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Circular Economy Applied in Brazilian Civil Construction

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Abstract

Construction activities consume 32% of the world's resources; worldwide buildings account for up to 40% of the waste consumed (by volume), and approximately 40% of waste generation (by volume) and contribute 20% to 35% to environmental impacts such as global warming and air pollution formation. The understanding of theoretical advances and the identification of technological solutions able to reduce the barriers that hinder the expansion of circular economy practices in civil construction are also within the scope of this study. Literature research was conducted, followed by a case study to maps the practical application of circular economy principles in a building protected by historical heritage in one of the main Brazilian metropolises. The semi-structured interview technique was applied on the collaboration of four players who acted directly in the planning and execution of the construction that resulted in the application of circular economy concepts. As a result, a roadmap emerges about the steps to be taken to obtain sustainable certification for buildings, accompanied by the expansion of strategies to be applied to optimize the score of the enterprise. In terms of innovation, was not possible to perceive a great movement in innovations of techniques, methods, and materials used in this sector. Thus, this study guides the replication of the method in other Brazilian buildings but, above all, it highlights the potential for applying the circular economy in a property to be restored, which represents the greatest potential for application in view of the greater volume of existing buildings to be renovated than the volume of new buildings to be designed with a view to obtaining certifications.

Key-words: circular economy; civil construction; LEED

1. Introduction

It is not news that the world is becoming increasingly populous. By 2030, the amount of people will be 8.6 billion and grow by 2 billion by 2050, reaching 9.7 billion people (United Nations 2019). Projections also indicate that population growth will trigger a 30% increase in the middle class and consequently a rural exodus, which will contribute to more than 70% of the population moving to urban areas (FAO 2019). As the population increases, the demand for energy, food, products, and housing will also increase, and the production of municipal solid waste is expected to rise to 2.2 billion tons, doubling in volume by 2025 (TWB 2012). The problem is that natural resources are finite, and industrialization has imprinted a linear dynamic that envisions "take, use, and dispose" (Foster et al. 2016; Islam & Jashimuddin 2017).

This linear system of production, consumption, and disposal has caused the level of CO_2 concentration in the atmosphere in 2017 to have increased 146% since before 1750, pre-industrial times (WMO 2018). Moreover, this linearity has been generating 1.4 billion Municipal Solid Residues globally each year, equivalent to 1.2 kg of MSW per person per day (EOS 2018). Each year, approximately 50 million tonnes of electronic and electrical waste (e-waste) are produced and only 20% is formally recycled. If nothing is done, the amount of waste will more than double by 2050, to 120 million tonnes annually (WEF 2019).

Civil Construction has important weight in the Brazilian economy with more than 6% share in the national GDP between 2011 and 2014, although this share has been reduced to 3.7% in 2019, after a systematic reduction in its share in previous years (Dieese 2020). However, in 2020, even considering the difficulties imposed by the arrival of the pandemic, construction was the sector that generated the most part of the new formal jobs in the country (CBIC 2021). With high resource consumption, waste generation, and environmental impact, construction is one of the priority industries that require more attention. The construction activities consume 32% of the world's resources (Yeheyis et al. 2013). Worldwide buildings account for up to 40% of waste consumed (by volume), approximately 40% of waste generation (by volume) (Becqué et al. 2016) and contribute 20% to 35% to environmental impacts such as global warming and air pollution formation. Furthermore, since 1949, the sector's energy consumption has increased by 72%, accounting for 19% of global energy consumption (Azari and Abbasabadi 2018).

In this study, the circular economy theory was reviewed by exploring its initial aspects (reduce, reuse and recycle) and their new context that includes six aspects (regenerate, share, optimize, loop, virtualize, and exchange). As a result, it was possible to identify strategies that can be implemented to solve barriers and improve the circular economy concept with different levels of integration by the big data model (volume, variety, velocity and veracity). In addition, this study maps the practical application of circular economy principles in a building protected by historical heritage in one of the main Brazilian metropolises. The main objective is to present a framework with the steps for implementing sustainable certification in civil construction and mapping the possibilities of obtaining points for the LEED® certification of sustainable buildings.

To present the issues inherent to the objectives, the method began with a literature search on the central themes of the study, namely sustainability, circular economy, and LEED® certification. In sequence, the Gloria Building, located in the city of Rio de Janeiro, was chosen to be a case study. This is a building protected by historical heritage, what increases the complexity of the project. The semi-structured interview technique was applied on the collaboration of four players who acted directly in the planning and execution of the construction that resulted in the application of circular economy concepts.

We sought to provide guidance on the procedures for the construction and adaptation of buildings based on the principles of sustainability, in order to inspire new practices and thus expand the use of circular economy in civil construction. Thus, this study guides the replication of the method in other Brazilian buildings but, above all, it highlights the potential for applying the circular economy in a property to be restored, which represents the greatest potential for application in view of the greater volume of existing buildings to be renovated than the volume of new buildings to be designed with a view to obtaining certifications. Based on the mapping of the steps to be carried out, opportunities are opened for the implementation of new circular economy projects, as well as for the replication or adjustment of their steps, either within the analysed country or in others.

2. Theoretical framework

This section introduces the concepts of sustainability, circular economy, and technology. These concepts are then applied to civil construction and LEED® certification for sustainable buildings.

2.1. Sustainability, Circular Economy, and Technology (Large-scale Data)

In the context of material waste, the concept of Circular Economy (CE) emerges defined as "an economy that is restorative and regenerative by design and which aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles (EMF 2015b). Then other concepts emerged, such as regenerative design and cradle-to-cradle, both with the purpose of discussing and promoting the reuse of raw materials, inserting them into a flow that consists of 3 R's: reduce, reuse, and recycle (EMF 2015a).

Continuing the discussion on circular economy, some major schools of thought related to this form of economy emerged in the 1970s, but gained prominence in the 1990s (EMF 2015a). Some examples are the functional service economy, also called performance economy by Stahel (2013). The "cradle to cradle" design philosophy developed by McDonough and Braungart (2003) and the concept of industrial ecology developed by Lifset and Graedel (2002) have also contributed to the advancement of the terms and their applications.

Twenty-three years after the introduction of the 3R's, with the recording of various technological and economic advances, the "ReSOLVE" structure emerges, formed by the acronym of the English terms regenerate, share, optimize, loop, virtualize, and exchange. According to MacArthur (EMF 2015a), the ReSOLVE framework offers companies and governments a tool to generate circular strategies and growth initiatives. In different ways, all the actions contained in the framework increase the use of physical assets, extend their useful life, and shift resource use from finite to renewable sources. Moreover, each action reinforces and accelerates the performance of the other actions. Such a concept corroborates with Koris et al. (2018) view where circular economy means tracking materials throughout their life cycles so that their location is known such that it is possible to design them for future reuse or recycling, contributing to a sustainable and efficient future.

Also with a view to reducing resource use, for Haas et al. (2015), the circular economy is a strategy that aims to both reduce the input of virgin materials and the production of waste, closing economic and ecological loops in resource flows. Even more recently, Jabbour et al. (2019) went beyond the analysis of circular strategies and growth initiatives by creating a pioneering study on the benefits not only of a circular economy, but on the connection between circular economy and technology, using the concepts of large-scale data (LD) and the ReSOLVE framework as a basis.

Despite this slow progress and barriers, the Gartner group proposed the 3Vs of Big Data theory, which was used years later as the basis for IBM to propose an additional V, becoming the theory known today as "The 4Vs of Big Data". Before these theories were formulated, Large Scale Data was analyzed and categorized based solely and exclusively on the amount of bytes they accumulated, i.e., by their size (Jagadish 2015). Having noticed this simplistic analysis of Big Data, IBM initiated studies to deepen its analysis and divide this technology into 4Vs, as described and explained below.

- Volume - Refers to the amount of bytes generated/acquired.
- Variety - Refers to the variety of data that is obtained from different sources.
- Velocity - Refers to the speed at which data is generated and processed.
- Veracity - The quality of the data generated/acquired.

Consequently, managing big data for the Circular Economy can help unlock greater potential for circularity (Lieder & Rashid 2016). Insights can be generated from understanding levels of integration between Circular Economy models centered on the ReSOLVE theory and big data (Jabbour et al. 2019).

Table 1 – Structure outline

Reduce	Consume fewer products and prefer those that offer less potential for waste generation and have greater durability.	→	**Re**generate	Switch to sustainable energy, restore healthy ecosystems, and return biological resources to the biosphere.	Veracity
			Share	Increase asset sharing, reuse, and extend service life through maintenance, design thinking for durability, and upgradeability.	Variety and Velocity
Reuse	It includes a set of actions that seek to eliminate the single use of materials and goods that we have in our daily lives. An example of the application of this concept would be to store the jars of a product, wash them, and then reuse them to store some food.		**O**ptimize	Increase product performance and efficiency by removing waste from the supply chain, leveraging big data and automation.	Volume and Veracity
			Loop	Remanufacture products or components, recycle materials, and extract biochemicals from organic waste.	Velocity, Veracity, and Volume
Recicle	It involves the transformation of materials to produce raw materials for other products through		**V**irtualize	Move into the virtual world, either directly through digitization (e.g., books on CDs) or indirectly (e.g. online shopping).	Variety and Volume

	industrial or craft processes. In short, it means manufacturing a product from used material.		**E**xchange	Replace old products that are not made with recyclable materials with advanced materials or new technologies.	Variety and Veracity

Source: Adapted from Jabbour et al. (2019).

Thus, this study presents the connections between the 3 aspects, 3 Rs – Reduce, Reuse and Recycle, ReSOLVE – Regenerate, Share, Optimize, Lopp, Virtualize and Exchange and 4 Vs – Volume, Variety, Velocity and Veracity, regarding the circular economy theme in civil construction, in order to highlight some of their similarities and possible actions to implement these theories.

2.2. Civil Construction

Buildings and construction are the main sources of economic activity, employment, and material production worldwide (Hopkinson et al. 2019; Karayannis 2016). Annually around 65% of total aggregates (sand, gravel, and crushed rock) and approximately 20% of total metals are used by the construction industry to create the built environment (Hopkinson et al. 2019). Furthermore, two studies, including one from Ecorys (2014), say that steel and aluminum together account for nearly 51% of the total embodied energy in building materials, and concrete accounts for another 17%.

Turning to the Brazilian scope, the construction industry has grown strongly since the 2000s in order to support the needs for infrastructure works demanded by society (CNI 2016). It is estimated that 85% of the Brazilian population lives in urban areas and this rate is expected to increase to 91% in the next 30 years. This is a sector that accounts for 7% of Brazilian GDP and represents 9% of jobs; however, it is becoming one of the sectors that generate the most waste.

According to Rocheta and Farinha (2007), the Brazilian population spends 90% of its time in buildings. If they have inadequate energy management, they strongly contribute to exorbitant expenses, both monetary and residual. The growth of the sector must come along with better sustainable techniques and materials. Hopkinson et al. (2019) show a limitation in the practices and techniques applied to the materials used in this sector. Additionally, he also states that "Industry codes of practice or standards do not prohibit the use of reclaimed products, but without such a specific code or industry standard, designers and specifiers do not know how to deal with them" (Hopkinson et al. 2019, p.3), reinforcing that the industry is unfamiliar with the use of recycled materials.

Becquè et al. (2016) follow in the same vein, saying that one of the actions needed to improve the efficiency of the sector is the creation of building efficiency codes and standards, i.e., regulatory tools that require a minimum level of energy efficiency in the design, construction, and/or operation of new or existing buildings or their systems. By studying various literature on the topic of circular economy in construction, Minunno et al. (2018) consolidated seven most common strategies for a circular economy to be implemented in this sector, namely:

Table 2 – Strategies for implementing circular economy

	Strategy	**Strategy implementation**
i	Reduction of construction waste and lean production chain	Adopt lean production chain to reduce construction waste
ii	Integration of scrap and waste into new by-products	Use concrete produced from scrap and waste
iii	Reuse of spare parts or entire components	Use second-life components
iv	Design geared toward adaptability (reduction through life extension) during operational phases. Adaptability with coordinated actions.	Adaptability throughout all operational phases
v	Design for the disassembly of goods into components to be reused. Disassembly of parts for reusing their components	Re-usability throughout the end-of-life cycle

vi	Design for recycling of building materials	Recyclability at the end of the life cycle. Correct destination for the recycling of materials and components.
vii	Systems for tracking materials and components in their supply chain	Tracking of materials and their components

Source: Adapted from Minunno et al. (2018).

The analysis of table 2 suggests that all the strategies studied are somehow linked to the 3Rs concept, justifying the concern with the waste generated by this sector. Therefore, the LEED® - Leadership in Energy and Environmental Design - certification arose from a natural movement in the civil construction sector to improve and advance more and more in line with sustainable development and the circular economy.

3. Research method

A case study was applied to map the practical application of circular economy principles at Gloria Building a historical heritage, located in the city of Rio de Janeiro, one of the main Brazilian metropolises, what increases the complexity of the project. The semi-structured interview technique was applied on the collaboration of four players who acted directly in the planning and execution of the construction that resulted in the application of circular economy concepts. According to Creswel and Creswel (2017), the steps of data collection include a collection of primary data through observations and interviews. The results were described, following the discussions.

As a way of analyzing the existing studies in the database generated for the research, an adapted categorization technique from Akhimien et al. (2020) was adopted. Thus, the 129 selected articles were categorized into: evolution of the circular economy, cities and communities, difficulties and barriers, techniques for applying the circular economy and materials and resources. As will be shown below, this last category brings together materials and resources topics, in line with one of the LEED categories, and represents most of the studies.

In the case study stage, the Glória Building, located in the city of Rio de Janeiro, was chosen. The research counted on the collaboration of four players who acted directly in the planning and execution of the construction that resulted in the application of circular economy concepts. These were the investor, the developer, and the technical consultancy, a company responsible for the legal procedures to adapt the building to the specified standards. With these fronts, the work was able to deepen into the specificities of the project and have the possibility of a broad analysis.

To collect information, the semi-structured interview technique was used. Three interview scripts were then prepared, one for each actor of the links selected according to their participation in the development of the building that was the object of this case study.

All four interviews were especially selected in order to analyze different perspectives, flowing through economic, sustainable/social and industry sectors, giving the study a broad view of the pros and cons of the practical application of circular economy principles in a building. At the end of the interviews, it is possible to understand the way of working of each of these stakeholders for the expansion of the use of circular economy techniques and the expansion of certifications in existing buildings.

4. Results

Among the articles it was possible to see a great importance of the construction sector in the circular economy theme, where Hopkinson et al. (2019) equates buildings to material banks, showing that, if well-constructed, buildings can be reused and will not generate waste.

With the article by Becquè et al. (2016) we were able to collect various data about the construction sector - amount of waste, share in GDP, and importance of the sector in the economy. Additionally, the article shows methods and techniques that can be applied in the construction industry to improve its efficiency.

During the literature review, it was possible to perceive a concentration of articles related to the construction of new buildings, taking into account new techniques such as the use of precast materials and new materials such as a new type of more efficient concrete. Few articles delved into the sustainable disposal part, such as the use of biodegradable materials, the rubble recycling process, or the reuse of reinforced concrete from a demolished building.

The categorization, adapted from Akhimien et al. (2020), contributed to highlighting the themes present in the studies, pointing out the trends and technological solutions that are being tested, as well as indicating gaps and opportunities for future studies.

4.1.1 Evolution of the circular economy

Mhatre et al. (2021) and Akhimien et al. (2020) bring the history and development of the Circular Economy over the years, passing through the 3Rs and Ellen MacArthur. The studies bring not only the evolution of the Circular Economy over the years, but also indicate the themes to which the researched articles refer and their origin. Understanding evolution means knowing the context in which a concept emerged that, although it suggests full agreement as to its importance, lacks guidance and incentives for it to reach scale within all possibilities of application.

4.1.2 Cities and Communities

This topic, despite not having a very large number of articles close to the hole sample, 7 articles, brings great contributions to this work, since, in line with this study, it discusses the Circular Economy applied in cities. Paiho et al. (2020) describes how social housing can not only take advantage of, but also contribute to, the Circular Economy in cities, helping to recreate consumption practices that prevent a good development of a Circular Economy. Chen (2021) in turn, discusses the rebound effect, an effect of deterioration of resources throughout their life cycle. The author emphasizes that this effect is often analyzed in articles only from the perspective of materials and energy, ending up not analyzing changes and damages to workers, citizens and well-being in general.

4.1.3 Difficulties and barriers

Among the barriers, the lack of legislation or a national action plan represents a barrier to the expansion of the Circular Economy in the United States (Cruz Rios et al. 2021) and the same can be said about Brazil that represents the case study of this research. Mignacca et al. (2021) point out relevant barriers are the lack of a second-hand market, economics, and regulatory challenges.

Kanters (2020) points out the conservativeness of the building industry, the lack of political priority and the dependency throughout the building industry were found to be the main barriers. Ambekar et al. (2022) show that macro level barriers such as lack of awareness of reverse logistics, insufficient government policies and unavailability of standard codes stimulate each other and also drive all other barriers, as well as categorize barriers into organizational levels, being them strategic, tactical and operational.

4.1.4 Materials and Resources

Materials and resources represent most of the studies, and waste is discussed in 65% of these studies. Increasing solutions for waste can result in a significant progress for raising urban development because it reduces the volume of materials that overload landfills and represents fewer natural resources to be used in the production of new materials. Besides all that, it can represent less cost (Gubanova et al 2019; Zhang et al 2021; Sobotka et al. (2021). The engineering has been contributing with many studies and solutions to develop new materials and to create new uses for waste, specially for concrete. It is justified by the volume of this material and the facility to reuse without necessity to separate their inputs.

4.1.5 Techniques for applying the Circular Economy

Studies in this category present solutions related to the use of information for planning the materials to be used and reflect the opinion of professionals dedicated to the topic, accessed from interviews and analysis of the techniques being tested in comparative scenarios. However, many studies in the sample present techniques associated with the life cycle of buildings, with the obligation to implement them from the design of the construction of the building, thus being invalid for all existing buildings in the world (Eberhardt et al 2021; Eberhardt et al 2022; van den Berg et al 2020, Asmone et al 2020).

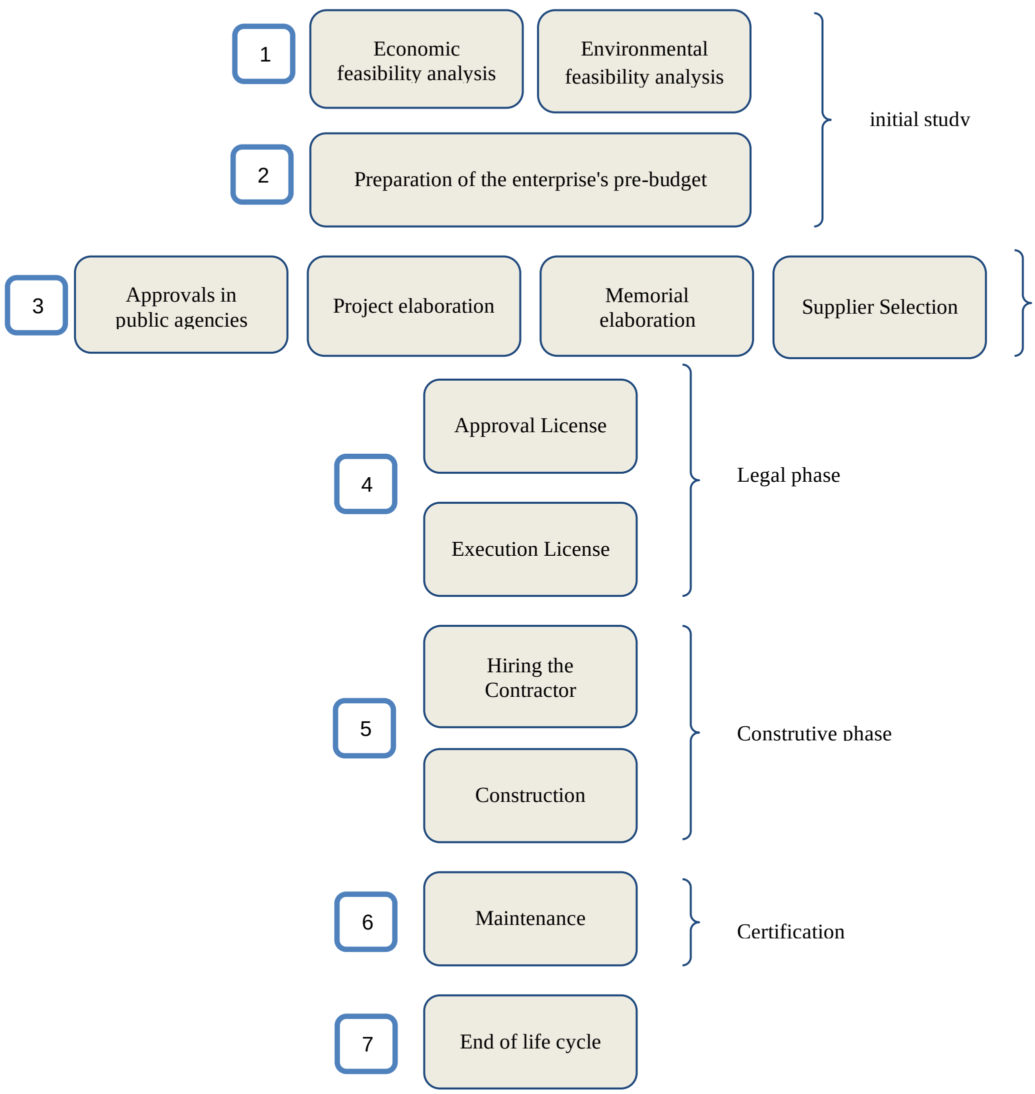
It was also found that many studies in this category refer to recycling techniques, also represented by symbiotic relationship (Genc 2021), as the biggest challenge, at the same time that it represents an important path for the expansion of the circular economy in civil construction (Finch et al 2021; Ebert et al 2020; Rakhshan et al 2021; Pavliuk et al 2021).

We used the structure of stages of the construction process proposed by Hossain et al. (2020), to create a new structure adapted with the information obtained from, mainly, interviews 2, 3 and 4. This study enabled the mapping of the stages of a circular economy project for sustainable buildings. The steps, divided into (i) initial study, (ii) project execution, and (iii) certification, indicate the chronological order of the tasks to be performed by the respective actors of a construction project aiming for LEED® certification.

4.2. Steps of a CE project for sustainable buildings

The method applied allowed for the elaboration of a map with the structure of the construction process of a LEED® building (Figure 1), favoring the visualization of the stages in the chronological sequence of execution and their respective key players.

Figure 1 – Structure of the LEED® building construction process



Source: Adapted from Hossain et al. (2020) with research data

Step 1 includes the economic and environmental feasibility studies. In this stage, an analysis of the soil, the existing means of transportation in the vicinity, and the history of the land are performed. In the case under analysis, the procedures for demolishing part of an existing building were necessary. From this first stage on, the preponderant aspects for the economic and environmental viability of the enterprise are already considered.

In step 2, if the land has been approved in the two previous analyses, the pre-budget of the project is prepared. Detailed studies of the estimated costs favor the detailing of the project to be implemented, enabling the decision about the possibility of LEED® certification, as well as its respective level. Among all the topics to be considered, the need for demolition of a pre-existing building is of relevant consideration in view of the scope of the LEED® standards for this stage. The case under study demonstrated the integration of the two consulting companies involved in the project execution. After the acquisition of the property, the Incorporator hires the Technical Consultant to manage the actions corresponding to the documents required for the building to obtain the desired certification.

Step 3 comprises the preparation of the executive project, including: (i) the choice of suppliers that will work in the construction; (ii) elaboration of the memorial with the definition of the materials and raw materials that can be used in the construction, including facade, decoration, and common and private areas, etc.; and (iii) description of the necessary approvals from the beginning of the project until its finalization, considering regulatory and inspection bodies of all public spheres. In step 4, legal authorizations must enable the obtaining of the development's approval permit and execution permit, and the possession of such documents represents the clearance to start construction. Step 5 comprises the contracting of the construction company to start the construction work.

Step 6 denotes the maintenance process with a view to the intended certification of the building. Commonly, lease contracts begin to be effective before the completion of construction work. In any case, in certified buildings, tenants have shared responsibilities regarding the achievement of goals to reduce natural resource consumption, for example. Therefore, the contracts usually establish criteria for the choice of materials, such as light bulbs, sanitary equipment, and faucet aerators, among others. Maintenance and replacement must also follow the parameters defined for the materials authorized for use in the building.

Stage 7 deals with actions only applicable at the end of the building's life, such as demolition and use of removed materials. The practices mapped by the actors involved in the research demonstrate the absence of such concerns during the construction phase of the buildings. A major goal of the developer and the construction market today is to get higher and higher scores, or at least more and more profitable scores. With this objective, companies that specialize in these certifications and in how to obtain the maximum points possible have emerged. This is justified by the long life span expected for each building.

Since most of the scoring of buildings in metropolises come from the characterization of the site and its surroundings, phase 1 (site analysis) is of significant importance. This phase verifies, among other criteria, population density, availability of leisure facilities such as theater, cinema, and parks, as well as routes for the use of alternative transportation such as bicycles. Phase 2 of the project design follow-up provides recommendations regarding the construction and technical specifications to be incorporated into the project in order to obtain more points in the certification. For example, the model of the air conditioning equipment and the existence of vegetable gardens are preponderant for additional gains in the LEED® score.

Phase 3, project execution, stands out in the interviews due to the volume of sensitive activities in the provision of services. Among many examples, one of them is the process of washing the trucks' wheels before they leave the construction site, selecting and directing the debris to the correct place, controlling the air flow inside the construction area, sweeping the outside of the construction site, and protecting the bucket of the truck that enters and leaves the construction area. In the last phase, the creation of a construction process report, the company consolidates all the information and documentation obtained during the entire construction process to send it to the U.S.G.B.C. – United States Green Building Council – so that the enterprise receives the certification.

4.3. Analysis of the Glória Building's certification

This study analyzed the design and execution of a renovation in the Glória Building, located in the city of Rio de Janeiro/Brazil. This is a heritage listed corporate building, increasing the complexity of the project. Stage 1, "environmental feasibility analysis", was carried out based on feasibility criteria of points to be obtained for LEED® certification, considering environmental, demographic, legal, and economic aspects.

The individual analysis of each factor makes it clear that *prerequisites* are items that, regardless of the level of difficulty, have to be met. Some examples are: reduction in water consumption by 20%, minimum energy efficiency based on a determined peer, and deposit of recyclables. On the topic of *sustainable land*, according to the report analyzed, thirteen LEED® points were obtained based on the location in which the building would be constructed.

As for the points corresponding to the rational use of water, since there are three categories of progressive credits for reducing water consumption (30%, 35%, or 40%), this categorization allows a maximum gain of 10 points for the highest level.

Following the report, we have the topic *atmosphere and energy*. This is composed of three prerequisites and seven credits that add up to a total of 37 possible points. Despite being the topic with the most possible points, the survey showed that it is one of the most difficult topics to obtain the highest score due to the difficulty in optimizing energy efficiency at high percentages, both technical and financial constraints.

The *materials and resources* aspects also include progressive scoring, allowing for a maximum gain of 13 points. This question includes recyclables storage with a requirement for an accessible common area for the collection and conditioning of recyclables, including, at minimum, the following materials: paper, cardboard, glass, plastics, and metals.

With a maximum score of 12 points, the topic of *indoor air quality* includes tobacco smoke control in order to prevent or minimize the exposure of indoor building users and ventilation systems to tobacco smoke. *Project innovation* contains no prerequisites, making it possible to achieve six credits, one point for each requirement met. Similarly, regional priorities contain no prerequisites, with four credits for criteria met. However, some regional priorities allow additional points to be earned if the eligible building meets them.

The analysis of the Glória Building project allows understanding about the points that motivated the classification in the respective level of LEED® certification. The building received 16 points for its location, representing characteristics intrinsic to the project. Another 35 points were obtained by meeting the established criteria, totaling 51 points, corresponding to the LEED® Certified level.

Due to characteristics intrinsic to the chosen site or project, a development may have to give up some points, such as the fact that the building is located in a rural area and therefore does not get the score for proximity to metro and train stations. Thus, considering the possible score, the development had the capacity to obtain 83 points, i.e., a Platinum level certification, should the Developer decide to meet all criteria, taking into consideration less complex or planned actions for the development (level 1) and more complex actions subject to technical and economic feasibility analyses (level 2). However, when evaluating the possibilities, the Company chose not to meet some criteria and to receive the Certified certification.

5. Analysis of Results

This study made use of the actions pointed out by MacArthur (EMF 2017) for the incorporation of the circular economy. Likewise, it used the framework proposed by Hossain et al. (2020) to present the steps contained in a LEED® certified building project. Another important theoretical support was the seven actions pointed out by Minunno et al. (2018), used here in order to incorporate circular economy concepts in the construction sector. As a result, it was possible to identify which of them are actually being applied in the Brazilian construction sector and what are the impeding barriers to implementing a circular economy in the sector (Table 3).

Table 3 – Strategies for applying a circular economy

	Strategy	**Strategy implementation**	**Strategy implementation according to the interviews**	**ReSolve**	**4Vs**
i	Reduction of construction waste and lean production chain	Adopt the lean production chain to reduce construction waste	Reuse of materials and reduction of water and energy use	Optimize, Exchange	Volume; Veracity; Variety.
ii	Integration of scrap and waste into new by-products	Use concrete produced from scrap and waste	We have not seen any application of this strategy	Regenerate, Optimize Loop	Volume; Veracity; Velocity;
iii	Reuse of spare parts or entire components	Use second-life components	We have not seen any application of this strategy	Regenerate, Loop	Volume; Veracity; Velocity;
iv	Design for adaptability (reduction through life extension) during operational phases. Adaptability with coordinated actions	Adaptability throughout all operational phases	From the beginning of the project, steps were taken to obtain certification.	Optimize, Exchange	Volume; Veracity; Variety.
v	Project for disassembling goods into components to be reused. Disassembly of parts for reuse of their components	Reusability throughout the end-of-life cycle	They separate reinforced concrete for reuse when an old building is demolished	Regenerate, Optimize Loop	Volume; Veracity; Velocity;
vi	Design for recycling construction materials	Recyclability at the end of the life cycle. Correct destination for recycling of materials and components	Space destined to residues and materials for recycling. Warehouse of recycled materials and management of on-site residues	Optimize Loop	Volume; Veracity; Velocity;
vii	Systems for tracking materials and components in their supply chain	Tracking of materials and their components	They control the materials, components, and waste used on the job site from the raw materials to the building and the waste to the correct location.	Share, Optimize, Virtualize	Volume; Veracity; Variety; Velocity;
viii	Building construction in tune with its surroundings	Building close to public transportation, bicycle paths, shopping centers, supermarkets, collection points, hospitals, among other facilities, thus favoring the life of the residents or visitors to the building	Early in the project there is a strong focus on choosing the best site in order to be more time efficient and reduce the carbon footprint.	Regenerate, Optimize, Exchange	Volume; Veracity; Variety.

Source: Adapted from Minunno et al. (2018)

The study also revealed that the strategies Scrap and waste integration into new by-products and Reuse of spare parts or whole components were not applied in the project under analysis. Thus, within the strategies where we could verify an application, we have:

I. This strategy is being put into practice through the reuse of materials and the reduction of water and energy. In addition, one of the controls we could verify is the existence of respective credits in LEED® certification.

IV. During the interviews, it was possible to see that the bonds do a lot of analysis before and during the project so that it has the maximum efficiency possible and, as a result, the building.
V. Many times before the construction of a sustainable building, it is necessary to do the demolition of an old building that is in place. In this case, we could see that work is done to separate the reinforced concrete so that the concrete and steel are recycled in the right way.
VI. This strategy is being put into practice through the deposit of on-site waste management. In addition, one of the controls that we could verify is the existence of respective credits in LEED® certification.
VII. Here, we could notice a great and effective effort to control the raw material from its origin to the building and also the debris, leaving the construction site to the correct place of disposal or recycling.

Contributing to the list of strategies to apply the circular economy created by Minunno et al. (2018), it is suggested to include an eighth strategy, "focus on constructing a building in tune with its surroundings". This additional strategy focuses on improving the lives of the people who use and live around the building, but can also draw on some points already mapped in LEED® certification, including i. Alternative Transportation, Access to public transportation, and ii. Heat islands, Non-coverage that add up to 17 certification points. Some of the possibilities for meeting these criteria are:

Constructing the building close to public transportation, bicycle paths, shopping centers, supermarkets, hospitals, and other facilities, thus favoring the lives of the building's residents or visitors; and constructing a vegetable garden on the slab of the building, which not only can be used as thermal insulator, reducing the need for internal cooling, but which would also benefit the building's inhabitants or people in vulnerable situations. In this way, the building is expected to be responsible regarding the principles of circular economy, not only in its construction, but also during its life cycle, offering possibilities for people to also develop healthier habits, contributing to the reduction of the carbon footprint, and social and ecological well-being.

Still on the strategies proposed by Minunno et al. (2018), we could notice a strong connection with two other theories: ReSOLVE, and the 4Vs of Large-Scale Data. Connection made with the help of the study by Jabbour et al. (2019), where it was possible to realize that the circular economy can be largely benefited by this technology and behaves as follows:

I. It relates directly to Optimize and Exchange; because by reducing waste, we decrease material consumption and exchange processes that generate a lot of waste for new processes that are leaner.
II. By integrating scrap and waste into new by-products, we can clearly see the connection to Regenerate, Optimize, and Loop, because waste will be reused, fewer products will be discarded, and by-products will be returned to the useful life cycle.
III. Following the same reasoning of the previous strategy, this one also connects with Regenerate and Loop since they reuse materials and return them to the useful life cycle.
IV. In this strategy we can see that, instead of returning the product to the life cycle, it chooses to extend its life through adaptive processes, thus connecting with Optimize and Exchange.
V. It connects with Regenerate, Optimize, and Loop since it disassembles products for recycling and reuse.
VI. Since this is a recycling project, you can see a connection to Optimize by making the process more efficient, and Loop by recycling the materials.
VII. Unlike the other strategies, this one has a great connection to the digital world, as it brings a traceability system for materials and components. Thus, we can see a connection with Share, Optimize, and Virtualize.

Furthermore, we can also draw parallels with the eighth strategy proposed by this paper. This one, unlike the others proposed by Minunno et al. (2018) is general and can adapt to various situations, thus being able to connect with Regenerate, Optimize, and Exchange given that there is a focus on sustainable transportation use, time, and money optimization, and a great influence on reducing the carbon footprint. When talking about the theory of the 4Vs, the analysis was supported by the connections proposed by Jabbour et al. (2019), and it was possible to verify that the eight strategies have at least three of the 4 Vs.

The strategies proposed by Minunno et al. (2018) revolve around the idea of Circular Economy, mostly focusing on waste reduction proposals, conscious disposal, and use of recycled materials. With this in mind, we can see that the strategies connect with the 4Vs in the following way:

A large amount of information about disposal and waste reduction will be generated and used for the implementation of this strategy (volume), but this large amount of information needs to be correct and accurate (veracity). Additionally, this concept of waste reduction, conscious disposal, and use of recycled materials is not limited to just one sector or one activity, it is a concept applied in several areas of the economy. Thus, the data collected and used will be diverse (variety). Finally, with this large volume of information being generated every second every day and the speed with which technologies are developing, it will be necessary for the data generated to be shared quickly (velocity) so that the economy in general will always have the most up-to-date information in order to apply the best strategies for the moment. Thus, we can see that all strategies generate and benefit from a connection to Large-Scale Data technology.

When it comes to LEED® certification, the results show that most of the actions related to circular economy are represented in the LEED® certification criteria, ensuring that the certification created by the Green Building Council encourages and favors the application of circular economy in civil construction.

6. Gaps and future studies

Following the articles analyzed, it was possible to comprehend that only two articles are dedicated to the history of the circular economy and none of them proposes to associate it with other more current concepts such as ReSOLVE and Big Data. Likewise, they do not consider new aspects of the evolution of businesses and social behaviors that change the dynamics of cities. It is therefore suggested that more researchers dedicate themselves to understanding the changes in people's lifestyles, associating them with the style of housing and space design, in the light of the best use of natural resources, ways of getting around, consumption options, among other aspects.

Regarding the LEED certification, projects encourage their teams to take advantage of every opportunity to significantly reduce total water use, as well as the reduction in the consumption of other resources and materials. However, the studies found do not focus on the economic approach as another best results obtained in this type of project.

Our recommendation in line with what we did in this study, is to expand research in terms of a business approach integrating the knowledge in engineering, new technologies, public policies, and social tendencies to evidence the financial advantages and the ways to implement the circular economy, especially in civil construction.

As the last suggestion for future studies, it is advisable that the three steps presented in this case of study be tested in other projects of the same nature, in such a way that their validation can provide guidance for the implementation of circular economy with a view to certification in other existing buildings (historical heritage or not) around the world.

7. Conclusion

In this work we reviewed the existing literature with the main goal of providing evidence to the environmental and circular economy in civil construction expanding their principles to ReSOLVE, formed by the acronym of the English terms regenerate, share, optimize, loop, virtualize, and exchange.

Besides the reflection in the literature, the evolution of the circular economy in the construction sector was also highlighted by the survey respondents, confirming their concern in terms of new forms of application in order to obtain certifications and the resulting gains. However, the research results corroborate Hopkinson et al. (2019) as it was not possible to perceive a great movement in innovations of techniques, methods, and materials used in this sector. According to the interviewees, innovations are often not used due to the great loss of quality when compared to the methods or materials used customarily.

Public policies would motivate (or become an obligation) the implementation of certifications in new buildings and the execution of complex renovations, especially with the development of the technologies to connect materials. Knowledge around the process and the possibilities for each project were portrayed in this article to inspire and orient new certifications. The technology could be directed to effective waste management and to decrease the barriers of the system.

With an increasing concern for the environment and the future of our planet, certifications can be a way out to curb CO_2 emissions, in addition to having great relevance for the future of the civil construction sector. Since buildings do not necessarily need to be demolished and built again but undergo restructuring to comply with LEED® certification, there is already a great gain in time and money, in addition to contributing to the environment and favoring the people who enjoy them, increasing their quality of life as well.

From an academic point of view, the objective of presenting a portrait of the evolution of the concepts that culminated in the development of the circular economy and its applications, with emphasis on civil construction, was achieved. More than showing the evolution of their benefits, this study combinates concepts in terms of usage and application.

From a practical perspective, it was possible to show the Brazilian steps to reach the certification, clarifying the steps, introducing the partners who can work in some tasks and making possible a holistic view about all process of certification in an existing building. The limitation of this study is related to the use of a single case, typical from case of study methodology, so that the parameters presented cannot be generalized, but can inspire other existing historical heritage. Specially because existing building represents the greatest potential for application in view of the greater volume in comparison of new ones to be designed with the goal of obtaining certifications.

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