | 68,634.00 | 217,079.00 | 0.00 | 285,713.00 |
| 2016 | 65,715.00 | 104,294.00 | 0.00 | 170,009.00 |
| 2017 | 57,849.00 | 74,709.00 | 0.00 | 132,558.00 |
| 2018 | 48,882.00 | 66,225.00 | 0.00 | 115,107.00 |
| 2019 | 49,238.00 | 48,896.00 | 28,840.00 | 101,018.00 |
| 2020 | 19,036.00 | 34,564.00 | 0.00 | 53,600.00 |

Source: SNIS (2006-2020).

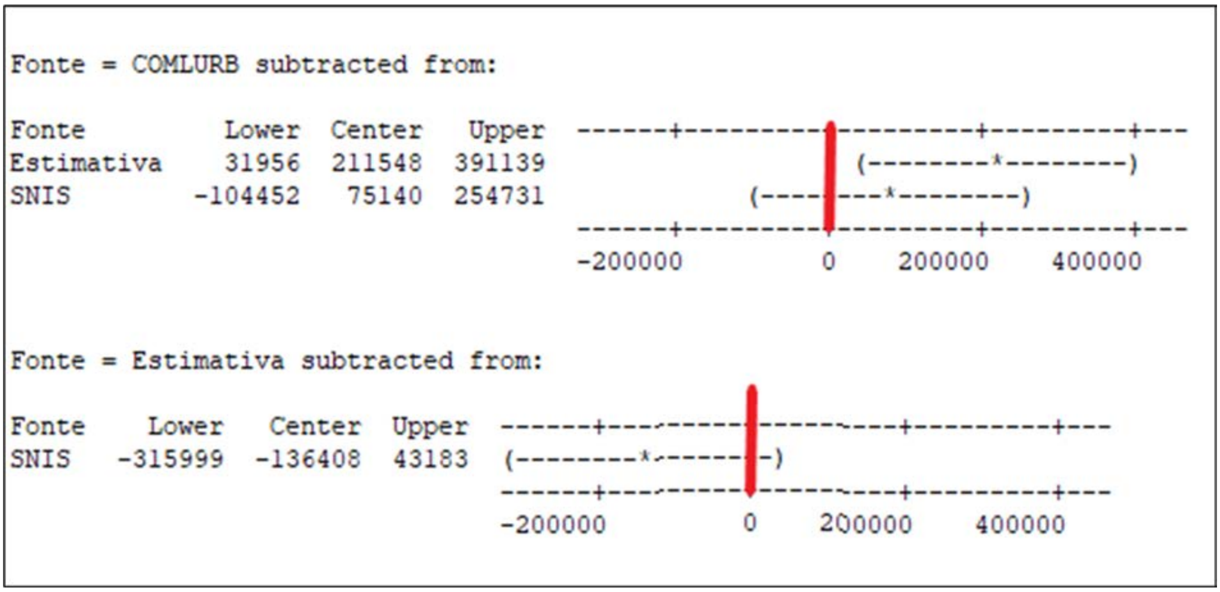


*Figure 2 - Tukey test result data construction waste generation period from 2011 to 2020*

Fonte: Autors (2022).

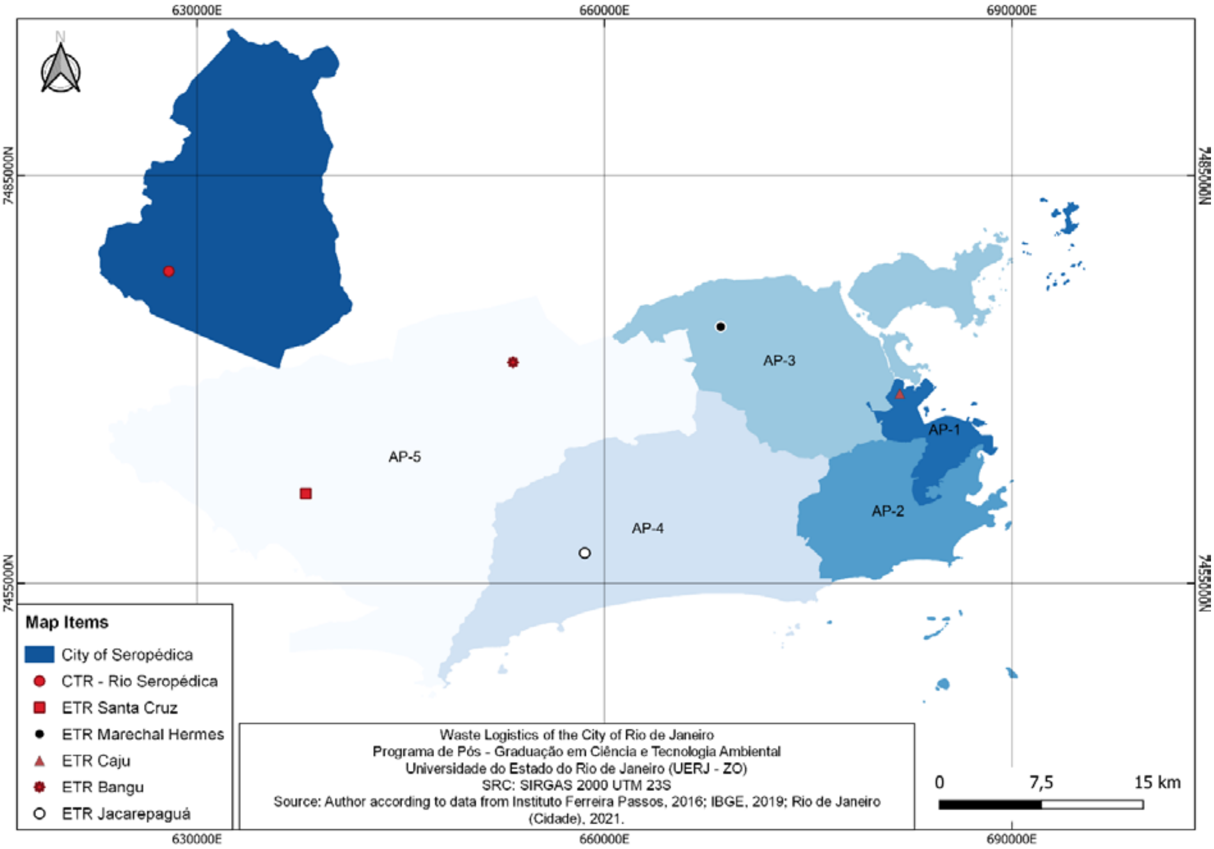


*Figure 3 - Waste transfer logistics to CTR - Rio in Seropédica*

Source: Authors according to information (Rio de Janeiro (Cidade), 2021).

*Table 4 - Municipal Operating Licenses for COMLURB ETR*

| Process number | Requester | Summary description | document number | Date of document |
|---|---|---|---|---|
| 142011952010 | ETR - Marechal Hermes | Solid Urban Waste Transfer Station | LMO 000692 | 04/16/2012 |
| 142011962010 | ETR - Santa Cruz | Solid Urban Waste Transfer Station | LMO 000732 | 06/20/2012 |
| | | Solid Urban Waste Transfer Station with an operational capacity of 21,000 ton/month | LMO 2862 | 10/20/2021 |
| 142007702011 | ETR – Caju | Solid Urban Waste Transfer Station with operational capacity for 4,000 ton/day | LMO 001229 | 04/09/2014 |
| 142000192014 | ETR - Bangu | Solid Urban Waste Transfer Station with an operating capacity of 3,000 ton/day | LMO 001244 | 05/09/2014 |
| 142004942011 | ETR - Jacarepaguá | Solid Urban Waste Transfer Station with an operational capacity of 20,000 ton/month | LMO 2793 | 06/17/2021 |

Source: Authors according to data (SMDEIS, 2022).

*Table 5 - Operating License CTR - Seropédica*

| Process number | Requester | Summary description | document number | Date of document |
|---|---|---|---|---|
| EXT-PD/ 014.10456/2021 | Ciclus Ambiental do Brasil S.A. (CTR - Seropédica) | Sanitary landfill (up to 10,400 t/d) in an area of 989,215.11 m², belonging to sub-landfill 1 and sub-landfill 3 (stages 1A, 1B1, 2A1, 2A2 and 3A), for disposal of class II waste of residential, commercial and industrial origin; Slurry Treatment Station (primary, secondary, tertiary) and Treatment of slurry by reverse osmosis; treated effluent discharge line; workshop and point of departure supply, biogas capture and burning system (04 centrifugal blowers and 05 burners) | LO Nº IN011445 | 02/08/2022 |

Source: Authors according to data (INEA, 2022).

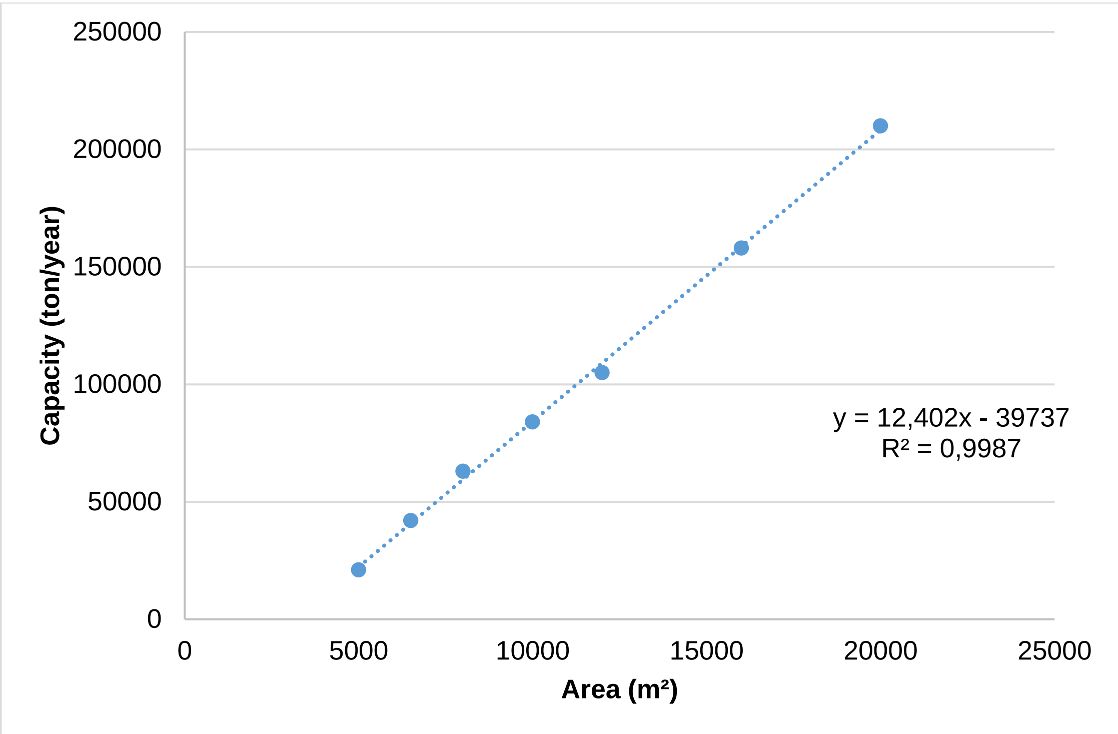


*Figure 4- Area calculation parameter for CDW recycling plant*

Source: Authors according to data (JadovskI, 2005).

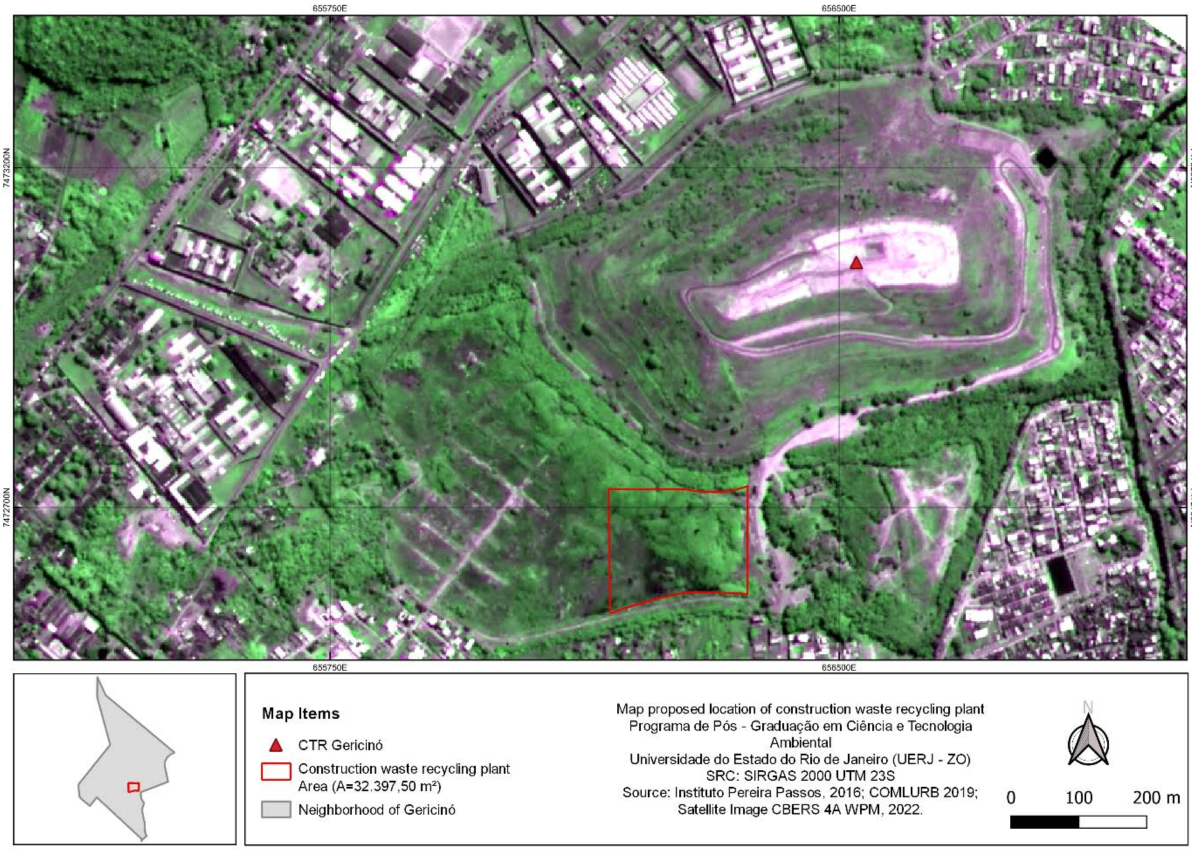


*Figure 5- Proposed area for the creation of construction waste recycling plant*

Source: Authors (2022).

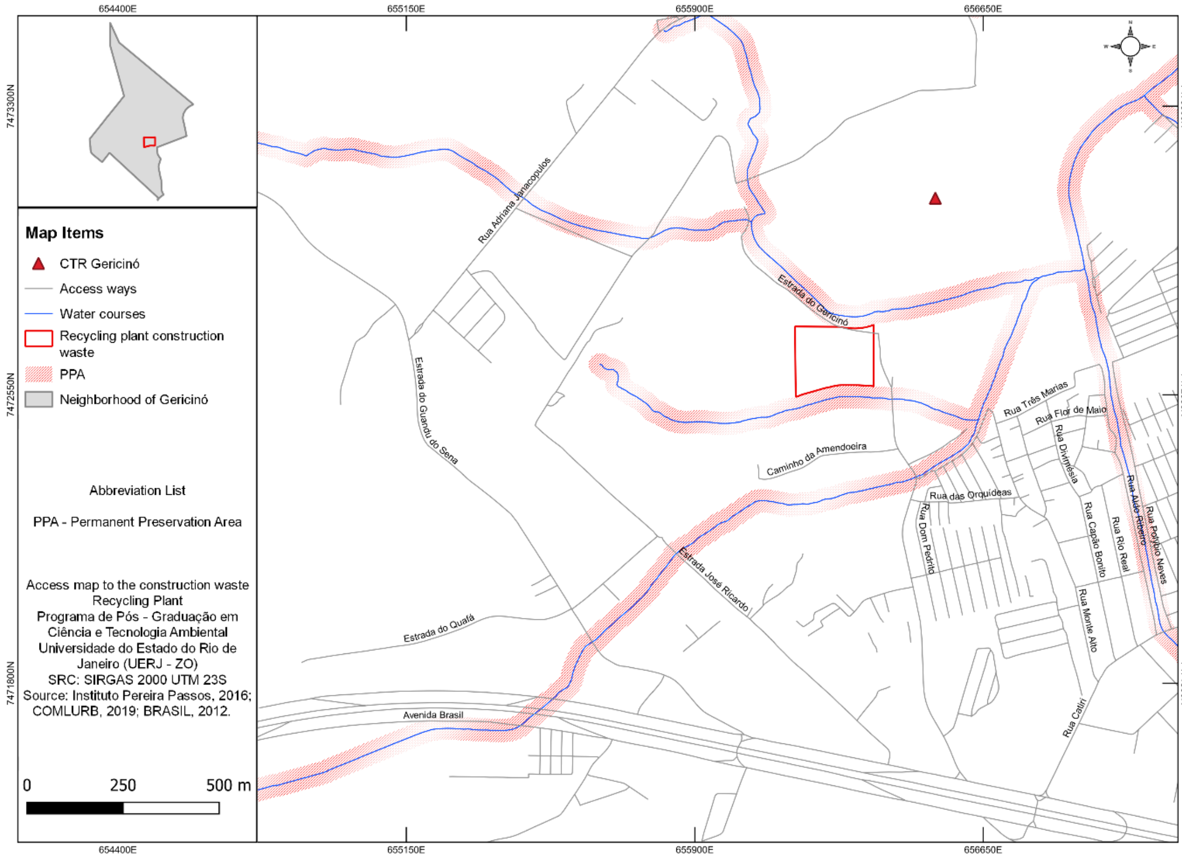


*Figure 6 - Access to the construction waste recycling plant according to selection criteria*

Source: Authors (2022).

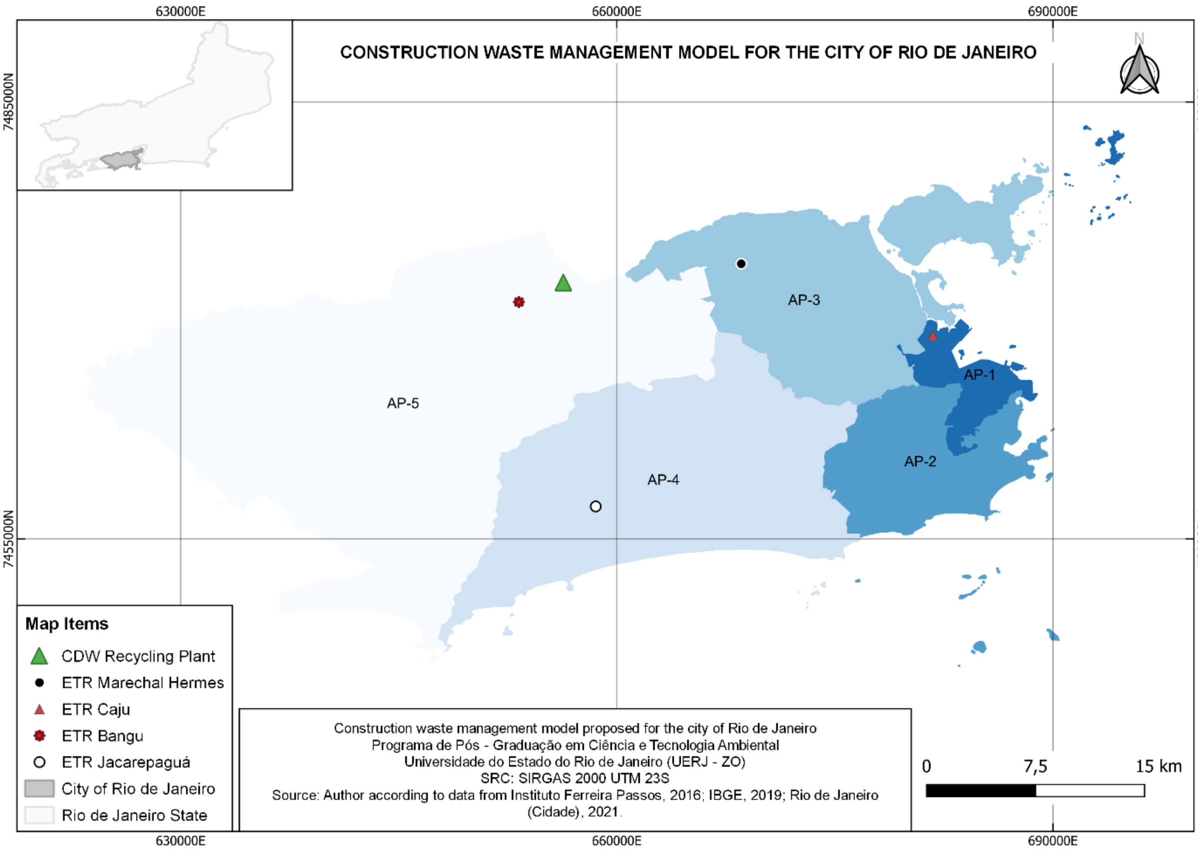


*Figure 7- Construction waste management model for the city of Rio de Janeiro*

Source: Authors (2022).