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Construction & Demolition Waste and Circular Economy: The Case Study of a Brazilian City

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Abstract

Construction and demolition waste (CDW) is a significant waste stream in Brazil. It represents 38.2% of the total CDW and MSW streams. The recycling of CDW in Brazil is estimated to be at least 7.2% by weight (collected CDW) or about 15% by volume (produced CDW). Therefore, only a tiny part of CDW is returned to construction activities. On the other hand, 48.9% of the total amount of the top fifty extracted minerals in the country is sand and gravel, which is used in the national construction industry. Considering the unexplored recycling potential of CDW, part of the total amount of extracted sand and gravel could be saved. This work aims to present a diagnosis of the management of CDW in Brazil and to estimate the potential contribution to the reduction of raw material consumption through intensive recycling of this waste, using the case study of Rio de Janeiro. Among the results of this research, it was estimated that approximately 10.3% of the natural aggregates consumed could be replaced by recycled aggregates. Furthermore, it was observed that the construction industry still operates in a linear economy and that the management of CDW is largely based on disposal in sanitary landfills, mixed with municipal solid waste, and in backfilling operations. The

information and data presented have been gathered from specialized literature and direct contacts with local authorities.

Keywords
Construction and demolition waste; recycling; circular economy; Brazil

1. Introduction

The average amount of CDW and MSW (municipal solid waste) collected in Brazil between 2014 and 2018 corresponds to 44.5 and 71.9 t million tonnes per year, respectively [1-4]. If the flow of CDW is divided by the sum of the flows of MSW and CDW, the result would be 38.2%.

Among the 26 Brazilian states and the capital, São Paulo is the largest producer of CDW, followed by Minas Gerais, Rio de Janeiro and Bahia. These four states account for half of the CDW produced in the country. The metropolitan regions (e.g. São Paulo, Rio de Janeiro, Brasília, Recife and Salvador) contain around 58 million inhabitants in areas of high population density. In these regions, 30% of total CDW is produced and where most of the waste management and illegal dumping problems are found [5].

According to a survey by the Ministry of Regional Development [6-10], covering 65.6% of Brazilian municipalities and 80.8% of the Brazilian population, the average of CDW treated in recycling centers or disposed of in CDW landfills between 2014 and 2018 was 3.2 million tonnes per year. Comparing the annual averages of (a) the amounts received in recycling centers and CDW landfills and (b) the total amount of CDW collected, it was verified that at least 7.2% of CDW by weight was recycled (considering CDW landfills as future deposits of recycled aggregates). This amount is underestimated as it does not cover the entire population, municipalities, or private recycling companies.

It is estimated that 360 facilities (private and public) recycle about 15% of the produced CDW (by volume). These facilities operate at less than 50% of their production capacity. The gate fees for accepting CDW vary considerably among the Brazilian federal entities. On average, the selling price of recycled aggregates is usually lower than that of natural aggregates. Between 2017 and 2018, the consumers of recycled aggregates were 27% construction companies, 24% private individuals, 14% public entities, 12% pavement companies, and 22% others [5].

Recycled aggregates can be used in pavements (base and subbase layers), structural and non-structural concrete (precast blocks and tiles), and geotechnical and sanitary works (topographic leveling, dam, and backfilling of trenches and drains), among other things [11].

Comparing Brazil with other regions, an average of 89% of CDW was recovered in the EU-28 countries [12]. However, among these countries, the level of CDW recovery varies from more than 95% (Netherlands, Luxembourg, Belgium and Italy) or 88% (Germany) to less than 10% (Greece) [13]. Resolution 307/2002 of CONAMA (Brazilian National Environment Council) establishes guidelines, criteria and procedures for the management of CDW. It established that Brazilian municipalities must implement integrated management plans for CDW by July 2004. It also stated that CDW could no longer be disposed of in dumps, landfills, or other inappropriate locations and that reusable or recyclable CDW fractions must be reintroduced into new production processes or deposited in inert landfills [14].

Although the Resolution has led to implementing many public and private actions, the results are still not significant after almost twenty years.

In a traditional linear economic model, companies use raw materials (e.g. sand, stones and metals), which are extracted or collected and transformed into products (e.g. construction materials and equipment). These products are used until discarded as waste, with little concern for their environmental impact. This model often consumes large amounts of materials and energy.

According to the EP [15], the circular economy can be seen as a model of production and consumption in which the life cycle of products is extended. It is an economic system based mainly on reusing, repairing, refurbishing and recycling existing materials and products as much as possible. In this way, waste can be significantly reduced.

Given the low recycling rates of CDW in Brazil, it can be concluded that the national construction industry operates in a linear economic model. Due to its relevant use of resources, the construction industry's efforts are crucial for the transition to a circular economy [16-18].

This work presents a diagnosis of the management of CDW in Brazil, based on the traditional linear economic model, using the case study of Rio de Janeiro. It also presents an estimate of the potential contribution to reducing raw material consumption in the construction industry through intensive recycling of CDW. This can support efforts to transition the industry to a circular economy model, not only in Brazil but also in countries with similar conditions.

2. Material and Methods

The information and data presented were initially collected from specialized bibliographies on the topics of construction and mineral industries, CDW, waste management, and circular economy. The bibliographies consulted included relevant national, state and municipal legislation, reports from associations, publications from public authorities, academic theses and papers presented at academic events or in scientific journals.

The geographical delimitation is the city of Rio de Janeiro, which had an average population of 6.56 million inhabitants during the period analyzed and represents the second-largest Brazilian GDP. The city is the capital of the State of Rio de Janeiro (16.70 million inhabitants) [19, 20].

In addition to the bibliographic research, direct contacts were made with municipal authorities and companies through visits with interviews or emails with questions related to CDW. The main objective of these direct contacts was to access some limited information (e.g., is the municipally collected CDW sorted in landfills or just mixed with other municipal waste? Is the CDW from large producers sorted in the authorized recycling facilities or just disposed of in CDW landfills?). The questions were specific to the operational activities of construction actors and waste managers. Reports and internal documents were obtained from the Municipal Sanitation Company, which included data on the managed wastes. In the case of private companies, most of the data was obtained through bibliographic research, as most contact attempts were unanswered.

This research considers the period between 2014 and 2018. The COVID-19 pandemic affected both the bibliography and the contacts with organizations. In Brazil, less relevant data and information on waste management and the mineral industry were made available, and their publication was significantly postponed, mainly due to personnel restrictions in public offices and private companies caused by the pandemic.

In this study, only the mineral fraction of CDW was considered for the city analyzed, as it was impossible to determine how much of the other fractions (recyclables and others) came from CDW within the different types of waste collected by the municipal sanitation company.

3. Results

3.1 Diagnosis: CDW Collected and/or Disposed of by the Municipal Urban Cleaning Company

3.1.1 Free Removal (Small Generators)

According to specific legislation in Rio de Janeiro, Municipal Solid Waste (MSW) can be classified as urban solid waste (USW) or Special Solid Waste (SSW). CDW is included in both waste classes. Among the different types of waste, USW includes (a) CDW from small producers (collected by the city's sanitation company's free collection service) and (b) waste from the cleaning of public spaces [21].

A small generator is defined as one that produces up to 2 m³ per week (residential). A large generator exceeds the limit for small generators and includes non-residential generators. SSW covers exceptional waste, including CDW exceeding the limit for small producers, among various wastes [22].

It is estimated that about 70% by volume of the generated CDW comes from renovations and informal constructions (self-constructions) in Brazil [23], which are often classified as small generators according to the municipal legislation of Rio de Janeiro [24]. CDW from small generators in the city is collected by the municipal company's free collection service and sent to one of the five municipal waste treatment stations (WTS). At these WTS, CDW is mixed with other waste and sent to the Seropédica landfill as municipal solid waste.

3.1.2 CDW of Large Generators Received by the Municipal Cleaning Company and Public Waste

The large producers are the only ones to separate CDW under the specific legislation [25]. Their CDW is sent to six recycling companies (quarries that need to fill old mining pits, CDW landfills, and temporary storage areas) that are authorized in the municipality to receive class A CDW (mineral inert materials). These residues are the responsibility of their producers (collection, transport and destination) [24].

Large producers can also send their MSW to two MSW landfills operated by the municipal cleaning company. The MSW received at the Gericinó landfill is briefly screened (recyclables and waste) and the class A fraction is used both to pave the internal accesses and as a covering material for the closure of the MSW landfill. The municipal cleaning company collects public waste from street cleaning and follows the same route as a free collection (WTS and then Seropédica landfill) [25].

<u>Alternatives for the Disposal of CDW.</u> Figure 1 describes the options for the disposal of CDW in the municipality. In addition to the alternatives for small and large generators, the option of illegal disposal is also presented, which should not be pursued. However, it can still be found in the cleaning of public spaces.

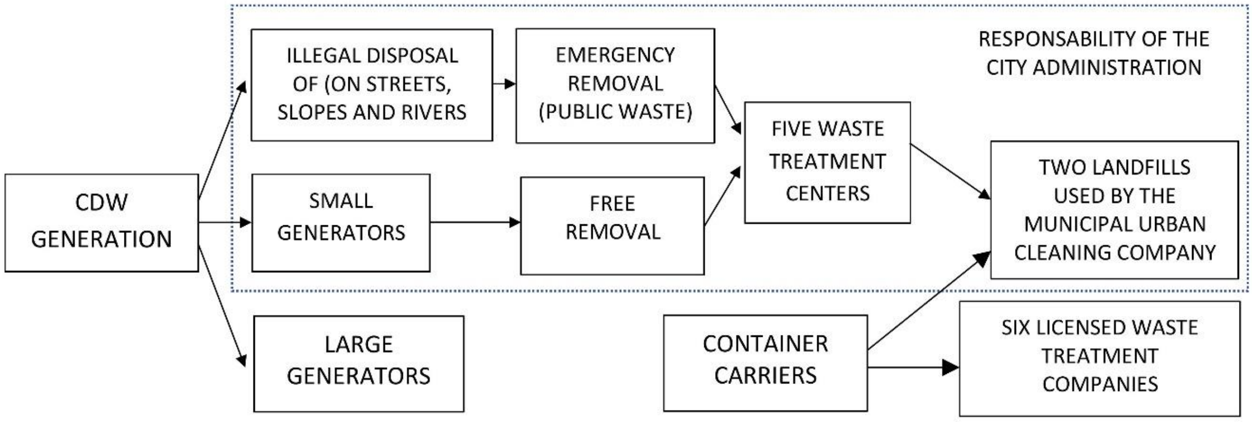

Figure 1 CDW disposal alternatives in the city of Rio de Janeiro.

Gravimetric Composition. The gravimetric compositions of free removal, public waste and large generators of CDW disposed of in licensed landfills used by the municipal cleaning company are shown in Table 1. The percentages of the mineral fractions contained in free collection, public waste and large generators are respectively 92.48%, 66.13% and 94.94% respectively.

Table 1 Gravimetric compositions of CDW in the city of Rio de Janeiro [26].

COMPONENTS		FREE REMOVAL	PUBLIC WASTE	CDW LARGE GENERATORS
		(%) in weight		
MINERAL FRACTION	Concrete/Stone	35.97	10.0	37.35
	Plaster	0.02	3.11	0.41
	Brick	4.15	5.25	17.01
	Clay/Ceramics	8.06	17.10	0.00
	Fine aggregate/Rubble	43.64	30.68	19.72
	Asbestos tile	0.18	0.18	20.45
	Marble	0.45	-	-
	Total Minerals	92.48	66.13	94.95
RECY-CABLES	Paper, plastic, glass, and metal	5.16	12.93	1.48
OTHERS	Wood, cloth, rubber, organic and miscellaneous	2.36	20.94	3.57
TOTAL		100.00	100.00	100.00
Specific weight (kg m^{-3})		1007.0	234.0	1297.0

Quantities Collected/Disposed of CDW by the Municipal Urban Cleaning Company. According to Table 2, the annual average of CDW managed between 2014 and 2018 was 0.83 million tonnes per year. Considering that the average of all waste handled by the company during this period was 3.31 million tonnes per year, 25.2% (by weight) was CDW [25].

Table 2 CDW quantities managed by the municipal cleaning company [25].

YEAR	FREE REMOVAL		PUBLIC WASTE		CDW LARGE GENERATORS		T.M. (tonnes)
	T.M. (tonnes)	M.F. 92.50%	T.M. (tonnes)	M.F. 66.13%	T.M. (tonnes)	M.F. 94.95%	
2014	70549.00	65257.83	1033623.00	683534.89	229202.00	217627.30	966420.01
2015	68634.00	63486.45	1060101.00	701044.79	217079.00	206116.51	970647.75
2016	65715.00	60786.38	1007808.00	666463.43	104285.00	99018.61	826268.41
2017	57849.00	53510.33	900733.00	595654.73	74709.00	70936.20	720101.25
2018	68645.18	63496.79	836212.00	552987.00	66225.00	62880.64	679364.42
AVERAGE	66278.43	61307.55	967695.00	639937.00	138300.00	131315.85	832560.40

T.M.: Total Managed; M.F.: Mineral Fraction.

Licensed CDW Recycling Centres. Large CDW producers rarely use the Gericinó or Seropédica landfills because the average distance is more than 50 km (one-way). Most of the recycling companies are quarries that need to fill old mining pits. A significant part of the CDW these companies receive is used only to fill the pits and serves as a deposit for the future needs of recycled aggregates [25].

Approximately 2.80 million tonnes of CDW were received annually in six licensed recycling facilities. CDW landfills were associated with ASSAERJ (Association of Construction Waste Landfills of the State of Rio de Janeiro), located in the analyzed city. The mineral fraction was approximately 70% (1.96 million tonnes) [27].

Considering only the mineral fraction, the sum of the amount managed by large CDW generators (1.96 million tonnes) and the amount of CDW managed by the Municipal Urban Cleaning Company (0.83 million tonnes) results in 2.79 million tonnes. If this is divided by the sum of the flows of MSW (from large producers) and municipal solid waste (the MSW from small producers is already included in the MSW), the result would be 53.0%.

According to ABRECON [11], the composition of the CDW that arrives at the recycling facilities is a mixture of grey and red materials (69%), predominantly grey material (19%), red material (11%), and predominantly concrete (1%). Due to these mixtures, just around 70% of the mineral fraction could be recycled (1.37 million tonnes) [28].

The six recycling facilities have charged gate fees. Depending on the stage of construction, the collected CDW arrives at the facilities with a greater or lesser potential for recycling. CDW removed from a construction site of a project in the structural phase can possibly be fully recycled. However, CDW removed in the excavation phase can have no use as recycled aggregate [27].

Considering that just 70% of the mineral fraction of CDW from small generators can be recycled (70% of 0.83 million tonnes = 0.58 million tonnes), the sum of the potential recyclable CDW amounts of small generators and large generators (1.37 million tonnes) in the city results in 1.95 million tonnes.

Illegal Disposals. Between 2014 and 2018, the collected CDW was estimated to be around 2.79 million tonnes yearly. However, this is the collected CDW. There is an additional amount of CDW, which would be the difference between generated and collected CDW. There is no precise information on the destination of this uncollected CDW. Illegal dumping is often found in inappropriate places such as streets, open spaces, hillsides, and riverbeds.

Part of this CDW is correctively collected by the municipal company, which costs two to three times more than everyday waste collection [25, 29]. Another part is incorporated into the city's landscape. As a result of the city's slum process, with its illegal dumping of CDW and unbridled construction, the city council must bear the costs of disaster risk prevention and mitigation, in addition to the costs of corrective waste collection. Approximately 22% of the city's population lives in slums [20].

Part of the public waste collected by the municipal cleaning company is the illegal disposal of CDW. Between 2014 and 2018, the annual average of materials in public waste with a composition like CDW in the city of Rio de Janeiro was 0.64 million tonnes, representing 76.9% of the total amount of CDW or 18.7% of the total amount of waste managed by the company [25].

<u>CDW: Material Flow Diagram.</u> In Figure 2, CDW flows from free removal and public waste to the five WTCs and then to the Seropédica landfill are shown. Also presented are the flows from private large generators, the Gericinó landfill, and six licensed private CDW landfills.

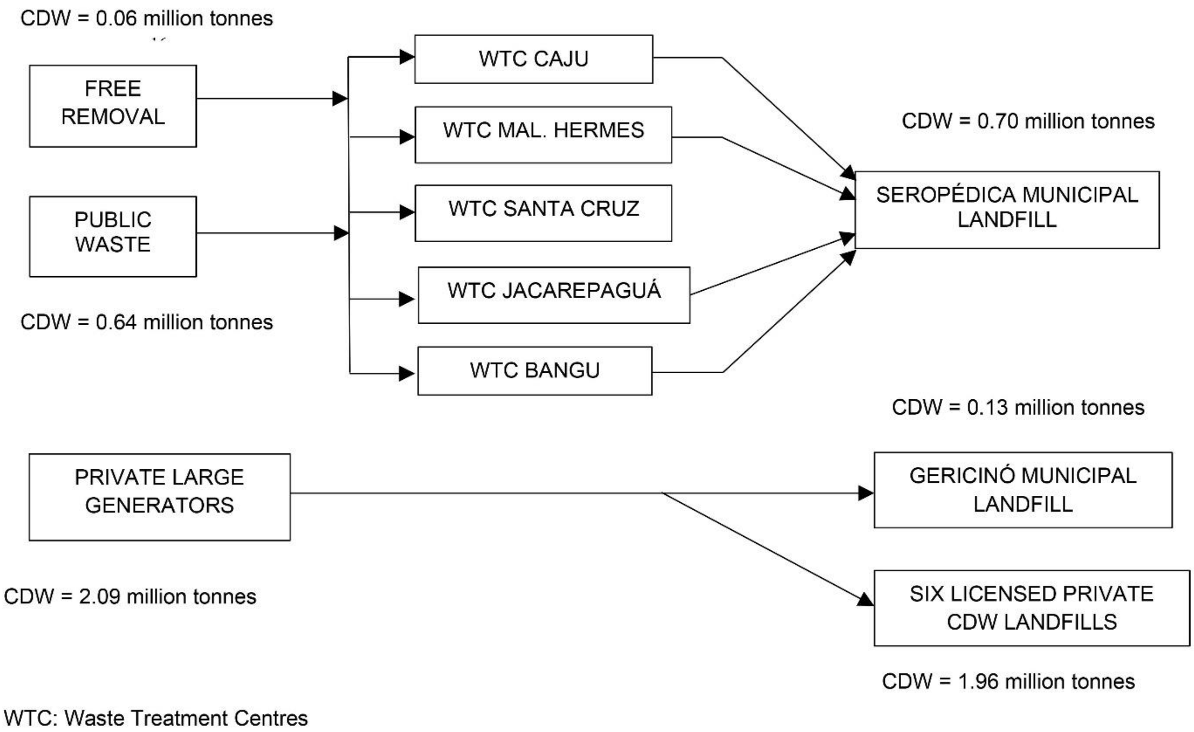

Figure 2 Material Flows of CDW from free removal, public waste, and large generators (per year).

<u>End-of-Life Phase of CDW in the Municipality of Rio de Janeiro.</u> Since the closure of the Jardim Gramacho landfill in 2012 (at the time the largest sanitary landfill in Latin America), the municipal company has been disposing of CDW in two ways: (a) the reserve area of the Gericinó landfill and used in the maintenance services of this landfill; and (b) transported and disposed of in the Seropédica landfill (mixed with USW and SSW) [25].

In 2013, the amount of MSW disposed at the Seropédica landfill was 2.95 million (95.8% from the city of Rio de Janeiro and 4.2% from other cities) [6]. The consumption of gravel in this landfill was approximately 0.21 million tonnes [28]. Thus, 71.2 kg of natural aggregates were required for each tonne of waste disposed of. For each tonne of municipal solid waste disposed in Rio de Janeiro, 244 kg were mineral materials. These mineral fractions (natural aggregates and CDW) could have more noble uses, such as returning to the construction industry and saving natural resources instead of taking up space and reducing the life cycle of the sanitary landfill.

Natural aggregates are needed in sanitary landfills for cell sealing systems, leachate drainage systems, gas drainage systems, cover layers, rainwater drainage systems and vehicle access.

CDW Recycling in the City. In the city, CDW managed by the municipal cleaning company is not recycled but (a) mixed with municipal waste in the Seropédica landfill or (b) used as a cover for the Gericinó landfill (which is in the process of being closed). The licensed mining companies have used almost all the CDW from the large producers to backfill the old mines, which can be explored for future needs of recycled aggregates (backfilling).

CDW has proven economically viable for the final covering of sanitary landfills (drainage and gas collection layers), showing a 20% reduction in execution costs compared to conventional materials (crushed gravel 0 and 4) [30]. This use was carried out in the Gericinó landfill [25].

According to Pereira [31], the Seropédica Landfill uses the most advanced technology to construct the landfill, unprecedented in Latin America. However, no comparison was made between the technology used for landfills in Brazil and other countries outside Latin America, such as Germany, Japan, and the USA. This landfill is in a neighboring municipality, and the average distance between the five WTC and the landfill is 55 km, which means 110 km for waste transport (round trip). It would therefore be essential to reduce the amount of waste transported: (a) to avoid air pollution (greenhouse gases such as CO_2 and N_2O); (b) to save on transport and gate fees; (c) to extend the life of the landfill, among other reasons.

3.2 Construction Industry in Brazil

3.2.1 Consumption of Resources in the Construction Industry

Between 2000 and 2018, the Brazilian construction industry generated an average of 7.13 million jobs per year (7.53% of the economically active population) and accounted for 5.35% of the country's Gross Value Added (GVA). The sector's composition is construction (52.5%), materials (13.0%), materials trade (11.3%), services (5.9%), machinery and equipment (0.9%), and other (16.7%) [32].

Table 3 provides data on the fifty most crucial mineral substances processed in Brazil between 2014 and 2018. These substances include cobalt, aluminum, chromium, tin, iron, graphite, lithium, manganese, and niobium. According to the averages of these data, 48.8% (575.80 million tonnes) of the total amount of the fifty main mineral substances extracted in Brazil (1175.75 million tonnes) is sand and gravel used in the national construction industry.

Table 3 Totals of the main mineral processed substances in Brazil between 2014 and 2018 (in million tonnes) [33-36].

SUBSTANCES		2014	2015	2016	2017	2018	AVERAGE
A	50 main mineral substances	1340.45	1257.50	1177.95	1045.41	1057.45	1175.75
B	Construction sand + gravel	700.60	610.11	548.43	499.80	516.80	575.15
	B/A	52.3%	48.5%	46.6%	47.8%	48.9%	48.8%

According to DNPM [36], the markets for natural aggregates are essentially regional, as they have a low unit value, and freight prices affect the final value. Table 4 lists the main consumers of natural aggregates.

Table 4 Consumers of natural aggregates [37].

CONSUMERS	AGGREGATES (in %)	
	SAND	GRAVEL
Mortar manufacturer	35	-
Concrete mix companies	20	32
Construction companies	15	24
Prefabricated product manufacturers	10	14
Dealers/Stores	10	10
Asphalt Pavers/Plants (Base/Sub-Base)	5	9
Public agencies	3	7
Others	2	4
TOTAL	100	100

3.2.2 Consumption of Mineral Substances in the Municipality of Rio de Janeiro

The study's geographical delimitation was the city of Rio de Janeiro, which had an average population of 6.56 million inhabitants between 2014 and 2018. Table 5 presents data on the production of the construction industry's main inputs in Rio de Janeiro (average population 16.70 million) [20]. In the absence of specific data for the city, an estimate has been made based on the ratio between the population of the state and that of the city.

Table 5 Production of the aggregates for the construction industry, in the analysed city (Adapted from ANEPAC [33, 34, 37], DNPM [35, 36], and IBGE [20]).

Population/Substances	YEARS					AVERAGE
	2014	2015	2016	2017	2018	
POPULATION (10^6 Inh.)						
State Rio de Janeiro	16.46	16.55	16.64	16.71	17.16	16.70
City of Rio de Janeiro	6.45	6.47	6.55	6.63	6.70	6.56
AGGREGATES (in million tonnes)						
Construction Sand						
State Rio de Janeiro	27.42	30.85	23.42	21.94	22.69	25.26

City of Rio de Janeiro	10.75	12.06	9.21	8.71	10.36	10.22
Gravel						
State Rio de Janeiro	25.02	24.81	23.64	19.74	20.41	22.72
City of Rio de Janeiro	9.13	9.12	9.31	7.83	7.97	8.67
TOTAL AGGREGATES (in million tonnes)						
State Rio de Janeiro	52.44	55.66	47.06	41.68	43.10	47.99
City of Rio de Janeiro	19.88	21.18	18.52	16.54	18.33	18.89

As already calculated, between 2014 and 2018, the sum of potentially recyclable CDW in the city of Rio de Janeiro was 1.95 million tonnes. Dividing this sum by the total amount of sand and gravel (18.89 million tonnes—Table 5) gives 10.3%.

CDW has the potential to replace sand, crushed stone, and gravel [36]. Pavement, in the form of crushed gravel or even in mixtures of recycled aggregate with soil, is the simplest form of recycled aggregate, requiring less technology and consequently resulting in lower recycling costs. This process allows the use of all mineral components of the CDW without sorting and energy savings in the crushing process [11, 27].

In 2011, the City of Rio de Janeiro issued a decree requiring recycled aggregates in some types of works in municipal construction projects (Table 6). This decree should provide an additional incentive to increase demand for recycled aggregates. However, using recycled aggregates is not mandatory if it is not economically or technically feasible, as is the case for emergency works [38].

Table 6 Examples of alternatives for the use of recycled aggregate [38].

TYPE OF WORK	ALTERNATIVES
Infra-Structure	Primary coating of roads (gravel or layers of reinforcement of subgrade, sub-base and base of pavements in parking lots and public roads); Sidewalks; Artifacts (seal blocks, precast blocks parts for floor coverings, curbs, gutters, tenors, gutters, tubes, and wall plates); Urban drainage (basements, leveling of the bottoms of ditch, drains, or mortar).
Buildings	Non-structural concrete (walls, sidewalks, counter floors, filling and sealing masonry); Non-structural mortars; Construction parts (seal blocks, precast block parts for floor coverings, curbs, gutters, tenors, gutters, pipes, and wall plates).

According to the municipal legislation, the major producers must draw up CDW management plans that promote the possibility of recycling CDW on construction sites, in licensed recycling centers, and in CDW landfills [24]. Due to the high population density in some parts of the city and the small size of urban plots, it is not easy to promote separation and recycling at construction sites. In 2018, there was only one mobile CDW recycling center in the city [25]. Therefore, the use of reuse and recycling on site as an alternative has not been explored meaningfully.

The household waste collection fee funds part of the MSW collection service. The costs not covered by MSW and other services, mainly the collection, transfer and disposal of public waste, are funded by other municipal taxes, such as the Urban Property and Land Tax [28]. In the period analyzed in this study, the municipal urban cleaning company had an expenditure of about 7.6% of the municipal budget [6-10]. There are proposals to introduce new alternatives for collecting and recycling CDW based on partnerships with the private sector. However, they have not yet been implemented for political and economic reasons [25].

4. Discussion

4.1 Circular Economy and Potentials to Increase the Consumption of Recycled Aggregates

In Brazil, at least 7.2% (by weight) or 15% (by volume) of the collected CDW was recycled during the period analyzed. Most of the CDW was disposed of in municipal solid waste landfills, a situation also found in some Latin American countries such as Bolivia, Mexico and Peru [39].

These data suggest that the Brazilian construction industry still operates in a linear economy, where the final treatment of CDW is largely based on disposal in sanitary landfills (mixed with MSW), backfilling of old quarries or CDW landfills.

In Rio de Janeiro, the mineral fraction of CDW managed by the municipal company represents 25.2% of the MSW flow [25]. All the CDW managed by the municipal company is not recycled but disposed of in landfills. The licensed mining companies (which receive almost all the CDW from large producers) have used a significant part of the CDW received to fill the old mines (backfilling).

If only the mineral fraction is considered, the sum of MSW managed by large producers (1.96 million tonnes) and the amount of MSW managed by the municipal cleaning company (0.83 million tonnes) would be 2.80 million tonnes. Dividing this by the sum of MSW and CDW from large producers (MSW already includes the CDW collected by the municipal cleaning company) (5.27 million tonnes) would give 53.0%.

Dividing the collected amount of EDW by the population of the city of Rio de Janeiro gives 425.6 kg inh-1. According to ABRECON [5], the amount of CDW produced in Brazil is estimated to be around 500 kg/inhabitant. This estimate does not include excavated soil. Based on these data, it could be calculated that about 0.49 million tonnes of CDW are not collected in the city each year (about 14.9% of the produced CDW).

The reasons for the low percentage of CDW recycling include [29, 40]: a) the economic infeasibility of recycling CDW when the business model is poorly planned; b) the construction practices of landfills in Brazil; c) the low prices of natural aggregates; d) the lack of reliable data on Brazilian waste management; e) the lack of consumption of recycled aggregates by local authorities; and f) little experience with the use of CDW standards.

In Rio de Janeiro, geographical and social aspects (lowland areas and the intense process of slum upgrading in the city) make it even more challenging to implement circular economy measures for CDW.

It has been estimated that recycled aggregates could replace 10.3% of the sand and gravel consumed in the city. This can be achieved without much difficulty, as 20% of sand consumers and 33% of gravel consumers are pavement and construction companies [37]. Pavement is the simplest form of recycled aggregate, requiring less technology, which consequently results in lower recycling costs [11, 27].

Construction companies can also use recycled aggregates in infrastructure and building works (Table 6) [38]. Between 2017 and 2018, pavement and construction companies consumed 39% of recycled aggregates in Brazil [5].

Even if all the CDW produced in Brazil were recycled (about 100 million per year), this amount would not cover more than 20% of the demand for natural aggregates [5]. However, recycled aggregates with good quality and lower logistic costs (CDW processed close to the sources of production and the consumer market) could be a sustainable alternative to natural aggregates, complementing the construction materials market.

In addition to these aspects, recycling CDW can create new jobs and reduce costs by preventing and mitigating disaster risks and costs associated with corrective waste management. The construction industry would also contribute more to many Sustainable Development Goals (SDGs), such as clean water and sanitation, sustainable cities and communities, responsible consumption and production, and climate action.

The eco-efficient use of resources can strongly support the transition to a circular economy model. Businesses can reap many benefits from this transition process [41, 42].

CDW recycling is also important for construction companies seeking sustainable building certificates (e.g., LEED—Leadership in Energy and Environmental Design). For such certification, it is necessary to show good results in terms of CDW management on construction sites and in buildings, such as reusing materials and using recycled content in new building production processes.

5. Conclusion

CDW is a significant waste stream in Brazil and most of it has been disposed of in MSW landfills. In Rio de Janeiro, CDW managed by the municipal cleaning company represents at least 25.2% of total MSW and almost all CDW has also been disposed of in a sanitary landfill. This landfill is in a neighboring municipality, and the average distance of waste transport to it is 110 km (round trip). For every tonne of MSW disposed of, 244 kg of the mineral fraction of CDW was disposed of, and natural aggregates were additionally used. Therefore, it would be essential to reduce the amount of waste transported, avoid global warming and air pollution (greenhouse gases such as CO_2 and N_2O) caused by transport, save on transport costs and gate fees, and extend the life of the landfill.

CDW recycling can also reduce the consumption of natural aggregates, create jobs in the recycling industry, and reduce costs associated with disaster risk prevention and corrective waste collection.

Nearly half of the top fifty mined minerals in Brazil are sand and gravel used by the national construction industry. CDW has the potential to replace sand, crushed stone, and gravel. Pavement is the simplest way to use recycled aggregate. In Rio de Janeiro, approximately 10.3% of the natural aggregates consumed could be replaced with recycled aggregates.

The Brazilian construction industry still operates in a linear economy, where CDW recovery is largely based on disposal in sanitary landfills, mixed with municipal solid waste, and in backfill operations. An uncollected amount is also illegally dumped in inappropriate places. If all generated CDW were collected, more natural aggregates could be substituted.

The municipality of Rio de Janeiro spent about 7.6% of its budget on urban cleaning services. Part of this is due to the cost of CDW management. Illegal dumping of CDW can also pose potential disaster risks and environmental and health risks to the surrounding population. The risk of flooding and landslides increases, indirectly increasing municipal costs for urban cleaning and infrastructure works. For political and economic reasons, proposals by the municipal sanitation company to improve the management of CDW in Rio de Janeiro through public-private partnerships have not yet been implemented.

The main recommendations to increase CDW recycling in Brazil would be better control of illegal dumping, provision of CDW collection points, implementation of public-private partnerships (enabling the establishment of recycling centers and specific collection for CDW), and tax reduction policies for recycled products.

Author Contributions

Kátia R. A. Nunes: Conceptualization, writing – original draft, writing – review and editing. Cláudio F. Mahler: Conceptualization and review. All authors have read and approved the published version of the manuscript.

Competing Interests

The authors have declared that no competing interests exist.

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