TECHNICAL FEASIBILITY STUDY OF A CCW RECYCLING PLANT IN JUAZEIRO DO NORTE-CE

ESTUDO DE VIABILIDADETÉCNICA DE USINA DE RECICLAGEM DE RCC EM JUAZEIRO DO NORTE-CE

ESTUDIO TÉCNICO DE FACTIBILIDAD DE PLANTA DE RECICLAJE DE RCC EN JUAZEIRO DO NORTE-CE

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ABSTRACT
The objective of the article is to analyze the technical feasibility of implementing a construction waste recycling plant in Juazeiro do Norte, for this purpose initially studying the feasibility in terms of demand for the plant by surveying the annual volume of waste recyclable materials from class A civil construction in the municipality of Juazeiro do Norte, which would host this hypothetical plant. In a second step, the path to be taken by the waste from its generation to its destination was studied under the local legislative perspective. Studies were also carried out on the national scenario of construction waste recycling plants to point out possible characteristics that the local plant should have to meet the intrinsic needs of Juazeiro. In this way, it was possible to observe that the municipality provides sufficient demand for a waste recycling plant, in addition to the fact that local legislation still lacks greater regulation for the sector, but with a more encouraging scenario with the study process and the implementation of a consortium intermunicipal project to deal with urban solid waste.

KEYWORDS
Environmental impacts; public policy; Generation profile; Cariri.

RESUMO
O objetivo do artigo é analisar a viabilidade técnica da implantação de uma usina de reciclagem de resíduos da construção civil em Juazeiro do Norte, para tanto inicialmente estudou-se a viabilidade em termos de demanda para a usina por meio do levantamento do volume anual de resíduos recicláveis da construção civil de classe A no município de Juazeiro do Norte, ao qual sediaria esta usina hipotética. Em um segundo momento foi estudado o caminho a ser realizado pelo resíduo desde sua geração até sua destinação final sob o olhar legislativo local. Foram também realizados estudos quanto ao cenário nacional das usinas de reciclagem de resíduos da construção civil para apontar possíveis características que a usina local deveria ter para atender as necessidades intrínsecas a Juazeiro. Desta forma pôde se observar que o município fornece demanda suficiente para uma usina de reciclagem de resíduos, além de que a legislação local ainda carece de maior regulação para o setor, porém com um cenário mais animador com o processo de estudo a implantação de um consórcio intermunicipal para tratar dos resíduos sólidos urbanos.

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PALAVRAS-CHAVE
Impactos ambientais; políticas públicas; geração de resíduos sólidos; Cariri.

RESUMEN
El objetivo del artículo es analizar la viabilidad técnica de implementar una planta de reciclaje de residuos de construcción en Juazeiro do Norte, para ello se estudia inicialmente la viabilidad en términos de demanda de la planta, mediante el levantamiento del volumen anual de residuos de materiales reciclables de clase A civil. construcción en el municipio de Juazeiro do Norte, que albergaría esta hipotética planta. En un segundo paso, se estudió el camino que seguirán los residuos desde su generación hasta su destino final bajo la perspectiva legislativa local. También se realizaron estudios sobre el escenario nacional de las plantas de reciclaje de residuos de la construcción para señalar posibles características que debería tener la planta local para satisfacer las necesidades intrínsecas de Juazeiro. De esta manera, se pudo observar que el municipio brinda suficiente demanda para una planta de reciclaje de residuos, además de que aún falta en la legislación local una mayor regulación para el sector, pero con un escenario más alentador con el proceso de estudio y la implementación. de un consorcio intermunicipal para abordar los residuos sólidos urbanos.

PALABRAS CLAVE
Impactos ambientales; políticas públicas; generación de residuos sólidos; Cariri.

1. INTRODUCTION

Nowadays, the city of Juazeiro do Norte, which is the largest in terms of population in the Cariri region of Ceará, generates tons of Civil Construction Waste (CCW) that are discarded of in landfills or at collection points called "bota-fora" (AMAJU, 2016).

Demonstration of leadership of the civil construction in this scenario is described by Evangelista (2010), when he mentions that in the sectors that have the most impact on the environment, the main generator of solid waste in a society are those from civil construction. and in relation to the impacts of the irregular disposal of construction waste, the Brazilian Association for Recycling of Civil Construction and Demolition Waste - ABRECON (2015), states that its irregular disposal can result in drainage problems, floods and pollution that result in more disease vectors, and also providing an increase in public expenditure. thus, in addition to avoiding social and environmental constraints, actions to inhibit this inappropriate disposal generate savings for the State.

For many years, the civil construction industry generated not so good impacts on the environment, causing scarcity and degradation of natural resources, so that it was necessary to instigate the way that environmental issues are thought and treated at the end of the 20th century (Klepa *et al*., 2019). To prove the environmentally appropriate destination of solid waste Bessa (2019), reports that an institution needs to prepare a management plan, which must fit the decisions adopted in the process of collection, transport and final disposal in order to give them a correct destination and sustainable management.

The civil construction industry and inadequate waste disposal have a high potential for degradation and are influenced by human activities amplified due to exacerbated consumption, resulting in damage to the environment (Silva; Fucale; Ferreira, 2020). Francisco et al. (2020), explains that the final disposal of waste in an appropriate way, leads to a healthy, clean and profitable environment for businesses, and also avoiding the propitiation of natural disasters and fines.

Law 1235/2010, which deals with the National Solid Waste Policy - NSWP, mentions these problems, opening the way for good solutions by encouraging the fight against waste generation, bringing reusable waste back to the production chain and depositing waste in appropriate places.

Vergani (2024) highlights the importance of higher education institutions in implementing the circular economy, contributing to the dissemination of information to future citizens.

In this way, the present work has the objective of analyzing the technical viability of implementing a recycling plant for civil construction waste in Juazeiro do Norte, using data about the legal cycle of recyclable waste from civil construction, as well as estimating the annual volume of recyclable waste from Class A civil construction in the municipality of Juazeiro do Norte, and the discussion of the national scenario of civil construction recycling plants and the local context for a hypothetical plant.

2. THEORETICAL FRAMES

2.1 Relevant legislation

The definition of construction waste is given by Brazil (2010) as waste arising from construction, renovations, repairs, demolitions, excavation and land preparation for civil works.

According to (Brazil, 2002), the National Council for the Environment (CONAMA), in its Art. 3 describes civil construction waste through classification, based on its characteristics, which are:

> I - Class A - are reusable or recyclable waste as aggregates, such as:
> a) construction, demolition, renovations and repairs of paving and other infrastructure works, including soil from earthworks;
> b) construction, demolition, renovations and repairs of buildings: ceramic components (bricks, blocks, tiles, cladding boards, etc.), mortar and concrete;
> c) manufacturing and/or demolition process of precast concrete parts (blocks, tubes, curbs, etc.) produced at construction sites;
> (Brazil, 2002, p. 95-96).

According to Souza (2021), the average gravimetry of these wastes for Class A corresponds to 87.7%, thus demonstrating their propensity for recycling and reuse.

And about the relationship between human beings and the environment Brazil (1988), guarantees in its Art. 225 that everyone has the right to an ecologically balanced environment and, to ensure this right, the principle of shared responsibility was established.

The goal of sustainable development can be achieved through the implementation of city solutions and technologies, thus contributing to improved efficiency and economic growth (Sharifi, 2024).

According to Brazileiro and Matos (2015), CONAMA Resolution No. 307/2002 was the first national initiative to establish guidelines, criteria and procedures in the management of civil construction waste. CONAMA Resolution No. 348/2004 (Brazil, 2004) promoted the inclusion of asbestos as Class D, considering it a hazardous waste, while Resolutions No. 431/2011 (Brazil, 2011) and No. 469/2015 (Brazil, 2015) promoted, respectively, the inclusion of plaster and paint packaging in class B, making them recyclable and consequently allowing their reinsertion in the production chain.

After all, Resolution nº 448/2012 (Brazil, 2012) updated the CONAMA resolutions bringing guidelines from Law 12.305/2010 that deals with the National Policy on Solid Waste, such as the responsibilities of the generator and the introduction of the objective of reusing this CCW.

In Chapter II, art. 3, item X of the national solid waste policy cited by Brazil (2010), it is evident the need to contemplate the municipal solid waste plan or the solid waste management plan to delimit actions directly or indirectly in waste management.

Regarding the current legislation in Juazeiro do Norte, we can mention Complementary Law nº 10/2016, which establishes the Code of Posture and mentions that the property owners are responsible for cleaning, and can be fined if they do not follow the rules. (Juazeiro do Norte, 2016). In addition to this, we have Law No. 3689/2010, which establishes the Integrated Plan for Civil Construction Waste Management (IPCCWM) and the Sustainable Management System for Civil Construction Waste (SGSR-CC).

This law punishes all generators, transporters and receivers of waste and disposes the waste by the name of rubble, understanding that it is a heterogeneous material from civil construction (Juazeiro do Norte, 2010).

The complementary Law nº 85/2012 promoted the creation of the Juazeiro do Norte Municipal Environmental Authority, an important milestone in environmental management related to the characteristic of promoting environmental licensing, still having the power of environmental control and inspection (Juazeiro do Norte, 2012).

The decree nº 219/2015 established the municipal sanitation plan that defined goals that will always be followed in this area, such as registration of solid waste transporters, study of the implementation of an intermunicipal consortium and continuous supervision of the management and disposal of solid waste (Juazeiro do Norte, 2015).

The decree No. 226/2016 developed improvements in aspects of Law No. 3,689 in relation to the regulation of the collection, storage, transport and disposal of construction waste that were not included in the regular collection, also including details to regulate registration and authorization of companies specializing in waste collection (Juazeiro do Norte, 2016).

2.2 Definitions of construction waste elements

The definition of civil construction waste generators is given by Brazil (2002), as being the public or private persons of a physical or legal nature responsible for the generation of waste. For Francisco et al. (2020), the actions and models of disposal and non-reuse of waste produced in civil construction are influenced by the priority criterion on environmental issues and the financial view of builders.

According to Brazil (2002), the carriers are responsible for collecting and transporting construction waste from origin to final destination and may be individuals or legal entities.

Han (2024) reports that strategies such as the use of BIM can help in the management of solid demolition waste, contributing to the environment, in addition to contributing to financial efficiency.

Municipal Law No. 3689 of 2010 reports that the dimensions of stationary buckets must have a capacity of 7 m^3, and the waste cannot overflow the edge, its transport must be carried out by buckets with specific colors according to the company, legible name, telephone number, number of the bucket, and a notice stating that it is forbidden to put domestic garbage (Juazeiro do Norte, 2010).

This same law also states that all transport must be carried out after printing a waste transport order (WTO) indicating information pertinent to the identification of the company, as well as the origin and destination of the material. As soon as the bucket is removed from the site, the company is obliged to clean it, this place being preferably inside the work and protected by fences, and as a last resort, placed on a public road (Juazeiro do Norte, 2010).

Brazil (2002) states that the area for transshipment and sorting of civil construction waste is a space whose function is sorting and temporary storage for a subsequent transition to the final destination that respect operational standards.

But the environmentally appropriate destination was given by Brazil (2010), which defines it as those who are able to reuse, recycle or dispose the waste following the current regulations, ensuring safety and preserving the environment. The destination is in charge of the indication of the municipal autarchy of the environment of Juazeiro do Norte since it is responsible for the management and inspection of the residues (Juazeiro do Norte, 2010).

2.3 Public Policies

In 2010, the NSWP was approved through Law nº 12.305 of 2010, being a legislative advance in the subject that uses the principle of shared responsibility and its implications set out in article 3 - item XVII, dealing with the disposal of waste produced (Brazil, 2010).

Concerning the legislation at states level, Ceará (2016) through Law No. 16.032/2016, instituted the State Policy on Solid Waste (SPSW) which brings together a range of guidelines, objects, principles and goals in line with the NSWP. However, adapting the particularities that are required due to the nature of the service.

This state legislation also encourages public-private partnership, promoting it in inter-municipal cooperation in the search for new solutions in the management of solid waste. In addition, it also provides for the formulation of what would become the state waste plan, as well as the need for a municipal plan for the integrated management of solid waste in force for an indefinite period and horizon of every 20 years, being updated in at least, every four years.

By Law No. 3689 of Juazeiro do Norte (2010), the generator has a series of responsibilities through the production of construction waste, and must be careful not to dispose of it in a public environment or inappropriate place. In addition, it is also up to the generator the removal of this material, being able to transport it or hiring another company to do it.

Those responsible for the waste must have a permit from the city hall, which will also indicate the designated place for the correct disposal of the material. In the aforementioned law, through Article 5 in § 1, the law also gives the possibility of using material of a mineral nature, provided that it is suitable for application as a landfill (Moura, 2018).

The municipal waste management policy was further detailed through Decree No. 226 of Juazeiro do Norte (2016), which included the Juazeiro do Norte Municipal Environmental Authority (AMAJU) in the process of controlling and inspecting transporters. In addition, it also included new regulatory aspects for transport companies specializing in construction waste in their registration, authorization and operation.

A recent positive environmental inspection action according to Juazeiro do Norte (2021) was the creation of a group to combat inappropriate disposal at clandestine accumulation points in the municipality, initially having an educational character, but with the possibility of applying the legislation.

2.4 Recycling Plants

According to Brazil (2010), recycling is the process of changing the physical, physio-chemical and biological properties that aim to create a new material that can be reinserted into the production chain, provided it meets the minimum standards required. In this way, construction waste can be considered as recycled products.

Klepa *et al*. (2019), reports that civil construction has a high potential for generating job and business opportunities, contributing substantially to the gross national product, thus being a great promoter in the economy. Technological innovation and inputs in the civil construction industry, motivated by sustainability, can generate alternatives to the problem of reducing the availability of resources available in nature (Marques *et al*., 2020).

In this context, for Paschoalin (2019), recycling plants reduce the environmental impact and have a high potential for contributing to the circular economy of waste management. However, they still have difficulties in controlling processes and products.

2.4.1 Profile of recycling plants in Brazil

The recycling plants come to contribute with a sustainable gain. In order to become viable, an amount is charged per cubic meter of waste received, which according to ABRECON (2015), ranged from R$10.00 to R$20.00 (quotation made in Brazilian currency, reais) per meter cubic received, which is much cheaper when compared to values practiced in Europe when converting currencies.

For Lima (2013), it is common to observe, within an international experience, charging the value of waste based on established content. Heterogeneity is considered to avoid contaminating elements that could damage the equipment or disrupt recycling. A good example of this way of working is a container that is considered as homogeneously containing concrete in Spain must have 95% of this material to be accepted, while in Germany the minimum admissible value rises to 99% to be accepted.

For Lino (2023), waste can no longer be seen as valueless materials, given their embedded economic, social, and environmental potential.

Even though they don't charge for material content when recycled, their products don't usually go through very rigorous quality control processing. Considering that, according to ABRECON (2015), 23% of recycling plants do not or have never carried out technical testing of products; 25% only perform when requested, in addition to the fact that just over a quarter of these plants are implemented in cities with up to 200 thousand inhabitants; and 60% of recycling plants in the country employ only 5 to 10 employees, demonstrating that it is possible to implement them in small and medium-sized cities and with low cost in terms of labor.

Francisco *et al*. (2020), states that the scenario with the existence of proper disposal of this waste can provide profitability and sustainability, in addition to avoiding fines. This fact is confirmed, since, according to ABRECON (2015), most Brazilian recycling plants are managed by the private sector, in addition to the fact that construction companies are also their biggest customers, followed by the public authorities. However, the main difficulties in selling recycled waste from civil construction, according to those responsible for the plants, are due to the high tax rates, the lack of knowledge of the market and the absence of legislation that encourages consumption.

According to ABRECON (2018), most recycling plants are concentrated in the Southeast, more precisely in São Paulo, demonstrating a great potential for expansion in the sector in other states, with a national growth rate of 10.5 plants per year.

2.4.2 Regulatory rules for recycling plants in Brazil

The NBR 15112 contributes to the temporary and environmental preservation of the transshipment areas that receive the material, performing first the sorting and then the destination of the rejects to an appropriate landfill that follows the NBR 15113 molds. However, the recyclable portion will pass to the step of recycling that is designated by NBR 15114, making the material re-applicable in society along with reusable waste that, in case of application in road paving and non-structural concrete, will follow the descriptions said by NBR 15116.

2.4.3 Classifications of recycling plants in Brazil

The recycling of construction waste can be classified according to mobility, which can be classified as fixed, mobile and semi-mobile (Damasceno, 2019).

Another possible classification for the plants is the occurrence of a simple screening until it promotes the complete removal of contaminants from the material, which can be designated as first, second or third generation (Sobral, 2012).

Stationary recycling plants have, according to Damasceno (2019), positive characteristics, such as plants that present higher quality of their products and have more robust equipment, being able to obtain a higher production than the others.

For Damasceno (2019), the mobile recycling plant, on the other hand, has the advantage of not needing to be fixed in a certain location and not having costs associated with the assembly and disassembly of the equipment. In his work, Sobral (2012) reported that mobile recycling plants are common in undertakings with constant movement such as the construction of highways, and may be transported using special trailers.

The semi-mobile recycling plant, on the other hand, has the practicality of allowing its displacement, but at the same time presents a cost associated with its mobilization and demobilization, as exposed by Damasceno (2019). The use of this type of recycling plant is intended for businesses that have a specific installation period, such as the construction of hydroelectric plants, and it is also common to have their bases in metallic structure to facilitate assembly and disassembly.

Comparatively, when observing ABRECON (2015), it is noticed that fixed plants have priority, compared to the others and followed by the mobile plant, which showed growth in the period between 2013 and 2015. This is due to the flexibility of use and greater economic viability due to the economy of transporting waste containers to the recycling plant.

Table 1 systematically shows the types of plants mentioned above, as well as their application and their advantages and disadvantages.

Type of plant	Applicability	Advantages	Disadvantages
Mobile	Works that require constant movement	Easy mobility	Low volume recycled compared to other
Semi-mobile	Works with a defined term and that are large enough to demand a plant	Can be moved and tend to recycle more material than the mobile	cost of mobilization
Fixed	Receiving a large volume of waste	highest potential volume to be recycled	High implementation cost

Table 1: Summary table of civil construction recycling plants aspects in terms of mobility.
Source : The researchers (2024)

According to Sobral (2012), plants can also be classified as first, second and third generation. The first type is when there is a removal through machinery such as electromagnets, the second presents a greater sophistication in the cleaning and sorting processes guaranteeing a greater removal of impurities and the third presents the complete removal of these impurities being often associated with dry or wet aggregate separation processes, and sometimes the combination of both.

For Fogliarini (2018), the first generation is the simplest, containing conventional crushing equipment and magnetic magnets, as being responsible for the separation of contained metallic elements. The second generation are comparable to the first in terms of design simplicity, however they include greater sophistication compared to the first in terms of separation, sometimes material can be removed, in addition to the use of electromagnets. Finally, the third generation aims at the almost complete removal of impurities based on dry, wet or thermal processes, or even a combination of them.

According to Sobral (2012), recycling plants can also be classified as first, second and third generation. The first type is when there is a removal through machinery such as electromagnets, the second presents a greater sophistication in the cleaning and sorting processes guaranteeing a greater removal of impurities and the third presents the complete removal of these impurities being often associated with dry or wet aggregate separation processes, and sometimes the combination of both.

The equipment for such use can range from magnetic separators for the removal of ferrous and metallic elements, floatation purification tanks aimed at separating materials by their density, and furthermore the equipment for wet processes such as water jets and immersion of waste.

2.5 Civil Construction Waste Recycling Stages

For Oliveira (2020), the process begins with the collection of material so that a content screening can be initiated. After this stage, the content is processed to be sieved and distributed according to the granulometry, and only then to be sold. Figure 1 illustrates this path through a flowchart.

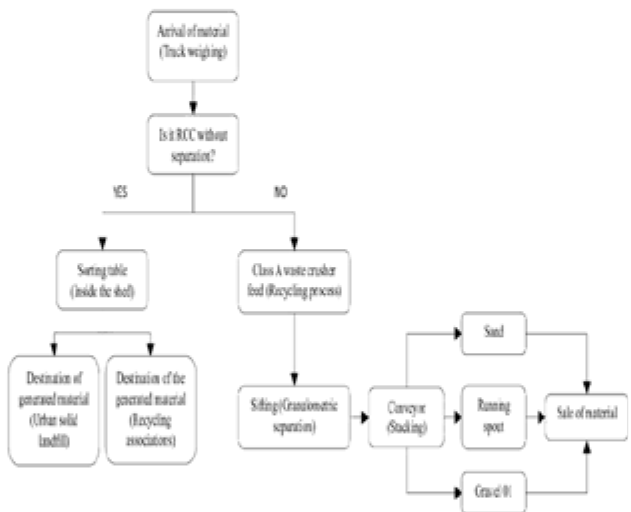

Figure 1: Construction waste recycling flowchart.
Source : Adapted from Oliveira (2020, p. 4)

For Lima (2013), initially a separation and collection of materials is carried out, to then feed the crusher. The remaining metallic and ferrous residues would be segregated by the magnetic separator and, based on their granulometry, the sieves would divide the materials, generating products such as running spout and splitting. Figure 2 elucidates the idea cited by Lima (2013).

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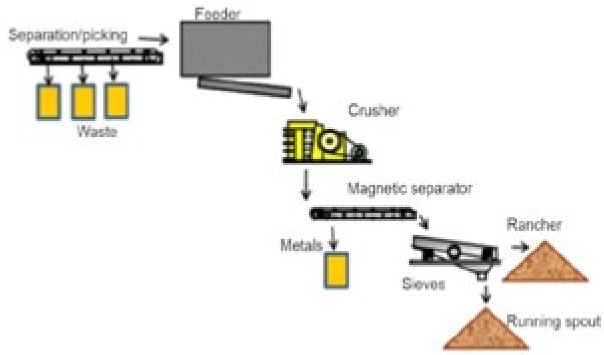

Figure 2: Typical circuits of the emerging recycling industry in countries like Brazil and China
Source : Lima (2013, p. 38)- adapted by the author

Already observing a more complex circuit, one can observe the European experience that, according to Lima (2013), uses more specific devices for the operation, such as the Wind Shifter, which is a pneumatic classifier, and the Jigue, which is a classifier that guarantees a very low portion of organic matter. As shown in Figure 3.

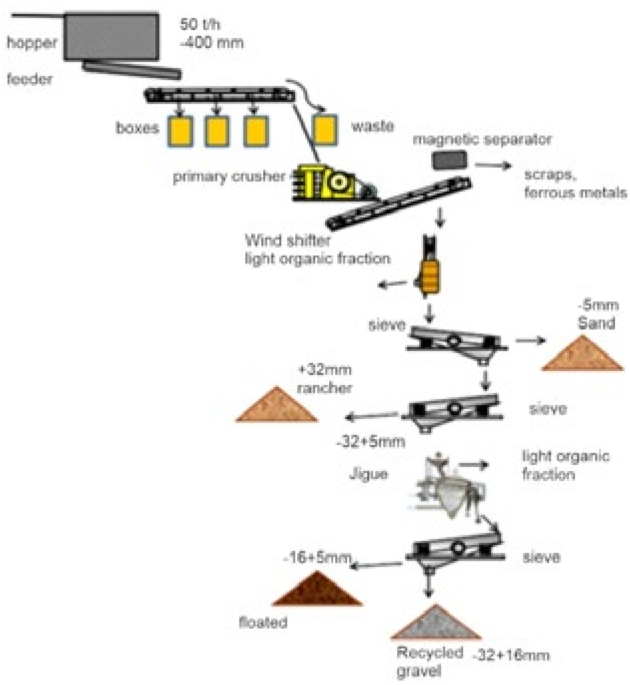

Figure 3: Typical circuit of the mature recycling industry existing in Germany and the Netherlands to obtain concrete gravel.
Source : Adapted by Lima (2013) Usina VAR in Angulo et al. (2009)- adapted by the author

The feeder places the material in the system and transports it through the conveyor belt, which is previously sorted to allow the removal of the identified waste. Subsequently, a primary crusher is used to reduce the material to a maximum granulometry.

The crushed material is placed on the magnetic conveyor belt to remove metallic and ferrous elements. The Wind Shifter and the Jigue together promote the removal of contaminants, while the sieves are responsible for the separation of recycled products.

2.6 Construction waste processing equipment

According to Fogliarini (2018), the equipment used in a recycling plant is diverse, from vibrating feeders, crushers, vibrating sieves and conveyor belts.

The use of technologies for decision-making processes in waste management for Al Awadh (2023) can contribute to a cleaner and more sustainable future worldwide, in addition to allowing automation.

The vibrating feeder is, according to Fogliarini (2018), a reinforced metallic funnel that promotes the separation of the material while promoting feeding through a directed vibrating system. The last one is carried out through a metal table with springs, moved by an eccentric shaft.

For equipment sales company Odebraz, he reports that the insertion of the vibrating feeder, shown in Figure 4, helps to facilitate waste handling and reduces maintenance costs, making it important to insert it before the primary crusher (Odebraz, 2021).

Figure 4: Vibrating feeder
Source : YLS (2024, https://www.yls.net.br/trituradores2.html)

The crusher is responsible for the civil construction waste, and transforming it into aggregates of different granulometries, which may be, according to Odebraz (2021), jaw, conical or impact type.

For the Brazilian Association of Public Cleaning and Special Waste Companies (2020), the jaw crusher is the most common in Brazil being used in plants in the national territory. It is usually allocated as a primary crusher for having a cheaper price and lower maintenance cost, however, the crushed product tends to have a more lamellar characteristic than the others. Impact crushers, on the other hand, generally tend to be allocated in a secondary position because they have a higher acquisition and maintenance cost, in addition to the possibility of generating aggregate with better characteristics. As for the cone crusher, it is also used as a secondary or tertiary crusher because it has characteristics depending on the characteristics of the aggregate to be recycled.

The conveyor belt is used, according to Odebraz (2021), to promote the automated transport of waste to the next recycling stages to be carried out in a more practical and automated way, as seen in Figure 5.

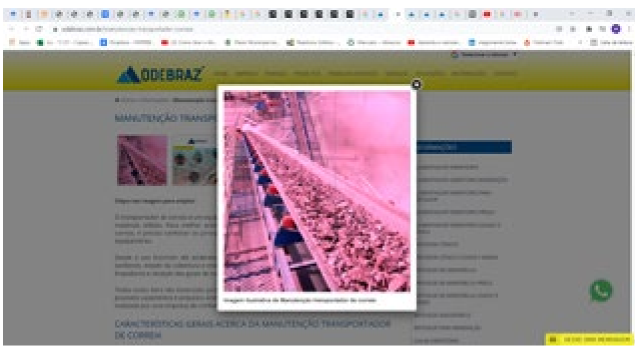

Figure 5: Conveyor belt
Source : Odebraz (2024, https://www.odebraz.com.br/transportador-continuo-correia)

The magnetic separator (Figure 6), for the company Metal Detector, is used for the removal of metals, and can be replaced by electromagnets, and its operating principle is the generation of a magnetic field that attracts metallic and ferrous elements (Metal Detecor, 2021).

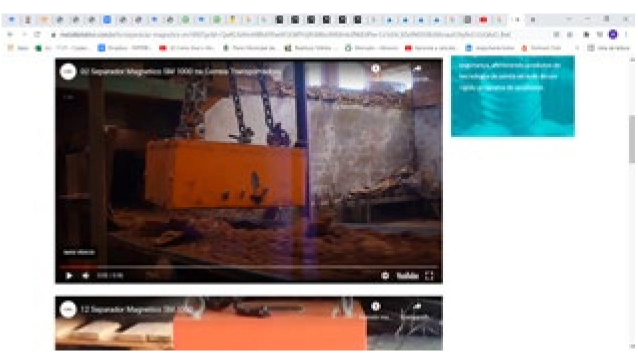

Figure 6: Magnetic separator SM - 1000
Source : Metal Detector (2024, https://metaldetektor.com.br/br/separacao-magnetica-sm1000)

The vibrating sieve, as seen in Figure 07 and Odebraz (2021) understanding, is the equipment responsible for segregating each crushed product according to granulometry, in addition to the vibration process also contributing to the elimination of remaining impurities.

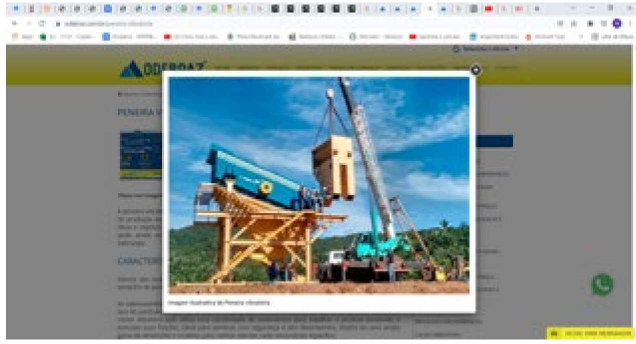

Figure 7: Vibrating Sieve
Source: ODEBRAZ (2024, https://www.odebraz.com.br/peneira-vibratoria-a-venda)

For Lima (2013) Jigues can be inserted, as seen in Figure 8, which are equipment for use to generate coarse aggregates with low concentration of organic matter and is a gravity concentration equipment.

Figure 8: Jigs from Deisl-Beton, Salzburg, Austria
Source: Lima (2013, p. 36)

2.7 Products obtained from recycling

Interest in the circular economy in the context of Latin America is still in its early stages, with a greater volume of publications starting in 2017, therefore it is necessary to develop further studies on this multidisciplinary topic to better mature the theme and find paths for its development practical (Ospina-Mateus, 2023).

For Möslinger (2023), solid waste management and the circular economy are essential for promoting a sustainable environment, as they are intelligent alternatives to solving the problem of inadequate disposal.

According to Salomão (2019), the products obtained after the recycling of waste from Class A civil construction can vary greatly, depending on the function and granulometry, which can be:

a) recycled sand, material with maximum dimensions of less than 4.8 mm and derived from recycling concrete and blocks, and application can be carried out from the production of masonry laying mortar without structural function to subfloors.

b) recycled gravel, a material with a maximum dimension of 6.3 mm and with applications in concrete artifacts such as benches and tables in the square, in addition to being able to also be used in sewage pipes.

c) recycled gravel, a material with a maximum dimension of 39 mm, commonly used in drainage works and in the manufacture of non-structural concrete.

d) running spout, material with a maximum dimension of 63 mm, whose use ranges from subgrade reinforcement, and sub-base for paving to regularization of the ground level in topographic terms.

e) recycled stone or cracked stone is a material from recycling that contains a maximum dimension of 150 mm, and is more common in paving, drainage, in addition to the possibility of use in earthworks.

The cost compared by Damasceno (2019) demonstrates the disparity in values between natural and recycled aggregate.

Product	Natural R$/m³	Recyclable R$/m³
Thin sand	80,00	35,00
Medium sand	80,00	35,00
Thick sand	80,00	35,00
Gravel #2	100,00	35,00
Gravel #3	100,00	35,00
Ranch	56,75	35,00

Table 2: Price comparison of natural and recyclable products from recycling plant
Source: Damasceno (2019, p. 9)

For Marques *et al.* (2020), products from recycling have similar characteristics to the natural ones, but at a lower cost, thus making the material more attractive from a practical point of view.

Akter (2024) describes that the use of artificial intelligence in the service of environmental management is of substantial impact, in addition to the fact that its use can also be used on market performance determination of recycled inputs.

3. METHOD

For Severino (2014), bibliographical research is the one made from previous research such as books, articles, theses, and documental research is that which is based on objects without analytical treatment. In this way, a bibliographical and documentary research was carried out using articles, monographs, laws, diagnosis, overview and information from associations, being necessary to carry out the study of a quantitative approach, which for the same cited author, is the one whose relationship of cause and effect are described under mathematical function, and yet the qualitative approach is one that focuses on epistemological foundations.

Research stage	Activity
Beginning of the Research	Delimitation of the field of study
Bibliographic research	Search in monographs, studies, articles and books that deal with the matter
Documentary Research	Search through legislation, agency data government and consortia
Data analysis	Annual estimate of construction waste from class A in the municipality
Conclusion	Response to the problem

Table 3: Framework of Research
Source: The researchers (2024)

The field of study was delimited, in addition to documentary and bibliographical research to understand the flow of recyclable construction waste from a normative Perspective. An estimate of recyclable waste from civil construction was also made, as well as its corresponding analysis, and discussion on the national scenario of recycling plants.

3.1 Delimitation of the field of study

The object of study of this work is the municipality of Juazeiro do Norte-CE, located in the region of Cariri, with coordinates with Latitude: -7.23718, and with Longitude: -39.3222, as shown in Figure 15, which according to the Brazilian Institute of Geography and Statistics – IBGE (2021) has a population of 276.264 inhabitants, the largest in the

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Cariri region in terms of population. Still under the same source, the development of the city also stands out in the Cariri region, since its Gross Domestic Product (GDP) per capita is in the order of R$ 17.725.62, the highest in the region. As civil construction takes place more intensely in cities whose economy is growing, this justifies that this municipality is a parameter for this present study.

The municipality still has a territory of 258.788 km^2, which is one of the smallest in the region, in addition to having the highest percentage of inhabitants living in urban areas, thus facilitating the transport of waste to an area eventually chosen in the municipality.

3.2 Research approaches

In a qualitative approach to waste in the study municipality, a bibliographical review was carried out using scientific articles, reports, diagnoses, overviews on solid waste from civil construction, its classification, environmental impacts and regulation of the subject.

The current legislation is very important to understand this theme, because public policies are established from it, where various pertinent information can be found, such as the definition of solid construction waste, or the classification. Its occurrence goes from the national, state and ends in municipal terms. Similarly, the public policies created by these laws will also be analyzed. The legal flow of waste was determined, covering the legal aspects foreseen from the generation of the waste to its destination.

Law 12.305/2010 was responsible for establishing the National Solid Waste Policy (NSWP) and presenting a range of guidelines in national terms. At the state level, it is possible to highlight Law No. 16.032/2016, which constitutes the State Policy on Solid Waste, and in municipal terms, Law No. 3.689/2010 deals with the Integrated Plan for the Management of Civil Construction Waste and the Management System Sustainable Development of Civil Construction Waste (CEARÁ, 2016), as detailed in Figure 09.

Other municipal laws used were: Complementary Law No. 85 of May 10, 2012, which promoted the creation of the Municipal Environmental Authority of Juazeiro do Norte (AMAJU), which is responsible for environmental management, licensing and inspection; and Decree No. 226 of January 21, 2016, which updates the provision of Law 12.305/2010 regulating the collection, storage, transport and disposal of construction waste not included in the regular collection.

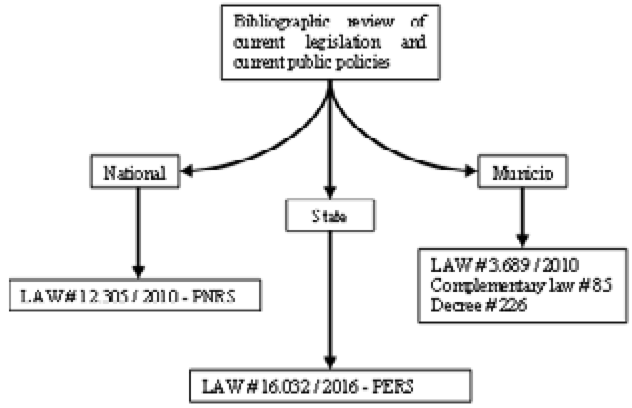

Figure 9: Bibliographic review of current legislation and policies
Source: The Searchers (2024)

Giving more focus to the municipal sphere, one documentary research was done, and later another bibliographical research using articles that had an analytical treatment. Subsequently, it was specified how the flow of civil construction waste should happen, from its generation to disposal as described in this legislation.

In a quantitative approach to civil construction waste, an annual estimate of its class A volume was calculated, based on secondary data. To calculate the estimate of the recyclable mass of CCW, seeking to understand the scenario set in the municipality, the per capita collection index of collected civil construction waste was taken from the Brazilian Association of Public Cleaning Companies and Special Waste (2020). in Brazilian municipalities it is 213.5 kg/inhabitant/year. As reported by the Brazilian Institute of Geography and Statistics (2021), the estimated population for 2021 in the municipality of Juazeiro do Norte is 276.264 thousand. Thus, the annual mass of construction and civil waste generation in Juazeiro do Norte can be estimated using Equation 1:

$$\text{Estimated total mass} = \text{Population and CDW per capita Collection index} \quad (1)$$

According to Souza (2021), the average recyclable portion of class A construction waste is 87,7%, to estimate the total recyclable mass, Equation 2 was used:

$$\text{Total estimated recyclable mass} = \text{Total estimated mass} \times \text{average recyclable mass} \quad (2)$$

However, it is common in the literature to use values in volume to quantify the size of plants. Therefore, it was necessary to use the specific density calculated by the diagnosis of waste in the municipality, to estimate the volume of recyclable waste from civil construction in the city with a value of 760 kg/m^3 (AMAJU, 2016). To estimate the total recyclable volume, Equation 3 was used.

$$\text{Estimated total recyclable volume} = \frac{\text{Total estimated recyclable mass}}{\text{Apparent density}} \quad (3)$$

Figure 10 describes the methodology for calculating the estimate of CCW in the municipality that was carried out in the methodology.

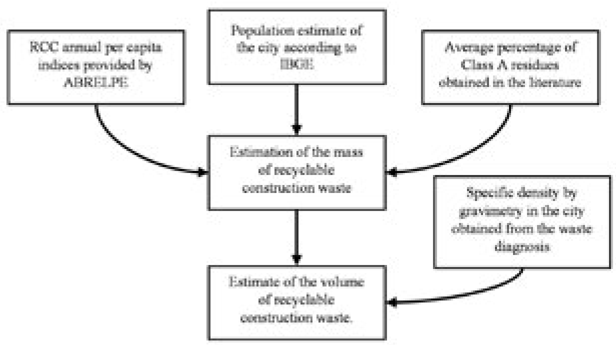

Figure 10: Calculation methodology for estimating the volume of CCW in the municipality.
Source: The researchers (2024)

4. RESULTS AND DISCUSSIONS

The environmental problems arising from the improper disposal of construction waste require society's intervention. Initiatives such as the use of a specialized recycling plant to process this product is an alternative for its reinsertion into the production chain, providing what, according to Paschoalin (2019), would reflect in the reduction of environmental impacts and in the generation of jobs and income for the population.

To enable the implementation of this experience in Juazeiro do Norte city, a survey was carried out on the legal flow of waste, observing how the recycling plant would fit into the current policy and the quantification of the volume of waste to be placed in the local context and frame the power plant that would best meet the demand.

4.1 Legal flow of construction waste

The municipality of Juazeiro do Norte has the Law nº 3.689/2010 that deals with the Integrated Plan for the Management of Civil Construction Waste and the Sustainable Management System of Civil Construction Waste. In this law, the waste generator is obliged to properly dispose of the material and is subject to a fine in case of non-compliance.

Decree No. 226 of January 21, 2016 was also used to analyze the collection, transport and disposal of construction waste. In addition, there was an analysis of Complementary Law No. 85 of May 10, 2012, which establishes the disciplinary and licensing function of AMAJU for waste management, also providing for the need to encourage recycling in the municipality (Juazeiro do Norte, 2016).

To use the disposal, the generator should hire companies specialized in the transport of waste. These are responsible for the collection and regulated transport of waste between the source and its destination, the entire flow will be registered by means of a Waste Transport Order (WTO), however, after Ordinance number 280 of June 29, 2020 of the journal union official, the necessary document is the Waste Transport Manifest (MTR) through the National Information System on Solid Waste Management (SINIR).

For Juazeiro do Norte (2016), the transported material is taken to the municipal controlled landfill or receivers, which are discharge points authorized and regulated by the Municipal Environmental Authority of Juazeiro do Norte, and reuse in private areas may also occur through the detailed study of the implications of using real estate for this purpose. Another destination foreseen by Law nº 3.689/2010, are those of receivers who are operators of registered and authorized waste management enterprises for this purpose, in addition to opening up the possibility of reuse of CCW in sanitary landfills for the purposes of internal services to the landfill. In this way, the plant would be cataloged as a receiver. Although, according to Moura (2018), Law nº 3.689/2010 does not provide any incentive for recycling construction waste in the municipality.

Legally, Complementary Law No. 85, of May 10, 2012 presumes the incentive to recycling to make the National Solid Waste Policy effective, however it does not directly expose how this incentive would occur. However, Figure 11 demonstrates the legal flow of construction waste in the city of Juazeiro do Norte in Brazil that was previously described.

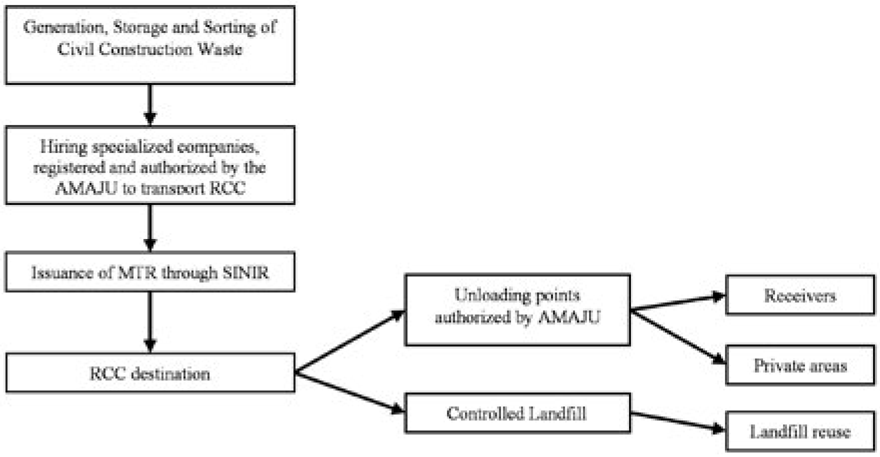

Figure 11: Fluxo legal dos resíduos de reciclagem em Juazeiro do Norte.
Source: The Searchers (2024)

Currently, the city has a controlled municipal landfill, which Moura (2018) reports to be a municipal dump in use, and two others. The first one is made by the company Construrban Logística Ambiental LTDA, with a total area of 150,000.00m^2, and the second is made by Revert - Soluções Ambientais LTDA, with an area of 455,380m^2, all three located near Horto.

According to Juazeiro do Norte (2016), 90% of the collected construction waste is sent to a controlled landfill, while 10% is sent to a landfill in private buildings and for city hall works. However, the legislation still does not directly regulate the disposal of construction waste to recycling plants.

4.2 Estimate of the volume of recyclable waste in the municipality

To study the volume of recyclable waste in the city, demographic characteristics and construction waste generation were taken to determine the volume of construction waste generated. Then, taking the average of class A waste generated in Brazil, an estimate of waste of this class generated by the municipality was made in terms of mass and volume corresponding to taking the specific density of municipal waste.

So that Equation 1 found the estimated total mass considering the population of the municipality and the per capita collection index:

Estimated total mass =
276.264 x 213,5kg/hab/year

Estimated total mass = 58.982.364Kg/
year or 58.982t/year

According to Equation 2, the total recyclable mass estimated through the estimated mass, and the average percentage of the amount of Class A waste, or recyclables:

Estimated total mass=
58.982.364 kg/year x 87,7%

Estimated total mass=
51.727.533 kg/year or 51.727 t/year

Taking the results of gravimetry in transitory points of AMAJU (2016), 19.823,75 tons of waste were found, which represented a volume of 26.076,78 m^3, thus inferring that its specific density of 760 kg/m^3, value within the specific density range reported by Vasconcelos et al. (2015), whose upper and lower limits are 916,67 and 629,33 kg/m^3.

By Equation 3, the estimated recyclable volume was obtained by the estimated total recyclable mass, and by the specific density of the municipal waste:

$$\text{Estimated total recycable volume} = \frac{51.727.533\ \text{kg/year}}{760\text{kg/m3}} = 68.062\ \text{m3/year}$$

The mass values of recyclable civil construction waste in the municipality are 51,727 ton/year, and in volume are 68,062 m^3, contrasting with the 37.27 tons that were collected by private transport companies according to data from (Juazeiro do Norte, 2016) in a previous period with a smaller population, in addition to the fact that this total only accounts for the portion transported by companies regulated by the municipality, and not the total generated.

4.3 Reflection of the scenario of Brazilian CCW recycling plants and the scenario in Juazeiro do Norte for a hypothetical recycling plant

According to ABRECON (2015), there are several experiences in force in the country of civil construction recycling plants in cities similar to or smaller than Juazeiro do Norte, representing 27% of the total number of plants.

In terms of potential nominal capacity, when analyzing the data mentioned so far, the annual volume of waste is in the order of 68,062 m^3/year or 5,666 m^3/month which, when compared to the national average, would be in the range of up to 10,000 m^3/month which corresponds to 70% of the total national nominal capacity. The municipality does not have a public policy or specific legislation to encourage the recycling of civil construction waste, also accompanying the difficulties addressed by the sector in national terms, on the other hand, state legislation provides for public-private partnerships to contribute to the development of this sector.

The municipal sanitation plan foresees, until 2021, an evaluation of the destination of civil construction waste, in addition to an evaluation and implementation of the intermunicipal consortium that deals with solid urban waste that until the present moment is still being processed by the municipal council. For Araújo (2020), the implementation of an intermunicipal consortium will not contribute to the reduction of costs in the management of urban solid waste.

operation of the enterprise would be regulated.

In this sense, public policies could contribute by offering information to guide the recycling plant, also foreseeing the possibility of a management model based on public-private partnership or inclusion of this theme in the intermunicipal consortium, thus seeking economy for the public power and efficiency in the processes. The national legislation still sets precedent for differentiated scores in public tenders in the case of the use of sustainable materials, thus being able to be inserted in the municipal context.

The results of estimating the volume of recyclable waste from civil construction demonstrate that the municipality has sufficient demand for the implementation of the plant when compared to other realities of Brazilian plants.

Subsequently, in other works, the author intends to conduct an interview with those responsible for the companies regulated by the city that carry out the transport of waste, in order to understand what would be the position of each one in the face of a new scenario generated by the recycling plant in the city, the which was unfeasible due to the short research time that was further reduced due to the pandemic period.

Another aspect that can also be addressed in future work is the receptiveness of companies and professionals towards recycled products in civil construction, understanding the inherent market aspects, and thus also enabling an economic feasibility study of a recycling plant, thus validating methodological form of its implementation.

5. CONCLUSIONS

The construction industry is historically linked to environmental degradation. The processes generate impacts on the environment and, therefore, must be disciplined.

In this scenario, the recycling plant as a management tool is essential, as it contributes to the processing of waste that would otherwise be discarded, thus resuming its economic importance. In cases of cities with treatment that is still not very advanced in the matter, as is the case of Juazeiro do Norte, this disposal can represent great damage in terms of sustainability.

The recycling plant, from the perspective of municipal legislation, would be characterized as a receiver, requiring registration and authorization to receive construction waste. On the other hand, it does not provide an in-depth treatment explaining how the implementation and

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MSL: conceptualization, data curation, formal analysis, investigation, methodology, project administration, software, supervision, validation, preview, writing - original draft, writing - review and editing.

MVOB: conceptualization, formal analysis, investigation, methodology, project administration, supervision, validation, preview, writing - review and editing.

MGSLB: conceptualization, formal analysis, investigation, methodology, project adminstration, supervision, validation, preview, writing - review and editing.

GAR: writing - review and editing.

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