

**Review Article**

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Circular Economy and Decarbonization in the Construction Waste Chain: Integration of Sustainable Practices and Multisectoral Impacts

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Abstract

Civil construction is responsible for a significant portion of global greenhouse gas emissions and for the generation of large volumes of solid waste, configuring one of the main challenges for urban sustainability and the energy transition. This article presents a systematic review of the literature, conducted according to the PRISMA protocol, with the objective of analyzing the integration between Circular Economy (CE) and decarbonization in the Civil Construction Waste (CCR) chain. The Scopus, Web of Science, ScienceDirect, PubMed, and SciELO databases were consulted, covering publications from 2015 to 2025. The results show that the application of CE principles such as reuse, recycling, reverse logistics and regenerative design can substantially reduce embodied emissions, promote the valorization of materials and strengthen sustainable production chains. The analysis highlighted the importance of civil engineering in the development of low-carbon materials and efficient construction systems; environmental engineering, integrated waste management and life cycle assessment; and biomedicine, in the identification of toxicological and ecotoxicological risks associated with RCC. In addition, technical, economic, and regulatory barriers have been identified that hinder the implementation of large-scale circular models, especially in developing countries, where there is still a lack of infrastructure and economic incentives. Future trends point to the incorporation of digital technologies such as Building Information Modeling (BIM) and blockchain for traceability, as well as the advancement of biomaterials and biocements that reduce the carbon footprint. It is concluded that the integration between CE and decarbonization constitutes a viable and necessary path to achieve climate neutrality and meet the Sustainable Development Goals (SDGs), promoting environmental, social and public health co-benefits.

Keywords: Circular Economy; Decarbonization; Civil Construction Waste; Urban Sustainability; Environmental Health

Introduction

The contemporary environmental crisis emerges as one of the greatest challenges of modern society, driven by population growth, accelerated urbanization, and unsustainable consumption patterns. The exponential increase in greenhouse gas (GHG) emissions and the intensive exploitation of natural resources have compromised the resilience of ecosystems, triggering climate change with significant social and economic impacts [1,2]. According to the Intergovernmental Panel on Climate Change, the atmospheric concentration of carbon dioxide exceeded 420 ppm in 2022, an unprecedented value in the last 800 thousand years, requiring structural

transformations in production and consumption models to limit global warming to 1.5 °C (IPCC, 2023). Civil construction, responsible for approximately 40% of global energy consumption and 36% of energy-related CO₂ emissions, occupies a central position in discussions on climate mitigation and transition to a low-carbon economy [3]. This sector is characterized by a heavy dependence on energy-intensive materials, such as cement, steel, and glass, whose production processes release large amounts of direct and indirect emissions [4]. At the same time, the generation of construction and demolition waste (CDW) has become a growing concern, representing more than 50% of the total urban solid waste in several Latin American cities [5].

The interdependence between urbanization, energy consumption and waste generation reveals the need for a systemic and integrated approach, which simultaneously considers the life cycle of materials, energy efficiency and emissions associates. In this context, the concept of Circular Economy (CE) emerges as an alternative paradigm to the linear logic of production, by proposing the maximization of the value of resources, the extension of the use of materials, and the reintegration of waste into production cycles [6]. CE is directly connected to decarbonization strategies by allowing the reduction of emissions in multiple stages of the production chain, from the extraction of raw materials to final disposal [7]. The global energy transition, driven by international agreements such as the Paris Agreement (2015) and the carbon neutrality goals set by 2050, requires the repositioning of emission-intensive sectors, including civil construction, within a new model of environmental governance [8,3]. This transition involves not only replacing fossil sources with renewable ones, but also adopting eco-design principles, material efficiency, and smart management of energy and waste streams. The convergence between CE and decarbonization, therefore, is established as a strategic axis to reconcile economic growth, technological innovation and environmental sustainability [9].

From a political and economic point of view, the incorporation of the circular economy into decarbonization policies has been recognized by international organizations as an instrument for increasing industrial competitiveness and creating green jobs [10]. In Brazil, the National Policy on Climate Change (Law No. 12,187/2009) and the National Solid Waste Plan (PNRS) establish guidelines that converge with the Sustainable Development Goals (SDGs), especially SDGs 9, 11, 12 and 13, which deal with innovation, sustainable cities, responsible consumption and climate action [11,12]. However, the effective application of these policies in the civil construction sector still encounters structural, institutional and technological barriers. The environmental crisis, therefore, cannot be dissociated from the crisis of development models. The decarbonization of the economy and the circularity of resources configure not only environmental goals, but civilizational transformations that redefine the relationship between infrastructure, nature, and society. In the civil construction waste chain, this movement demands the redesign of production processes, the valorisation of waste as inputs, and the creation of indicators that quantify the environmental and economic gains resulting from circularity. Thus, understanding the interactions between circular economy and decarbonization becomes key to designing integrated strategies that promote urban sustainability and ecological transition on a global scale.

The civil construction sector plays a decisive role in the contemporary environmental configuration, both for its economic relevance and for its impact on the cycles of materials, energy and emissions. It is estimated that the construction production chain encompassing extraction, transportation, manufacturing, operation, and demolition is responsible for approximately 40% of global carbon dioxide (CO₂) emissions and 36% of total energy consumption [3]. These indices reflect the intense dependence on inputs with a high carbon footprint, such as Portland cement, whose production alone accounts for about 8% of global CO₂ emissions [13].

Thus, understanding the magnitude of these emissions is essential to design mitigation policies and sectoral decarbonization strategies.

The production of cement, steel, and glass involves thermo-intensive processes that use fossil fuels and release greenhouse gases (GHG) directly in the calcination and combustion stages. In the case of cement, CO₂ is released both by the burning of fuels and by the thermal decomposition of limestone ($\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$), and this second route is responsible for approximately 60% of the sector's total emissions (SCRIVENER; JOHN; GARTNER, 2018). In addition, the operation of buildings, especially in tropical and developing countries, contributes significantly to the consumption of electricity, ventilation, and cooling, perpetuating the cycle of indirect emissions associated with the use of buildings [14]. In addition to emissions, the generation of construction and demolition waste (CDW) is one of the largest environmental externalities in the sector. In Brazil, this waste represents between 50% and 70% of total urban solid waste [15], reflecting construction patterns that are still unsustainable and the absence of large-scale circular practices. The inadequate disposal of these materials in landfills or irregular areas generates significant impacts, such as occupation of fertile areas, contamination of soils and watercourses, in addition to increased logistics and transportation costs [16]. These problems reveal the urgency of integrated public policies that prioritize prevention, reuse, and recycling.

The demolition stage, in particular, is a critical source of indirect emissions, as the transportation and final disposal processes demand high energy consumption and involve diesel-powered machinery [17]. Recent studies indicate that up to 30% of the total embedded energy of a building can be associated with the construction and demolition phases [18]. In this sense, the concept of "gray energy" referring to the sum of the energy spent throughout the life cycle of the material becomes a strategic indicator for the environmental assessment of buildings, especially when considered in synergy with Life Cycle Analysis (LCA) methodologies [19].

Another relevant challenge is the lack of standardization and traceability of waste streams. The lack of reliable data on the volumes, composition and final destination of CDW limits the effectiveness of management instruments and circular economy strategies [20]. In developed countries, the implementation of Building Information Modeling (BIM) and integrated databases has allowed greater predictability and reduction of material losses, while in Brazil such tools are still incipient. The integration between technology, regulation, and innovation becomes, therefore, essential to reduce emissions associated with the production chain and mitigate environmental impacts. Finally, it is essential to recognize that sustainability in civil construction goes beyond energy efficiency and waste recycling: it involves a paradigmatic change in the way urban spaces are designed, built, and managed. Strategies such as modular design, the use of recycled materials, off-site construction, and the reuse of waste as recycled aggregates represent viable paths to align the sector with global carbon neutrality goals [21]. In this way, civil construction assumes the role of a transforming agent, being simultaneously a source of impact and a potential solution to the global environmental and climate crisis.

The transition from a linear economic model characterized by the stages of extraction, production, consumption and disposal to a circular model represents one of the most relevant structural transformations of the twenty-first century. The Circular Economy (CE) proposes a systemic redesign of production and consumption, seeking to optimize material and energy flows, reduce waste generation, and regenerate natural capital [22]. This approach recognizes that planetary resources are finite and that efficiency alone is not sufficient to mitigate environmental impacts; it is necessary to reintegrate waste as inputs and maintain the value of products through reuse, recycling and remanufacturing [6]. In the global context, CE has been consolidated as a structuring axis of sustainability and industrial innovation policies. The European Union has been a pioneer in the formulation of strategic plans that incorporate circularity as a tool for competitiveness, decarbonization and the generation of green jobs [10]. Such policies aim to decouple economic growth from natural resource extraction, promoting a regenerative and resilient economy. This vision broadens the reach of climate policies, articulating material efficiency, carbon neutrality, and sustainable economic development [7].

The relationship between CE and decarbonization is direct and multidimensional. Circular strategies such as recycling materials, reusing components, and extending the useful life of products significantly reduce the demand for virgin raw materials, whose production is highly energy- and carbon-intensive [23]. In addition, circularity practices contribute to the reduction of emissions associated with transportation, storage, and disposal, promoting significant reductions in greenhouse gas (GHG) emissions throughout the life cycle of products [24]. Thus, the EC constitutes an essential strategy to achieve the goals of carbon neutrality by 2050, as agreed in the Paris Agreement [8]. The incorporation of the principles of the Circular Economy (CE) in civil construction represents one of the most promising strategies for mitigating the environmental impacts of the sector. The application of these concepts aims to extend the life cycle of materials, reduce the consumption of natural resources, and minimize waste generation [6]. In the context of the construction production chain, this translates into practices such as the recycling of construction and demolition waste (CDW), the use of materials with low environmental impact and the reuse of structural components in new projects [25]. These strategies contribute to reducing emissions associated with extraction, transportation, and disposal, strengthening the transition towards carbon neutrality.

One of the central pillars of CE applied to construction is Life Cycle Analysis (LCA), which allows the evaluation of the inputs and outputs of energy and matter at all stages of the construction process. This tool makes it possible to compare constructive alternatives, quantify emissions and identify opportunities for environmental improvement [19]. Studies show that the use of recycled aggregates from RCC can reduce between 15% and 30% the CO₂ emissions associated with concrete production, without compromising its structural performance [17]. In addition, the use of technologies such as Building Information Modeling (BIM) and Design for Disassembly (DfD) has enhanced the planning of more efficient and dismantlable buildings, favoring the reuse of materials and the traceability of waste [18]. Another important vector of circularity

in construction is ecodesign, which integrates environmental criteria from the early stages of architectural design. This approach considers the choice of local materials, the use of recyclable inputs, and the reduction of energy incorporated in construction systems [26]. The introduction of green roofs, rainwater harvesting systems, and ventilated facades are examples of sustainable design solutions that increase energy performance and reduce the carbon footprint of buildings [4]. Such initiatives demonstrate that sustainability is not just a technical attribute, but an aesthetic and functional component of architectural innovation.

However, the practical application of CE in civil construction faces significant barriers. Among the main challenges are the lack of economic incentives, the scarcity of infrastructure for sorting and recycling, the absence of specific technical standards, and the cultural resistance of the sector to adopt new technologies [20]. The still prevalent informality in CCR management and the difficulty of tracking material flows limit the advancement of circular policies, especially in developing countries. In addition, the initial costs of implementing innovative solutions can discourage small and medium-sized companies, which operate with reduced financial margins. From a socioeconomic point of view, the benefits of CE in construction are broad and intersectoral. The recovery of waste and the reuse of materials create new production chains and green jobs, promoting social inclusion and local economic dynamism [10]. At the same time, reducing dependence on virgin raw materials contributes to mitigating pressures on ecosystems and reducing transportation and disposal costs. When articulated with decarbonization policies and a low-carbon economy, circularity offers an integrated response to the environmental, energy, and climate crises, with the potential to reconfigure the entire production cycle of civil construction [9].

Thus, the effective implementation of the circular economy in civil construction depends on the integration between technological innovation, public governance, and environmental education. It is essential that universities, regulatory bodies, and the productive sector act together in the formulation of policies and projects that encourage circularity, from the conception to the demolition of buildings. This interinstitutional articulation must be aligned with the Sustainable Development Goals (SDGs), especially SDGs 9, 11, 12 and 13, and with international commitments to carbon neutrality by 2050. In this scenario, circularity is no longer a trend and consolidates itself as a strategic axis of contemporary urban and industrial sustainability. Circularity also stimulates technological innovation and the reconfiguration of production systems, by favoring design for disassembly, modularity, and the use of materials with low environmental impact [26]. Such innovations drive new value chains and encourage business models based on services and sharing, reducing dependence on non-renewable resources and embodied energy costs. In the construction sector, for example, the adoption of circularity practices such as the use of recycled aggregates, the reuse of metal structures, and eco-design has the potential to reduce between 20% and 30% of sectoral CO₂ emissions [4].

In Brazil, the incorporation of CE is still incipient, but it has been gaining strength in public policies and national plans aligned with the Sustainable Development Goals (SDGs) and the National

Solid Waste Policy (PNRS) [12,27]. Initiatives such as the Brazilian Coalition for the Circular Economy have sought to promote articulation between government, academia and the productive sector to accelerate the adoption of sustainable practices. However, challenges persist, especially in the lack of infrastructure for waste sorting, recycling and traceability, as well as in the scarcity of economic incentives for the reuse of materials [28]. Therefore, CE presents itself as an essential vector of decarbonization and sustainable innovation. By integrating principles of efficiency, regeneration, and environmental responsibility, it offers a concrete path to make economic growth compatible with global climate mitigation goals. In the context of civil construction, circularity represents a strategic opportunity to reconnect the production cycle to nature, transforming waste into resources and drastically reducing emissions associated with extraction and disposal. This convergence between CE and decarbonization not only redefines industrial paradigms, but also consolidates a new logic of fairer, more resilient, and environmentally balanced development.

The civil construction waste chain (CCR) is not restricted to a technical issue of materials management, but involves a field of complex environmental and public health interactions, requiring interdisciplinary approaches. The presence of chemical contaminants, fine dust, and heavy metals in demolition and refurbishment waste confers on these materials a potential toxicological risk for ecosystems and exposed human populations [29]. Studies indicate that CCRs containing paints, solvents, cement and plaster can release substances such as lead, cadmium, arsenic and chromium, elements known for their environmental persistence and bioaccumulation capacity [30]. Thus, the analysis of the toxicity of CCRs goes beyond the field of civil engineering and enters the domain of environmental engineering and biomedicine, integrating chemical, ecological and sanitary dimensions. From an environmental point of view, CCRs present a complex behavior due to the heterogeneity of the materials and the conditions of disposal. When deposited in inappropriate areas, they can promote leaching of alkaline compounds and heavy metals, altering the pH and electrical conductivity of soil and groundwater [31]. These contamination processes generate ecotoxicological effects, affecting microorganisms, invertebrates and plants, and compromising the structure and structure of the functioning of ecosystems [32]. In this context, environmental engineering contributes with monitoring, modeling, and remediation tools, such as ion mobility analyses, leaching assays [33], and acute and chronic toxicity bioassays.

On the other hand, civil engineering plays a key role in minimizing these impacts by incorporating sustainable design principles, the use of recycled materials, and the development of clean technologies. The use of recycled aggregates from RCC, when properly treated, reduces the extraction of natural resources and contributes to the closure of production cycles [25]. However, the reuse of this waste requires strict control of contaminants and evaluation of physical and chemical properties, in order to ensure the structural and environmental safety of buildings [16]. This interface between civil and environmental engineering becomes essential for the effective implementation of circular economy and decarbonization practices. The biomedical dimension of RCC is manifested in occupational and community exposure to toxic particles and com-

pounds released during demolition, transport and storage processes. Dusts rich in crystalline silica, for example, are associated with lung diseases such as silicosis, chronic bronchitis, and lung cancer [34]. Prolonged exposure to heavy metals can generate neurotoxic, hepatotoxic, and genotoxic effects, as well as interfere with endocrine and immune processes [35]. Thus, biomedicine contributes with analytical methodologies for the detection of exposure biomarkers and evaluation of the physiological and cellular effects resulting from the pollution generated by RCCs.

This convergence between civil engineering, environmental engineering, and biomedicine also favors the development of more integrated and effective public policies. The interdisciplinary approach allows the evaluation of the impacts of CCR management from the perspective of One Health, recognizing that built environments, ecosystems, and human health are intrinsically connected [36]. Integrated environmental and health risk assessments considering the waste life cycle, exposure routes and cumulative effects are essential to guide decisions on urban planning, environmental licensing and technical standardization. Finally, the integration between these scientific fields reinforces the need for an evidence-based ecological transition. Solutions to the environmental crisis and the decarbonization of the construction sector require not only technological innovation, but also knowledge about the toxicological and epidemiological impacts arising from poor waste management. Progress in sustainable and circular practices, therefore, must go hand in hand with the assessment of risks to human health and the integrity of ecosystems. This interdisciplinary synergy is the basis for the development of resilient, healthy cities aligned with global sustainability and carbon neutrality goals. The main objective of the review is to analyze, through a systematic review of the literature, the interrelationships between the circular economy and the strategies of decarbonization applied to the civil construction waste chain, identifying sustainable practices, management instruments and interdisciplinary interfaces between civil engineering, environmental engineering and biomedicine, with a focus on mitigating environmental, ecotoxicological and health impacts.

The growing intensification of the climate crisis, associated with rapid urbanization and the expansion of the civil construction sector, has highlighted the urgency of new productive paradigms that reconcile economic development and environmental preservation. The construction sector is currently one of the largest emitters of greenhouse gases (GHG), responsible for approximately 40% of global CO₂ emissions and 36% of global energy consumption [3]. In Brazil, the scenario is equally challenging, with construction and demolition waste (CDW) representing more than half of the total municipal solid waste generated [15]. These indicators demonstrate the need to reformulate the prevailing linear logic based on extract, produce, consume and discard and replace it with a circular economy (CE) model capable of promoting the decarbonization of the production chain and the regeneration of ecosystems.

From a scientific point of view, this topic is justified by the scarcity of integrated studies that address the convergence between circular economy, decarbonization and environmental health in a multisectoral way. Although the international literature highlights technological advances aimed at recycling, sustainable design, and

energy efficiency [6,4], there are still significant gaps in the assessment of the ecotoxicological and health impacts of construction waste [28]. In this context, the articulation between civil engineering, environmental engineering and biomedicine becomes essential to understand not only the material and energy dimensions, but also the biological and epidemiological effects resulting from the mismanagement of CCRs. This integration of knowledge expands the potential for scientific and technological innovation in line with the principles of sustainability and One Health. In addition to its scientific relevance, the topic has a direct social and economic impact, especially in developing countries. The implementation of circular practices in construction can generate new green jobs, reduce operating costs and boost local production chains based on waste reuse [10]. At the same time, the mitigation of emissions and the proper disposal of CCRs contribute to the improvement of air, water and soil quality, promoting healthier and more resilient urban environments. Such actions dialogue with the Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, innovation and infrastructure), SDG 11 (Sustainable cities and communities), SDG 12 (Responsible consumption and production) and SDG 13 (Action against global climate change) [8].

In the Brazilian context, the social relevance of this study is also based on the need to strengthen public policies and normative instruments such as the National Solid Waste Policy (PNRS) and the National Policy on Climate Change (PNMC), which establish goals for reducing waste and GHG emissions [11,12]. However, the effective implementation of these policies still faces obstacles related to institutional fragmentation, lack of infrastructure for sorting and recycling and the absence of economic incentives aimed at circularity. Scientific advances in the area, therefore, can support the improvement of regulatory frameworks, contributing to the formulation of integrated strategies for sustainable urban planning. The proposed investigation also has educational and formative relevance, by encouraging the training of engineering and health sciences professionals to work in sustainable projects with a systemic vision. Technical and scientific training based on sustainability, decarbonization, and circular economy is essential for building a future with less dependence on fossil resources and greater socio-environmental equity [27]. In addition, the theme offers potential for the creation of university extension projects and technological innovation, bringing academia, the productive sector and the community closer together, and strengthening the relationship between science and society.

Finally, the scientific and social justification of this work is based on the urgency of rethinking urban infrastructure from an ecological and regenerative perspective. The transition to circular models of production and consumption is not only an environmental imperative, but a civilizing one. By investigating the integration between circular economy and decarbonization in the construction waste chain, this systematic review aims to contribute to the advancement of applied science and to the formulation of viable and inclusive solutions, capable of promoting environmental sustainability, collective health and the well-being of future generations.

Review Methodology

The present study is characterized as a systematic review of the literature, conducted in accordance with the recommendations

of the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), with the objective of identifying, analyzing and synthesizing scientific evidence on the integration between Circular Economy (CE), decarbonization and management of civil construction waste (RCC). The choice of this type of review is based on the need to gather information from primary studies dispersed in different databases, in order to produce a comprehensive, critical, and updated view of the state of the art on the subject. The search strategy was structured and applied in the Scopus, Web of Science, ScienceDirect and PubMed databases, selected for their broad multidisciplinary coverage and relevance to the fields of engineering, environmental sciences and biomedicine. In addition, the SciELO and Google Scholar databases were consulted for the inclusion of scientific literature produced in the Latin American and national context, in order to ensure regional representativeness. The search was carried out between February and March 2025, considering the publication period from 2015 to 2025, in order to cover the most recent scientific advances on the application of the circular economy and decarbonization strategies in the construction sector.

To compose the search strategy, standardized keywords in English were used.

The descriptors were selected based on the controlled terms of the MeSH (Medical Subject Headings) and Elsevier Thesaurus databases, covering related concepts

waste management, carbon footprint, energy efficiency, circular economy, civil engineering and environmental sustainability.

Inclusion criteria were defined to ensure the relevance and quality of the evidence analyzed:

- a. Peer-reviewed scientific articles, published between 2015 and 2025;
- b. Original studies, revisions or technical reports that directly address the application of the circular economy, decarbonization practices or CCR management;
- c. Texts available entirely in English, Portuguese or Spanish;
- d. Works that presented empirical data, comparative analyses or conceptual discussions applied to the construction sector.

Documents that did not present an explicit methodology, studies focusing on other types of waste (such as industrial or hospital), duplicates, and publications of an opinionated or non-scientific nature (such as expanded abstracts, editorials, and dissemination articles) were excluded.

After the search stage, the results were subjected to a screening and eligibility process in three phases:

- a) Reading of titles and abstracts, to eliminate out-of-scope records;
- b) Analysis of the full text, to verify alignment with the inclusion criteria;
- c) Qualitative evaluation of the content, with categorization of the studies according to the thematic axes of interest.

The strategy of synthesis and categorization of the results was carried out qualitatively, based on thematic and comparative analysis of the findings. The selected studies were grouped into four analytical categories:

- a. Circular economy practices in civil construction;
- b. Decarbonization and energy efficiency strategies;
- c. Management and recovery of construction and demolition waste (CDW);
- d. Interdisciplinary interfaces and environmental health impacts.

The data extracted from each study included: author, year, country, type of research, objectives, methods, results, and main conclusions. The synthesis of the results will be presented in a narrative and interpretative way, highlighting convergences, gaps and emerging trends. The PRISMA flowchart, representing the process of identification, screening, eligibility and inclusion of articles, will be used to document the transparency and reproducibility of the review.

Circular Economy: Principles and Models Applied

The Circular Economy (CE) is a systemic approach aimed at the redesign of production processes, with the objective of maximizing efficiency in the use of resources and minimizing the generation of waste throughout the life cycle of products. In opposition to the traditional linear model “extract, produce, consume, and dispose”, CE proposes the creation of closed material cycles, in which waste from one process becomes inputs for another [22]. This logic is based on the waste hierarchy, which establishes an order of priority in management strategies: prevention, reuse, recycling, energy recovery and, finally, final disposal [37]. This hierarchy guides environmental decision-making and is recognized as one of the pillars for the transition towards carbon neutrality and global sustainability. The concept of a closed cycle of materials involves not only the physical reinsertion of waste into production streams, but also the preservation of the economic and functional value of products over time [7]. This requires the development of integrated strategies that contemplate eco-design, durability, modularity, and ease of repair. In civil construction, this principle translates into the use of recyclable materials, the use of structural components from demolitions and the creation of reverse supply chains. The closed loop does not completely eliminate environmental impacts, but it substantially reduces the dependence on virgin raw materials and the energy embodied in products, directly contributing to the decarbonization of the economy [6].

Circular business models expand the applicability of CE and reconfigure the way companies and consumers relate to goods and services. Among the main models, the following stand out: remanufacturing, which involves the restoration of used products to conditions of use equivalent to those of new ones; reuse, which extends the useful life through repairs and sharing; recycling, which converts waste into secondary raw materials; and regenerative design, which incorporates ecological principles to restore and regenerate degraded ecosystems [26]. In civil construction, such models can be observed in the adoption of modular techniques, in the use of materials of recycled origin, in the maintenance of structural compo-

nents and in the redesign of buildings for disassembly [25]. These mechanisms consolidate the concept of “cradle to cradle”, in which the end of one production cycle represents the beginning of another. In the global context, the European Union emerges as a reference in the institutionalization of the circular economy through the European Green Deal and the Action Plan for the Circular Economy, which establish binding targets for reducing emissions, resource efficiency, and stimulating sustainable innovation [10]. Such policies guide the adoption of circularity indicators and promote integration between climate, industrial, and waste policies. At the international level, the ISO 14001:2015 [38] standard, aimed at Environmental Management Systems, provides a normative reference that encourages organizations to monitor their impacts, adopt continuous improvement practices and ensure compliance with environmental regulations [38]. This methodological framework has been widely incorporated by industrial and construction sectors as a tool for auditing and reducing the carbon footprint.

In Brazil, the National Solid Waste Policy (PNRS), instituted by Law No. 12,305/2010, represents the regulatory framework for sustainable waste management and incorporates principles aligned with CE, such as shared responsibility for the life cycle of products and reverse logistics [12]. Although the PNRS still faces challenges in its effective implementation, it has boosted the development of recycling chains and fostered the discussion on sustainability in the civil construction sector. The integration of the PNRS with the National Plan on Climate Change (PNMC) and the commitments made under the Paris Agreement [8] reinforces the country's strategic role in the transition to a low-carbon economy.

Therefore, the theoretical foundations of the circular economy are intrinsically related to resource efficiency, technological innovation, and environmental governance. Its application to civil construction is not limited to the reuse of waste, but involves a systemic reconfiguration of production chains, requiring collaboration between government, companies, and academia. By promoting the synergy between circularity and decarbonization, CE consolidates itself as an axis of economic and environmental transformation capable of redefining the patterns of production, consumption, and regeneration of resources in the twenty-first century.

Decarbonization and Carbon Footprint in Construction

The decarbonization of civil construction is one of the main fronts for mitigating climate change, given the magnitude of emissions associated with this sector. It is estimated that the construction production chain is responsible for approximately 40% of global carbon dioxide (CO₂) emissions and 36% of global energy consumption [3]. These emissions derive from multiple sources, ranging from the production of mineral-based materials to energy consumption during the operation of buildings. Direct emissions are those from production processes and the use of fossil fuels, such as cement calcination ($\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$), the burning of coal and fuel oil in furnaces and the transportation of materials [39]. Indirect emissions, on the other hand, result from electricity consumption and the supply chain, encompassing the transportation of inputs and the disposal of demolition waste [4].

The carbon footprint in construction is therefore an essential metric for quantifying the climate impacts associated with the en-

tire life cycle of a building. The concept of carbon footprint is defined as the sum of greenhouse gas emissions expressed in carbon dioxide equivalents (CO₂ e), covering direct and indirect emissions [40]. For the calculation and management of these emissions, two consolidated methodologies stand out: the GHG Protocol (Greenhouse Gas Protocol) and the Life Cycle Assessment (LCA). The GHG Protocol, developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), classifies emissions into three scopes Scope 1 (direct emissions), Scope 2 (indirect energy emissions), and Scope 3 (value chain emissions), allowing comparability across organizations and sectors [41]. The LCA, standardized by ISO 14040 and 14044, evaluates the inputs and outputs of matter and energy throughout all stages of the life cycle, identifying opportunities to reduce environmental impact [19].

In civil construction, the combined application of these methodologies makes it possible to estimate embodied energy and embodied carbon emissions in each phase of the enterprise. This analysis includes everything from the extraction of raw materials and the manufacture of materials (such as steel, glass, ceramics, and cement), to construction, operation, maintenance, and demolition [42]. Studies show that cementitious materials, alone, account for about 8% of global CO₂ emissions, which makes their partial replacement by alternative materials, such as pozzolans and fly ash, a priority measure [13]. The identification of critical points in the life cycle helps in the formulation of public policies and incentives for the adoption of low-carbon technologies in the construction sector. Carbon mitigation strategies in civil construction include energy efficiency measures, material substitution, technological innovation, and waste management. The adoption of ecological cement, the use of recycled aggregates, and the use of renewable energy in production processes are practices that significantly reduce the carbon footprint [17]. In addition, the digitalization of construction processes, through tools such as Building Information Modeling (BIM), allows optimizing the use of resources, reducing losses, and simulating emission scenarios [18]. Other approaches include passive building design, the incorporation of local materials and low embodied energy, and the implementation of ventilation and daylighting systems that reduce energy consumption during operation.

Carbon offsetting, in turn, is a complementary strategy that seeks to neutralize unavoidable residual emissions through investments in carbon sequestration projects or certified carbon credits. Programs such as the Clean Development Mechanism (CDM) and the Certified Emission Reduction Projects (CER), provided for in the Kyoto Protocol and maintained under the aegis of the Paris Agreement, enable compensation via reforestation, recovery of degraded areas and clean energy [8]. In Brazil, the National Policy on Climate Change (Law No. 12,187/2009) and the Brazilian Emissions Reduction Market (MBRE) provide guidelines for the regulation of these initiatives, integrating the construction sector into the national carbon neutrality goals [11]. It should be noted that the effectiveness of mitigation and compensation strategies depends on solid environmental governance, standardized measurement, and transparency of emissions data. The absence of standardized sectoral inventories and the fragmentation of policies still represent barriers to the full decarbonization of civil construction, especially in emerging countries [20]. Thus, the rigorous application of internationally

recognized methodologies and the strengthening of environmental performance indicators are indispensable conditions for aligning the sector with global commitments to reduce emissions by 2050.

In this way, decarbonization in civil construction transcends mere technological substitution, configuring itself as a strategic process of ecological and systemic transition. By integrating carbon footprint measurement with the principles of the circular economy, the sector has the potential to become an active agent in climate mitigation, promoting the rational use of resources, the valorization of waste, and the construction of sustainable and resilient cities.

Civil Construction Waste (RCC) and its Production Chain

Civil Construction Waste (CCR) represents one of the most voluminous fractions of urban solid waste, constituting a technical, environmental and public health challenge for the sustainable management of cities. According to Resolution No. 307/2002 of the National Council for the Environment (CONAMA), CCRs are defined as materials resulting from constructions, renovations, repairs and demolitions of civil works, including those resulting from the preparation and excavation of land [43]. The characterization of RCC shows a wide diversity of materials, such as concrete, mortar, ceramics, metals, wood, glass, plaster and plastics [16]. This waste can be classified according to its origin public works, residential buildings, urban infrastructure or demolition activities and, according to its composition, into RCC class A (reusable materials such as aggregates), class B (plastics, paper, metals and glass), class C (without viable recycling technology) and class D (containing hazardous substances, such as paints, solvents and asbestos). In the global scenario, it is estimated that the construction sector generates between 30% and 40% of total municipal solid waste, corresponding to approximately 2.2 billion tons per year [44]. In Brazil, the volume is equally significant: in 2022, about 48 million tons of RCC were registered, of which more than 60% were disposed of inappropriately [15]. The absence of infrastructure for sorting and recycling, associated with informality in the sector, contributes to the irregular disposal and accumulation of these materials in urban and peri-urban areas [31]. Although the National Solid Waste Policy (PNRS) has established targets for reduction and reuse, RCC recycling rates in the country remain below 10%, contrasting with rates above 70% in European countries such as Germany and the Netherlands [45].

The environmental impacts resulting from the mismanagement of CCRs are broad and multi-scalar. Improper disposal in vacant lots, slopes, and river banks causes soil impermeabilization, obstruction of drainages, increased risk of flooding, and landscape degradation [32]. The decomposition of organic compounds present in mixed waste generates methane (CH₄) emissions, contributing to the greenhouse effect, while the fragmentation of fine materials releases crystalline silica particles and microdust, which affect urban air quality [34]. In addition, the leaching process of heavy metals such as lead, cadmium, copper, and zinc from contaminated CCRs can alter the pH and electrical conductivity of soil and groundwater, compromising aquatic and terrestrial ecosystems [31,28]. From a public health perspective, CCRs are an emerging problem, especially in expanding metropolitan regions. The accumulation of waste in open areas favors the proliferation of pathogenic vectors, such

as mosquitoes, rodents, and cockroaches, which transmit diseases such as dengue, leptospirosis, and leishmaniasis [46]. Occupational exposure of construction workers and waste pickers to dust and toxic compounds also poses a significant risk, and can result in respiratory diseases, dermatitis, poisoning, and neurotoxic effects [35]. These risks reinforce the need for integration between environmental engineering, public health and biomedicine, in order to understand the combined effects of pollution generated by RCC on the quality of life of urban populations.

Interfaces with biomedicine are particularly relevant when considering the toxicity of RCC components. Studies indicate that microparticles derived from concrete, cement, and ceramics can induce inflammatory responses and oxidative stress in lung epithelial cells, promoting tissue and genotoxic damage [34]. Chronic exposure to heavy metals such as lead, arsenic, and chromium, often present in waste contaminated by paints and coatings, is associated with endocrine, hepatotoxic, and carcinogenic disorders [30,35]. In addition, the inhalation of respirable crystalline silica is recognized by the World Health Organization as one of the main etiological agents of silicosis, an irreversible and occupationally prevalent lung disease in construction workers [35]. These effects show that environmental toxicology should be considered a structuring axis in the formulation of waste management policies and in the environmental impact assessment of civil works. In this context, the interdisciplinary analysis of the CCR production chain is essential for the advancement of circular economy and decarbonization practices. The transformation of waste into secondary inputs, in addition to reducing environmental impacts, can minimize human exposure to contaminants and contribute to meeting carbon neutrality goals by 2050 [2]. Therefore, understanding the technical, environmental, and biomedical aspects of CCRs not only subsidizes the development of new recycling and monitoring technologies, but also strengthens integrated public policies aimed at urban sustainability and One Health.

Circular Economy Practices in the CCR Chain

The application of the principles of the Circular Economy (CE) in the production chain of civil construction waste (CCR) is one of the most effective strategies to reduce environmental impacts and promote the decarbonization of the sector. The transition from the linear model to a circular system involves not only recycling, but the redesign of material and logistical flows, ensuring that waste returns to the production chain as secondary value-added inputs [6]. This approach integrates technological innovation, environmental governance, and sustainable urban planning, in line with the goals of the Paris Agreement and the Sustainable Development Goals (SDGs), especially SDGs 9, 11, 12, and 13 [8].

Reuse and Recycling of Materials

Reuse and recycling represent the fundamental pillars of the circular economy applied to CCRs, making it possible to reduce the extraction of natural resources and reduce the carbon footprint of buildings. The initial stage involves the separation and sorting of waste at construction sites and processing units, where advanced technologies have been implemented to optimize the efficiency of the process. Among the separation techniques, vibratory sieving systems, optical classification by color and density, and the use of

magnetic and electrostatic sensors for the identification of metals and plastics stand out [17]. In Brazil, the NBR 15114 [47] establishes criteria for the operation of RCC recycling areas, including quality parameters for recycled aggregates and guidelines for environmental and emission control. Processing technologies make it possible to transform inert waste (class A) into recycled aggregates, applicable in paving, sealing blocks, non-structural concretes and road bases [25]. These materials have satisfactory mechanical performance and reduce energy consumption by up to 30% compared to natural aggregates [18]. The production of eco-concretes, formulated with low-clinker cement, mineral additions, and recycled aggregates, has proven to be a viable alternative to mitigate the emissions associated with cement production responsible for about 8% of global CO₂ [13]. In addition, the incorporation of pozzolanic materials, such as fly ash and silica fume, improves durability and reduces the permeability of concrete, promoting greater structural efficiency and sustainability.

Recently, scientific research has expanded the use of biotechnology and nanomaterials as instruments to minimize the environmental impact of CCRs. Bio cements produced by micro-organism-induced precipitation (MICP) have been studied as a sustainable alternative to Portland cement, significantly reducing CO₂ emissions during production [48]. The application of nanosilica, carbon nanotubes, and graphene in recycled concrete matrices increases strength, reduces cracks, and enhances the absorption of air pollutants [4]. These advances demonstrate that the integration between civil, environmental and biotechnology engineering is essential for the development of regenerative materials, which combine technical performance with the mitigation of ecotoxicological and climate impacts. In addition to the environmental gains, the reuse and recycling of CCR generate significant socioeconomic benefits. The creation of cooperatives and micro-enterprises contributes to the social inclusion of waste pickers and informal workers, promoting green jobs and strengthening local economies [27]. Thus, the recycling of CCR goes beyond the technical character, configuring itself as a strategic tool for environmental justice and socioeconomic transition to more sustainable urban models.

Reverse Logistics and Sustainable Chain

Reverse logistics is one of the central instruments of the National Solid Waste Policy (PNRS) and constitutes the link that connects the generation of RCC to its productive reinsertion. Its objective is to plan, implement and control the return flow of post-consumption or post-demolition materials, promoting the reintegration of these resources into the production chains [12]. In civil construction, reverse logistics involves selective collection at construction sites, transportation to sorting points, and disposal to licensed recycling units. Successful models, such as the European one, use integrated logistics centers, which operate with digital traceability and certification of the origin of waste [10]. In Brazil, experiences in cities such as São Paulo and Curitiba have demonstrated the economic and environmental potential of this practice when articulated with municipal policies and public-private partnerships [31].

Governance and traceability are key elements to ensure the efficiency of reverse logistics. The use of digital monitoring systems, such as georeferencing platforms and QR Codes, allows you to follow the path of waste from generation to final reuse [29]. This

traceability is essential to curb irregular disposal and strengthen environmental control. In addition, shared responsibility mechanisms between construction companies, suppliers and public authorities ensure that each agent in the production chain contributes to the closure of material cycles, as provided for in the PNRS [12]. Circular performance indicators have emerged as essential instruments for evaluation and monitoring. Among the main indicators used, the following stand out: the RCC recycling rate (% of the total collected), the landfill diversion rate, the substitution factor of natural aggregates for recycled ones and the avoided emissions index (t CO₂ e) [10]. The adoption of these indicators makes it possible to measure progress towards circularity and carbon neutrality, in addition to subsidizing evidence-based public policies. At the international level, the combined use of the Material Circularity Indicator (MCI), proposed by the Ellen MacArthur Foundation, and the carbon footprint indicators (GHG Protocol) has proven effective in assessing the environmental performance of construction chains [22].

Therefore, the integration between reuse, recycling and reverse logistics constitutes the operational core of the circular economy applied to civil construction. The creation of sustainable chains depends on a collaborative ecosystem that unites technology, regulation and social responsibility. By promoting regenerative and traceable material flows, reverse logistics consolidates circularity as a strategic vector of decarbonization, reinforcing the role of civil construction as a transforming agent in mitigating climate change and promoting environmental health.

Interdisciplinary Integration: Civil, Environmental and Biomedical Engineering

The complexity of contemporary environmental challenges demands interdisciplinary approaches capable of articulating different fields of knowledge around common goals of sustainability, decarbonization, and promotion of One Health. In the context of the civil construction waste chain (CCR), this integration is essential to understand the totality of the impacts from the conception of the material to its final disposal and to develop innovative solutions that reconcile technical efficiency, environmental responsibility and health safety [36]. The collaboration between civil engineering, environmental engineering and biomedicine represents, therefore, a strategic axis in the consolidation of sustainable and socially responsible construction models. Civil engineering plays a central role in developing sustainable materials and high-efficiency construction systems. Research in the area has advanced in the creation of eco-concrete, low-carbon cementitious materials, demountable modular structures and recyclable components, in line with the principles of the circular economy [25]. These developments reduce the energy embodied in materials and extend the useful life of buildings, reducing the need for new extraction and demolition [4]. In addition, the integration of tools such as Building Information Modeling (BIM) and Analysis

in the design phase has made it possible to optimize the use of resources and predict the emissions associated with each construction stage [18]. Thus, civil engineering repositions itself not only as a producer of infrastructure, but as an active agent in the transition to low-carbon cities. Environmental engineering, in turn, provides the scientific and regulatory basis for sustainable waste manage-

ment and control of associated impacts. Its activities include the integrated management of RCCs, the development of municipal solid waste plans and the environmental licensing of sorting and recycling areas [12]. Tools such as Life Cycle Assessment (LCA) and Greenhouse Gas (GHG) Emissions Inventory are applied to identify critical points of impact, guide the choice of materials, and support mitigation decisions [19,41]. In addition, environmental engineering plays a crucial role in the formulation of public policies and economic instruments such as destination fees and carbon credits that encourage circular practices and strengthen climate governance [2]. This interface between technique, politics, and economics is indispensable to consolidate the decarbonization of civil construction. Biomedicine introduces a complementary and indispensable dimension to this process, by studying the impacts of construction waste on human and environmental health. Occupational exposure to fine dusts, volatile compounds, and heavy metals derived from CCR is associated with respiratory diseases, dermal lesions, endocrine disorders, and genotoxic effects [34,35]. Biomedicine contributes to the identification of exposure biomarkers and ecotoxicology studies, which assess the bioaccumulation of contaminants in organisms and trophic transfer in impacted ecosystems [28]. In addition, the integration with environmental engineering allows the joint monitoring of air, water and soil quality, while the interaction with civil engineering promotes ergonomic and sanitary improvements at construction sites, reducing occupational risks. This dialogue between the areas is essential to ensure that technological solutions are also safe and healthy.

The convergence between these fields of knowledge generates environmental and public health co-benefits of great relevance. The reduction of emissions and environmental pollution resulting from the application of circular economy principles results in the direct improvement of air and water quality, reducing the incidence of respiratory and infectious diseases in densely occupied urban areas [10]. The valorization of waste and the creation of sustainable production chains promote social inclusion, generation of green jobs and strengthening of local economies [27]. In addition, reuse and recycling practices prevent the irregular occupation of areas and the formation of environmental liabilities, contributing to more resilient and healthy cities. This synergy demonstrates that urban sustainability goes beyond technical efficiency: it involves the promotion of healthy built environments that integrate human well-being, ecological balance, and social justice. Therefore, the interdisciplinary integration between civil engineering, environmental engineering and biomedicine represents a concrete way to operationalize the principles of the circular economy and achieve the decarbonization of civil construction. This cooperation not only enhances technological and scientific development, but also redefines the sector's role in the global climate and health agenda. The consolidation of this interface is an indispensable condition for the effectiveness of sustainability policies, constituting a replicable model of innovation and social responsibility for the twenty-first century.

Future Challenges and Opportunities

The transition to circular and decarbonized models in the civil construction waste (CCR) chain presents a complex set of technical, economic, and regulatory barriers that still limit its consolidation

on a global scale. From a technical point of view, challenges persist related to the standardization of recycled aggregates, the variable quality of waste, and the lack of adequate infrastructure for sorting and processing [25]. The absence of specialized regional laboratories and quality certification systems for recycled materials reduces market confidence and restricts their use in structural applications. In the economic aspect, the initial costs of implementing clean technologies and the lack of tax and financial incentives discourage small and medium-sized construction companies from investing in innovation [27]. In the regulatory field, institutional fragmentation and overlapping of competencies between spheres of government are observed, which hinders the coordinated implementation of the National Solid Waste Policy (PNRS) and the Municipal Plans for Integrated Waste Management [12].

Overcoming these barriers requires the effective integration of public policies, combining environmental, economic and technological instruments from a systemic perspective. Synergy between climate action plans, innovation policies and green financing instruments is essential to stimulate circularity in construction [10]. Tax incentive programs, sustainable public procurement, and public-private partnerships can accelerate the adoption of recycling and low-carbon technologies. In addition, the creation of carbon pricing mechanisms and voluntary markets for emission credits encourages companies to quantify and reduce their carbon footprints, aligning the sector with the National Policy on Climate Change (PNMC) and the Paris Agreement [11,8]. This integration of policies must be accompanied by institutional strengthening and technical training of public managers and engineering professionals, ensuring efficient governance and inspection.

Future trends in the circular economy in construction converge on digitalization, traceability and biotechnology as strategic axes of innovation. The adoption of Building Information Modeling (BIM) enables the detailed mapping of material and energy flows from design to demolition, allowing the planning of disassembly and the reuse of construction components [18]. At the same time, the use of blockchain technologies has emerged as a tool for traceability and transparency, ensuring the authenticity of the origin of waste and compliance with environmental standards [4]. In the field of materials, research in biotechnology and bioengineering has produced biocements, microbial composites and self-healing materials, capable of drastically reducing the carbon footprint and restoring structural properties autonomously [48]. These advances indicate a movement of convergence between engineering, bioscience and information technology, forming a new paradigm of industrial sustainability. For developing countries, the challenges are even more pronounced, but so are the opportunities. The lack of waste management infrastructure, combined with the informality of the sector, requires adaptive and inclusive models that reconcile technological innovation with social inclusion policies [15]. Strengthening recycling cooperatives, local productive arrangements (LPAs), and green incubators can boost regional economies and generate green jobs, reducing socioeconomic inequalities [27]. In addition, the implementation of integrated environmental monitoring systems, using remote sensors and artificial intelligence, expands the capacity for diagnosis and inspection. To achieve urban sustainability, it is essential to incorporate circular planning principles, prioritizing sustainable mobility, energy efficiency, green infrastructure and en-

vironmental sanitation, integrated with a vision of One Health [36].

Thus, the challenges that limit the full implementation of the circular economy in civil construction also configure strategic opportunities for innovation, social development and urban resilience. The integration of public policies, technological advancement, and collaboration between academia, the productive sector, and government are essential conditions to achieve this transition. In the medium-term horizon, the convergence between digitalization, decarbonization, and biotechnological regeneration represents the most promising path for building carbon-neutral, economically competitive, and socially healthy cities, central pillars of a new era of sustainable and integrated infrastructure.

Conclusions

The present systematic review showed that the integration between circular economy (CE) and decarbonization constitutes a transformative axis for the future of civil construction, both in environmental and socioeconomic terms. The study revealed that the civil construction waste chain (CCR) is responsible for a significant portion of global greenhouse gas (GHG) emissions and for the generation of large volumes of inert waste, whose inadequate management compromises the ecological balance and public health. However, the results demonstrate that the adoption of circular practices such as reuse, recycling, reverse logistics, and regenerative design has concrete potential to reduce embodied emissions and strengthen sustainable production chains, especially when supported by public policies and technological innovations.

The analysis of international and national evidence indicates that the circular economy is a strategic instrument for carbon neutrality in the construction sector. The replacement of high-impact materials, the valorization of waste and the redesign of production flows allow the direct mitigation of emissions and the optimization of the use of energy and natural resources. In addition, the incorporation of methodologies such as Life Cycle Analysis (LCA) and GHG Protocol has proven essential to quantify and compare environmental impacts, contributing to the formulation of consistent and transparent environmental performance indicators. Such approaches, when associated with the use of digital technologies (BIM) and traceability via blockchain,

They configure a new paradigm of data-driven environmental governance and aligned with the global decarbonization agenda. In the social and health sphere, the findings reinforce that the integration between civil engineering, environmental engineering and biomedicine is essential to understand the effects of the construction chain on human health and the environment. Environmental toxicology, ecotoxicology and studies on occupational exposure reveal that inadequate management of CCRs generates direct risks to the population and workers, highlighting the urgency of policies that integrate public health and urban sustainability from the perspective of One Health. At the same time, recycling and reuse practices can promote green jobs, social inclusion, and vulnerability reduction, demonstrating that the circular economy generates long-term social and environmental co-benefits.

The contributions identified throughout this review speak directly to several Sustainable Development Goals (SDGs), including SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustain-

able Cities and Communities), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) [8]. The integrated application of these principles contributes not only to the fulfillment of Brazilian and international climate goals, but also to the construction of more resilient, inclusive, and healthy cities. CE emerges, therefore, as a guiding axis of urban sustainability, articulating innovation, green economy and quality of life. As future developments, it is recommended to strengthen public and regulatory policies aimed at circularity in construction, with a focus on economic incentive instruments, technical standardization, and sectoral integration. Scientific research is expected to advance the creation of low-carbon biomaterials, the development of more accurate life cycle assessment methods, and the use of artificial intelligence and remote sensing to monitor material flows and emissions. In addition, it is urgent to expand interdisciplinary studies on waste toxicity, occupational health, and ecotoxicological impacts, consolidating the interface between technology and public health. In summary, the transition to circular and decarbonized civil construction requires a paradigm shift from an extractive and linear economy to a regenerative and integrative economy. The consolidation of this model depends on collaboration between academia, the productive sector, and public authorities, in order to build not only more sustainable buildings, but also more humane, intelligent cities aligned with planetary balance.

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