Development of Strategies to Promote Circular Economy in the Management of Construction and Demolition Waste: A Case Study in Manaus, Brazil

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Abstract

Construction and Demolition Waste (CDW) cause environmental impacts in a worldwide scale. The existing international concern regarding the adequate management of CDW is justified by the large amount of this waste produced in a daily basis, together with its potential hazardous effects on ecosystems and human health. In countries with growing economies, like Brazil, it is of the utmost importance to promote sustainability-oriented practices that can co-exist with economic development. In this scope, the present research proposes strategies regarding the management of CDW based on the Circular Economy principles, focusing the case study of the municipality of Manaus, in the centre of the Amazon Forest. The characterization of the reference situation regarding CDW management in Manaus revealed several deficiencies, namely the lack of reuse and recycling opportunities, the unsupervised disposal of CDW in illegal landfills, together with insufficient surveillance procedures and inadequate policies from regional authorities like the Manaus City Hall and the Amazon's Regional Council of Engineering and Agronomy (CREA-AM). The acknowledgement of these problems led to the identification of improvement opportunities and to the development and operationalization of Circular Economy promotion strategies: valorisation of CDW through the enhancement of reuse and recycling opportunities, operationalized through a mobile phone application; inclusion of sensibilization and surveillance practices regarding professional activities related to CDW management on the CREA-AM inspection plan; and the proposal of alterations in the municipal policies regarding CDW disposal in the public landfill. These strategies have been implemented in the Manaus municipality, but are easily adaptable to other Brazilian municipalities and even to other countries' realities.

Introduction

Inadequate management of construction and demolition waste (CDW) is a worldwide environmental problem that has been increasing over the years due to the growth of the construction industry in developed and developing countries. It is widely recognized that the generation of CDW is a consequence of economic and social development, since these wastes are a subproduct of urban lifestyle (Mesjasz-lech 2014; Aslam et al. 2020; Li et al. 2020b), and therefore the adequate disposal of CDW is an important challenge of modern urban management.

The amount of CDW generated and the correspondent management practices differ from country to country, depending on the existing policies, regulations, and waste disposal infrastructures (Blaisi 2019; Li et al. 2020b; Lv et al. 2020). For example, Singapore reports a 99% recycling rate regarding CDW, while China only recycles 5% of the estimated 2,36 billion tons of CDW produced in a year (Lv et al. 2020); in Europe the amount of CDW produced is over 870 million tons per year (Bonoli and Zanni 2021), with recovery rates around 90% (European Commission 2020); the Environmental Protection Agency of the United States of America reports 600 million tons of CDW produced in 2018, 24% of which have their final disposal in landfills (U.S. EPA 2020); in Brazil the amount of CDW generated in 2019 is estimated as 44,5 million ton (ABRELP 2020), but the recycling practices for CDW in Brazil are scarce (Contreras et al. 2016; Paz et al. 2018, 2020; Oliveira et al. 2019a).

As waste material produced in the process of construction, renovation or demolition of structures, CDW mainly consists of concrete, bricks, asphalt, excavated soil, metals, wood, ceramics, plastics, glass and cardboard (Yeheyis et al. 2013; Ossa et al. 2016; Cai and Waldmann 2019; Oliveira et al. 2019a). Hazardous substances may be found in CDW, like oil, paints, solvents and wood preservatives, as well as toxic materials resulting from demolition works, like for example asbestos and polychlorinated biphenyls (PCB) (Esa et al. 2017). Therefore, the inadequate handling and disposal of CDW can cause several negative environmental impacts, such as soil and water contamination, proliferation of plagues and diseases' transmission vectors (like insects and rats), landscape degradation, and obstruction of rivers and other drainage channels (Yeheyis et al. 2013; Blaisi 2019; Paz et al. 2020).

Linear based practices using the model "extract-produce-consume-dispose" are still the dominant rule in the construction industry (Esa et al. 2017; Ogunmakinde et al. 2021), in spite of the widely demonstrated economic and environmental benefits of CDW reuse and recycling. Based on the principles of Circular Economy, CDW reduction, reuse and recycling practices have relevant impacts on the amount of disposed waste, and at the same time contribute to preserve the natural resources used as raw material in the construction industry (Yeheyis et al. 2013; Contreras et al. 2016; Ossa et al. 2016). Therefore, there is a high potential to apply Circular Economy principles to CDW management (Adams et al. 2017; Gálvez-Martos et al. 2018; Mhatre et al. 2021; Ogunmakinde et al. 2021; Singh et al. 2021).

The focus of the present study is the municipality of Manaus (Amazonas-Brazil), located in the centre of the Amazon Forest, with more than 2 million inhabitants and a rising construction industry. Clandestine illegal landfills are common in the outskirts of Manaus, and are considered a low-cost solution for the disposal of CDW as an alternative to the disposal in the city's official landfill complex. These clandestine landfills lack environmental professionals to supervise the mitigation of the negative environmental impacts caused, and in addition, no inspection from competent government sectors occurs in these sites. Therefore, the current situation regarding CDW management and disposal in Manaus is harmful for the environment, negatively affects the ecosystem of the Amazon region, and has direct negative impacts on public health.

In this context, the present research aims to develop and operationalize new strategies to improve the management of CDW in the municipality of Manaus, involving different stakeholders in the public and private sectors. To achieve the research goal, literature has been reviewed in order to understand the state of the art regarding circular economy principles applied to the management of CDW. A detailed analysis of the current practices for CDW management in the municipality of Manaus has been performed, enabling the identification of improvement opportunities. New strategies have been defined and operationalized to reduce the environmental burden caused by CDW, benefiting the residents of Manaus and contributing to the preservation of the Amazon.

Literature Review

Circular Economy

The concept of Circular Economy (CE), introduced by Boulding (1966) and complemented by Pearce and Turner (1990), defends the need for the establishment of closed-loop resource systems (Boulding 1966; Pearce and Turner 1990). Counteracting on traditional linear production and consumption practices, CE defends industrial models that are restorative by design, where materials are recovered and reused instead of being discarded as waste (Smol et al. 2017; Fiksel et al. 2020).

CE is based on the following principles (Adams et al. 2017; Smol et al. 2017):

- To preserve natural resources by increasing materials' productivity.

- To increase or maintain the value of materials and to circulate them at the highest utility, thus eliminating (or at least minimising) waste.

- To re-design production systems to enhance closed-loop processes regarding material and energy flows.

Pursuing these goals, CE models are supported by concepts like Industrial Ecology, reverse logistics, cradle-to-cradle design, eco-efficiency, and the 3R hierarchy for waste management – reduce, reuse, recycle (Fiksel et al. 2020; Ogunmakinde et al. 2021).

Considering that there is a relevant number of waste streams that are presently underutilized (Fiksel et al. 2020), the promotion of CE-based business models could result in considerable economic and environmental benefits: conservation of natural resources, economic valorisation of waste, opportunities for new economic activities with job creation, reduction in energy consumption and consequentially in greenhouse gas emissions, besides the avoidance of costs and environmental burdens associated with waste treatment (Smol et al. 2017; Ogunmakinde et al. 2021). Also, by reducing dependence on scarce resources and long-distance supply chains, CE enhances business and community resilience (Fiksel et al. 2020).

Many countries have introduced CE principles in their policies and legislations – e.g. China, Japan, United Kingdom and all the countries belonging to the European Union (Smol et al. 2017). However, the implementation of CE in different industrial sectors has followed diverse approaches, and the lack of common strategies and instruments has limited the desired widespread of CE (Singh et al. 2021).

Modern technological tools have a fundamental role in the support of CE strategies: digital networks and intelligent robotics are frequently used in waste management processes, like for example sensor-based infrastructures for waste collection, digital image analysis and robotics for waste separation, geographic information systems and global positioning system to assist waste disposal, and data sharing technologies to support product lifecycle analysis (Paz et al. 2018; Esmaeilian et al. 2018; Sarc et al. 2019; Kabirifar et al. 2020; Li et al. 2020a; Lv et al. 2020; Yu et al. 2021).

With significant impacts on the consumption of raw materials and on waste production, CE is crucial for the promotion of Sustainable Development strategies (Lin 2020). In fact, CE enables economic growth without increasing resources' consumption, and is a concept that implies the redesign of industrial

systems, and deep transformations on production chains and consumption habits. Thus, CE strategies are clearly aligned with the United Nations Sustainable Development Goals (United Nations 2015), specially with Goal 8 - *Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all* , Goal 9 - *Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation* and Goal 12 - *Ensure sustainable consumption and production patterns*.

Circular Economy applied to CDW management

An industry with high material intensity like construction can achieve considerable economic and environmental benefits by increasing material efficiency through the adoption of CE strategies. In what concerns CDW management, CE relies upon the 3Rs principles: promote waste reduction opportunities, and enhance reuse and recycle to close material loops.

CDW reduction is the waste management option having the least negative environmental impacts, therefore it should be the highest priority in waste management plans. CDW reduction is highly dependent on strategies developed in the design stage to enhance resource efficiency. For example, the use of prefabricated modules can reduce CDW by 80% (Gálvez-Martos et al. 2018), among other strategies that could have relevant impacts on waste reduction like Building Information Modelling (BIM) (Yeheyis et al. 2013; Huang et al. 2018; Cai and Waldmann 2019; Li et al. 2020a) and lean construction (Kabirifar et al. 2020; Osobajo et al. 2020). However, effective CDW reduction is conditioned by the lack of design standards focusing waste reduction and by the lack of awareness among architects and engineers regarding waste reduction opportunities in the design phase (Huang et al. 2018; Kabirifar et al. 2020).

Reuse of CDW consists in using building materials more than once, either in their original function or considering a different purpose. This implies effective CDW collection and sorting practices, which may be difficult to operationalize due to lack of knowledge and technical equipment regarding waste sorting at the source, and lack of space to store separated waste. Also, the lack of formal criteria to assure the quality of reused building materials affects consumers' quality perceptions, and are therefore major drawbacks for CDW reusing practices (Huang et al. 2018; He and Yuan 2020; Cristiano et al. 2021). Nevertheless, several studies defend that adopting effective material reuse practices is an essential pathway to the success of the construction industry (Osobajo et al. 2020).

CDW has significant recycling potential: metallic waste, clay, glass and wood are valuable materials, and concrete and ceramic waste can be recycled as aggregates that may be used to produce new concrete and asphalt (Yeheyis et al. 2013; Bonoli and Zanni 2021). However, CDW recycling requires adequate waste collection and sorting technologies, and often the high cost of the recycling techniques decreases the price advantage of recycled material when compared to original materials (Gálvez-Martos et al. 2018; Huang et al. 2018). Also, effective recycling of CDW requires the existence of an organized market for secondary materials to uptake recycled waste (Gálvez-Martos et al. 2018; Singh et al. 2021).

Several authors have studied best practices and improvement opportunities regarding CDW management strategies in the different phases of the construction and demolition process. Table 1 presents a summary of the main results obtained from these studies. Nevertheless, the results of the implementation of these strategies are beyond expectations, mainly due to the inadequate understanding of the following key factors: regulatory framework (obligation), stakeholders' attitudes (who), CDW life-cycle design (when) and CDW management tools (how) (Kabirifar et al. 2020).

Table 1 - Best practices for CDW reduction, reuse and recycling

Pre-construction / pre-demolition phase	
Best practices	Referred by
- To foster offsite construction: use prefabricated elements, precast beams, modern methods of construction, rental and re-use of auxiliaries; - To maximize the recovery of materials in end-of-life stages: limited number of different materials and components; use of easy-to-separate materials; standard sizes; - To adequately plan on-site waste management: identify all potential waste and define specific actions for every type of waste produced, including re-use and recycling opportunities; - To assure the existence of all the required technical equipment for effective waste management; - To train and educate the construction workforce regarding effective ways to minimize waste generation; - To adequately plan supply chain management in order to control material stocks.	(Yeheyis et al. 2013; Esa et al. 2017; Gálvez-Martos et al. 2018; Cai and Waldmann 2019; Kabirifar et al. 2020; Osobajo et al. 2020)
Construction / Demolition phase	
Best practices	Referred by
- To separate and process mono-fractional waste streams whenever possible; - To avoid material loss by adequate logistics, promoting adequate material storage and handling practices; - To promote reverse logistics and other business-to-business schemes; - To use selective building deconstruction; - To supervise the adequate application of the waste management plan; - To monitor on-site and off-site waste sorting practices; - To assure the adequate handling and maintenance of technical equipment required in waste management operations; - To assure the adequate storage of waste in order to avoid material degradation; - To assure safe transport of waste, including preventive measures for potential environmental hazards	(Yeheyis et al. 2013; Esa et al. 2017; Gálvez-Martos et al. 2018; Cai and Waldmann 2019; Kabirifar et al. 2020; Ogunmakinde et al. 2021)

- To promote adequate communication among stakeholders relevant for the CDW management operations.

Policies for the promotion of CE-based practices in CDW management

Local and central administration policies have a relevant role in the promotion of Circular Economy principles in CDW management practices. Gálvez-Martos et al. (2018) defend that public authorities, at the national and local levels, should: develop CDW management plans prioritizing waste reduction and reuse and fostering innovation regarding recycling opportunities; define standards or regulations for on-site management of every type of waste; and promote the definition of quality assurance schemes regarding recycled products. These authors also refer the importance of using economic instruments to enhance the performance of waste management systems (landfill taxes, recycling subsidies and refunds).

Li et al. (2020b) identified nine policy instruments with potential to foster the CDW recycling industry, and used regression analysis to explore the relation between these policies and the development of the CDW recycling industry in 52 Chinese cities. Their results indicate landfill disposal taxes had the most effective results in the Chinese context, followed by the creation of quality labels and quality standards for recycled materials (Li et al. 2020b).

In this scope, Jia et al. (2018), using dynamic simulation and decision analysis techniques, concluded that a combination of policies including penalties for inadequate waste disposal, subsidies for waste recycling, and fees for waste discharging, would greatly reduce the amount of CDW disposed in illegal damps (Jia et al. 2018).

Ajayi and Oyedele (2017) defend that adequate legislation and fiscal policies are crucial for CDW minimisation, namely the inclusion of tax benefits and incentives to good performers, and the requirement to use proven waste efficient design, procurement and construction methods. These authors also highlight the importance of the following enablers and facilitators to corroborate policy requirements – adequate information regarding the quality, availability and benefits of secondary materials; and adequate markets to provide access to recycled materials (Ajayi and Oyedele 2017).

Yu et al. (2021) highlight the importance of CE promoting policies in the construction industry, namely the definition of strict waste classifications on-site to promote reuse and recyclability, the promotion of information-sharing technologies to enhance communication between different stakeholders, and the creation of financial incentives for innovation and circular business models (Yu et al. 2021).

Analysis of the current practices for CDW management in Manaus

The city of Manaus is located in the North of Brazil, in the centre of the Amazon Forest. With a territorial area of 11 400 km^2, Manaus has a growing population (Fig. 1) which is presently around 2 220 000

inhabitants. This population growth resulted in increasing demands for housing and infrastructures, and consequently the construction industry in Manaus has doubled in the last decade, reaching 1700 registered construction companies in 2018 (Brazilian Institute of Geography and Statistics 2020).

According to official data from the Manaus City Hall (Manaus Urban Cleaning Department 2020), the average rate of Municipal Solid Waste (MSW) collected in Manaus in 2020 was 1,083 kg per capita, from which only 2,2% were recycled. The main destination of these solid waste is the municipal landfill, under the direct management of the Manaus City Hall. With a total area of 66 ha, this public landfill received 967 277 ton of waste during 2019 (Manaus Urban Cleaning Department 2021), and its lifetime expectancy has been decreasing over the years due to the rise in waste production.

The Urban Cleaning Department of Manaus is also responsible for the collection of waste from illegal dumps - over 144 000 ton collected in 2019 - and from the margins and riverbeds of the urban streams belonging to Manaus' watershed - 29,3 ton of waste collected daily in 2020 (Manaus Urban Cleaning Department 2020). These numbers demonstrate the existing practices of waste deposition in inadequate and illegal places in Manaus.

In what concerns CDW, Brazilian legislation stipulates that the responsibility for its adequate disposal belongs to the waste producers. In the municipality of Manaus, the only available legal solution for CDW disposal is the municipal landfill. However, high deposition costs are applied, and therefore construction companies tend to outsource the transport and disposal of their CDW to private companies operating in this area (Oliveira et al. 2019a).

As reported by Oliveira et al. (2021b), the majority of these outsourced companies lack environmental permits and do not have the adequate technical qualifications to prevent environmental hazards in the CDW management process. Therefore, inadequate CDW management practices are occurring in Manaus, including the use of illegal clandestine landfills for CDW disposal (Oliveira et al. 2021a).

The inadequate disposal of CDW in unprepared places currently occurring in Manaus has substantial negative impacts, described in Table 2.

Table 2 Impacts of inadequate CDW management practices occurring in Manaus

Inadequate CDW management practices	Negative Impacts			
	Urban	Environmental	Social	Economic
Lack of CDW selective sorting and valorisation		Loss of reuse and recycling opportunities	Decrease in the useful lifetime of the public landfill	Loss of economic value from material with reuse and recycling potential
		Overcharging of public landfills	Loss of job opportunities in the waste sorting and valorisation areas	
CDW disposal in inadequate places inside the city	Destruction of sidewalks	Dust emissions	Traffic accidents	
	Creation of obstacles for pedestrians	Visual impacts	Proliferation of diseases	Road and sidewalks reparation costs
	Road obstruction	Noise	Injuries for pedestrians	Gutter unclogging costs
	Clogging of gutters	Attraction of insects and rats		
CDW disposal in illegal landfills	Floods caused by the accumulation of waste in the margins and riverbeds of urban streams	Soil contamination	Proliferation of diseases	Illegal landfills removal and cleaning costs
		Water pollution		Flood reparation costs
		Visual impacts		
		Ecosystem disturbance and biodiversity loss		
CDW management companies not registered in		Lack of technical skills to prevent	Lack of surveillance in the operations of CDW collection,	Loss of opportunities for tax and fines collection

regional administration bodies	environmental impacts	transport and disposal

Oliveira et al. (2019a) studied the waste management practices regarding the CDW produced in construction works developed in 2018 by three major construction industries operating in Manaus, corresponding to over 90 000 m^2 of constructed area. Wood, paper/cardboard and debris (concrete, bricks and ceramics) represent the majority of the CDW produced in the construction works under analysis. These construction companies refer very high costs with CDW management - only metal waste is sold for recycling purposes, and the transport and disposal of other produced waste is outsourced to private companies. Wood and paper/cardboard waste, produced in high quantities in these industries and having high reuse and recycling potential, are not being valorised due to the lack of an organized system for waste commercialization (Oliveira et al. 2019a).

The role of regional administration authorities in the CDW management process in Manaus has also been studied through the analysis of the actions promoted and the results obtained by the Regional Council of Engineering and Agronomy of the state of Amazonas (CREA-AM) (Oliveira et al. 2021b). This regional administration body is responsible for the supervision of technical professions to prevent inadequate practices and has, since 2017, an Inspection and Surveillance Plan for the Civil Engineering Chamber focusing professionals and companies in the construction industry area. The analysis of the records of inadequate practices regarding the construction industry and CDW management companies during 2017 and 2018 led to the conclusion that the major irregularities detected were related with the lack of adequate company's licencing procedures and with the development of activities without the supervision of technicians duly registered in CREA-AM. In what concerns the records existing in CREA-AM regarding the activities of environmental professionals in CDW management, a significant decrease was verified from 2017 to 2018 (Fig. 2). These results demonstrate that construction activities in Manaus are being performed without the adequate support of skilled professionals to mitigate the negative environmental impacts associated with CDW, highlighting the need to increase educational and surveillance actions directed both to technicians and construction industries (Oliveira et al. 2021b).

Identification and operationalization of improvement strategies

The analysis of the current practices of CDW management in Manaus described in the previous section highlights the following existing problems:

- There are very little reuse and recycling opportunities regarding CDW;
- Construction industries are not hiring environmental technicians to support the management of the produced CDW;

- Construction industries and CDW management companies are using illegal landfills to dispose waste;
- Most companies operating in the CDW management, transport and disposal areas do not have the required technical skills to prevent environmental burdens;
- The public landfill does not have the necessary infrastructures to promote the reuse and recycling of CDW;
- The surveillance of regional administration bodies is not effective in the prevention of inadequate practices from construction industries and CDW management companies.

In this context, improvement opportunities have been identified, at the light of the Circular Economy principles referred in the Literature Review section. Different stakeholders have been considered in the establishment and operationalization of the improvement strategies, considering that the successful implementation of Circular Economy projects in the construction industry requires de adequate engagement of different actors (Adams et al. 2017; Gálvez-Martos et al. 2018; Mak et al. 2019).

The proposed improvement strategies regarding CDW management in Manaus are summarized in Fig. 3, and are described in the following sections.

Promotion of CDW valorisation opportunities

To operationalize the principles of Circular Economy, it is imperative to promote an organized market to promote reuse and recycling opportunities for the CDW produced in Manaus. Through an organized market for CDW it would be possible to commercialize, exchange or donate sub-products of construction with value for other industries. This requires the creation of adequate communication channels involving construction professionals, waste management companies, recycling industries, among other stakeholders with potential interest in recycling or reusing CDW. For this purpose the use of new technologies is highly recommended (Lv et al. 2020; Yu et al. 2021).

Under this premise, the operationalization of an organized market for CDW reuse and recycling in Manaus was enhanced through the development of a mobile app (Oliveira et al. 2019b). Focusing the disclosure of reuse and recycling opportunities for the most common CDW produced in Manaus, this tool can be used by construction professionals and even common citizens who need to dispose construction waste from private construction works (Fig. 4). Waste disposal companies can also be an important user of this mobile app tool, since it can be used to advertise their services regarding the different disposal options. Since it is aimed to promote good practices in CDW management, the mobile app includes the possibility of tracking and inspecting the disposal of CDW by citizens, companies and public sectors responsible for inspection in the environmental area. Therefore, only companies dully registered and legalized can access the mobile app for advertisement purposes, and all information regarding the destination of the waste transacted through the mobile app must be communicated.

The adequate use of this mobile app tool requires its potential users to have high awareness levels regarding CDW management options, including the environmental and social impacts of inadequate practices. This can be achieved through education and training programs. A few pilot tests have already been performed, and the interest and acceptability levels associated with the mobile app tool were very high among construction professionals and common citizens (Oliveira et al. 2019b).

Revision of the policies regarding the public landfill of Manaus

The presently occurring overload of the capacity of Manaus' public landfill is unsustainable, and measures should be promoted to effectively reduce the amount of waste disposed in this landfill, specially focusing waste with reuse and recycling potential.

On the other hand, the promotion of CDW disposal in the public landfill is important to assure that all necessary precautions are being taken regarding the prevention of environmental hazards – which do not occur when CDW disposal is performed in illegal dumps. The promotion of the public landfill as a legal and safe disposal option for CDW could be made through the definition of adequate disposal fees. The definition of the fees applied to CDW disposal in the public landfill must consider the balance between low-cost options, which would be inefficient in the promotion of reduction opportunities, and high-cost options that would enhance the use of illegal dumps (Huang et al. 2018; Cristiano et al. 2021).

In this context, the following measures have been proposed to the Manaus City Hall, the entity responsible for the management of the public landfill:

1. to install equipment for adequately sorting the CDW received in the public landfill, therefore enabling materials reuse and recycling;
2. to install equipment for crushing CDW, reducing its volume and promoting its safe and costly transport to recycling facilities;
3. to promote the donation, sale or exchange of the material with reuse and recycling potential using the mobile app tool developed on the scope of the present study; and
4. to implement tax favouring policies for companies that promote reduce, reuse and recycling practices regarding CDW.

Improvement of surveillance practices

Current surveillance practices regarding CDW management in Manaus are not being effective, as demonstrated in the previous section. Regional administration bodies like CREA-AM can have a relevant role in the promotion of adequate practices for CDW management and disposal (Oliveira et al. 2021b), either through the definition and operationalization of adequate surveillance plans, as well as through the promotion of awareness and education among technical professionals and construction industries (Kabirifar et al. 2020).

In this scope, alterations were proposed to the existing Inspection and Surveillance Plan for the Civil Engineering Chamber of CREA-AM, and are expected to be operationalized in the biennium 2021-2022. The alterations proposed aim to intensify the surveillance on CDW management, transport, disposal and treatment practices, specifically focusing:

- the registration and GPS tracking of all CDW collection boxes that are stored in construction sites;
- the verification of compliance regarding the existence of legal permits / legal registration for all companies operating with CDW management, transport and disposal;
- the surveillance of clandestine landfills used to dispose CDW; and
- the supervision of technical activity registration processes to ensure that the necessary technical environmental support is being provided.

It must be highlighted that CREA-AM surveillance activities should be complemented with environmental education actions to promote adequate waste management procedures in construction sites, enhancing the existing options regarding construction waste materials reuse and recycling.

Conclusion

The analysis of the current practices of CDW production, management and disposal in the municipality of Manaus revealed several deficiencies that are affecting the Amazonian ecosystem and the health of the population: due to the lack of recycling and reuse opportunities for CDW, these wastes are being disposed in illegal and clandestine landfills, and the surveillance of local administration bodies is not enough to assure the minimization of the corresponding negative environmental impacts.

The acknowledgement of these problems and the understanding of their causes led to the identification of important improvement opportunities, considering the Circular Economy principles applied to the construction industry analysed in the literature review. The following strategic measures were identified and operationalized:

i. Promotion of CDW reuse and recycling practices, operationalized through the elaboration of a mobile phone application promoting good practices for exchanging, donating, selling and disposing of CDW;
ii. Promotion of awareness, education and training sessions for technical professionals and construction industries regarding adequate CDW management practices to prevent environmental impacts;
iii. Improvement of the role of local administration bodies regarding the prevention of inadequate practices among technical professionals and companies operating in the construction area, operationalized through the updating of the CREA-AM Inspection and Surveillance Plan, to enhance the adequate environmental surveillance of landfills used for CDW disposal, including GPS tracking of CDW collection boxes; and
iv. Adaptation of the regional public policies to promote the adequate management of CDW, proposed to the Manaus City Hall in the scope of the management of the Manaus Landfill Complex.

The operationalization of the strategies developed within this research are expected to result in the reduction of the amount of CDW produced – due to the reuse and recycling opportunities identified and operationalized – and in the promotion of adequate CDW disposal practices – due to the improvement of policies and surveillance practices from regional authorities. These are the main contributions of the present research, which are expected to lead to an important reduction of the negative environmental impacts caused by the inadequate disposal of CDW presently occurring in Manaus.

The new CDW management strategies developed within the scope of this research were based on the case study of the municipality of Manaus, but are extendable to any other municipality in Brazil or in other developing countries. Thus, it is hoped to contribute to foster the principles of the Circular Economy in Brazil, which are currently taking their first steps, but are essential for the promotion of Sustainability that brings co-existence between economic, social and environmental growth.

Declarations

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Conflicts of interest/Competing interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Availability of data and material (data transparency)

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Maria do Perpétuo Socorro Lamego Oliveira, with the support of the other authors. The first draft of the manuscript was written by Ana Margarida Fonseca and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

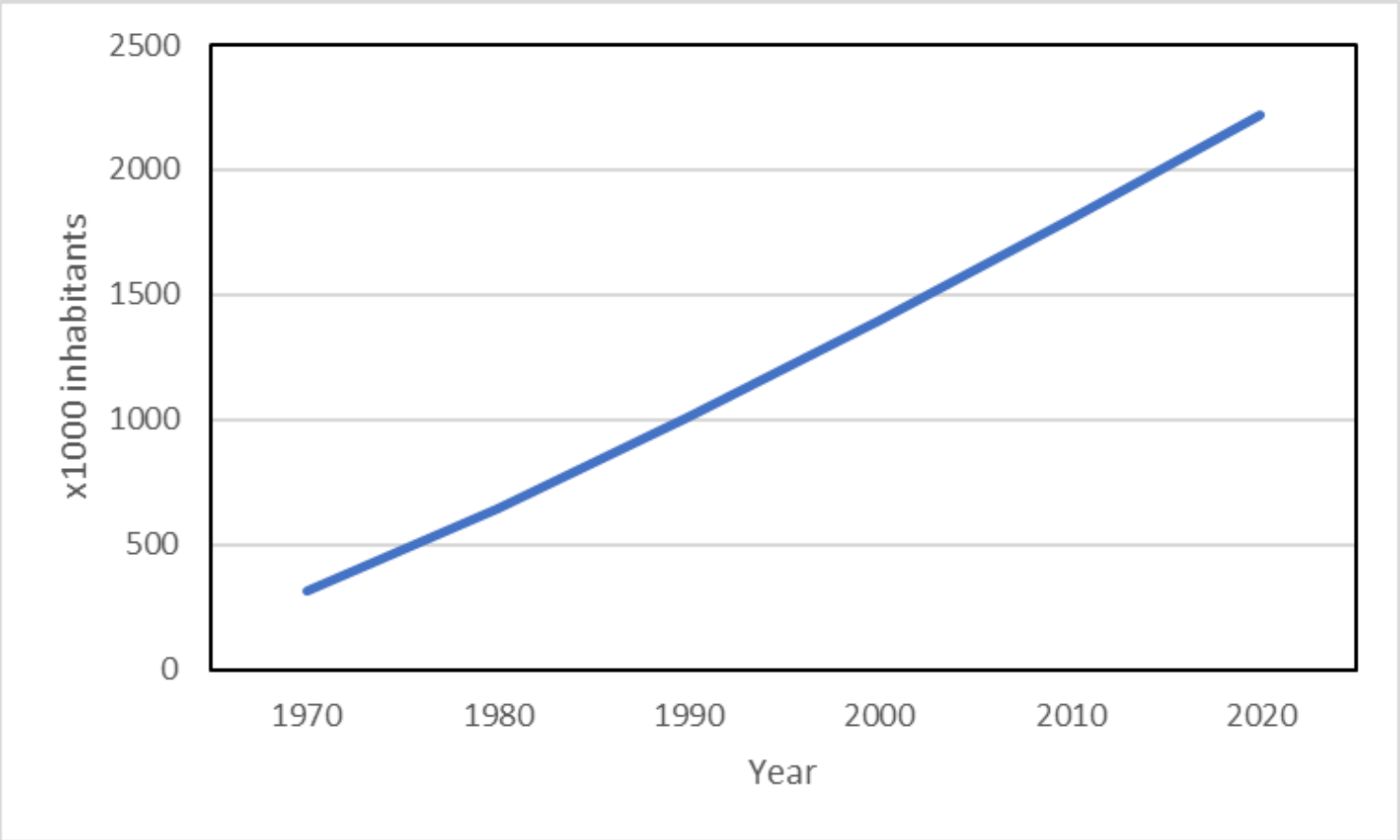

Figure 1

Evolution of Manaus population (Brazilian Institute of Geography and Statistics 2021)

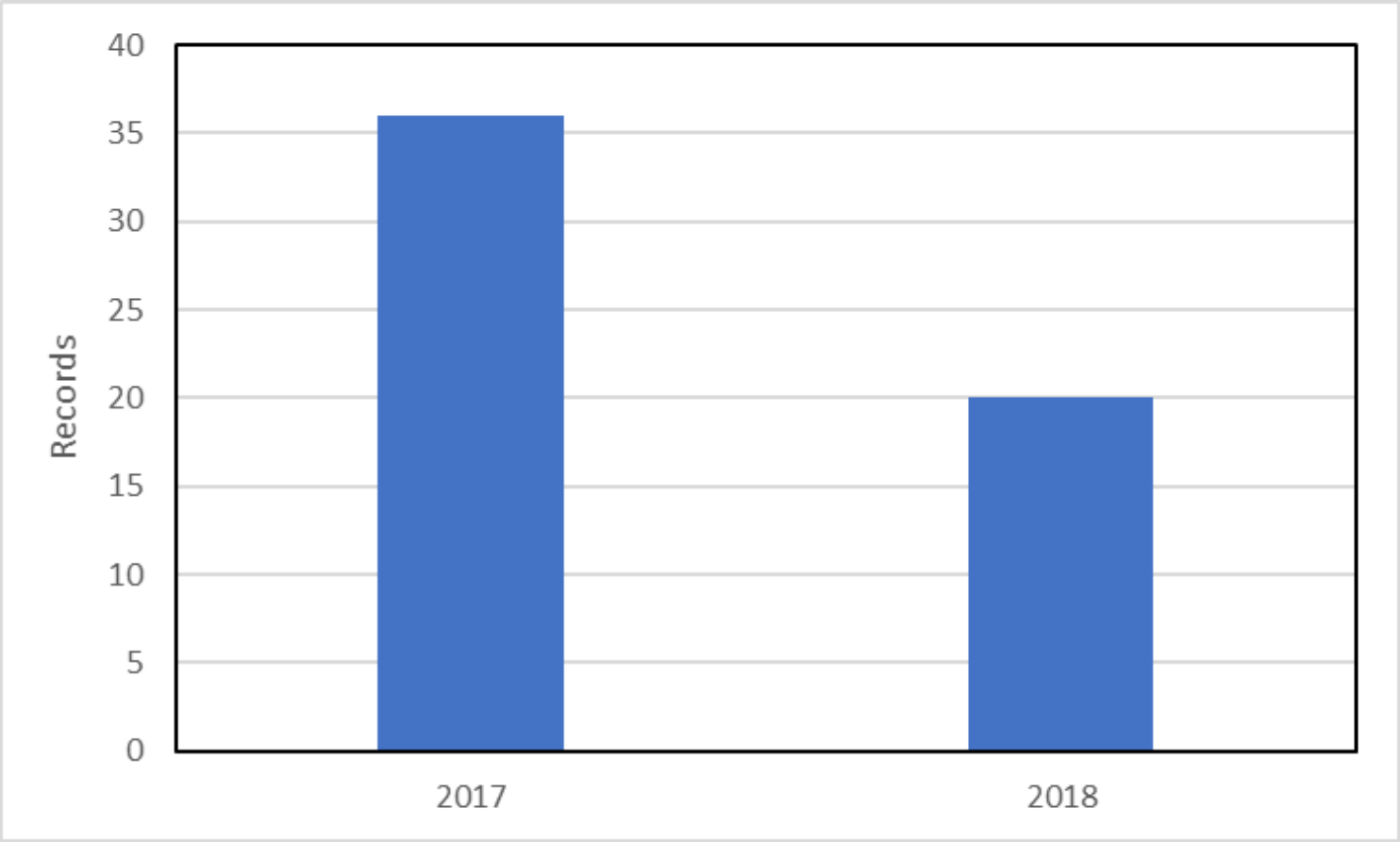

Figure 2

Number of CREA-AM records regarding the activities of environmental professionals in CDW management (adapted from Oliveira et al. 2021b)

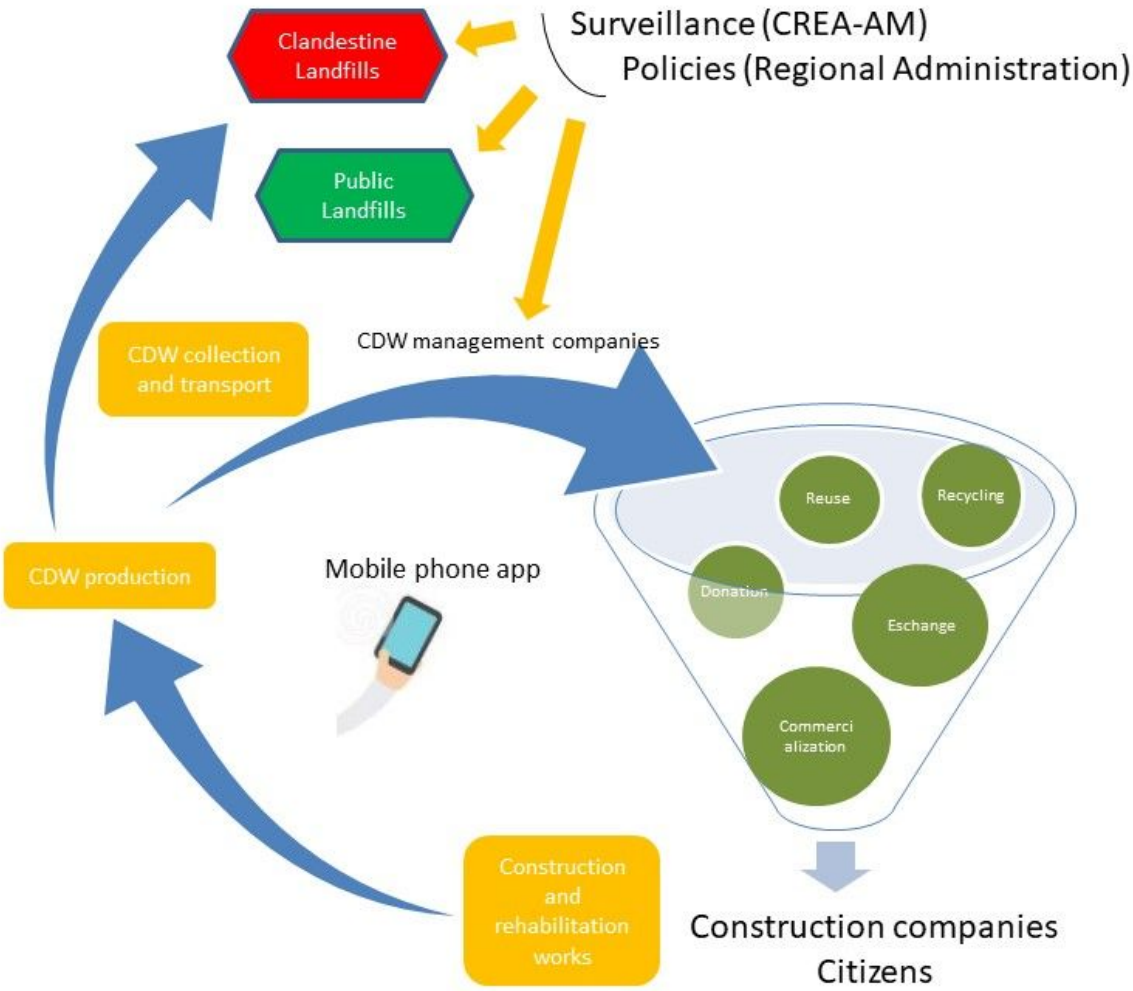

Figure 3

Improvement strategies regarding CDW management in Manaus

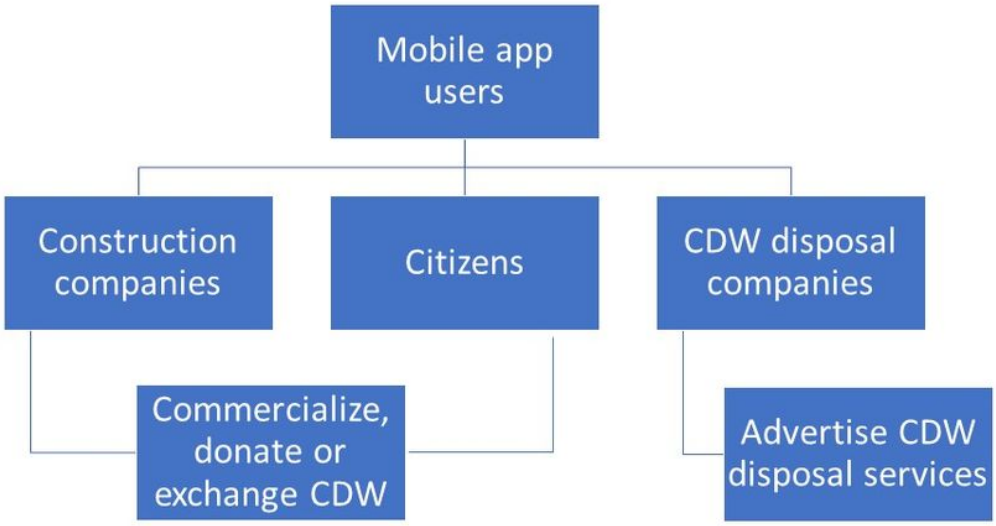

Figure 4

Mobile app functions for different types of users (adapted from Oliveira et al. 2019b)

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