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Actions Aimed at Reducing, Reusing, and Recycling Waste in Building Construction

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RESUMO

Being responsible for the generation of more than 50% of urban solid waste poses incessant challenges to the construction industry. Commonly called rubble, civil construction waste (CCW) causes major environmental impacts when an order of priority of actions in forwarding the management of discarded materials is not observed. It is a situation that requires the application of practices that aim to reduce, reuse and recycle (3R's) the waste generated by civil construction at construction sites. This work aims to present good practice guidelines, through an action plan, for the reduction, reuse and recycling of RCC in construction sites. The methodology included a systematic review of scientific articles considering the indications of the PRISMA method (Preferred Reporting Items for Systematic reviews and Meta-Analyses). It also included a field research, with seven case studies, with five works located in the city of Recife and two works located in the city of Caruaru, both in the State of Pernambuco, in which we sought to investigate waste management in the works and the actions reduction, reuse and recycling carried out at construction sites. The results showed the identification of reduction actions applied to the management of services, materials and equipment used in the execution of works and good practices of reuse and recycling for the main construction materials, such as: concrete, wood, plastic, plaster and metal. The main contribution of this work was to identify and describe good practice guidelines for a better management of civil construction waste regarding the 3R's.

PALAVRAS-CHAVE: Redução. Reutilização. Reciclagem

1 CONTEXTUALIZATION

Despite being economically fundamental to the country, the civil construction industry accounts for the use of up to 50% of the total natural resources consumed by society and for the generation of up to 70% of the urban solid residues (SILVA; SANTOS; KLAMT, 2015; DUARTE; MACHADO; PASCHOALIN FILHO, 2019).

Regarding the waste produced by civil construction, ABRELPE (2021) reported that in its 2020 sector survey, about 47 million CCWs were collected by municipalities, representing an increase of 5.5% and an amount of 221.2 kg per inhabitant/year. According to ABRECON (2020), 70% of this waste could be reused in the construction process. However, the country recycles only 16% of the total generated because more than half of the CCWs are disposed of clandestinely and irregularly in Brazil. Therefore, construction companies' practices of reducing, reusing, and recycling (3Rs) are effective alternatives for the environmentally appropriate management of civil construction waste (CCW) without disregarding the need to properly dispose of waste, refuse, and rethink processes. It is important to develop a system for effective environmental management (VILLORIA et al. 2014). Thus, this article aims to present guidelines for best practices in reducing, reusing, and recycling CCW on construction sites.

Dondo (2017) advocates the 3Rs principle (reducing, reusing, and recycling) as primordial for sustainable management, in which the author argues that correlating these actions in an integrated manner constitutes the environmentally sound structure of waste management and that adopting control, monitoring, and enforcement measures are part of related activities of solid waste management, highlighting the need to minimize environmental impacts through the application of these principles.

In this context, the waste management tools have aroused the construction companies' interest in the technical environment and in academia since the adoption of management practices based on principles consistent with the concept of sustainability is essential for reducing the environmental impact caused by the sector r (CASTRO, 2018; DUARTE; MACHADO; PASCHOALIN FILHO, 2019).

2 METHODOLOGY

Exploratory research aims to provide greater familiarity with the problem, making it more explicit and enabling the construction of hypotheses as well as improving ideas and discovering institutions. This research classification involves a bibliographic survey, interviews with people who have practical experience with the topic, and the analysis of examples that allow a better understanding (GIL, 2017). The research in this work is therefore of the exploratory type, and the methodological procedure used consisted of the steps presented in Chart 1.

Chart 1: Stages of the methodology used

Stages	Characteristics
Stage 1	A literature review on the theme was carried out using the PRISMA systematic review method through the CAPES Periodical Portal and Google Scholar, researching the main waste reduction, reuse, and recycling measures in building construction.
Stage 2	Selection of the works chosen from the research database of Lins (2020), whose study analyzed information from Recife's waste database, consulted in the physical processes of EMLURB (Maintenance and Urban Cleaning Autarchy of Recife), from 2018 to 2020. The indicators were selected according to the following criteria: waste generated in the construction stage; building use as residential; and building typology as a group of apartments. Then, a ranking was prepared with the construction companies with the lowest waste generation indicators, and five of them were the targets of the field research (Works A, B1, B2, C, and F). Certified works were sought to obtain potential actions focused on applying the 3Rs in building construction; thus, two companies provided two works for study in the city of Caruaru in the interior of Pernambuco (Works D and E).
Stage 3	Elaboration of the checklist with the necessary information to be applied in the field of research. This checklist was developed through the literature review and was refined through the field research at site A, where the following data were collected: construction companies (registration, year of foundation, and size); respondents (registration, education, and sector); works (registration, years of beginning and end, typology, number of floors, built area, amount of waste/m², and previous waste study); CCWMP - Civil Construction Waste Management Plan stages (data on the characterization, segregation, conditioning, transport, and destination of the CCW); production control of materials and services at the construction sites; and application of the 3Rs (reduction, reuse, and recycling) at the construction sites.
Stage 4	A case study was conducted at the seven selected construction sites, and the application of a checklist conducted between April and June 2021. The checklist focused on investigating the reduction, reuse, and recycling practices that were carried out at the construction sites. In addition, photos were taken to complement the case study.

Source: Authors.

3 RESULTS

The case studies provided knowledge of other practices related to the 3Rs. The information was collected by applying the checklist at the construction sites, and the images were captured during visits to the construction sites. Chart 2 shows the characteristics of the studied works.

Chart 2: Characteristics of the works studied

Works	Construction data	Place
A	A 20-story residential building with a total constructed area of 7,630.85m2. It had ISO 9001 quality certification and ISO 14001 environmental certification.	RECIFE
B1	A 35-story residential building with 13,178.49m² of total constructed area. It had ISO 9001 and PBQP-H (Brazilian Habitat Quality and Productivity Program) quality certifications.	RECIFE
B2	A 23-story residential building with 7881.18m² of total constructed area. It has ISO 9001 and PBQP-H quality certifications.	RECIFE
C	A 14-story residential building with 3066.8m² of total constructed area. It has ISO 9001 and PBQP-H quality certifications.	RECIFE
D	A residential condominium of houses composed of 2,469 houses with 114,314.07m² of total built area. It has ISO 9001 and PBQP-H quality certifications.	CARUARU
E	A 17-story residential building with 699.20m² of total constructed area. It had the ISO 9001 quality certification and the Casa Azul + Caixa environmental certification with gold classification.	CARUARU
F	A 13-story residential building with 3380.52 m² of total constructed area. It has ISO 9001 quality certification.	RECIFE

Source: Authors.

The analysis of the results was divided into four parts: a) analysis of reduction actions; b) analysis of reuse actions; c) analysis of recycling actions; and d) guidelines.

3.1 Analysis of reduction actions

The analysis of the CCW reducing actions presented measures and details of each activity performed at the construction sites that provided waste reduction, such as: the care with the flow and storage of materials; the use of correct transportation equipment for waste and materials; the careful choice of materials for construction works with the choice of materials that provided low waste generation; the choice of rationalized and/or innovative building systems in construction works; the application of waste management measures, such as environmental education ministered at the construction sites for the production teams; the application of reverse logistics of materials; and selective demolition.

Concerning the reduction actions, the careful flow and storage of materials proved to be a concern to the entrepreneurs since all the construction sites presented lean stocks. This measure facilitated the disposition of materials by obeying the entry and exit orders, thus avoiding overuse by workers and damage to materials due to bad storage

It was observed that the transportation of waste and materials on all the construction sites was done with the appropriate equipment for each specific situation. The most commonly used were the following: the handcarts (100%) and wheel barrows (71%) for transporting waste and fall collection tubes (43%); the bobcat was used only in the horizontal construction site due to the need for long distance transport; the use of the pallet jack (100%) for transporting palletized materials such as mortar and ceramic blocks; aided by vertical transport such as cranes, hoists, and freight elevators (except in the horizontal construction site that did not make use of this equipment). According to Silva, Santos, and Klamt (2015), the correct use of transportation equipment is of utmost importance to avoid material waste.

The actions applied to the choice of materials were highlighted on all the construction sites. through the use of materials such as: cut and bent steel, industrialized mortar, recycled materials, PEX pipes and precast materials; 86% construction sites used cut and folded steel, and 14% used cut, folded, and assembled steel. These two actions avoided steel leftovers on the construction sites. Industrialized ready-mix mortar was also used in 71% of the building sites, and 14% used ready-to-use mortar (stabilized mortar). Both actions provided a reduction of mortar waste by providing a longer time of application (AKBUULUT; GURER, 2007; BRAGANÇA; PORTELLA; TREVISOL, 2015), which, in the case of stabilized mortar, can reach 24 hours according to the studied project. The horizontal building work used conventional mortar since the use of industrialized mortar was under study to be used by it.

The use of recycled materials for execution stood out in 71% of the works, with the use of ecological recycled material sheets for siding, temporary buildings on construction sites, and the floor of protection trays. Plates of reforested wood were also used to close the shafts. Products using recycled waste in their manufacture deserve to choose ecological materials in construction because they contribute to reducing the environmental burden of the disposal of this waste (WANG; LI; TAM, 2015; TAM; HAO, 2016).

The use of PEX pipes (flexible pipes made of reticulated polyethylene) in 14% of the construction sites for the installation of cold and hot water and kitchen gas was also noteworthy. As this material is flexible, it generates less waste and requires fewer connections than PVC pipes. Precast concrete slab walls were also significantly used in 28% of the works, and precast concrete pillars for the installation of water tanks in 14%, which, as they are parts produced within a manufacturing park, were transported according to the needs of the works and arrived ready for assembly, providing benefits such as speed of execution and waste reduction.

Rationalized construction was present in all the construction sites through rationalized masonry projects (85%) with the application of blocks vertically in places for the passage of installations, prior execution planning, production project, trained labor, and the use of a family of compensating blocks to avoid the breakage of blocks during execution, thus contributing to reducing material waste and improving the cleanliness and organization of the construction site. Cast-in-place concrete walls (15%) with internal plasterboard partitions were also used. According to Gehbauer (2004) and ABD (2018), rationalized systems increase productivity and competitiveness in construction and reduce waste and waste volumes generated at construction sites, providing gains for the environment.

The construction works also demonstrated the importance of material production on the construction site as a means of reducing CCW (100%), avoiding overproduction through the planning of each stage of execution. Another reducing measure was the use of pre-defined boxes made with wood waste to be used in the structure during concreting and to serve as a subsequent passage for various installations, thus avoiding drilling and cutting the structure, which would generate concrete waste.

As a waste management measure, environmental education was provided by the companies' quality engineering team in 100% of the studied construction sites, aiming to make the production teams (workers, foremen, technicians, trainees, and production managers) aware of the importance of environmental management for a clean and organized construction site.

Silva and Pertel (2020) mention that the environmental education given to the workers at the construction sites ensures a greater prevention of failures in the planning of the stages of segregation, packaging, and transport of waste, and contributes to social gain since the use of the knowledge acquired is not restricted to the work environment and can be applied in people's day-to-day lives.

In 71% of the studied works, reverse logistics was used with the return to material supply companies, such as cement bags (57%), mortar bags (57%), and damaged granite pieces (14%). According to Housseini et al. (2015) and Santos and Marchesini (2018), reverse logistics provides benefits to construction companies, such as the possibility of obtaining more profits with the reduction of disposal costs and the possibility of marketing the waste, in addition to legal aspects and an improved image with consumers.

Selective demolition occurred in 43% of the construction sites. Gangolells et al. (2014) consider it possible to reduce waste on construction sites by introducing the deconstruction or selective demolition system, which seeks to project the disassembly of the building in the reverse system of the construction to enable the recovery of the construction's materials and components, promoting their reuse and recycling.

In 29% of the works, innovative building systems were used, such as ventilated facades on site B2 and incorporated metal formwork and earth-probe pile without adding material on site C. These three systems resulted in cleaner systems and leaner executions with minimal waste generation (Freitas et al., 2015; BEZERRA, 2018).

For Mendes, Morais, and Brandão (2016) and Bezerra (2018), in ventilated facades, the environmental impact is much lower than that of traditional cladding because they have modulated structures that are fixed to the structure by means of bolts, screws, and light metal structures, not requiring the execution of all the steps involved in conventional tile facades, such as roughcasting and plastering.

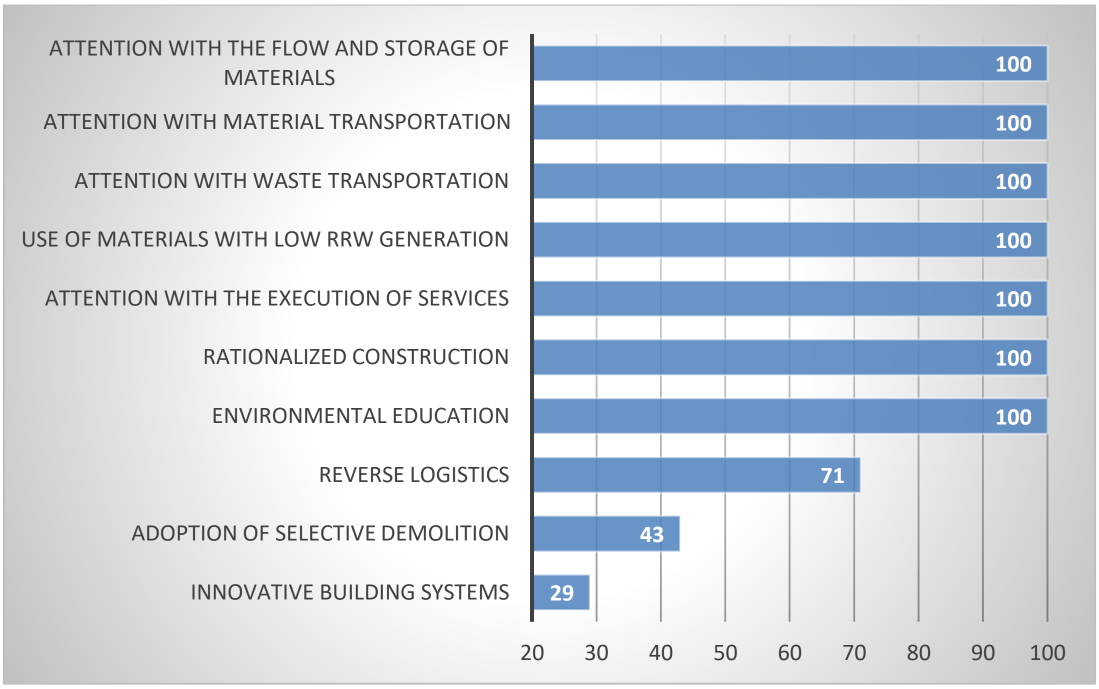
Embedded metal formworks are comprised of a ribbed metal structure with holes where they are assembled together with frames, which are incorporated into them, becoming part of the structure; their advantage is the non-reuse of the material since they do not have to be unformed and do not require storage and disposal of used parts, as happens with wood formwork that becomes waste after construction, ensuring the sustainability of the product (FREITAS et al., 2015).

Earth-probe pile without material addition consists of a soil compaction method that uses a vibrator and a tube of a specific diameter as main tools, which, by means of vertical vibrations, introduces the tube into the soil to densify it without injection of water or improved material (AMORIM, 2019). This piling without material addition constitutes a sustainable method as it does not require granular materials in comparison to conventional soil improvement piles and does not generate construction waste compared to precast concrete piles that require the dragging of pile "heads".

The implementation of all the measures cited in Figure 1 was crucial to obtaining executive processes with less labor and input waste, which, in addition to contributing to reducing the amount of errors and rework, provided for higher quality construction in constructive terms and leaner and more environmentally sustainable production, resulting in more efficient executive processes that reduced waste generation.

Given the above, the adoption of waste reduction measures by companies constitutes an important step towards changing the paradigm and strengthening the learning of the construction industry since it prepares and empowers companies and their employees for a new scenario of legal, commercial, and environmental requirements aimed at sustainable development (DUARTE; MACHADO; PASCHOALIN FILHO, 2019). Figure 1 presents the compliance frequency indicators of the waste reduction items found in the studied construction sites.

Figure 1: Frequency indicators (%) of compliance of waste reduction items



Source: Authors.

3.2 Analysis of reuse actions

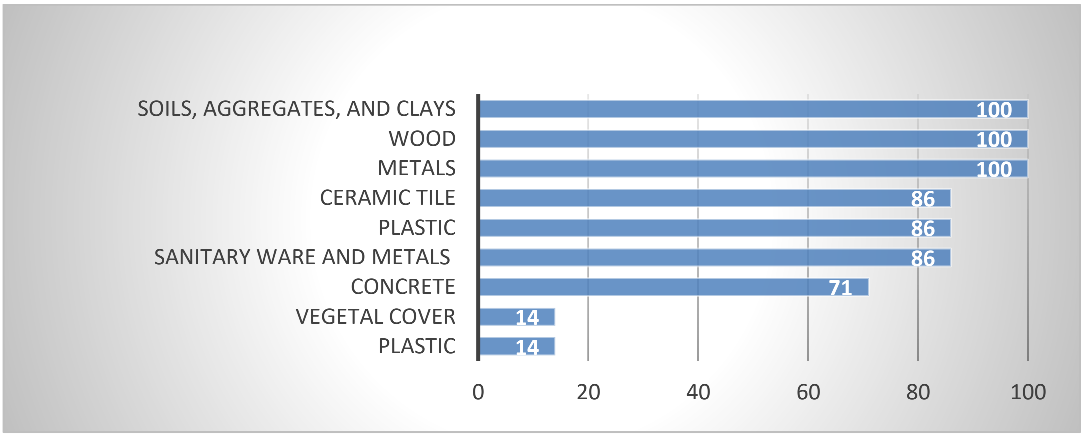
The analysis of the reuse actions contemplates the good practices for the materials found in the execution of the studied construction sites, such as wood, ceramic tiles, plastic, sanitary ware, plaster, metals, and aggregates.

Regarding reuse actions, soil residues, aggregates and clays; wood and metals were used in 100% of the works studied. Followed by the residues of ceramic tiles, plastic, sanitary ware and metals (86%), of concrete (71%) and finally the residues of plaster, vegetation cover and native trees that corresponded to 14% of reuse.

The main application for the residues was as follows: the wood waste was used for the manufacturing of molds for the passage of several installations before the concrete pouring, installation in trays, and use in signaling; the ceramic waste was used for the manufacturing of latches; the sanitary ware and metals and the frames and tiles were used in the building of new construction sites; the concrete waste was used in the manufacturing of lintels and sills, besides backfill; the soil and granular materials in general were used in the leveling of terrains; the metallic waste was used in the manufacturing of protection trays for the next works and the plastic waste for storing materials.

The gypsum waste (plasterboard) was reused for closing shafts and retrofitting in common areas (14%) of the construction sites. At the other construction sites, the gypsum was not reused in any way, and the vegetal cover waste and native trees were reused in the construction landscaping at 14% of the construction sites. Figure 2 presents the indicators of the frequency of compliance of the waste reuse items.

Figure 2: Frequency indicators (%) of compliance of waste reuse items



Source: Authors.

The study of the reuse actions shown in Figure 2 shows that it is possible to reuse a large quantity and diversity of waste generated in building construction and that many of them can be reused, such as aggregates, wood, and metal waste, which were reused in 100% of the sites, and that others need more studies to expand these measures, such as plaster waste, which was reused in 14% of the sites. According to Bertol (2015), CCW reuse reduces the amount of raw materials needed in building construction and reduces pollution by lowering the environmental load resulting from their final disposal. This is in addition to providing a reduction in expenses on the part of companies with their disposal to the CCW landfills.

3.3 Analysis of recycling actions

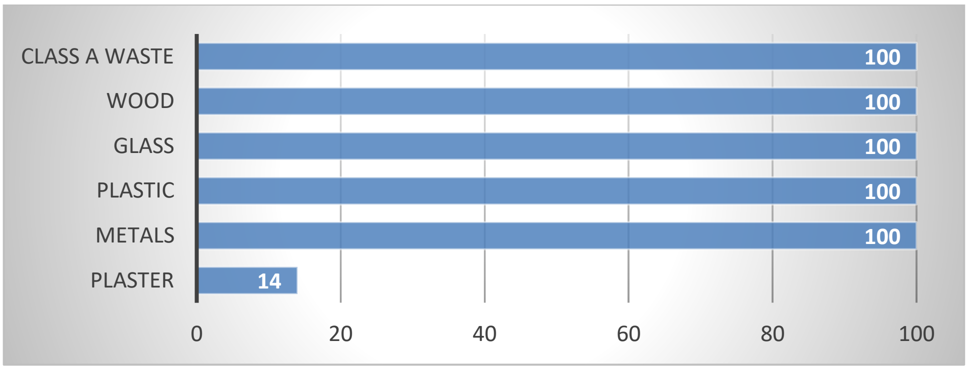
The analysis of the recycling actions, in turn, contemplated the good practices for the materials found in the execution of the studied works, such as wood, ceramic tiles, plastic, sanitary ware, plaster, metals, and aggregates.

Regarding the recycling actions, only work site D performed this activity within the construction site. In the others, it was left to the companies selected for final disposal (landfill of RCC). At this work site, most of the class A residues were recycled by means of treatment with sorting if they were mixed, and, after this process, they were crushed on site by means of rock crushers that transformed them into aggregates to be later reused in landfills and street leveling at the work site. The class A waste that could not be reused was then sent to the CCW landfills. The company also stated that plaster was not used in the lining or ceiling of the houses because the lining was made with PVA paste and then painted, and the ceiling was made of metal structure with tiles.

All construction sites send waste to civil construction waste landfills, which perform CCW processing (crushing) and recycling, producing new materials in accordance with CONAMA 307/2002 (BRASIL, 2002), such as sand, gravel, cracked rock (except for site E), and wood chips (small pieces of wood resulting from a crushing), to be traded. The construction works B1, B2, and C mentioned that they send most of the wood waste to local dealers to be used as firewood for ovens, and the remaining part was sent to the CCW landfills.

Another important piece of information is that construction site F sent most of the plastic, cardboard, paper, wood, and glass residues to the collectors' association, which produced and sold bales of these materials as raw material for various processing industries, and the remaining part was sent to the CCW landfills. At the other sites, these residues were exclusively sent to the CCW landfills. Site E (14%) sent the gypsum waste to local farmers to be recycled and used as fertilizer. Figure 3 presents the frequency indicators of compliance of the waste recycling items.

Figure 3: Frequency indicators (%) of compliance for waste recycling items



Source: Authors.

All the landfills to which the CCW were sent said they recycle all the waste received, such as the class A waste, wood, glass, plastic, and metals, either in the unit or by forwarding it to cooperatives of collectors. Only the gypsum is stored for transformation into new slabs or gypsum for soil correction through a future process unit of this material. Gangolells (2014) highlights that CCW recycling brings numerous economic and environmental benefits since it minimizes natural resource extraction, besides decreasing the levels of pollution in the environment through the transformation of waste into new materials.

3.4 Proposed guidelines and actions

The guidelines consist of the guidelines that should guide the conduct of the proposed actions. According to Barros (1996), Lordsleem Jr. (2002), Carneiro and Rabbani (2018), the guidelines seek to direct the forwarding of actions so that the final result has greater chances of success. As for the actions, they must be contemplated in a plan (document), through which the activities to be carried out, necessary to achieve the objective, are identified. For the detailing of the plan that includes the proposed actions for the implementation of the 3R's, the 5W2H quality tool was used, whose systematization allows better organizing the necessary information. Daychoum (2007) states that this tool basically consists of asking questions in order to obtain information that will support planning in general. The quantity and complexity of the actions for the implementation of the 3R's presented in Chart 3, were those whose perception and/or frequency of use resulted in qualitative and quantitative benefits to, at least, minimize the generation of waste.

Chart 3: Proposed action plan for the application of the 3Rs in building construction considering the tool 5W2H

ACTION (What)	REASON (Why)	DEADLINE (When)	PLACE (Where)	PERSON (Who)	ACTIVITY DESCRIPTION (How)	INVESTMENT (How much)
Construction Processes Choice	Waste reduction	Long-term	Materials used at the construction sites	Management and technical team of the construction company	Choice for rationalized construction processes, such as rationalized masonry, which, by presenting a specific project and trained labor, avoids waste generation; the use of cast-in-place concrete walls and project mortar; and the option for innovative technologies for building construction that contribute to the application of the 3Rs.	Not applicable
Choice of materials used in the execution of works	Waste reduction	Long-term	Materials used at the construction sites	Management and technical team of the construction company	Choose industrialized and/or ecological materials, such as: the use of industrialized mortar ready for application (stabilized mortar); steel cut, folded, and assembled because both arrive at the site ready for use; ecological bricks, which are produced with recycled materials from plastics, tires, pet bottle waste, and soil-cement.	Not applicable
Production of materials at the construction site	Waste reduction	Short Term	Services carried out at the construction sites	Construction site production team (foremen and workers)	Production control through planning for each stage of execution of the work and consultation of compatible projects, thus avoiding waste and overproduction.	Not applicable
Material flow and storage	Waste reduction	Short Term	Services carried out at the construction sites	Construction site management team (Engineer and Warehouse Manager)	Material storage control through the option for lean stocks, which is possible through planned purchases delivered according to the project's needs, facilitates the flow and disposal of these materials in the warehouse, thus avoiding damage due to bad storage.	Not applicable
Transportation of materials and waste on the construction site	Waste reduction	Short Term	Equipment used at the construction sites	Construction site production team (foremen and workers)	The correct equipment must be used for each material, such as the use of horizontal transports like handcarts, wheel barrows, pallet jacks, and	Not applicable

ACTION (What)	REASON (Why)	DEADLINE (When)	PLACE (Where)	PERSON (Who)	ACTIVITY DESCRIPTION (How)	INVESTMENT (How much)
					vertical transports such as freight elevators, cranes, and hoists; in addition to specific ones for transporting waste such as drop pipes.	
Waste management	Waste reduction	Medium Term	Services and materials used at the construction sites	Site Administration and Quality Team (Civil and Quality Engineer)	Environmental education should be applied at the construction sites through lectures to guide and raise awareness of the production teams about the importance of environmental management of waste. Another good practice is the use of reverse logistics of packaging, such as bags of cement, mortar, metal or plastic containers, and granite slabs, thus contributing to the CCWs reduction at the final destination.	Not applicable
Soil, sand, and clay waste reuse	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	Used in landfills or backfill. Soil, sand, and clay waste reuse in road construction.	Not applicable
Rock waste reuse	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	Construction of retaining walls and gardens.	Not applicable
Crushed rock residues reuse	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	Total or partial replacement of conventional aggregates, such as sand, pebble, crushed stone, and stone powder, in the production of simple concrete hollow blocks for sealing masonry.	Not applicable
Reuse of residues from ceramic blocks, concrete, sand and gravel	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	Floors, fills, paving, and concrete without structural function. Reuse of concrete residues for leveling the construction site. Ceramic and floor remnants can be reused in other floors, artistic works such as mosaics, mirror edges, stair edges, or walls.	Not applicable
Wood waste reuse	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	They can be used in reforming forms, props, braces, fences, gates, signs, and bays; as fuel in furnaces or boilers. Manufacture of boxes for passing installations in structural elements. They can also be used in scaffolding when in good condition.	Not applicable

ACTION (What)	REASON (Why)	DEADLINE (When)	PLACE (Where)	PERSON (Who)	ACTIVITY DESCRIPTION (How)	INVESTMENT (How much)
Gypsum plasterboard waste reuse	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	Readjustment in the common area, with shaft closures.	Not applicable
Gypsum waste reuse	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	Lining and artifacts for recycling by recycling companies and the plaster industry.	Not applicable
Plastic waste reuse	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	For packaging of other materials if not contaminated.	Not applicable
Reuse of ceramic and sanitary fixtures, frames, and tile waste	Waste reduction and reuse	Short Term	Materials used at construction sites	Administration and production team of the construction site	Reuse in temporary installations or new construction.	Not applicable
Metal residues reuse	Waste reduction and Recycling	Short Term	Materials used at construction sites	Administration and production team of the construction site	The metal waste can be reused in other construction sites to make siding, protection trays, and scaffolding.	Not applicable
Concrete waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	As aggregates in paving works, manufacture of recycled sand, manufacture of precast, and asphalt mixtures	Not applicable
Mixed waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	Conservation and paving of urban roads	Not applicable
Aggregate waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	Drainage materials in deep road drains, paving, slope containment, stream channeling, and use in mortar and concrete	Not applicable
Red ceramics waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	New bricks for aggregate production in sidewalk construction	Not applicable
Masonry waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	Light concrete with high thermal insulation power and the manufacture of new bricks	Not applicable
Wood waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	It can be recycled and used by the paper and cardboard industry, or it can be recycled in the construction of houses and furniture	Not applicable
Glass waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	Recycled into new glass, fiberglass, tile, and paving blocks, or as an addition, in asphalt manufacturing	Not applicable

ACTION (What)	REASON (Why)	DEADLINE (When)	PLACE (Where)	PERSON (Who)	ACTIVITY DESCRIPTION (How)	INVESTMENT (How much)
Marble waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	Asphalt concrete	Not applicable
Granite waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	Alternative materials for mortar production	Not applicable
Metal waste recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	Manufacturing of metal tiles, footings, or precast.	Not applicable
Plaster Residue Recycling	Waste reduction and Recycling	Long-term and medium-term	Materials used at construction sites	Administration and production team of the construction site	Manufacture of new drywall sheets; cement industry; use in the agricultural industry as a soil corrective; production of fertilizers and additives in composting processes and artifacts for plaster recycling.	Not applicable

Source: Authors.

The guidelines and the proposed actions presented in this research enable the application of practical measures for reducing, reusing, and recycling waste in building construction, contributing directly to minimizing CCW generation and decreasing the environmental load at the final destination. The proposed actions must be complemented with the specific study of other activities that can be performed according to the needs of each work, such as the choice of other systems and construction processes that are applied in the execution of buildings and/or innovations in the execution of the works or waste management, which may contribute to the application of the 3Rs.

4 CONCLUSION

Through the results obtained in the literature review and case studies, we conclude that it was possible to improve waste management at construction sites through reduction, reuse, and recycling practices that helped in the environmentally adequate treatment of CCW.

The following actions were identified as important contributions to reducing civil construction waste at the investigated construction sites: execution of rationalized construction; use of stabilized mortar; implementation of reverse logistics; and use of innovative building systems, such as ventilated facades, incorporated formwork, foundations, and compaction columns by the earth-probe technique without the introduction of material. The reduction actions were the priority goal of the construction companies to contribute to the maintenance of environmental management with clean and organized construction sites, besides reducing material resource consumption in the construction work.

With regard to waste reuse actions, the following were identified mainly: reuse of concrete, brick, and mortar waste to level the construction site; wood waste reused for temporary construction on the construction site; and ceramic waste reused to produce lintels and thresholds on the construction site.

The recycling was carried out by CCW landfills, recycling areas, and collectors' cooperatives duly licensed, in which recycling was performed with environmentally adequate treatment in accordance with the requirements of CONAMA, Resolution 307/2002, to the residues.

The systematization of reduction, reuse, and recycling actions performed in this research through the literature review and field research contributes to the development of guidelines on best practices for the 3Rs' application in building construction. These actions can be replicated to improve construction sites regarding the management of civil construction waste.

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