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Master's Degree Thesis

Comprehensive Analysis of Construction and Demolition Waste Management in Colombia: Regulation, Environmental and Social Impacts, Opportunities

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A la Sara del 2023: gracias a ti chiquita, porque por tomar decisiones locas… mira a dónde vinimos a parar.

A mi familia y pareja por el apoyo incondicional.

A todos mis amigos en Colombia, que siempre me reciben con los brazos abiertos.

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Abstract

Colombia has a population of 52.33 million and is constantly growing, which presents an increasing demand for civil infrastructure work. This situation directly drives the development of the construction sector and simultaneously increases the demolition, remodeling, and replacement processes of obsolete structures. Consequently, greater construction and demolition waste (CDW) production is generated, representing significant management challenges causing emerging socio-environmental impacts. This literature review aimed to analyze these challenges, identify the factors that hinder their proper implementation, and propose improvement opportunities that contribute to strengthening sustainable strategies within the framework of a circular economy.

The methodology consisted of three interconnected stages: information gathering using databases such as Google Scholar, Scielo, ScienceDirect, and prominent institutional repositories in the country; categorization through the reading of titles and abstracts; and full reading to understand the issue and achieve the objectives proposed in this work. The selected documents provided detailed data on the management of CDW in the urban context, focusing on recycling and recovery processes, collection systems, current regulations, and social and environmental impacts. After a thorough analysis, limitations and improvement opportunities were outlined regarding the CDW issue.

Ultimately, this review aimed to gather scattered information about CDW management and present the Colombian context to the national and international audience. It is expected to serve as a basis for new research, funding proposals, and public policy recommendations that promote solutions that are not only sustainable but also in favor of the community.

Keywords: Construction and Demolition Waste (CDW), Circular Economy, Waste

Management, Recycled Materials, Recycling, Recovery, Environmental Regulation, Colombia, Environmental Impacts, Social Impacts.

Resumen

Colombia cuenta con una población en crecimiento de 52,33 millones, por lo que presenta una demanda sostenida de obras de infraestructuras civil. Esta situación esta impulsando directamente el desarrollo del sector de la construcción, y a su vez incrementa los procesos de demolición, remodelación y reemplazo de estructuras obsoletas. Como consecuencia, se genera una mayor producción de residuos de construcción y demolición (RCD), lo que representa importantes desafíos de gestión provocando impactos socio ambientales emergentes. Esta revisión bibliográfica tiene como objetivo analizar dichos retos, identificar los factores que dificultan su adecuada implementación y proponer oportunidades de mejora que contribuyan a fortalecer estrategias sostenibles en el marco de una economía circular.

La metodología consta de tres etapas interconectadas: recopilación de información utilizando bases de datos como Google Scholar, Scielo, ScienceDirect y repositorios institucionales destacados en el país; categorización mediante la lectura de títulos y resúmenes; y lectura completa para comprender la problemática y cumplir los objetivos propuestos en este trabajo. Se seleccionaron documentos que proporcionaran datos detallados sobre la gestión de RCD en el contexto urbano, enfocados en procesos de reutilización y aprovechamiento, sistemas de recolección, normativas vigentes e impactos sociales y ambientales. Tras un exhaustivo análisis, se planearon limitaciones y oportunidades de mejora de la problemática de los RCD.

En definitiva, este trabajo de revisión busca reunir información dispersa sobre la gestión de los RCD y visualizar el contexto colombiano ante la audiencia nacional e internacional. Se espera que sirva como base de nuevas investigaciones, propuestas de financiamiento y

recomendaciones de políticas públicas que promuevan soluciones no solo sostenibles, sino que también en pro de la comunidad.

Palabras Claves: Residuos de Construcción y Demolición (RCD), Economía Circular, Gestión de residuos, Materiales Reciclados, Reciclaje, Aprovechamiento, Normativa Ambiental, Colombia, Impactos Ambientales, Impactos Sociales.

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1. Introduction

The construction sector is one of the most relevant and strategic for global economic progress (Ramírez Vargas, 2021), as it can be categorized as one of the fundamental supports in developing communities. However, due to this activity, significant environmental impacts arise due to its dynamic linearity, with the production of Construction and Demolition Waste (CDW) and the consumption of virgin raw materials being the primary concerns. So far, the construction industry has stood out as one of the largest generators of waste (Pacheco et al., 2017), representing a serious environmental problem, especially when this type of waste is not correctly managed (Suárez Silgado et al., 2018).

On a global scale, it is estimated that the production of solid waste generated in 2020 corresponded to approximately 2,24 billion tonnes. CDW accounts for 30% of this waste, and an increase is expected in the coming years due to rapid urban growth. In Europe, the annual production of CDW above 820 million tonnes is estimated (Soto-Paz et al., 2023), equivalent to 34,7% of total waste. Its recycling and recovery rates range between 15% and 90% (Suárez Silgado et al., 2019), with recovery targets above 70% for 2020 (Mora Castro, 2021).

Similarly, Japan generated approximately 4.5 million tonnes per year of CDW (Ouda et al., 2023), with recycling and reuse rates reaching 97% (Suárez Silgado et al., 2019). The United States generated more than 500 million tonnes annually (Soto-Paz et al., 2023), which is equivalent to twice the amount of municipal solid waste generated (EPA, 2025), with a recovery rate of 40% (Suárez Silgado et al., 2019). Although the production numbers for this type of waste are usually unavailable in Latin America, approximately 160 million tonnes per year is estimated, with a management approach mainly focused on final disposal and low recovery rates (Mora Castro, 2021).

In addition to the significant volume of CDW generated globally, the sector is responsible for a high environmental impact due to the intensive and excessive use of resources. It is estimated to use 40% of the extracted natural resources (Alzate Rodríguez, 2022) and around 70% of the electricity in industrialized countries (Chica Osorio & Beltrán Montoya, 2018). In addition to the above, this industrial sector globally also contributes to a considerable fraction of global greenhouse gas (GHG) emissions, with CO2 values associated with energy and operations ranging between 30% and 40% of the total (Peña Castañeda & Rincón Pineda, 2018).

In the specific case of Colombia, in recent years, the construction sector has shown sustained growth with an estimated increase of 9.8% for the year 2023, representing more than 6.5% of the Gross Domestic Product (GDP) and (CAMACOL, 2022, and Departamento Nacional de Planeación (DNP), 2022). This progress leads to a significant increase in the production of CDW generated during the different stages of an infrastructure project, from the execution of the work, its operation, maintenance, use, and finally, its demolition (Duque Rúa, 2023).

Regarding the socio-environmental impacts it entails, it is estimated that this sector is one of the primary consumers of resources in the country, using about 60% of non-renewable natural resources, 40% of total energy consumption, and 1% of total water. Additionally, the sector generates 30% of CO2 emissions and is responsible for 25% of the waste generated (Ministerio de Ambiente y Desarrollo Sostenible (MADS), 2021). It is estimated that approximately 100 million tonnes of materials are used each year (UNEP, 2018), and more than 22 million tonnes of CDW are generated (MADS, 2017). However, there is still a lack of accurate and systematized information regarding the categorization and quantification of this type of waste in the national territory (LOGYCA, 2022).

The CDW generated during the construction stage has significant recovery potential, which becomes evident when it is adequately managed through source separation, classification, collection, storage, and final disposal processes. This strengthens recycling, reuse, and treatment by reducing the use of natural resources such as virgin raw materials, decreasing environmental costs, emissions, and ecosystem degradation. In addition to the above, developing a Circular Economy (CE) is essential to optimize both the use of resources and promote more competitive and resilient economic systems (Duque Rúa, 2023).

Based on the above, the present bibliographic review has been developed, whose purpose is to compile and present in detail how CDW is currently managed in Colombia, the current regulations regarding such waste, adopted strategies, and its contribution to the transition towards a CE, understanding environmental and social impacts. Additionally, this study gathers information from the construction sector, including generation data in the main cities of the country, reuse methods, final disposal, incentives, financing methods, and successful cases, as well as making specific comparisons with international references. Finally, the analysis identifies the country's difficulties regarding CDW management, the challenges for promoting responsible practices, and opportunities for improvement.

1.2. Objectives

1.2.1. General Objective

Analyze Colombia's main challenges in properly managing CDW, identify the factors hindering its implementation, and propose improvement opportunities that contribute to strengthening sustainable strategies within the circular economy framework.

1.2.2. Specific Objectives

- Identify the main characteristics and gaps of the current regulatory framework regarding CDW at the national and local levels and its relation to the guidelines established in the European context.
- Assess the contributions and limitations of the regulatory framework to strengthen the sustainable management of CDW in the country.
- Highlight success cases of CDW reuse and recovery in the Colombian context to understand local opportunities and challenges.
- Recognize the role of recyclers in Colombia as key actors within the management of CDW and their contribution to the circular economy.
- Analyze successful experiences in some European and Latin American countries to explore best practices regarding CDW and their applicability in the national context.
- Explore existing incentives and available financing methods to promote the recovery and reuse of CDW in the country.
- Assess the main social and environmental impacts generated by the inadequate management of CDW in Colombia.

1.3. Methodology

This research corresponds to a narrative, panoramic, and realistic literature review to identify and analyze the management of CDW in Colombia, evaluate the current practices of the country, and build a generic and open-access source of information for future studies and projects.

The sources consulted include academic databases, institutional sources, and reports to analyze critical and contextualized approaches to managing CDW in Colombia. Among the academic sources are Google Scholar, Scielo, and ScienceDirect, which provide access to scientific articles, reports, and technical documents both at the national and international levels.

It is clarified that NordVPN was used to find information and facilitate the search since most official Colombian websites can only be accessed from within the country.

Institutional repositories from Colombian universities were also used, among which the following stand out: Universidad de Antioquia (UdeA), Universidad Nacional de Colombia (UNAL), Universidad del Valle, Universidad La Salle, la Escuela Superior de Administración Pública (ESAP), la Universidad Cooperativa de Colombia, Instituto Tecnológico Metropolitano (ITM), el Colegio Mayor de Antioquia (Colmayor), la Universidad del Rosario y la Pontificia Universidad Javeriana (UPJ), among others.

Regarding the regulatory framework, laws, decrees, resolutions, and management plans were examined both from Colombia, at the national and local level, and from the 28 Member States (MS) of the European Union (EU). Additionally, it was decided to use information sources such as media outlets, both university, and press, given that in the country's context, everything related to the management of CDW is not only evident in the academic or industrial field but also in citizen's report and denounce problems associated with this type of waste, which adds a perspective closer to the local reality.

It is essential to clarify that the search for criteria was conducted in Spanish because most of the information is produced in the country, and it was uncommon to find documents in other languages addressing this topic. Therefore, keywords, in their Spanish equivalents, included such as “Construction and Demolition,” “Waste,” “Regulations,” “Circular Economy,” “Social Impacts,” “Environmental Impacts,” “Generation,” “Implementation of CDW Plans,” “Generation Percentages,” “CDW Colombia,” “CDW Management Plans in Colombia,” “Medellín and CDW,” “Bogotá and CDW,” “Solid Waste in Colombia,” “Reuse,” “Recovery,” “Recycled Aggregates,” “Colombia,” among others. Boolean operators (AND) and (OR) were used separately and in combination to retrieve relevant publications. Examples of search entries include: “circular economy” AND “construction and demolition waste,” “construction and demolition” AND “waste” AND “regulations,” “construction and demolition waste” AND “social impacts” OR “environmental impacts,” “generation” OR “generation percentages” AND “CDW Colombia,” “CDW Management Plans in Colombia” OR “Medellín” OR “Bogotá,” “Reuse” OR “Recycled aggregates” AND “construction and demolition waste,” among others. The search period was limited to between 2002 and 2025, with most publications obtained from the last 11 years. The above aimed to ensure innovation and relevance in retrieving research ideas and concepts. Documents without full access were excluded.

The process of analysis and selection was carried out in three stages. The first consisted of reading titles and abstracts to preselect the needed documents. The second was the categorization based on the abstracts of the papers; it was done by topics or chapters to be addressed, meaning if it contained regulations, information on generation, reuse and recovery methods, management plans by cities, final disposal, and if it addressed the international context. The thematic grouping was carried out with the help of NotebookLM. Finally, a complete reading of the texts was performed.

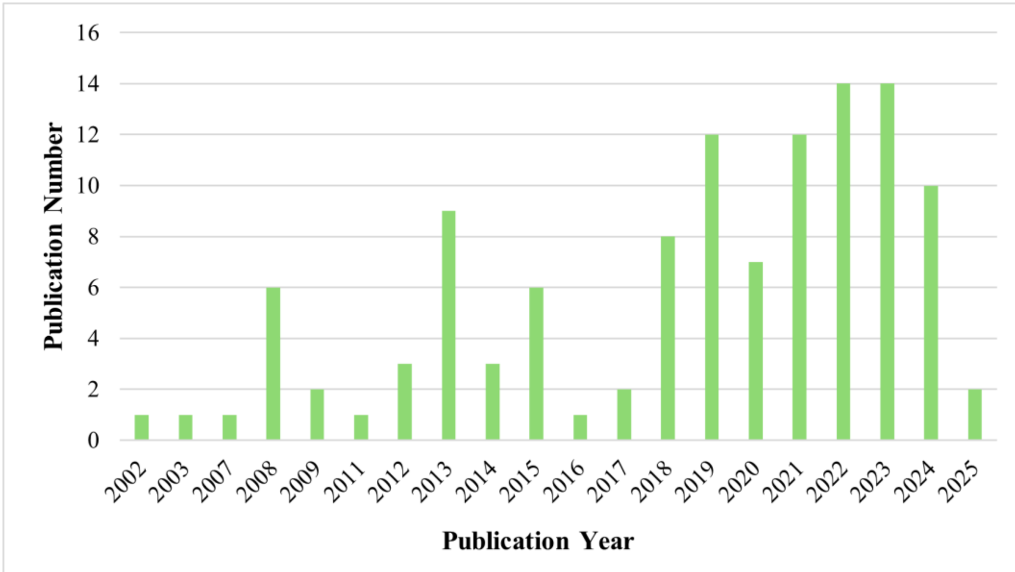
Since most of the information analyzed and collected for the development of this work was in the original language, that is, Spanish, the artificial intelligence tool ChatGPT was used to ensure coherence in the translations into English. It is essential to clarify that it was used only for linguistic and writing corrections, not for developing ideas, content creation, or complete translations.

Zotero was used to organize the references, and Excel was used to analyze the temporal evolution of the publications. Figure 1 shows the distribution of the documents used in this work according to their year of publication from 2002 to 2025.

An increase in the number of publications on CDW management is observed. Between 2019 and 2023, there was a significant rise in academic production related to the topic, reaching up to 10 publications per year. The above shows that experts, academics, governmental bodies, and citizens are interested in managing this type of waste.

The increase in publications in recent years means that since 2020, the topic has continued to be relevant and points to developing a sustainable future. The management of CDW will remain essential for research, the development of public policies, and, above all, the creation of new solutions seeking socio-environmental benefits.

Figure 1
Trend in Academic Publications on CDW Management (2002-2025)



Source: Own Elaboration

1.4. Limitations

The following are some of the limitations identified during the bibliographic research.

Firstly, there were restrictions on accessing institutional databases because not all repositories are available to the outside public. Therefore, most of the information was obtained through those that are either open access or subscribed to by Universidad de Antioquia. Likewise, it is essential to highlight that to access some governmental documents from Colombia and obtain many national results on the internet, it was necessary to use a paid VPN (NordVPN), which allowed access to location-blocked sites.

Another relevant limitation lies in the absence of updated information, at least for the last two years. Although it was possible to collect data on the generation of CDW in certain major cities, their records mainly cover the period between 2017 and 2021. In addition, in many cities of the country, there is no precise data on such generation, disposal, or even methodologies for reuse and recovery.

Additionally, it is necessary to consider the potential bias when incorporating journalistic sources. Although these provide a closer perspective of what communities truly experience, subjective or incomplete information may be presented.

On the other hand, most of the information collected, analyzed, and then presented in this work comes from documents in Spanish, as it is the original language of Colombia. However, the search was not restricted to this language, so international scientific studies, thesis papers, and government websites were also included.

Regarding the review of international documents, although the regulatory frameworks of European countries were included, no reference was made to comparative studies of countries closer to the national context, such as Latin American countries. Including these would have enhanced the analysis; however, it was not the primary objective of the research.

Finally, this study had a theoretical approach. As it is a literature review, no fieldwork was conducted, such as interviews with companies in the sector or academics. Therefore, not being in Colombia means that the search for printed documents or direct interaction with industry experts was limited, so all the information was obtained only from sources available on the Internet.

2. Background Information

Construction and Demolition Waste (CDW) refers to solid waste originating from excavation, construction, demolition, repairs, or locative improvements of a building, whether public or private (Departamento Nacional de Planeación, 2022, p.11). They represent a significant portion of the total waste generated globally, estimated to be approximately 30% (Purchase et al., 2021).

Some types of CDW are considered hazardous due to the materials used for their production, including fiber cement, lead, tars, adhesives, sealants, and certain plastics. That can produce dangerous combinations when mixed with other materials, also related to the fact that these residues usually remain long, meaning deterioration of the original material. (Suárez Castrillon et al., 2011) However, CDW is generally highly susceptible to being utilized through transformation and reintegration as raw material for aggregates in manufacturing new products (Castaño et al., 2013, p.122).

Since the term CDW refers to a large variety of materials, Fatta et al. (2003) state that one of the ways to classify these kinds of waste internationally is by categorizing them according to their origin or source, such as:

- Excavation materials: Includes excavated soils, sand, gravel, rocks, clay, and other materials derived from excavations. They are generated in construction activities, especially in underground constructions and geotechnical engineering works. They can also be formed from natural phenomena such as river overflows or landslides.
- Road planning and maintenance materials: This covers asphalt and paving materials such as sand, gravel, metal, and materials originating from road

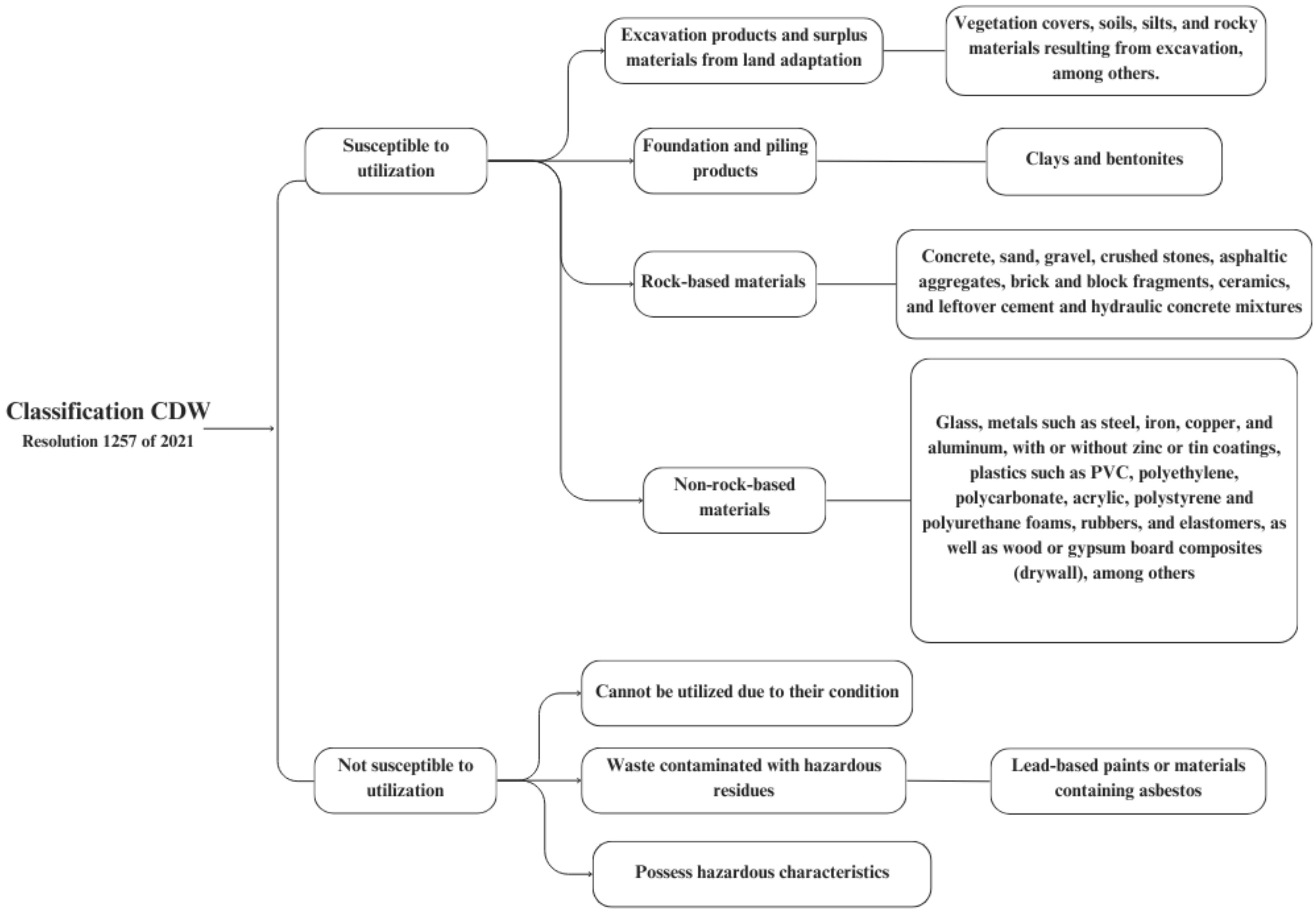
demolition and renovation.

- Demolition materials or debris: Includes soil, gravel, concrete fragments, lime, bricks, overlay plates, gypsum, sand, dressed stone, and porcelain, among others. These come from the demolition of civil engineering infrastructures.
- Worksite waste materials: This covers materials generated during the construction, repair, expansion, or renovation phase of a worksite, such as wood, plastic, paper, glass, metal, cables, pigments, enamels, coverings, adhesives, and other materials produced during the mentioned phases.

According to Resolution 1257 of 2021 of Colombia, and considering the already mentioned categories, CDW can be classified into two groups according to their potential for exploitation (Figure 2).

Figure 2

Classification of CDW according to Resolution 1257 of 2021.



Source: Own elaboration, information taken from Departamento Nacional de Planeación (2022, p.12)

As explained by Tukker et al. (2023), around 50% of all the materials used by humans are construction minerals (gravel, clay, sand, limestone) used to make bricks and cement for building structures and infrastructure. Additionally, to carry out these projects, large amounts of cement, steel, and plastic are used, whose production is responsible for 20% of global carbon emissions, biodiversity loss, and water stress due to the involvement of processes such as cement kilns and blast furnaces. Likewise, the authors mentioned above also stated that one of the long-term solutions for CDW would be for the production system to recirculate used materials instead of using and discarding them.

The construction and demolition sector operates under a conventional linear economy model based on taking, making, and disposing of, where the destination of such waste is landfilled, where more than 35% of the total waste produced globally ends up. Here is where the circular economy (CE) emerges as a new model that maximizes the utilization of raw materials and guarantees the value of materials throughout their life cycle (Purchase et al., 2021).

According to Ghisellini et al. (2016), the CE is an economic model that aims to minimize waste, maximize resource use, and recover products at the end of their life cycle. This concept primarily emerges through three key actions: Reduce, Reuse, and Recycle, known as the 3Rs, which over time evolved into the 4Rs framework, incorporating Raw Material Recovery (Purchase et al., 2021). This model opposes the traditional linear model, as the CE promotes an idealistic approach in which all materials used, from extraction to the end of their use, circulate continuously through production and consumption systems, reducing the need to extract new resources (Ghisellini et al., 2016).

The main objective of the 4Rs framework is to prevent excessive waste generation and preserve natural resources as much as possible, in this way demonstrating that most of the product can be recycled, reprocessed, or reused, adding value to materials that would typically end up in a landfill, allowing them to re-enter the market and be reused (Purchase et al., 2021).

The Reduction principle aims to minimize the use of raw materials, primary energy, and waste through the implementation of eco-efficiency, which is the production of more goods with less waste and fewer resources (Pakseresht et al., 2022), and the improvement of consumption processes, such as replacing traditional technology with a more innovative and cleaner, introducing more compact and lightweight products, simplifying packaging, etc. (Feng & Yan, 2007; Su et al., 2013., as cited in Ghisellini et al., 2016).

The Reuse principle refers to any operation in which a product or its components, which are not considered waste, can be used for the same function for which they were designed. This process brings positive environmental benefits as it does not require new raw materials or additional resources. On the contrary, it requires less energy and labor (European Union, 2008).

The recycling principle refers to all actions or operations aimed at recovery, where waste transforms, including reprocessing organic material to generate new products that fulfill the original purpose or a new one (European Union, 2008).

Finally, the recovery principle refers to any process whose main principal result is to grant waste a new functional purpose, either by directly substituting resources that would otherwise be consumed or by being prepared to serve an industrial operation role (European Union, 2008).

In summary, Geissdoerfer et al. (2017) state that CE aims to create a system that promotes more efficient use of natural resources. Several key strategies are required to achieve this, such as product redesign to improve recyclability, material reuse, and product lifespan extension through repair or refurbishment.

In the context of CDW management, the circular economy plays a crucial role by proposing sustainable alternatives for handling surplus materials and waste generated in the construction sector. Additionally, it aims to contribute to resource efficiency and reduce operational costs. Consequently, it proposes various methodologies to minimize the negative environmental impact generated by such waste, attempting to preserve the value of materials and products for as long as possible, in this way reducing waste generation and dependence on natural resources (Purchase et al., 2021).

Some of these methodologies or strategies include the following mentioned below.

Recycling and Reusing CDW is mentioned by Kumbhar et al. (2013) as a strategy with great potential that companies can adopt for sustainable construction while reducing disposal costs. Similarly, it increases the company's marketing opportunities, attracting new clients interested in participating in cleaner construction programs. In addition, it creates new job opportunities and, most importantly, reduces environmental impacts such as the depletion of natural resources (deforestation, extraction of minerals and oils). Finally, it reduces pollution by lowering emissions from manufacturing and transportation and decreases energy and water use compared to producing new products generated from virgin raw materials.

In addition, reductions in carbon footprint are expected to occur when implementing this strategy, as it promotes local reuse and recycling, in this way, reducing emissions associated with long-distance transportation and diverting more amounts of waste from landfills (Purchase et al., 2021).

The CE promotes Prevention and Reduction at the source (Purchase et al., 2021), which implies better integrated planning before starting the construction phase (Colorado et al., 2022), design for disassembly (Purchase et al., 2021), optimization in the use of materials, adoption of new technologies that generate little waste (Swarnakar & Khalfan, 2024), and efficient management of resources throughout the project lifecycle (Purchase et al., 2021).

Circular Design is presented by Purchase et al. (2021) as another strategy, where the goal is to incorporate circular design principles in constructing buildings and infrastructure. However, this implies a design aimed at extending its useful life and facilitating the disassembly and recovery of materials in the final stage.

The practical implementation of Circular Business Models in the construction and demolition (CD) sector depends on the development of business models that encourage prevention, reuse, recycling, and recovery, such as secondary material markets, equipment rental services, and schemes where responsibilities are assigned to the producer (Swarnakar & Khalfan, 2024).

Despite the significant potential, various authors indicate that implementing the CE in CDW management faces multiple challenges.

Purchase et al. (2021) mention limitations, regulations, technical restrictions, and a lack of innovative technologies; additionally, they highlight social barriers such as a lack of awareness and education. Swarnakar and Khalfan (2024) identify economic obstacles, including the initial implementation costs and the lack of markets for recycled materials. Colorado et al. (2022) have highlighted the lack of reliable information and adequate systems to quantify these wastes. Likewise, they argue that implementing circular strategies is complicated due to the significant variability in the composition and quality of the generated waste.

Finally, Tukker et al. (2023) present three key challenges. The first concern is that infrastructures have not been built using circularity principles; on the contrary, what can be used as material for their construction is already established by the past, meaning that it is not advisable to reform or modify them. Secondly, despite the efforts of many countries to improve the recovery of CDW, waste management is still not designed to provide significant value to its recycling and reuse. Lastly, the authors warn that the constant expansion of the construction sector in many countries requires an inevitable extraction of new raw materials to meet all renovation needs, intensifying extraction and consumption.

3. Current Situation in Colombia

The Republic of Colombia is a State composed of 32 departments and 1 101 municipalities, which in 2023 generated approximately 11 803 407 tonnes of solid waste per day. The Super Intendencia de Servicios Publicos [Superintendence of Public Utilities] (SSPD) determined that approximately 44.99% of the total volume produced in national level corresponds to the eight most populated cities: Bogotá D.C., Medellín, Cali, Barranquilla, Cartagena, Cúcuta, Soacha, and Soledad (Superintendencia de Servicios Públicos Domiciliarios, 2023).

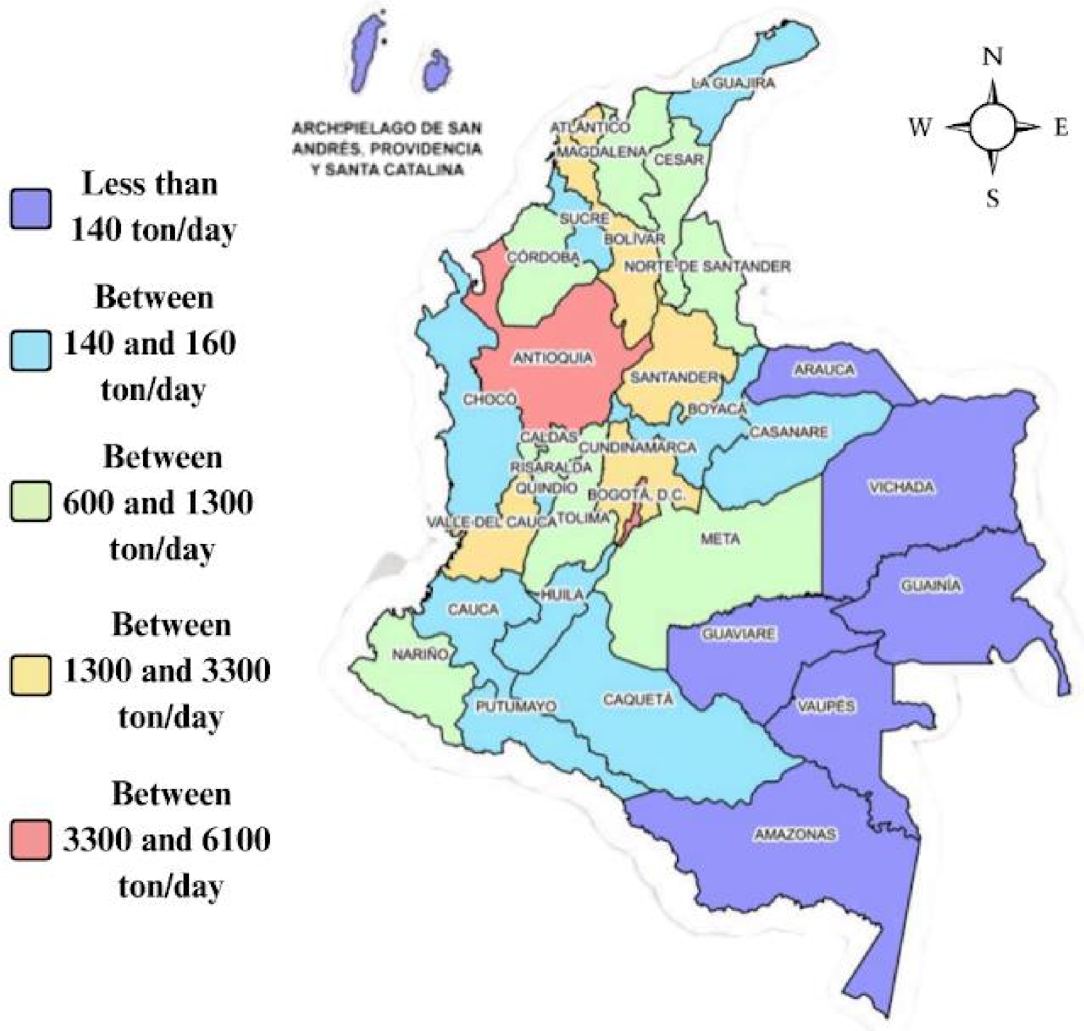
The country's per capita solid waste production is 515 kilograms annually (DNP, 2022). However, it varies depending on the size of the city; in the case of Bogotá, one of the largest cities, the average value is 0.858 kg/inhabitant/day (Consorcio NCU-UAESP, 2018), in intermediate cities (Ibague, Pasto, San Andres Islas) it is 0.81 kg/inhabitant/day, and in small towns (Jardin, Finlandia, Guatape), is 0.31 kg/inhabitant/day (Marmolejo de Oro, 2012).

Regarding collection and transportation coverage at the national level, it is provided in approximately 96% of urban areas, corresponding to 78,2% of the population. In contrast, only 1.6% of the rural areas (15,8% of the population) have these services (Marmolejo de Oro, 2012., Departamento Administrativo Nacional de Estadística (DANE), 2018).

Furthermore, the final disposal of solid waste at the departmental level for 2023 is shown in Figure 3, emphasizing that Bogotá, Antioquia, Valle del Cauca, Atlántico, Bolívar, and Cundinamarca have the highest number of disposed tonnes. The above directly relates to these departments' largest population and economic activities. This disposal is carried out as 63.05% in sanitary landfills, 29.32% in open dumps, 4.02% in contingency cells, and 3.61% in temporary cells (Superintendencia de Servicios Públicos Domiciliarios, 2023).

Figure 3

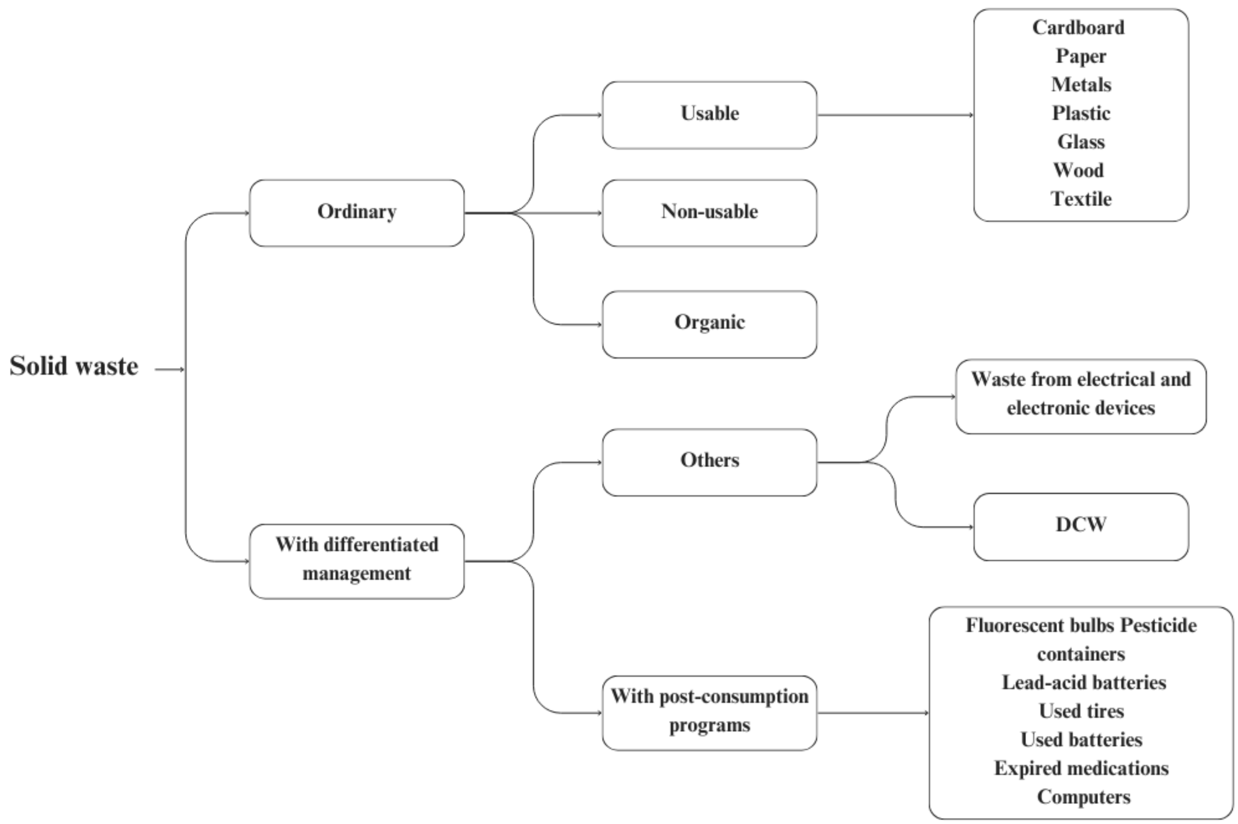
Average Waste Disposal Map by Department.



Source: Taken from Superintendencia de Servicios Públicos Domiciliarios, 2023, adapted into English

Colombia has various types of urban waste, such as ordinary waste and waste with differentiated management. In Figure 4, it is possible to observe the classification of solid waste according to the DPN (2022).

Figure 4
Types of Solid Waste Generated in Colombia



Source: Prepared by DNP (2022). Adapted into English

3.1. Generation of CDW in Colombia

In Colombia, the construction industry has constantly grown since 2004, becoming the sector that produces and generates the most CDW (Pacheco et al., 2017), corresponding to 60% of the total solid waste (Antequera Barrios & Jiménez Pinzón, 2019). This growth has been fundamental for its development, contributing significantly to the national Gross Domestic Product (GDP). In the capital of Colombia, Bogotá, this sector produces between 20% and 30% of total waste. However, this same growth is also responsible for the considerable increase in CDW production, representing a primary environmental concern at both national and global levels (Carvajal Muñoz & Carmona García, 2016).

According to the Ministerio de Ambiente y Desarrollo Sostenible [Ministry of Environment and Sustainable Development] (2017), it was found that for the period between 2008 and 2017, the main cities of the country (Bogotá, Medellín, Santiago de Cali, Manizales, Cartagena, Pereira, Ibagué, Pasto, Barranquilla, Neiva, Valledupar, and San Andrés) generated 22 million tonnes of CDW per year, with Bogotá being the city that produces the most of this kind of waste, with about 15 million tonnes per year (Guevara Chacón & Sierra Perdomo, 2020). The daily production of this waste in the country is estimated at 100.000 tonnes, equivalent to three times the urban solid waste generation (Silgado et al., 2018).

The study conducted by Colorado et al. (2022) shows that CDW in the country is distributed as follows: 4% mortar, 8% ceramics, 22% brick, 28% concrete, and 38% classified as others. Likewise, Guevara Chacón and Sierra Perdomo (2020) emphasize that each construction work or activity contributes a different percentage of waste. In their study, they present results obtained in 2018 by the Ascociacion Española de Reciclaje [Spanish Recycling Association] (ARS) regarding the volume produced by activity in Colombia based on four square meters of construction, as presented in Table 1.

Table 1

The volume produced by activity in Colombia based on four square meters of construction

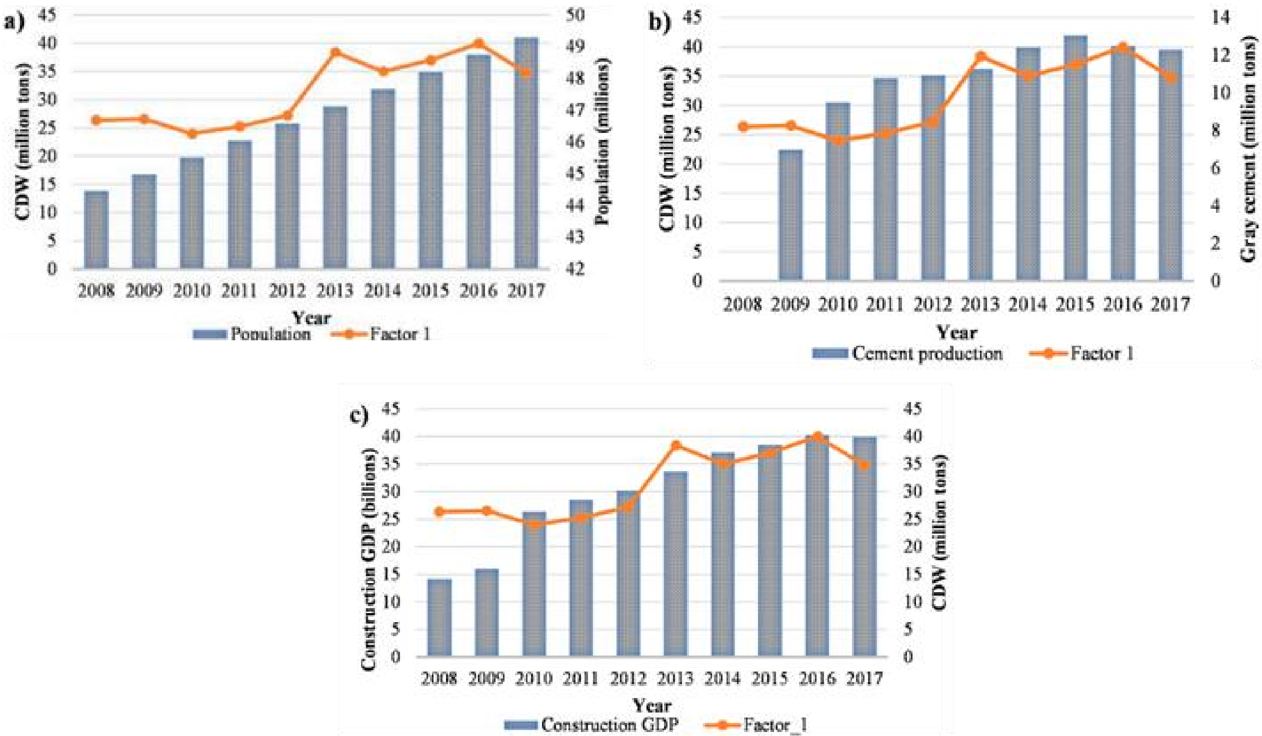
Activity	Volume [m^3/m^2]
The road infrastructure with a production	1.56
Reform or rehabilitation works	0.57
New building construction	0.14
Complete demolition of masonry work	0.74
Complete demolition of concrete structures	1.22
Demolition of industrial buildings with metal structures	1.26
Demolition of industrial buildings with concrete structures	1.19

The above data allows for an understanding of the generation of CDW in the territory; however, it is important to analyze the factors that could affect it. Colorado et al. (2022) investigated three variables that could modify its generation, comparing this waste with population growth, gray cement production, and the Gross Domestic Product (GDP) of the construction sector in Colombia.

The results showed that while the population is growing linearly, the number of CDW varies over the years, meaning that this variable does not affect it directly, as seen in Figure 5a. On the other hand, cement production also fluctuates but does not follow the same trend as CDW, as shown in Figure 5b. In contrast, the GDP of the construction sector shows a better correlation with its generation, displaying similar increases and decreases, as seen in Figure 5c. The study also found that, over time, CDW decreased during the periods 2008-2009, 2009-2010, and 2013-2014 due to reduced construction areas in those years. Finally, it is concluded that economic activity in the sector is key to its generation.

Figure 5

a) CDW generation concerning population growth, b) CDW generation concerning gray cement, and c) Gross Domestic Product of the construction sector concerning CDW generation



Source: Taken from Colorado et al. (2022).

The previous analysis provides context regarding the generation and composition in the country's main cities. Following that, this thesis also analyzes specific data on the production and types of CDW in Bogotá, the Área Metropolitana del Valle de Áburra [Metropolitan Area of the Aburrá Valley] (Medellín), Cali, Ibagué, Barranquilla, Cartagena, Pasto, and Valledupar.

In Bogotá, the leading CDW producers are the Instituto de Desarollo Urbano [Urban Development Institute] (IDU) with 28% of the generation, private construction companies with 43%, the Empresa de Acueducto y Alcantarillado de Bogotá [Bogotá Sewerage and Aqueduct Company] (EAAB) with 22%, the Special Administrative Unit of Public Services (UAESP) with 3%, making private construction companies the largest generators of CDW (Guevara Chacón & Sierra Perdomo, 2020). The most frequently observed waste types are concrete, soil, brick, and ceramics. Moreover, other materials such as sand, gravel, stones, rock fragments, tiles, mortar, and inert materials that do not exceed sieve #200, as well as fine non-expansive residues and other non-rock materials waste like plastics, PVC, wood, and glass, are also generated (Aguilar Maldonado, 2023).

The report generated in Medellín is the Plan de Gestion Integral de Residuos Solidos [Integrated Solid Waste Management Plan (PGIRS). It covers 10 surrounding municipalities: Barbosa, Copacabana, Girardota, Bello, Medellín, Envigado, Itagüí, Sabaneta, La Estrella, and Caldas, which together form a public law administrative entity known as the Área Metropolitana del Valle de Áburra [Metropolitan Area of the Aburrá Valley] (AMVA). Consequently, according to the REGIONAL PGIRS 2006-2020, in 2016, 187 678 tonnes per month were generated, of which only 3 924 tonnes/day were recovered, representing 21% of the total generated. The main waste generated is concrete (Peña Muñoz et al., 2018); however, asphalt pavement (Silgado et al., 2018), excavation material, rock, ceramic fragments, and rebar are also observed (Cadavid, 2014).

In the city of Santiago de Cali, approximately 2 500 m³ of CDW is produced per year (Jiménez Bolaños et al., 2019), where, on average, these wastes account for 27% of the total solid waste annually. CDW mainly originates from large-scale construction, excavations, road repairs, public infrastructure, and housing (Marmolejo de Oro, 2012). Various types are observed, including stone aggregates (Silgado et al., 2018), concrete, bricks, rebar, treated wood, wood, and metals (Marmolejo de Oro, 2012).

In Ibagué, an annual generation of approximately 488 thousand tonnes is reported, with 80% corresponding to excavation soil, 10% to concrete and asphalt, 4% to brick and mortar, 4% to concrete blocks and mortar, and 2% to metals, plastic, and gypsum (Silgado et al., 2018).

Meanwhile, an average generation rate of 2506.4 m³ per year is recorded in Barranquilla. Much of the waste comprises concrete, wood, plastic, mortar, masonry, asphalt, metals, soil, plastics, bricks, and ceramic materials (Pacheco et al., 2017).

Finally, according to various literature sources, the estimated values for the remaining major cities are as follows: Manizales with 306 000 m³/year, Cartagena with 1 900 00 m³/year (Sierra Perdomo, 2020), Pasto with 152100 m³/year (Secretaria Gestión Ambiental, 2021), and Valledupar with 1 000 00 tonnes/year (Tinoco & Santiago, 2020).

3.2. Regulatory Framework of CDW at the National, Local, and International Level.

The regulatory framework related to this study begins with Law 23 of 1973, which granted extraordinary powers to the President of the Republic to issue the Natural Resources and Environmental Protection Code. This law is a starting point because it establishes basic environmental protection principles regarding solid waste management (Aguilar Maldonado, 2023). Likewise, the rise of research focused on the utilization of CDW and the need for a cultural shift among both generators and users has motivated the issuance of the current laws, decrees, and resolutions in the country. It is essential to highlight that these regulations do not have extensive experience in utilization, recycling, and reuse. However, they aim to mitigate impacts for future generations (Pacheco et al., 2017).

3.2.1. National Regulations

Decree-Law 2811 of 1974 National Code of Renewable Natural Resources and Environmental Protection

- Art. 35. Prohibition of discharges without authorization of any type of waste that affects the environment or causes discomfort to society (Decreto Ley 2811 de 1974).
- Art. 36. Establishes that waste processing and final disposal are preferable if they

prevent environmental and human deterioration, allow the reuse of their components, enable the production of new goods, or contribute to soil restoration or improvement (Decreto Ley 2811 of 1974).

Law 99 of 1993

The Ministry of the Environment is created, reorganizes the public sector responsible for environmental management and the conservation of renewable natural resources, establishes the Sistema Nacional Ambiental [National Environmental System] (SINA), and enacts other provisions (Ley 99 de 1993).

- Art. 5. Functions of the Ministry. The Ministry of the Environment is responsible for these functions (Ley 99 de 1993).

✓ Clause 2. Regulate the general conditions for environmental sanitation, as well as the use, management, utilization, conservation, restoration, and recovery of natural resources, to prevent, suppress, eliminate, or mitigate the impact of polluting, degrading, or destructive activities on the environment or natural heritage (Ley 99 de 1993).

✓ Clause 10. Establish the minimum environmental standards and general environmental regulations that urban centers, human settlements, mining, industrial, transportation activities, and, in general, any service or activity that may directly or indirectly cause environmental damage must comply with (Ley 99 de 1993).

✓ Clause 11. Issue general regulations aimed at controlling and reducing geospheric, water, landscape, noise, and atmospheric pollution throughout the national territory (Ley 99 de 1993).

✓ Clause 13. Define the execution of programs and projects that the Nation, or the Nation in partnership with other public entities, must carry out for environmental sanitation or about the management, utilization, conservation, recovery, or protection of renewable natural resources and the environment (Ley 99 de 1993).

Resolution 0541 of 1994

Using the loading, unloading, transportation, storage, and final disposal of debris, materials, elements, loose concrete and aggregates, construction and demolition waste, organic layer, soil, and subsoil from the excavation are regulated (Resolución 0541 de 1994).

Decree 948 of 1995

The purpose of this Decree is to define the framework for actions and administrative mechanisms available to environmental authorities to improve and preserve air quality and to prevent and reduce environmental degradation, damage to renewable natural resources, and health issues caused by the emission of chemical and physical pollutants into the air; to improve the quality of life of the population and ensure their well-being under the principle of Sustainable Development (Decretro 948 de 1995).

- Article 22. Waste Materials in Public Areas. Individuals are prohibited from depositing or storing construction, demolition, or waste materials on public roads or in public-use areas, as they may cause the emission of airborne particles (Decretro 948 de 1995).
- Article 56. Operation of Construction, Demolition, and Road Repair Equipment. The operation of construction, demolition, or road repair equipment and tools that generate environmental noise in residential areas is restricted between 7:00 p.m. and 7:00 a.m. from Monday to Saturday or at any time on Sundays and holidays, requiring a special permit from the mayor or the competent police authority (Decretro 948 de 1995).

Decree 1713 of 2002, modified by National Decree 838 of 2005, Repealed by Article 120, National Decree 2981 of 2013.

- Article 44. Debris collection is established, and the producers of such materials are designated as responsible. These agents must ensure the transportation and disposal of debris in authorized disposal sites (Decreto 1713 2002).

Decree 4741 of 2005

Its purpose is to prevent the generation of hazardous waste or refuse and regulate the management of the generated waste to protect human health and the environment (Decreto 4741de 2005).

Law 1259 of 2008

Using this law, the environmental fine system is implemented in the national territory for violators of the cleanliness, waste disposal, and debris collection regulations, and other provisions are established (Ley 1259 de 2008).

Regarding the imposed sanction, for natural persons, a fine of up to 2 minimum monthly legal wages (SMMLV, by its Spanish acronym) is established for each violation. In the case of legal entities, a fine of up to 20 SMMLV is imposed for each violation committed, with a minimum fine of 5 SMMLV; this could also result in the cancellation of the registration or operating license (Ley 1259 de 2008).

Decree 2981 of 2013. This way, the public cleaning service is regulated.

- Article 45. The collection of construction and demolition waste. The responsibility for the management and disposal of CDW will lie with the generator by the regulations governing the matter (Decretro 2981 de 2013).

It is considered the responsibility of the municipality or district to coordinate with the providers of the public cleaning service or with third parties who are responsible for executing these activities, to agree on their remuneration and, in this way, ensure the collection, transport, and final disposal of the waste (Decretro 2981 de 2013).

CONPES 3874 of 2016 National Policy for Comprehensive Solid Waste Management

The national policy for integrated solid waste management has as one of its specific objectives the development of instruments that promote the prevention, minimization, reuse, recovery, and treatment of solid waste for valorization (CONPES 3874 de 2016).

This national policy is valid until 2030, focusing on contributing to the transition from a linear model to a circular economy, using the hierarchy in waste management to prevent, optimize, and extend, maximizing raw materials and their energy potential (Aguilar Maldonado, 2023).

Resolution 0472 of 2017 issued by the Ministry of Environment and Sustainable Development

The comprehensive management of waste generated in construction and demolition activities is regulated, and other provisions are issued (Resolución 0472 de 2017).

▪ Chapter III

✓ Article 13. It establishes an environmental management program for CDW.

✓ Article 14. It establishes the content of the environmental management program for CDW

▪ Chapter IV

✓ Article 15. It establishes the obligations of CDW generators.

✓ Article 16. It establishes the obligations of CDW managers.

✓ Article 17. It establishes the obligations of municipalities and districts.

✓ Article 18. It establishes the obligations of the competent environmental authority.

▪ Chapter V

✓ Article 20. Prohibitions on the final disposal of CDW

It incorporates the prevention and reduction of CDW through specific actions such as the planning and precise quantifying of materials required for the construction activity and on-site storage processes that minimize material loss. It also establishes the development and submission of an environmental management program to the relevant authorities, in which the general characteristics of the project are indicated, as well as the generalities of the CDW to be produced, including volumes and the disposal of these according to the waste valorization processes. These authorities must monitor the environmental management plans and provide the public with the necessary information about CDW managers for waste treatment, recovery, recycling, and final disposal (Resolución 0472 de 2017).

Resolution 1257 of 2021 modifies Resolution 0472 of 2017 on the comprehensive management of CDW and adopts other considerations.

Adopted considerations: promote the use of waste and by-products, as well as their valorization, in a way that allows closing the material cycles to strengthen the national circular economy strategy. The obligations of generators and managers to departments, districts, municipalities, and CDW receivers are modified, and procedures are established to carry out periodic control of CDW generation and utilization (Resolución 1257 de 2021).

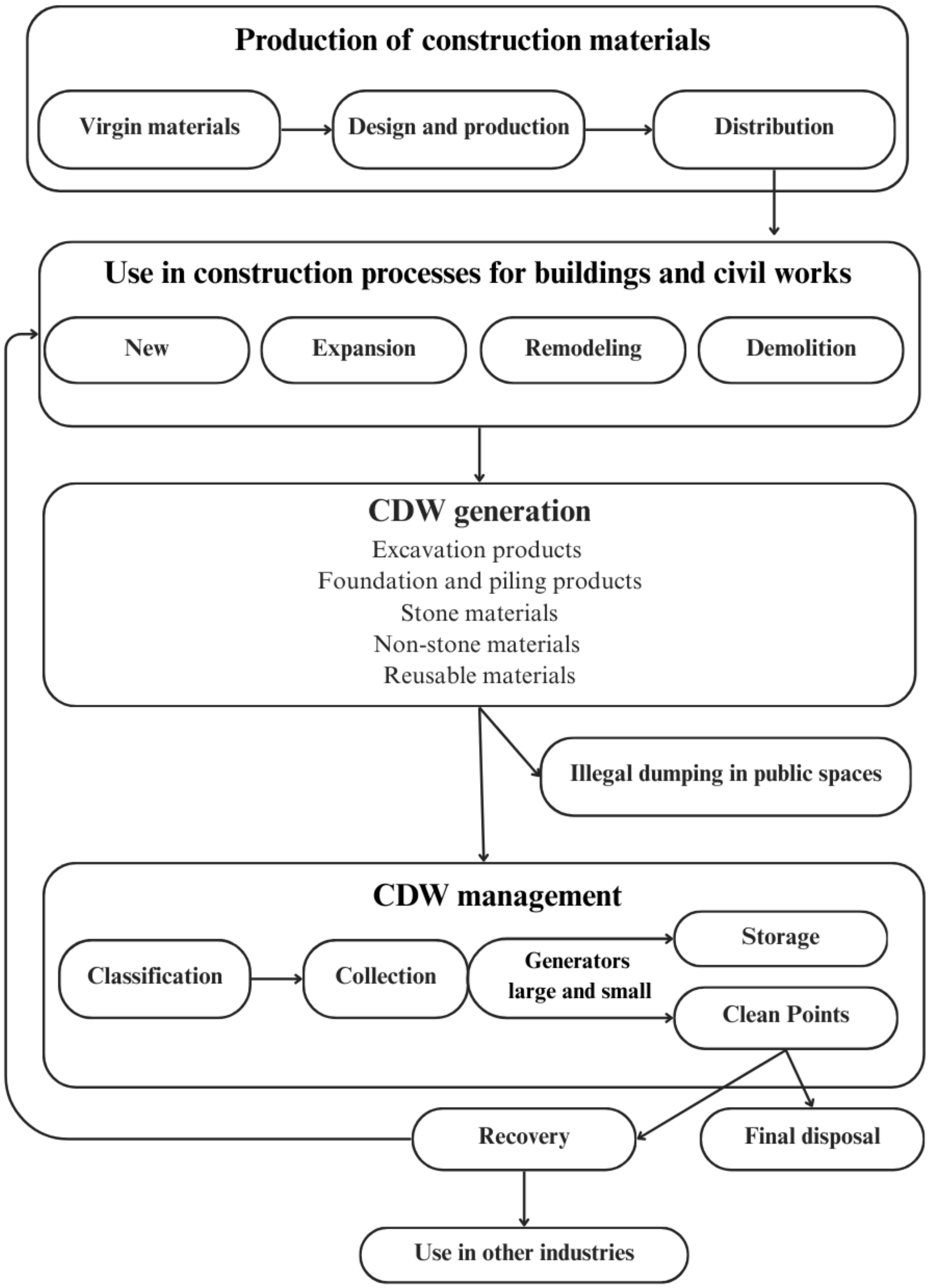
▪ Article 6. Modify Article 16 of Resolution 0475 of 2017. It establishes the obligations of CDW managers. Specify what those in charge of collection points, recovery plants, and final disposal sites must do.

This national regulation demonstrates the progressive interest of the State in regulating CDW disposal activities, as it is evident that since the 1974 regulation, where there was insufficient public policy reach, it is possible to understand that the country has reached high levels of development in recent years, where a better distribution of responsibilities and penalties for individuals and legal entities that do not contribute to the proper management of such waste has been achieved (Aguilar Maldonado, 2023).

Resolutions 0472 of 2017 and 1257 of 2021 are, to date, the most complete legal instruments addressing CDW management. These resolutions establish specific actions for better utilization and management, delegating responsibilities to the various stakeholders. Additionally, procedures for control and monitoring of CDW are defined (Aguilar Maldonado, 2023).

Figure 6 shows how CDW flows according to what is established in Resolution 0472 of 2017.

Figure 6.
Schematic representation of the CDW flow



Source: Extracted from Resolution 0472 of 2017. Adapted into English.

The Ministry of Environment and Sustainable Development identified specific barriers in implementing Resolution 0472 of 2017 since its entry into force in 2018. The above led to modifying and adopting other considerations through Resolution 1257 of 2021. One of these refers to actions regarding the utilization of CDW in the country. Consequently, Resolution 0472 is based only on the exclusive management of waste at utilization points, whose operation is not under the responsibility of public entities and is not present in most of the country. All the above limited the possibility of exchanging recoverable materials within the industry, such as real estate projects and the sale of scrap metal (Duque Rúa, 2024).

Likewise, Article 2 of Resolution 1257 modifies Article 9 of Resolution 0472, expanding the options for certifying the utilization of CDW by adopting a third receiver. The above implies that supporting documents and environmental permits backing the activity must be presented to the competent environmental authorities. Furthermore, Article 7 of Resolution 1257 modifies Article 12 of Resolution 0472, establishing that departments, municipalities, and districts may create incentives to promote the use of recycled material in public infrastructure projects within each jurisdiction (Aguilar Maldonado, 2023).

3.2.2. Local Regulations

To complement the current management of CDW in Colombia, it is essential to analyze the local context of Bogotá and the Metropolitan Area of the Aburrá Valley, as these are the cities in the country with the most comprehensive and applicable environmental public policies. Additionally, they serve as a reference for issuing new municipal and departmental regulations nationwide. Likewise, a brief analysis of the European context is conducted to serve as a model, highlighting strengths and lessons learned.

3.2.2.1 Current Regulations in Bogotá

Below are the specific regulations applicable to CDW management at the local level in Bogotá.

Table 2

Regulations that apply to CDW management locally in Bogotá

Regulation	Description
Resolution 01138 of 2013	By which the Environmental Management Guide for the Construction Sector is adopted, and other determinations are made.
Decree 586 of 2015	The efficient and sustainable model for managing CDW in Bogotá, D.C., is adopted through this.
Resolution 1115 of 2012	Through this, the Technical-Environmental guidelines for the utilization and treatment activities of construction and demolition waste in the Capital District are adopted.
Resolution 932 of 2015	Resolution 1115 of 2012 is modified and supplemented.
Resolution 00715 of 2013	Resolution 1115 of September 26, 2012, is modified, and the technical-environmental guidelines for the utilization and treatment activities of CDW in the Capital District are adopted.
Bogotá Humana Development Plan 2024-2027	Its main objective is to improve the quality of life for all citizens by addressing issues and creating opportunities for a better future. It details the proposals presented in the government program to strengthen security, improve infrastructure, ensure essential services such as health and education, and promote culture and sports for all. It also addresses climate change challenges and fosters opportunities in various sectors.
Decree 507 of 2023	Through this, the model and guidelines for the comprehensive management of CDW in Bogotá, D.C., are adopted, and other provisions are issued.

Source: Own Elaboration

The Bogotá Development Plan is aimed at an efficient and sustainable model for the CDW generated in the city. Its goal is to propose strategies to achieve higher recovery rates, reintegration into the construction sector, and the use of recycling plants. This district policy aligns with Resolution 1257 of 2021. Within Article 30, the Zero Waste program is outlined, focusing on reducing the impact generated by CDW with medium- and long-term targets. While reducing waste generation, the amount of recovered waste increases, and social segregation, environmental discrimination, and the current mismanagement of the sanitation service decrease (Secretaría Distrital de Ambiente de Bogotá, n.d.).

Among the priority projects of this program are sustainable production strategies, awareness campaigns on waste reduction culture and source separation, plans such as the implementation of a recycling model in the city, maximizing final recovery and redirecting final disposal to landfills, achieving zero net debris, and finally integrated management of special and hazardous waste (Secretaría Distrital de Ambiente de Bogotá, n.d.).

3.2.2.2 Current Regulations in the Área Metropolitana Del Valle De Aburrá (AMVA)

Below are the specific regulations applicable to CDW management at the local level in AMVA.

Table 3

Regulations that apply to CDW management locally in AMVA

Regulation	Description
Municipal Agreement 0062 of 2009	Establishes the Public Policy for debris management in Medellín.
Municipal Decree 1609 of 2013	Regulates Municipal Agreement 062 of 2009.
Metropolitan Agreement No. 23 of 2018	Adopts the PGRIS, Regional Plan for the Aburrá Valley, 2017-2030, updated according to the methodology of Resolution No. 0754 of 2014 by the Ministry of Environment and Sustainable Development and the Ministry of Housing, City and Territory.
Decree 1131 of 2021	Adopts the updated PGIRS for the Municipality of Medellín, establishing tools with a circular economy approach for solid waste

	management in the district.
Agreement 043 of 2021	Establishes the Public Policy on Circular Economy guidelines for the Municipality of Medellín.

Source: Own Elaboration

The regulatory framework for CDW management in the AMVA is also governed by the provisions established in Resolutions 0472 of 2017 and 1257 of 2021. These mainly highlight the guidelines for CDW management in civil works, public projects, and demolition activities. These regulations establish responsibilities to ensure the reduction of waste volumes sent to authorized disposal sites. This reduction must be achieved through classification, reuse, recovery, and recycling processes, allowing the construction industry to ensure sustainable development in alignment with the circular economy (Aguilar Maldonado, 2023).

Consequently, the AMVA has complementary guidelines to the resolutions mentioned before, focusing on improving CDW management through aspects of design and applicable processes for these types of waste. Additionally, these guidelines serve as decision-making tools in the early phases of construction projects, preventing or reducing CDW generation (Aguilar Maldonado, 2023).

Additionally, Municipal Agreement 0062 of 2009, in its Article 42, promotes the integration of materials derived from the reuse of debris, provided that these materials comply with the technical specifications established by the contracting authority to ensure the stability, durability, and resistance of the work without compromising its integrity (Acuerdo Municipal 062 de 2009).

Municipal Decree 1609 of 2013 establishes in Paragraph 1 of Article 17 that new products generated from materials derived from the reuse of CDW, which are reintegrated as raw materials in various construction processes, must comply with the applicable legal, regulatory, or technical specifications. These specifications may be determined by technical regulations or by the contracting entity, whether public or private, according to the specific needs of each project. Additionally, it is an essential requirement that these new products have certified laboratory tests duly accredited, ensuring compliance with the established technical specifications (Decreto 1609 del 2013).

3.2.2.3 Current European Regulations

Table 4 shows the regulations applicable within the framework of CDW at both the national and local levels for the EU's 28 Member States (MS)

Table 4
Regulations that apply to CDW management for EU's 28 MS

Regulation Level	Regulation	Description
MS EU-28	Directive 2008/98/EC	The Waste Framework Directive establishes the legislative framework for handling waste in the Community of the 28 MS of the EU
	CONDEREFF Project	It brings together eight partners from 7 countries to exchange experiences and practices on how to move forward from existing procedures on CDW management towards the adoption and further exploitation of the best practices and measures applied in the field (Interreg Europe, n.d.).
	The EU Construction & Demolition Waste Management Protocol	Its overall aim is to increase confidence in the Construction and Demolition waste management process and trust in the quality of Construction and Demolition recycled materials (European Commission, 2018).
National	Austria - Federal Act amending the Waste Management	These amendments aim to strengthen environmental protection measures, ensure responsible waste management, and promote greater public engagement in environmental decision-making.

Act 2002	
France- Law 2009-967 and Law 2010-788	Make pre-audits compulsory on demolition sites and CDW management plans (Sáez & Osmani, 2019).
Germany- The Circular Economy Act	Currently, it is the central waste disposal regulation. The legal framework for CDW recycling is specified in different state laws (Sáez & Osmani, 2019).
Netherlands - Act of 3 February 2011	Amending the Environmental Management Act, the Environmental Taxes Act, and the Economic Offenses Act to implement Waste Framework Directive (WFD) (Sáez & Osmani, 2019).
Croatia - The Act on Sustainable Waste Management (OG 94/13)	This Act lays down measures for preventing or reducing adverse impacts of waste on human health and the environment by reducing amounts of waste generated and/or produced. It regulates waste management, including no operations posing a risk to human health and the environment, and involves the use of valuable properties of waste.
Portugal - Decree-Law 46/2008	Establishes the legal framework for waste management resulting from construction works, demolition of buildings, or collapses (Sáez & Osmani, 2019).
Slovenia - Decree on the management of waste arising from construction work of 22 April 2008	It establishes compulsory treatment of waste generated from construction work during construction, reconstruction, alterations, or removal of the facility.
Spain - Royal Decree 105/2008	Its purpose is to establish a legal regime for the production and management of CDW and to promote its prevention, reuse, recycling, and other forms of recovery. Ensuring that waste with no recovery opportunity receives appropriate treatment and contributes to the construction sector's sustainable development.
Poland - Act on	The new Waste Act was enacted primarily to implement the Waste

	Waste of 2012	Framework Directive (2008/98/EC) into Polish law.
	Italy - Decree June 28, 2024. n27	It contains provisions for the cessation of waste classification, including inert waste from construction and demolition and other inert waste of mineral origin.
	Italy - Legislative Decree 3 April 2006, n. 152	Known as Codice dell'Ambiente, it provides the general framework for waste management in Italy, including specific provisions for CDW

Source: Own Elaboration

The Waste Framework Directive 2008/98/EC is the fundamental law for all solid waste policies for the 28 Member States of the European Union (MS 28 EU). This directive defines waste-related concepts and provides a general framework for its prevention and management (Sáez & Osmani, 2019). Additionally, it explains what to do when waste becomes a secondary raw material and how to distinguish it from a by-product. Finally, it introduces the principles of "polluter pays" and "extended producer responsibility" (European Commission, n.d.).

Article 4 of this directive establishes that all MS must implement waste management by applying the five steps of the Waste Hierarchy, which sets the order of preference, starting with prevention, reuse, recycling, energy recovery, and as a last resort, disposal in landfills (Sönmez & Kalfa, 2023).

Consequently, the EU aims to implement the WFD to transition into a recycling society that prevents waste generation, reuses waste as a resource, and reduces negative impacts on both the environment and human health, all directed towards a circular economy (Sönmez & Kalfa, 2023).

4. Strategies and Methods of Recycling and Final Disposal

On November 23, 2021, the Ministry of Environment and Sustainable Development issued Resolution 1257 of 2021, which, as previously explained, modifies Resolution 0472 of 2017 about the integral management of CDW, which applies to all natural and legal people who generate, collect, transport, store, recover, and dispose of this type of waste. Likewise, it establishes the Environmental Management Program for CDW to monitor all activities. Another of the Resolution 1257/2021 processes is the definition of objectives for including such useful waste in constructions carried out by major producers. These goals are progressive, with different timelines depending on the municipality (Resolución 1257 de 2021).

However, it is essential to highlight that the new resolution only establishes recovery objectives, regardless of whether these are effectively used in building projects. Therefore, the management of CDW is encouraged in recovery facilities. Still, the use of recycled materials in executing the construction work is not promoted, as established by the 2017 Resolution. (Duque Rúa, 2023).

According to the regulation, the objective is for large generators to recover a percentage by the weight of all CDW generated in the project. This percentage will depend on where the project, construction, or work is located and how this location is categorized. Table 5 shows this percentage, exemplifying some cities and fulfilling this goal until 2030 (Resolución 1257 de 2021).

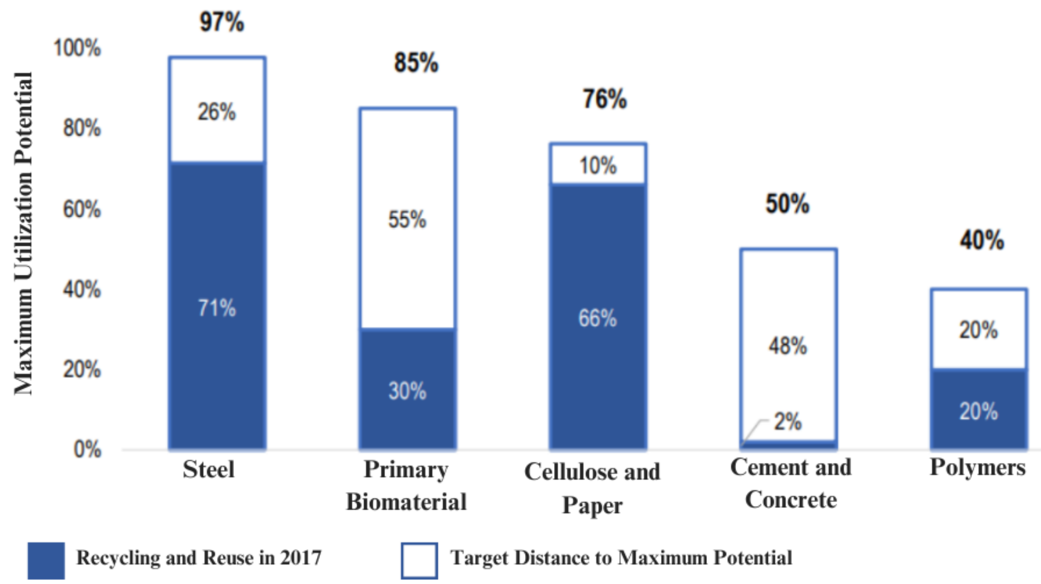
Table 5
CDW recovery percentage is determined by the municipality where the project is located.

Large Municipalities: Bogotá, Medellín, Barranquilla.	Intermediate Municipalities: Ibagué, Pasto.	Basic Municipalities: San Andrés Islas.	Goal Fulfillment
20%	15%	5%	2023
50%	30%	20%	2026
75%	60%	40%	203

Source: Taken from Duque Rúa (2023) and Resolución 429 de 2024, modified and adapted into English

Before analyzing the effective strategies for the reuse and recycling of CDW in the country, most of the waste generated in the construction sector ends up in landfills and often in illegal sites due to the lack of awareness, education, socioeconomic level, sensitization, negligence in the provision of collection and transport services, the advantageous price conditions offered by these places with a dumping cost that makes any other operation non-competitive, among others (Mora Castro, 2021). The above not only results in the loss of material with potential for valorization or reuse, as shown in Figure 7, but also leads to adverse effects on Colombians' social and environmental medium (Mejía et al., 2013).

Figure 7
Utilization potential of CDW



Source: Taken from Mora Castro (2021) and adapted into English

4.1. Strategies Used in Colombia

The National Circular Economy Strategy of the country suggests improving the efficiency of construction materials in the CE due to the growth of the industry and its significant influence on the economic development of the country by carrying out goals such as (Mora Castro, 2021):

- Better instruments to facilitate the closure of production cycles
- Increase the recovery of CDW generated in demolition works
- Integrate sterile material generated in mining and energy projects for later use in construction.
- Promote eco-design that uses fewer materials
- Application of regional models for the management and recovery of CDW

materials

- Increase LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Methodology), and EDGE certifications (Excellence in Design for Greater Efficiencies), CASA Colombia, and Colombian Environmental Seal, among others, to promote sustainable constructions.

Furthermore, the management of CDW is aligned with the CE model, where the aim is to preserve materials in the production cycle for as long as possible through reuse, recovery, and treatment. Therefore, the main objective of this alignment is to minimize both the use of new resources and the volume that goes to sanitary landfills (Alzate Rodríguez, 2022).

In this way, the hierarchy of CDW management is essential, which is why Colombia proposes approaches prioritizing prevention or reduction, then recovery, and as a last option, final disposal (Alzate Rodríguez, 2022). The evaluation of these wastes is crucial in this process since their recovery is sought to incorporate them into the production of new products in a regulated way, avoiding risks to quality and stability in construction works (Aguilar Maldonado, 2023).

Within the context of the strategies used to improve CDW management in the country, methods have been established to ensure proper source separation. Among these is selective demolition, which allows the separation of materials during the demolition process and, at the same time, prevents recyclable materials from becoming contaminated, and the implementation of specific containers for each type of waste (Pacheco et al., 2017).

Additionally, actions are being implemented to increase confidence in waste transformation processes and in the quality of recycled materials (Silgado et al., 2018).

The management models aim to implement CDW management plans in both public and private works, promote reuse and on-site treatment, manage the treatment and use of new products, handle the final disposal of non-recoverable materials, incorporate all managers in the chain, promote technological innovation and research initiatives, encourage technical collaboration, and create evaluation and monitoring tools (Alzate Rodríguez, 2022).

At the same time, the purchase of recycled CDW in public projects is being promoted as a method to improve sustainability based on the CE (Duque Rúa, 2023). In addition, logistics units are being formed to recover waste, and new strategies are being developed to facilitate reuse in construction works (Puerta Ortiz, 2019).

Finally, in large cities, research initiatives have emerged on the reuse potential of CDW based on their physical, mineralogical, and energy properties, with results focused on the reincorporation of excavation and block masonry waste, as these are the materials with the most significant potential (Chica Osorio & Beltrán Montoya, 2018). Likewise, municipal agreements propose public policies regarding managing such waste, such as reusing mining pits in quarries as possible sanitary landfills, as long as specific technical guidelines are followed (Zapata et al., 2022).

4.2. Recovery Methods in Colombia

The act of reuse and recycling are a fundamental strategy to achieve sustainability in the construction sector (Peña Castañeda & Rincón Pineda, 2018) since it makes it possible to extend the durability of materials, meaning their useful life, and reduce the need to manufacture new components or products so that the amount of waste in landfills does not increase (Aguilar Maldonado, 2023).

To maximize the recovery of CDW, it is essential to apply good practices in its management, separating the materials at the different stages of the construction work, thus allowing their subsequent reuse to ultimately optimize the use of raw materials (Ramírez Vargas, 2021).

One of the most effective strategies in this aspect is deconstruction, which is the task of gradually disassembling or dismantling a building to recover its components for reuse and recycling while reducing the amount of material that ends up in landfills. In this way, this alternative helps to increase the potential for the reuse of CDW generated during the process, since a general assessment of the construction is carried out, proposing in this way the best path to manage such waste. All are orientated to starting processes of recovery, reuse, recycling, treatment, and final disposal (Aguilar Maldonado, 2023).

Reuse does not always involve highly complex procedures; in many cases, in many cases, materials can be reintegrated into the same construction project (Alzate Rodríguez, 2022). Additionally, integration between different companies can be promoted, where the waste from one becomes the raw material for another, intending to minimize the consumption of raw materials (Ramírez Vargas, 2021).

In Colombia, the recovery and recycling of CDW is very low. According to the Departamento Nacional de Planeación (2019), 96% of this waste is neither recycled nor reused. By 2021, it was estimated that only 2% was destined for this process. However, the country has a reuse potential of up to 50% (Ramírez Vargas, 2021).

It is estimated that the recovery rate in the country does not exceed 20% (Duque Rúa, 2023). In the reality of construction projects, only between 5% and 10% of CDW undergo treatment processes to be reused or recycled. Despite extensive legislation for the proper management of debris, its implementation is still minimal, and the control by the competent environmental authorities is insufficient. All the above shows a difference between what is established in the legislation and what is occurring in the national territory (Mora Castro, 2021).

At this point, it is essential to highlight the work of recyclers, who are key players in the integrated management of CDW (solid waste in general) and make significant contributions to recycling, especially in the city of Medellín, where in 2020, they helped with the reuse of approximately 59 000 tonnes of waste. These individuals are those who, in situations of homelessness or with limited job opportunities, provide the service of collecting, separating, transporting, and reintegrating waste into the production chain (Camargo Sánchez, 2023).

Below, the potential for the recovery of specific materials present in CDW in Colombia is described according to various literature sources.

4.2.1. Reuse of concrete waste

Among the CDW, concrete stands out because it is the waste with the highest generation volume. According to Chica Osorio and Beltrán Montoya (2018), in the national territory, although it is uncommon, four main lines for its recovery can be followed, such as the production of concrete using these wastes as a complete replacement for natural aggregates or as an alternative for coarse or fine fractions; the production of prefabricated items such as partition blocks, curbs, and pipes; use in roads as base and sub-base; and the use of concrete waste as raw material for the create of new high-quality products.

On the other hand, it is also used as a structural eco-block for rural housing using reused concrete and polyethylene terephthalate (PET) bottles, as well as for the manufacture of hydraulic concrete using fine and coarse aggregates obtained from the separation or crushing of concrete and mortar waste, without organic matter, metals, or hazardous waste content (Mora Castro, 2021).

Additionally, in the research conducted by Martínez Ussa & Poveda (2015), it was used as a paving stone made from a combination of concrete, where fine and coarse aggregates were replaced by selected recycled material.

In some cities, recycled concrete is used to manufacture non-structural elements such as tire stops in parking lots, chairs for public areas, and plant pots (Arango Hurtado, 2023).

Finally, Colombia has the possibility of exporting pre-mixed cement made with CDW to international markets such as the United States, Venezuela, Ecuador, Peru, Brazil, Costa Rica, Puerto Rico, Panama, Dominican Republic, Chile, Canada, Jamaica, Haiti, Cuba, United Kingdom, Taiwan, and Trinidad and Tobago. In this way, a business opportunity is sought through secondary products generated from these wastes, which have high quality and durability for any construction work (Mora Castro, 2021).

4.2.2. Reuse of Natural Aggregates

Natural Aggregates such as sand, gravel, and crushed rocks can be reused in the construction sector and the industry in general. According to the study carried out by Mejía et al., 2013 about the impacts and management of CDW, this type of waste is used as follows:

- In the construction sector, it can be reused as mortars, concrete, prefabricated elements, filling materials, road bases and sub-bases, railway track ballast, asphalt aggregate pavement, and riprap stones.
- In the industrial sector, it can be reused in the ceramic and glass industry, filtering beds, insulating and refractory coatings, abrasive materials, industries of paper, plastics, paint, detergent, chemical and pharmaceutical, cement manufacturing, water treatment, agricultural uses, feed additives, and soil correction.

4.2.3. Reuse of Masonry Waste

The most common type of reuse of recycled aggregates from masonry waste is as a substitute for natural aggregates in manufacturing concrete and mortars. However, this leads to the final products' physical and mechanical properties not being as optimal as they should be. Additionally, waste with pozzolanic activity can be reused as soil stabilizers or as new raw material to produce expanded aggregates (Chica Osorio & Beltrán Montoya, 2018).

The study by Silva et al. (2019) proposes that one of the viable alternatives for the recovery of masonry waste is to use it as a supplementary cementitious material and aggregate for concrete production. Mainly when the waste also contains residues of fired clay bricks that act as a pozzolan. The pozzolanic activity depends on the type of clay, the amount of silica and alumina available to react with CH, the degree of crystallinity, the surface area of the particles, and the ratio between the fired clay material and the mortar present in this waste.

Likewise, in the same study, the same kind of waste was analyzed as a partial replacement for Portland cement, where it was concluded that it does have value as a raw material and can be incorporated into its production (Silva et al., 2019).

4.2.4. Reuse of Ceramic Waste

Following again the approach proposed by Chica Osorio and Beltrán Montoya (2018) on the characterization of CDW for the identification of its potential use, it analyzes how usable ceramics are due to their pozzolanic activity, even though their production volume compared to other waste is very low. This waste can be transformed by reducing its size or subjecting it to high temperatures. Those with high pozzolanic activity can be raw materials for manufacturing eco-blocks and porous ceramics. In contrast, those with low activity are used as fine aggregates in producing paving stones, masonry mortars, and both asphalt and conventional concrete.

Recycling ceramics in many towns in Colombia is a traditional practice used to decorate the streets and attract tourists. There is a technique called trencadís, a Spanish word used to refer to the Catalan mosaic technique, where broken pieces of this material are used to create mosaics and frames, especially in architecture such as facades, parks, gardens, bridges, benches, designs, logos, interiors, and bathrooms; providing resistance and beautifying spaces (El campesino, 2022).

Additionally, a beautiful and well-known tradition in a town in Antioquia Department is used to attract tourists, and it has been carried out for generations. El Carmen de Viboral artisans use ceramic waste to produce cups, vases, plates, and flower pots. These materials are made to generate income for their households (Artesanías de Colombia, 2015).

4.2.5. General Reuse of CDW

After addressing the various forms of utilization of specific waste, it is essential to cover other types of CDW in the country and their several forms of utilization. Table 6 below summarizes the kinds of materials and their current reuse in the national scenario. This collection allows for understanding how these wastes are reintegrated into new activities.

Table 6
Summary of some CDW reuse and recycling activities in Colombia

Material Type	Reuse or Recycling
Light Aggregates (particle density <200 kg/m3)	Pozzolanic mortars, lightweight concrete, special fill materials, lightweight prefabricates, and ceramics (Mejía et al., 2013).
Secondary Aggregates (artificial)	Filling material, concrete production, cement or brick manufacturing, road base and sub-base (Mejía et al., 2013).
Bricks	Second-hand material, filling material,

	concrete or brick production, road construction, sand for tennis courts (Mejía et al., 2013), and paving stones (Martínez Ussa & Poveda, 2015).
Tiles	Second-hand material and filling material (Mejía et al., 2013).
Soil	Filling material, landscaping, and gardens (Mejía et al., 2013).
Wood	Furniture manufacturing, second-hand material, composting (Mejía et al., 2013), production of formwork, fences, and boundaries (Ramírez Vargas, 2021), boiler fuel, landscaping covers, soil amendments (Duque Rúa, 2023).
Asphalt	Asphalt production, road construction (Mejía et al., 2013), and filling mass (Ramírez Vargas, 2021).
Glass	Glass product manufacturing, concrete production, road construction, and landscaping (Mejía et al., 2013).
Metals	Smelting and manufacturing of new metal products (Mejía et al., 2013). Steel can be sold to scrap dealers (Duque Rúa, 2023).
Plastics	Manufacturing various plastic products, flooring, and coatings (Mejía et al., 2013).
Oils	Oil regeneration (Mejía et al., 2013).
Gypsum	Filling material and partition wall manufacturing (Mejía et al., 2013).
Architectural Elements	Reuse as new products (Ramírez Vargas, 2021).

Stone	Reuse as fine and coarse aggregates (Ramírez Vargas, 2021).
Tar-free Asphalt	When mixed with fresh asphalt aggregates, material for a new pavement surface is made (Duque Rúa, 2023).
Excavation Waste	Filling material, land leveling (Sánchez Pacheco, 2020), formation of ramps within construction projects for heavy machinery, wall-filling (Maat, 2022), internal filling within the same construction project (Silgado et al., 2018), and use in pottery (Arango Hurtado, 2023).

Source: own elaboration

4.2.6. Use of Recycled Aggregates

The annual consumption of aggregates in Colombia is approximately 100 million tonnes (three tonnes per capita), which is why the emergence of new research and investments in the use of recycled aggregates as an alternative or in combination with conventional ones is significant (Cámara Colombiana del Cemento y el Concreto, 2022)

Recycled aggregate is a granular material derived, separated, or removed from a solid waste source, which has already been processed for raw material or as a new product (NTC 174 de 2018). It presents better physical performance than the traditional one, especially in strength and material purity (Agencia UNAL, 2020).

In Colombia, no national decrees regulate implementing materials derived from CDW. However, in response to the need to reduce the demand for virgin materials and enhance the use of such waste, in 2019 in Bogotá, Resolution 010910 was issued, which includes the "General Technical Specifications for Construction Materials for Road Infrastructure and Public Space

Projects in Bogotá D.C." by IDU (Instituto de Desarrollo Urbano, 2019).

This resolution symbolizes significant local progress and an essential development for creating future regulations at the national level and in other cities of the country. This initiative offers a framework for the conscious and responsible implementation of recycled CDW materials in building and infrastructure projects, showing a path toward more sustainable and mindful practices in the construction sector (Duque Rúa, 2023).

On the other hand, the regulation on aggregates for concrete is defined in the Norma Técnica Colombiana [Colombian Technical Standard] (NTC) 174 of 2018, which details the gradation and quality requirements for fine and coarse aggregates, excluding lightweight and heavyweight ones, that are used for concrete production. It is essential to highlight that this standard includes possibly using recycled aggregate (Gutierrez, 2024). This inclusion enables using these materials in the concrete industry, promoting more sustainable and environmentally friendly construction practices. The above is because incorporating them into the concrete manufacturing process helps to reduce waste and boost CE in the sector (Duque Rúa, 2023).

NTC 174/2018 establishes the properties of aggregates to be reused in concrete and the test methods that must be followed. It also emphasizes that some recycled aggregates may contain materials and characteristics that are not included. In addition, they may require environmental evaluations on air quality, water, and storage.

By 2021, two new regulations began to be implemented. On one hand, NTC 6421 deals with reusing aggregates in hydraulic concrete, where guidelines for their incorporation are introduced, ensuring that they meet the requirements for use in the sector. On the other hand, NTC 6422 focuses on classifying the elements that make up recycled aggregates, offering assessment techniques for the components of coarse aggregates obtained from recycled materials. These tests are essential to establish the quality and characteristics of the recycled materials before being incorporated into construction projects (NTC 6421 de 2021).

Both NTC 6421 and NTC 6422 are important to ensure the quality and suitability of recycled aggregates for their later uses in the construction sector, establishing precise guidelines for categorizing them and, in this way, facilitating their application in hydraulic concrete as well as in other construction projects. As the regulations are flexible regarding the composition of the aggregates, they allow for better integration of these materials into the production process, reducing the demand for natural resources (Duque Rúa, 2023).

In Colombia, research and technologies prepared for producing recycled aggregates are very scarce. However, some studies and certain public and private institutions have proposed and initiated projects to eliminate debris from cities (García, 2019).

Based on those mentioned above, the most recognized companies in the country (especially in the capital and its surroundings) specialize in the treatment and use of recycled aggregates from CDW are summarized.

Granulados Reciclados de Colombia (GRECO) transforms CDW into sand and gravel for concrete and granular bases and sub-bases for later commercialization. They reintegrate recycled aggregates into the city's production chain. Additionally, they aim to process around one million tonnes of such waste annually (Granulados Reciclados de Colombia GRECO SAS, 2024). The products offered by the company and how buyers use them are summarized in Table 7.

Table 7
Summary of products offered by GRECO SAS

Product	Description of use
Filters (classified sand)	Construction of drainage filters, pipe beds, and improvement of tertiary roads
Crushed gravel and sand	Concrete production (unspecified, whether structural or non-structural)
Filling material	The base for installing pavement structures (compacted)
Granular base / sub-base	Pavement structure (between the subbase and the asphalt layer)

Source: Taken from García (2019) and adapted to English.

CICLOMAT S.A. specializes in the utilization and wholesale commercialization of CDW. They focus on managing and recovering recycled aggregates from concrete, asphalt, or mixed material waste (EMIS, 2023). The products offered by the company and how buyers use them are shown in Table 8.

Table 8
Summary of products offered by the company CICLOMAT S.A

Product	Description of use
Granular bases and subbases type A, B, C	Construction of vehicular roads, bike lanes, pedestrian paths, and hard zones
Ciclomat T5 sand	Preparation of floor mortar and subfloor
1/2” mix	Sidewalks and non-structural concretes
3/4” mix	
Prefabricated materials	Vehicular cobblestone, colored vehicular cobblestone, pedestrian cobblestone, colored pedestrian cobblestone, A10 type curb, A80 type curb, A120 type cañuela

Source: Taken from García (2019) and adapted to English.

Reciclados Industriales de Colombia S.A.S manufactures construction materials from recycling debris to preserve the environment and promote sustainable construction and urban development processes (Reciclados Industriales, 2013). The products offered by the company and how the buyers use them are shown in Table 9.

Table 9
Summary of products offered by Reciclados Industriales de Colombia S.A.S

<table>
<tr><th>Product</th><th>Description of use</th></tr>
<tr><td>Granular bases and subbases type A, B, C</td><td>Materials type IDU: BG-A, BG-B, BG-C, PEA 1, PEA 2</td></tr>
<tr><td>Sand</td><td>Materials type IDU: SBG-A, SBG-B, SBG-C, Asphalt B200, B400, and B600 debris sand</td></tr>
<tr><td>1/2” mix</td><td rowspan="2">Non-structural sidewalks and concrete</td></tr>
<tr><td>Gravel</td></tr>
</table>

Source: Taken from García (2019) and adapted into English.

Based on the information gathered by García (2019) about the products commercialized by these companies and their potential uses in the country, it is possible to determine that the industry is moving into the production of coarse recycled aggregates, which will later be reused in the production of non-structural recycled concrete. However, these do not meet the technical requirements for producing such material as specified in the NTC 174 regulation.

Furthermore, some of the country's most notable research and projects regarding reusing recycled aggregates were compiled.

In the study by Hincapié Henao & Aguja López (2003), the mortar produced from recycled aggregates derived from cement cylinders was evaluated, and it was concluded that it exhibits favorable behavior for being introduced into the masonry sector. According to the NTC, all its property values fall within an acceptable range.

In the experimental study carried out by Vanegas Cabrera and Robles Castellanos (2008), the reuse of hardened concrete extracted from laboratory cylinder waste was implemented. This recycled concrete aggregate was transformed into new concrete with physical and mechanical characteristics similar to traditional concrete.

In the investigation undertaken by Ferreira (2009), it was demonstrated that the use of debris-recycled aggregates for producing new concrete is economically and technically viable, presenting potential applications to produce pavers. In this way, it contributes to job creation and reduces negative environmental impact.

At the Escuela Colombiana de Ingeniería Julio Garavito, research was performed about the implementation of coarse recycled concrete aggregate, but this time in reinforced concrete structural elements. Traditional concrete mixtures were made with 20% replacement of this aggregate to understand the structural behavior of high beams, corbels, and slabs supported on three edges. It was concluded that the behaviors were satisfactory regarding mechanical resistance, allowing its reuse without experiencing negative consequences in terms of safety (Arriaga, 2013).

In the research conducted by Ágreda Sotelo and Moncada Moreno (2015), the technical feasibility of using coarse recycled aggregates to produce prefabricated products used in public areas, such as curbs, gutters, and tire stops, was analyzed. It was demonstrated that this is a potential alternative to replace conventional coarse aggregate, as it meets the NTC regulations.

Similarly, Bedoya and Luis (2015) undertook a project to analyze how recycled aggregates could be incorporated into urban sustainability projects in the country. The authors evaluated the compression strengths of concrete with recycled aggregates on different days and its behavior against atmospheric agents. The goal was to predict its durability. As a result, they found that these recycled aggregates are suitable for reuse as raw materials in the construction sector.

Finally, according to Agencia UNAL (2020), recently a research was published by civil engineer Jairo Andrés Guaje Guerra, a master's degree holder in Construction from the Universidad Nacional de Colombia [National University of Colombia] (UNAL), on the use of recycled aggregates in lateral confinement cells with tire waste in low traffic volume road constructions. The confinement with reused tires enhances the properties of the aggregates, generating greater support for the structure. This alternative presents a lower content of organic matter and clay particles, making the roads less slippery. It is worth noting that the country will be a pioneer in this new utilization option, as there are no global precedents.

4.2.7. Successful Cases of CDW Reuse

Within the context of appropriate practices in reusing recycled CDW materials, some experiences from some cities in the country are shown below.

In the research paper regarding the criteria for the incorporation of recycled materials from CDW for public works in the city of Medellín, carried out by Duque Rúa (2023), different experiences were collected where it is observed that works incorporating such materials have been made in the city. However, the author states that there is no record of the exact amount of material used in these constructions. Some of these works include the Plaza de la Libertad building, the Belén Library Park, the San Cristóbal Library Park, the Poblado Avenue, the San Germán Literature House, and the Inflexion Memorial Park, as illustrated in Figures 8 (a), (b), (c), (d), (e), and (f), respectively.

Figure 8

Public works built using recycled CDW in Medellín City

Source: Extracted from Duque Rúa (2023), a. (M Photographie, 2024), b. (Comfenalco Antioquia, 2021), c. (Pastorelli, 2024), d. (Luco, 2022), e. (Ortiz, 2022) y f. (Correa, 2008)

It is essential to mention that the amount of reused material incorporated in the restructuring of the Spain Library Park is available, where 331 m^2 of marble flooring, 219.96 m^2 of wooden railing, and 80.44 m^2 of metal railing were used (Duque Rúa, 2023).

Moreover, Duque Rúa (2023) states that in Medellín, in 2021, recycled asphalt pavement began to be implemented, reducing by 25% the exploitation of raw materials from quarries designed to produce asphalt mixtures.

Figure 9
Illustration of the pavimentation process in the city of Medellín

Source: Taken from Balbín (2023)

Another example of successful cases in the city is the construction of the Prado Centro Park, where 4 000 m² of recycled CDW material from old houses acquired in the area was used. With the demolition materials, recovered bricks and public benches were also produced. The original facades of the houses were preserved, but platforms were added that work as viewpoints, also made using recycled material (Osorio, 2021).

Figure 10
Construction of the Prado Centro Park using recycled CDW material

Source: Taken from Mesa Gonzáles (2020)

Finally, at the end of 2023, recycled CDW material was incorporated into the renovation of the Metropolitan Sports Court in Comuna 13, a neighborhood in Medellín. A total of 9.45 tonnes of CDW were reused (Duque Rúa, 2023).

Figure 11
Metropolitan Sports Court in Medellín

Source: Taken from Alcaldía de Medellín (2023)

On the other hand, in Bogotá, the company Enel, in 2021 incorporated recycled aggregates as part of the backfill in excavations for underground network channeling works, where up to 75% of granular material from recycling plants was used. At the same time, they tried to send almost half of the waste generated to the same recycling plants for subsequent treatment (Enel, 2022).

Figure 12
Underground network channeling using recycled aggregates.

Source: Taken from Enel (2022)

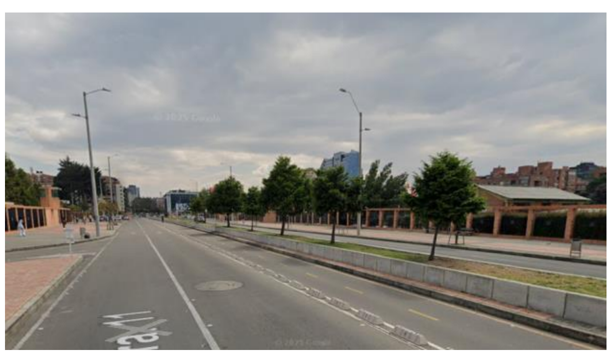
In this same city, specifically in Mochuelo, a rural area of the Ciudad Bolívar district, the Unidad de Mantenimiento Vial [Road Maintenance Unit] (UMV) has paved more than 5 km of rural road using recycled asphalt material from the demolition of deteriorated roads in the city. In this pilot civil works project, the percentage of recycled material incorporated into the raw material corresponds to 95% (Sánchez, 2024).

Figure 13
The paving process carried out by UMV

Source: Taken from Sánchez (2024)

The UDI of Bogotá in 2014 used 23% recycled CDW material, equivalent to 7 786 m³, for the construction of the Germán Arciniegas Avenue (Carrera 11), located between Carlos Lleras Restrepo Avenue (Calle 100) and Calle 106 (Cantón Norte). Where 43% of this material came from waste generated at the same construction site, the rest from the city's CDW recovery center (IDU, 2014).

Figure 14
Carrera 11 is located between Calle 100 and 106 in Bogotá city



Source: Obtained from Google Maps with coordinates 4°41'06.0"N 74°02'31.8"W

Likewise, in the city of Barranquilla, there is a company called ÍgNEO dedicated to the design of products for urban and architectural furniture using recycled aggregates of CDW. Its goal is to generate sustainable urban construction in the city's public spaces, aiming to eliminate waste of this material in the streets. They replace stone and sand in concrete mixtures with 100% recycled aggregates, in this way, creating plant pots, facades, 3D walls, decorative coatings, benches, bike racks, bollards, trash cans, table lamps, sinks, and signage. Among their most important constructions are the plaques with the names of the Junior players (Ventana de Campeones), the María Mulata sculpture (Carrera 51 with Calle 79), and the furniture of the Gran Malecón, as illustrated in figure 15 (a), (b), (c) (Miredvista.Co, 2021).

Figure 15
Urban projects developed by the company ÍgNEO

(a) (b) (c)

4.3. Final Disposal of CDW

In Colombia, the Superintentencia de Servicios Publicos [Superintendence of Public Services] (2023) has categorized final disposal systems into authorized and unauthorized. The categorization started with the first national report on solid waste final disposal. Authorized systems have environmental permits, such as the ecological license (Decree 1076 of 2015), the Environmental Management Plan, or an administrative act that allows site operation. Inside this category, there are sanitary landfills and contingency cells. Finally, unauthorized systems include transitional cells and open-air dumps.

The inadequate management of CDW in the country, commonly called "Debris," has become a problem affecting various aspects of small cities and large metropolises (Carvajal Muñoz & Carmona García, 2016). The above has created environmental, social, and logistical issues due to the large volume of waste generated that is not subjected to a post-treatment process (Colorado et al., 2022) and, in most cases, ends up on the streets, in legal debris disposal sites (authorized final disposal sites), or illegal ones.

According to data recorded by DANE (2020), 30% of the cases are disposed of illegally, and only 2% are recovered due to business culture or because the company has characterization information. Similarly, Superintendencia de Servicios Públicos (2023) identified 249 final disposal sites for 2023, distributed as follows: 157 sanitary landfills, 73 open-air dumps, 10 contingency cells, and nine transitional cells.

In Colombia, it is very common to see debris inside vacant lots, on main streets, sidewalks, road dividers, green areas, parks, streams, etc. This situation is due to several factors, such as lack of knowledge and misinformation about legal debris disposal sites, ignorance of available recycling alternatives, lack of awareness of material recovery methods, lack of equipment for processing and reintegration into the production chain, lack of interest from both environmental authorities and the community in carrying out awareness campaigns on how to address and manage the current issue (Carvajal Muñoz & Carmona García, 2016), starting civil works without having a prepared waste management plan, no separation waste at the source, and the almost nonexistent market for processed CDW materials (Colorado et al., 2022).

Carvajal Muñoz and Carmona García (2016) also mention that the poor management of CDW depends not only on the source of generation but also on third-party activities related to its transportation, recovery, and final disposal. The transportation and disposal of debris in

Colombia generate economic income for people who do not have other income alternatives or have been engaged in this activity for generations.

Among them are recyclers and homeless individuals, who carry out clandestine dumping in many areas of main cities, using rudimentary or animal-drawn transport, and they don't have any financial resources to cover fines or public complaints (Montes Cortéz, 2020). It is essential to clarify that recyclers generally do valuable work, as they collect solid and CDW from the streets and, in many cases, take them to official final disposal sites to sell them to meet the costs of their essential needs.

On the other hand, it is essential to highlight that discharges into water sources, such as rivers, streams, and brooks, occur more frequently and are considered an immediate solution in most cities in the country. The above is because many areas, especially in peripheral regions with difficult access and rural areas, do not have a timely collection service for CDW. This situation coincides with a low economic and cultural level, leading the community to use these disposal practices to eliminate such waste (Flórez, 2009).

The improper disposal of waste is not only a social issue, It is also negligence on the part of the competent authorities due to the lack of effective means to require companies or small civil works to avoid final disposal in prohibited areas and, in this way, control the management of materials (Carvajal Muñoz & Carmona García, 2016).

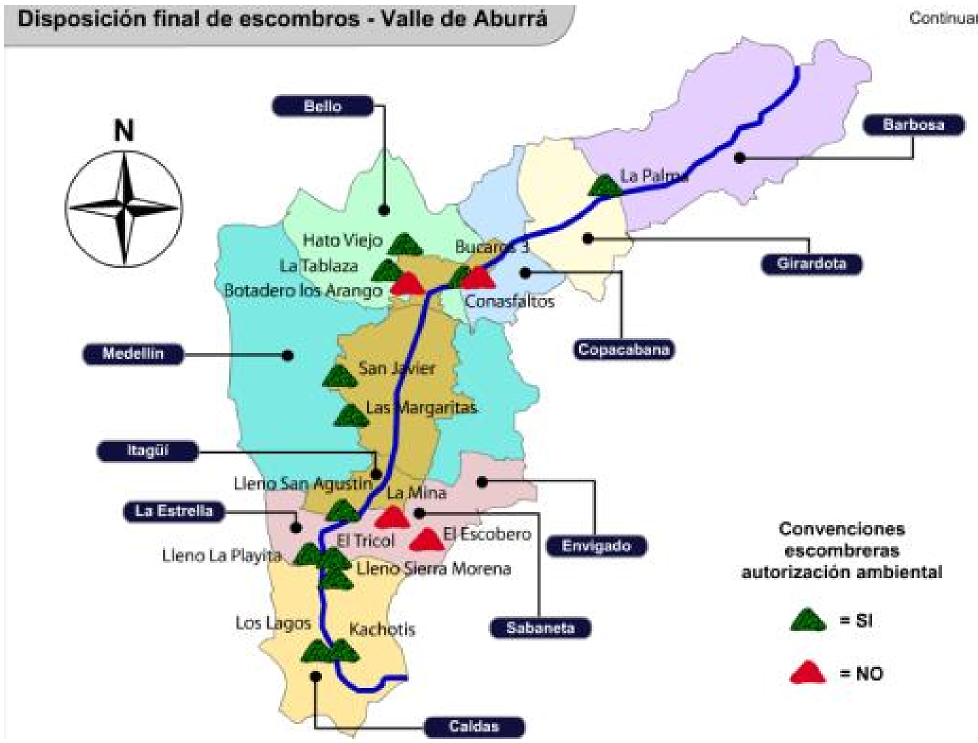
Specific information on the number of illegal dumping sites in Colombia is limited. However, the existence of this practice in different cities across the country is widely acknowledged, making it a national issue. It is commonly known that the number of illegal dumping sites far exceeds that of legal ones due to the lack of effective control and the high generation of waste.

In Bogotá, the traditional option for CDW management has been dumping, sometimes controlled but often uncontrolled because authorized disposal sites are being phased out (Castaño et al., 2013). According to the Secretaría Distrital de Ambiente and Subdirección del control ambiental del sector público. (2022), seven final disposal sites were approved by the Autoridad Nacional de Licencias Ambientales Environmental [National Licensing Authority] (ANLA), the Municipal Mayor's Office, and the Corporación Nacional Autonoma [Regional Autonomous Corporation] (CAR). However, in 2021, the Unidad Administrativa Especial de Servicios Publicos [Special Administrative Unit for Public Services] (UAESP) identified 743 critical points, unauthorized locations in the city and its surroundings where the community clandestinely disposes of CDW (Reinoso, 2021), including wetlands, rivers, streams, and public spaces (Castaño et al., 2013).

For the AMVA, according to the information collected in the regional PGIRS in 2016, the following summary is presented: The management of CDW is mainly final disposal, as slight recovery is carried out. The collection and transportation system are provided by public sanitation service companies, by dump truck operators whose estimated number is unknown due to the lack of regulation, and by the environmental authority. That same year, four authorized temporary storage points were called Centros de Acopio Temporal de Escombros [Construction Debris Storage Centers] (CATE). These centers lack surveillance and a structured management plan, and they mainly receive waste from small generators, primarily from remodeling activities. Furthermore, since the waste is not delivered pre-sorted, the vast majority is not recycled but ends up in debris disposal sites, of which only seven were authorized, with 18,687 tonnes/day disposed of (AMVA, 2011).

The following figure illustrates the location in 2014 of the leading authorized disposal sites for CDW in the AMVA.

Figure 16
Location of demolition debris in the AMVA



Source: Taken from Cadavid (2014).

Currently, Barranquilla has six authorized final disposal sites, which are managed by registered companies and comply with current environmental regulations (Corporación Autónoma Regional del Atlántico, 2023). However, as in all cities across the country, illegal disposal sites exist. In the study conducted by Pacheco et al. (2017), 44 sites were identified throughout the city (from the north to the southwest), specifically in roads, streams, and vacant lots, where the common factor is the lack of awareness of authorized sites and the general disinterest in knowing what happens after waste is generated.

Figure 17
Illegal CDW dumping in Medellín, Bogotá and Barranquilla

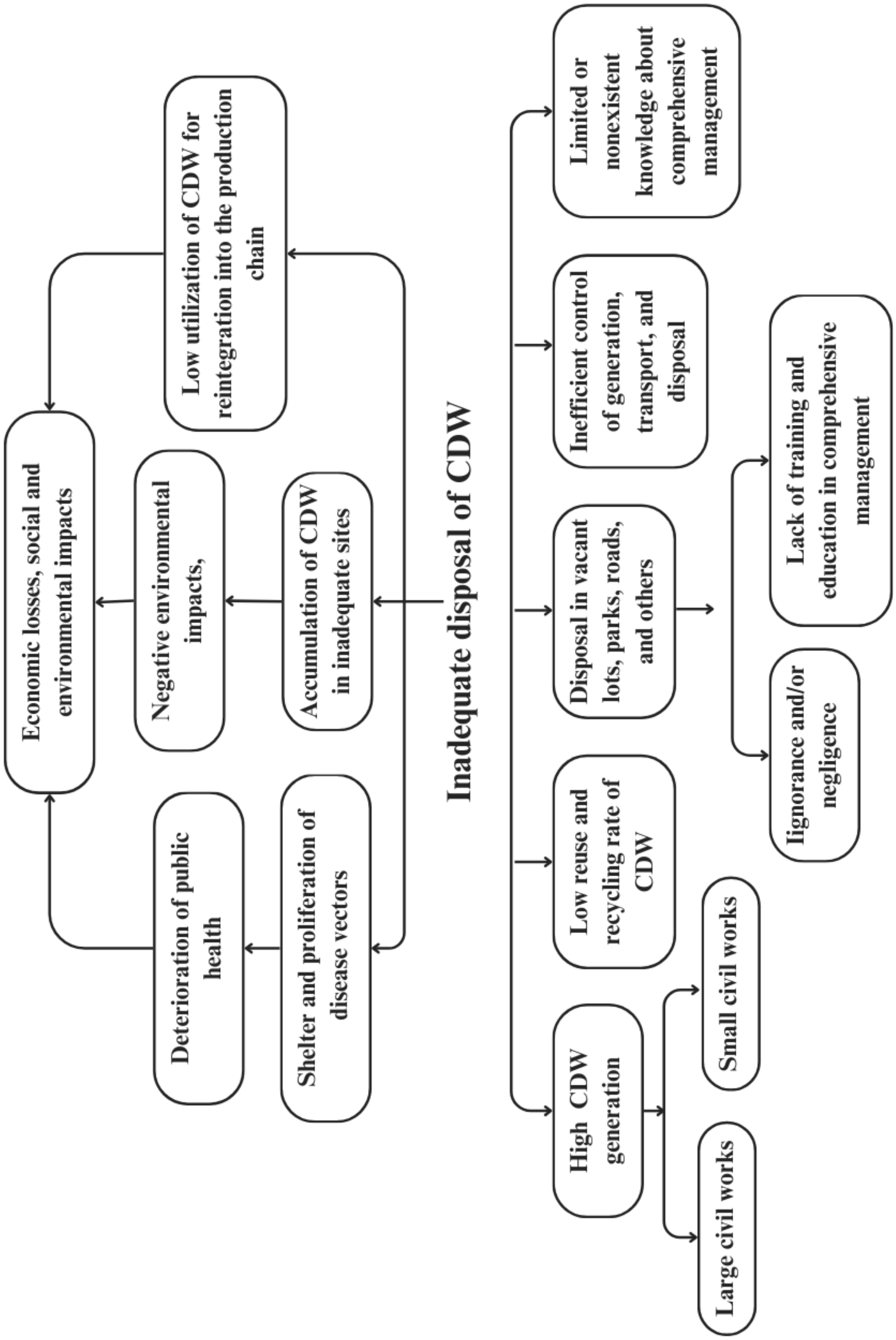
Medellín Bogotá Barranquilla

Source respectively: Colombiano (2023), Murcia (2024), Ortega (2022)

In Figure 18, a conceptual map extracted from Carvajal Muñoz and Carmona García (2016) is presented to summarize the poor disposal practices of CDW that are generally observed throughout Colombian territory, including economic, environmental, social, and technical aspects.

Figure 18

Factors leading to improper disposal of CDW and its consequences



Source: Taken from Carvajal Muñoz and Carmona García (2016) and adapted into English

4.4. Incentives and Policies

After analyzing the current situation regarding the management of CDW, its recovery, and final disposal in the country, it is essential to consider another key aspect to enhance its sustainable management.

Through incentives, financing mechanisms, and institutional and regulatory support, good practices in the sector can be achieved, meeting the strategies and objectives of sustainable development.

When tax benefits, funding sources, local institutional programs, certifications, and seals for good environmental practices are implemented within the framework of CDW, both public and private companies can discover new opportunities to integrate recycled materials into their processes, invest in greener technologies, and implement better environmental management plans, promoting a CE in the construction sector (Escandon Mejia, 2011).

4.4.1. Economic and Tax Incentives

Economic instruments have become a method of pressure for companies to comply and participate in environmental policies, bringing economic benefits to those whose objectives support the city's sustainable development. In this way, these are translated into tax reductions, subsidies, or, in many cases, fines for not complying with the percentages of recycled materials usage dictated in the regulation (Escandon Mejia, 2011).

The National Government, together with the Ministry of Environment and Sustainable Development, promotes tax benefits, presented in Table 10, for public and private companies that are interested in implementing sustainable practices, protecting the environment, and moving towards a circular and low-carbon economy (Ministerio de Ambiente y Desarrollo Sostenible, 2022).

Table 10

Environmental tax incentives for public and private companies

Incentive	Description	Regulatory Framework.
Preferential Value Added Tax (VAT) rate (5%)	Preferential Value Added Tax (VAT) rate for goods and services whose production or consumption generates positive environmental impacts	Article 468-1 of the Tax Statute
25% discount on the value of environmental investments for income tax	Discount for investments made in the control, conservation, and improvement of the environment.	Article 255 of Law 1819 of 2016
Exempt from the National Carbon Tax	The National Carbon Tax does not apply to those who offset their emissions through emission reduction certificates.	Law 1819 of 2016 (Paragraph 3 of Article 221) Decree 926 of 2017 Resolution 1447 of 2018
VAT will be excluded from purchasing equipment or machinery destined for the Greenhouse Gas Mitigation project.	Exclusive for developing projects for generating energy from Non-Conventional Energy Sources (NCES) and efficient energy management.	Article 12 of Law 1715 of 2014
Income tax discount of 50% on the investment made in the Greenhouse Gas Mitigation project.	Taxpayers who directly invest in energy efficiency management will be entitled to deduct it from their income within a period not exceeding 15 years.	Article 11 of Law 1715 of 2014
Tariff incentive	Tariff elimination on the importation of machinery and other supplies necessary for the project, if they are investments in new NCES projects and the measurement and evaluation of potential resources or energy efficiency actions and measures.	Article 13 of Law 1715 of 2014

Source: Extracted from the Ministerio de Ambiente y Desarrollo Sostenible (2022, 2019) and

Ley 1715 de 2014 (Articles 11, 12, and 13)

More specifically, within the framework of CDW, the DPN (2022), in its executive report on the reverse logistics of CDW in the country, presents various economic incentives to promote the sustainable development of the construction industry, which are grouped in Table 11, especially those aimed at the collection, transport, proper disposal, and implementation of recovery methodologies.

Table 11
Incentives proposed by the DNP which are based on the market.

Incentive	Description
Establish responsibility for CDW collection within the public cleaning service.	The implementation of adjustments to collection models can generate new business opportunities for public cleaning service providers, CDW collection and recovery managers
Develop pedagogical programs with a regional focus on good practices for household-level separation and disposal of CDW	Competitive advantage for companies recognized for their good CDW management practices
	Obtaining a certificate accrediting participation in pedagogical programs related to good practices for household-level separation and disposal of CDW.
Develop a certification for the use of recycled materials	Private companies can improve their reputation by developing projects focused on sustainability and the reintegration of CDW
	Co-financing to by-product recovery managers for the implementation of innovative projects to produce materials under the guidelines of the standard
	Allocation of additional points in public tenders for the incorporation of certified recycled materials in the proposal
Strengthening monitoring and inspection instruments on the management and illegal dumping of CDW	Creation of new organizations related to dismantling services, recycling, and the use of specific equipment for these processes
Evaluate the capacity of the collection service	Implementing adjustments to collection

to ensure coverage, timing, and compliance	models can generate new business opportunities for public sanitation service providers and CDW collection and recovery managers.
Promote good practices in operational management and cost control to CDW transport managers	Higher economic returns for participating transporters derived from adopting the practices suggested in the program.
Generate research, development, and innovation programs that allow the identification and spreading of new processes and technologies for the management and recovery of CDW	Co-financing of research, development, and innovation projects on CDW by-products
	Economic returns derived from technology transfer, manufacturing, and marketing of new materials

Sources: Extracted from DPN (2022) and adapted into English.

4.4.2. Financing Methods

Additionally, Colombia has financing mechanisms for initiatives aimed at improving environmental issues. Specifically, the Fondo Nacional Ambiental [National Environmental Fund] (FONAM) financially supports the execution of activities, studies, research, and programs aligned with national environmental policies. This includes the reuse, recovery, and recycling of CDW and implementing management plans for proper collection, transportation, and final disposal. Moreover, it can finance projects that promote environmental education and awareness about the importance of appropriate CDW management, boosting environmental awareness regarding CD in each city (Ministerio de Ambiente y Desarrollo, 2023).

FONAM is an account management system of the Ministry of Environment with independent assets and no administrative structure, which has jurisdiction throughout the national territory (Ministerio de Ambiente y Desarrollo, 2023).

Similarly, the DNP (2022) states that for proper management and disposal of CDW, it is necessary to establish new financing mechanisms specifically aimed at developing sustainable infrastructures in line with the CE. For this reason, the need to implement new mechanisms that promote the participation of private companies to encourage investment in this sector is of vital importance. Consequently, this department seeks to boost symbiosis between the public and private sectors to achieve better financing options that improve the management of such waste.

Tables 12, 13, and 14 present a summary of the country's public, private, and cooperative financing mechanisms, respectively, for CDW management.

Table 12
Financing mechanisms by public entities.

Financing strategy	Description	Entity
Royalties	Co-financing mechanism for infrastructure projects that incorporate climate change adaptation	General Royalties System
Density bonuses	Additional buildability for buildings with sustainable certification or that include environmental criteria	Mayor’s Office of Bogotá
Fondo Emprender	Finances CDW management projects such as modernization and environmentally friendly technological reconversion and obtaining Environmental Certifications	Bancóldex, Banco Agrario
Property tax discount	Reduction in property tax and discount in the payment of construction license fees	Government and DIAN
Findeter	Financing public or private initiatives that improve	National Government

	quality of life, generating social and economic results within the framework of State policy	
Sovereign green bonds of Colombia	Fixed-income financial instrument specifically aimed at raising funds for climate and environmental projects.	

Source: Extracted from DPN (2022) and adapted into English.

Table 13

Financing mechanisms by private entities

Financing strategy	Description	Entity
Preferential rates	Granting preferential rates to sustainable building projects or initiatives for the recovery, disposal, and/or comprehensive management of CDW	Private Banking – Green Products and Services
Green bonds	Financing projects aligned with the Green Bond Principles (GBP)	Organizations willing to comply with environmental responsibility programs
Green credits	Green credit is a financing mechanism in which the bank uses information related to the project and its operating company as a standard for inspection in the loan granting process for making financing decisions.	Bancolombia, Banco de Bogotá, Fundación Santo Domingo, Banco Davivienda, Banco Caja Social.
Green Protocol	It is an agreement between the	National Government and

	Government and the financial sector that seeks to unify efforts to promote the country's sustainable development and work for environmental preservation and the sustainable use of natural resources.	Financial Sector Entities

Source: Extracted from DPN (2022) and adapted into English.

Table 14

Financing mechanisms by private and public entities.

Financing strategy	Description	Entity
Biocarbon Fund/ Biocarbon Fund Plus	It is the entity that supports the sustainable development of its shareholder countries and regional interaction	National Government, CAF allied entities
Swiss Contact	The organization that promotes economic, social, and environmental development to effectively contribute to the sustainable and widespread prosperity of emerging and developing economies	National Government, Swiss Contact
GIZ	German Agency for International Cooperation offers tailored and effective sustainable development services, defined according to demand.	GIZ

BID	It is the leading technical assistance provider for the private sector in Latin America and the Caribbean. It is one of the largest shareholders in the region in microfinance and venture capital funds for small businesses.	National Government, BID
BID INVEST	It is the private sector solutions bank of Latin America and the Caribbean. It focuses on supporting clean energy projects, modernization of production systems, and expanding access to financing.	BID INVEST, Private organization

Source: Extracted from DPN (2022) and adapted into English.

4.4.3. Local Recognitions

At the local level, major cities such as Bogotá and Medellín have established strategies to grant recognition to companies in the CD sector that demonstrate good management practices, such as sustainability seals, public recognition, and preference in contracting. These companies must carry out waste management plans, use recycled aggregates in their production chain, or include in some way the guidelines of the CE (Duque Rúa, 2023).

In this context, the Sustainable Public Purchasing Model of Medellín emerges as a strategy that encourages companies and consumers to include environmental quality criteria when acquiring goods, works, and services, taking into account the entire life cycle, reducing negative environmental impacts (Alcaldía de Medellín, 2022).

Similarly, Bogotá Sustainable Construction, promoted by the District Department of Environment, seeks to encourage construction projects where eco-urbanism and sustainable construction strategies are applied. Its program grants evaluation and recognition to projects that implement these strategies. Finally, it supports interested CD companies (Secretaria Distrital de Ambiente, n.d.).

5. Social and Environmental Impacts

The inadequate management, transport, and disposal of CDW in Colombia leads to several problems affecting citizens' daily lives. Its bad management has generated landscape, environmental, social, and economic impacts, putting at risk urban sustainability and the quality of life of those who live there (Carvajal Muñoz & Carmona García, 2016).

One of the main adverse effects is environmental pollution, which is generated from the increase in illegal disposal sites and the uncontrolled growth of illegal dump sites (ACODAL Seccional Noroccidente, 2017), as mentioned in the previous chapter. In the AMVA, the problem centers on the lack of articulation among the involved actors and the limited application of current regulations. Similarly, in cities like Barranquilla, this inadequate management impacts the environment, the economy, public health, and social life (Zapata et al., 2022).

In addition to the administrative and legal factors that make it challenging to manage, the generation of CDW is a permanent problem because it is directly related to activities such as urban development and infrastructure (Carvajal Muñoz & Carmona García, 2016). The lack of strategies for its reuse facilitates that the country still follows a linear economy model, in this way, increasing the demand for resource extraction to produce construction materials, resulting in impacts such as alteration of water flows, removal of vegetation cover, soil erosion, and an increase in airborne particles (Aguilar Maldonado, 2023).

In addition to the above, security and mobility in the cities are also affected, material losses with good potential for recovery are generated, and every single time, there is an increasing deterioration in the habitat of animal and plant species (ACODAL Seccional Noroccidente, 2017).

5.1. Environmental Impacts

An environmental impact is any alteration in the biotic, abiotic, and socioeconomic environment, whether adverse or beneficial, that can be attributed to developing a project, work, or activity (Decreto 2041 de 2014). It also refers to the alteration caused by human activity, interpreted as human health and well-being; it means the population's quality of life. It is understood as a change in the initial conditions of the environment that creates suitable conditions for health, resource availability, and biodiversity. Additionally, it has spatial and temporal elements that generate changes in environmental parameters over a specific period and in a determined area as a final consequence of an activity compared to the situation that would have occurred if the activity had not been carried out (Orea & María, 2013; Miedzinski, 2013; Wathern, 1998 as cited in Peña Castañeda & Rincón Pineda, 2018).

Several adverse effects are generated by the inadequate management of CDW, as evidenced in the soil, water, and air matrix, the loss of natural resources, and the improper and excessive use of spaces for its final disposal. These negative impacts can be gathered according to their effect on the abiotic and biotic environment (Mejía et al., 2013).

5.1.1. Impacts on the Abiotic Environment

It is the part of the environment composed of the physical surroundings, such as climate, atmosphere, geology, and hydrology (Mejía et al., 2013). According to some literature sources, in Colombia, the effects that have been discovered include consumption of raw materials, geomorphological modifications, aquifer contamination, river and atmospheric pollution (Mejía et al., 2013), an increase in erosion processes (Antequera Barrios & Jiménez Pinzón, 2019), leachate infiltration due to the organic matter content in the waste, contamination of surface and groundwater, an increase in harmful gas emissions (Pacheco et al., 2017), changes in soil nutrients (Phosphorus, Nitrogen, Calcium), emissions of particulate matter present in most debris, soot emissions and greenhouse gases, water contamination through rain percolation, possible changes in watershed characteristics, spills of bituminous fluids, changes in water quality parameters (Pérez & Rodríguez, 2021), and finally, alterations in water flows (Aguilar Maldonado, 2023).

5.1.2. Impacts on the Biotic Environment

It is the part of the natural environment made of the edaphic conditions of the soil, vegetation, and fauna. According to some literature sources, in Colombia, the effects that have been discovered include habitat loss due to raw material extraction and land occupation for disposal, loss of edaphic quality in soils where waste has been stored even if they are later removed, degradation of vegetation cover, forced migration of species (Mejía et al., 2013), destruction of vegetation (Pérez & Rodríguez, 2021), loss of biodiversity due to uncontrolled waste deposition and extreme consumption of natural resources (Ramírez Vargas, 2021).

5.1.3. Loss of Natural Resources

Likewise, inadequate management threatens the conservation of natural resources, leading to the loss of potentially reusable material that could be reincorporated into the production chain. The lack of strategies promoting reuse and the low interest in using recycled materials contribute to the depletion of natural resources, making the environmental impact generated by the industry bigger than before (ACODAL Seccional Noroccidente, 2017).

The construction sector is responsible for consuming non-renewable resources every time more and more, polluting water and air, and consuming the country's energy (Pacheco et al., 2017). Not taking advantage of CDW increases the demand for virgin raw materials, encouraging quarry exploitation and the extraction of natural aggregates (Peña Castañeda & Rincón Pineda, 2018). In cities like Bogotá, the inadequate disposal of debris represents a loss of potential resources because materials could still be recovered but end up as waste (Castaño et al., 2013).

A study carried out by Marmolejo de Oro (2012) in the city of Cali identified the level of impact of some deterioration variables directly related to the problem of bad debris disposal practices in critical points or dumpsites, which can be extrapolated to the rest of the country's cities. Below is a list of activities that showed a high level of impact:

- Presence of organic or biodegradable waste
- CDW invading the city's streams
- Invasion of protective strips and obstruction of stormwater channels
- Obstruction of drainage and sewage systems
- Presence of CDW recycling warehouses in residential areas
- Open-air burning of CDW

5.2. Social Impacts

The dumping of CDW causes significant physicochemical and environmental impacts. It leads to social and economic conflicts, becoming a high-risk factor for nearby communities and the general population, from the diminution in the quality of affected water resources to the potential occurrence of disasters related to the obstruction and reduction of the hydraulic capacity of watercourses, which can result in landslides and mass movements of soil and trapped debris. Likewise, there is a deterioration in the population's quality of life due to the increase in vectors and the rise in infant and adult morbidity, reflected in respiratory and digestive infections, malaria, and paralysis, among others (Flórez, 2009).

According to several literature sources, in Colombia, the impacts discovered include noise and vibrations caused by heavy vehicle traffic, both in extraction and disposal. Likewise, landscape degradation in urban environments is due to the accumulation of waste in streets and roads (Mejía et al., 2013). Also, there is a proliferation of pests such as rodents, snakes, mosquitoes, and other vectors capable of affecting public health (Carvajal Muñoz & Carmona García, 2016). The inhalation of particles released from CDW, such as cement, because of processes like cutting, transport, and disposal can potentially cause respiratory diseases. Some of this waste can become sediment when they have contact with water, contributing to sedimentation issues in sewage systems. Finally, the disposal of CDW in public areas generates a direct visual impact on the population, reducing their quality of life (Antequera Barrios & Jiménez Pinzón, 2019).

In the study carried out by Flórez (2009) on the evaluation of social and environmental impacts caused by the disposal of CDW in the Medellín River and its tributaries, it was found that one of the causes of the bad management of that waste is associated with the low socioeconomic conditions of the population. In this way, lower-income communities do not have basic public services and access to education and healthcare that would allow them a decent quality of life.

In the same study, the leading causes of improper disposal of CDW in Medellín were analyzed; however, given the size of the city and its importance, the results can be extrapolated to the rest of the country. These causes include: first, the rapid increase in population overloading transportation, health, and sanitation systems; Second, poverty is accompanied by unemployment, illiteracy, low social levels, environmental risks, and limited sanitary services. Third, low educational levels contribute to ecological deterioration. Fourth, communities with low resources in squatter areas and closer to riverbanks prefer to throw CDW directly from where they are to save time and effort in traveling to a proper disposal site. Fifth, many people currently have little sense of belonging and awareness of environmental degradation. Finally, the lack of financial resources makes it impossible to pay for public services, leading to additional costs for collecting and transporting CDW.

Another important social component to highlight is the working conditions of recyclers. Here, an analysis conducted by Camargo Sánchez (2023) on the implementation of the PGIRS in Medellín is presented, in which he states that the work of recyclers has been strengthened and made more visible. In this city, it is estimated that there are more than 3 080 people who perform this activity, but this number only refers to those who are registered with the authorized service-providing organizations. However, the reality in Medellín and other cities is that more people are collecting and selling CDW who do not formalize their work because they do not have identification or are avoiding the law. In this way is where awareness, education, and training projects come into play, leading to these individuals' not-so-elaborate and forced inclusion.

Camargo Sánchez (2023) also highlights that the work of recyclers has huge importance, as they walk daily through the city, helping to minimize environmental impacts and transform waste into new products, also reducing the consumption of natural resources and prolonging the life of the landfill.

In Colombia, most recyclers work informally (Gómez Correa et al., 2008), meaning they do not have labor contracts or job guarantees. For many, this activity represents their only source of income due to the low labor supply and the country's demanding working conditions. These people work longer than most of the population, often exceeding eight hours a day, starting very early in the morning, even before 5:30 a.m. (Gómez Correa et al., 2007). In addition, they cover very long distances on foot or in the so-called wooden hand carts, added to the fact that they must transport heavy loads, which in some situations can weigh up to 300 kilograms, implying a significant physical effort (Universidad Nacional de Colombia, 2024).

The income of recyclers tends to be limited and uncertain. It is estimated that 80% of them earn less than the country's daily legal minimum salary, with many earning less than 8 euros per day, which is insufficient to meet basic needs such as housing, health, and education (Gómez Correa et al., 2007). All the above is because their income depends on the cost of recyclable materials in the market; without recognizing their labor force or working in hazardous environments, elements such as the weather, health, and buyers can influence the amount of money they receive in exchange (Escobar Rincón & Del Carmen de Arco Canoles, 2021).

Continuously, recyclers put their lives at risk every single day, facing several dangers, such as solar exposure, contact with chemical substances and hazardous waste such as CDW, sharp objects, and biological materials (Universidad Nacional de Colombia, 2024), and inhalation of particulate matter (Gómez Correa et al., 2007). Likewise, these individuals are affected by precipitation and extreme temperatures, a high likelihood of traffic accidents, and potential conflicts with other recyclers because they are daily exposed to environments dominated by criminality and drug consumption; also, they have the risk of experiencing sexual assault and theft, particularly if they are female recyclers, and finally, they have physical and mental health difficulties because daily effort, stress, and social discrimination (Escobar Rincón & Del Carmen de Arco Canoles, 2021).

All those mentioned above seriously impact their health, and it is common for them to suffer from respiratory infections, tension disorders, and asthma attacks (Gómez Correa et al., 2008). Moreover, most of them do not have any medical insurance, so they self-medicate and, in many cases, use home remedies for their well-being (Escobar Rincón & Del Carmen de Arco Canoles, 2021).

6. Discussion and Analysis

6.1. Comparison Between Regulations and Reality in CDW Management

Colombia has a broad and detailed regulatory framework regarding CDW management, which includes the Código Nacional de Recursos Naturales Renovables y de Protección al Medio Ambiente [National Code of Renewable Natural Resources and Environmental Protection], Law 99 of 1993, Resolution 0541 of 1994, Decree 948 of 1995, Decree 1713 of 2002, Decree 4741 of 2005, Law 1259 of 2008, Decree 2981 of 2013, CONPES 3874 of 2016, Resolution 0472 of 2017, and Resolution 1257 of 2021, as mentioned in Chapter 3. However, the existence of these frameworks does not guarantee their application.

Multiple initiatives have been carried out by the academy to implement sustainable strategies and public policies that promote clean production; however, the national regulatory framework for CDW management focused on good practices has proven to be deficient or, in fact, neglected due to several factors, among them, the corruption of the competent authorities, the lack of budget allocated for the implementation of regulations, the failure to prioritize this emerging issue, the change of environmental public policies every time a new president is elected (meaning, every four years), the sectorized application which means that most cities in the country do not have CDW management plans or not even close to the same budget as cities like Medellín or Bogotá, the lack of community awareness, among others. Although local and national regulations exist, proper management and disposal of such waste in the country cannot be guaranteed.

Despite the significant effort that Colombia has made in issuing specific regulations for the proper management of CDW, there are gaps in the national and local regulatory framework and weaknesses in its implementation. In the rules analyzed, the actions corresponding to the prevention of CDW generation during the design, coordination, and planning phases of the project, in other words, before the start of the construction phase (selection of construction materials, identification and quantification of CDW to be generated), do not have any type of regulation that promotes the prevention of waste production at early stages.

The initial stages of projects were not included in the regulations established between 2005 and 2015. It was not until 2017 that elements related to CDW began to be considered during the project's planning stage, which represented a starting point for identifying such waste before the beginning of the project. Similarly, in addition to the lack of regulations regarding prevention in the early stages, incorporating the term Deconstruction as an alternative to traditional demolition is also not considered.

Several authors point out that the term Demolition should be re-evaluated by environmental authorities. In the case study conducted by Aguilar Maldonado (2023), emphasis is placed on the fact that to achieve maximum use of construction resources and, at the same time, improve recovery and source separation processes, it is essential to include the concept of Deconstruction as an alternative to traditional demolition. This term is defined as a process of selective dismantling of infrastructure that seeks to recover valuable materials so they can later be reused or recycled, focusing on selecting elements before the structure is dismantled.

Similarly, although the regulations cover concepts such as the prevention of CDW generation, implementation of management processes, source separation, reuse within the project and after its demolition, transportation to final disposal sites, recycling, reincorporation, and final disposal, in practice, very few projects, companies, and even citizens implement them, whether due to lack of knowledge, negligence, time, lack of budget, or interest.

Regarding the reality of reuse, Resolution 472 of 2017, modified by Resolution 1257 of 2021, establishes a hierarchical order for proper management, prioritizing prevention, then reuse, and, as a last option, final disposal. Even so, currently, the most frequent option, in most cases, is inadequate final disposal, as mentioned in Chapter 4.

Locally, the AMVA, as a complement to national and local regulations, within the framework of its public policies on sustainable construction, has developed a series of guides focused on the sustainability of this sector, which include objectives, guidelines, and actions that promote a change of perspective when a company proposes a building project from the design stage, always aiming at reducing environmental impacts. However, one of the most notable shortcomings in these regulations, as mentioned by Aguilar Maldonado (2023), is the lack of mechanisms to prevent generating CDW in the initial phases of construction projects.

6.2. Factors Hindering Better CDW Management in Colombia.

As previously indicated, although there is a regulatory framework for CDW management in Colombia, its application is currently one of the most significant challenges for the National Government to achieve its Sustainable Development Objectives by 2030.

Even though the guidelines established in the regulations are clear, in practice, as indicated by Aguilar Maldonado (2023), there are no guarantees of compliance nor solid monitoring mechanisms, so instead of promoting good practices, it ends up being an obstacle to its functioning as it is insufficient and poorly controlled. For example, in cities like Ibagué, there is a lack of control for compliance with the regulation and a lack of incentives and taxes to promote proper management (Silgado et al., 2018), while in the capital, efforts to implement new practices are compromised due to the absence of citizen culture and the limited control capacity (Jaramillo Quecan, 2019). The disobedience of CDW regulations is being normalized and is becoming an obstacle to advancing proper management.

Additionally, the lack of knowledge among construction companies and citizens is another crucial factor hindering the proper management of CDW. In cities like Ibagué, authors such as Silgado et al. (2018) state that there is little interest and a lack of knowledge about the problems caused by the inadequate management of such waste and the available alternatives for its handling. The lack of environmental awareness obstructs the correct classification of waste at infrastructure sites and restricts the use and recovery of recycled materials, as explained in Chapter 5. Education in sustainability remains limited; most of the population is still confused about concepts such as recycling, reuse, and recovery. Likewise, the same authors mentioned above, because of surveys conducted in their research, show that company workers do not have sufficient knowledge on the subject, leading to the reduction and effectiveness of any policy intended to be implemented.

Another critical factor is the inadequate infrastructure and the existence of technical limitations in the country. As explained in Chapter 4, few cities have transportation and certified sites for collecting and storing CDW, and those that exist usually do not operate with advanced technologies. Additionally, there are no design standards aimed at reducing the production of such waste, nor standardized information systems that facilitate measuring, classifying (Suárez Silgado et al., 2019), and conducting life cycle analysis of the waste (GIZ, 2024). The lack of standardization in production (Jaramillo Quecan, 2019), technical standards supported by research studies, and qualified technologies (Suárez Silgado et al., 2019) becomes a barrier to the proper implementation of management both for public and private companies in the construction industry and for the National Government.

Moreover, informal handling and illegal disposal intensify the inadequate management of CDW because it is becoming a widespread practice throughout the national territory. In addition to the increase in unlawful disposal sites, processes such as collection and disposal are dominated by informality. As mentioned in Chapter 4, in many streets of the city, this waste ends up being dumped by unauthorized collectors, such as wooden hand carts or non-formalized recyclers, in unauthorized sites, causing not only environmental impacts but also social and cultural ones. Finally, as Castaño et al. (2013) stated, improper dumping is becoming normalized in most cities as the final disposal system.

Another factor that hinders management is the limited information available to the community and companies in the sector. In this way, in many municipalities of the country, and as evidenced in several chapters of this document, there is no accurate data regarding the generation, treatment, or final disposal of CDW. Moreover, in large cities such as Medellín, Bogotá, and Barranquilla, authors like Zapata et al. (2022) and Duque Rúa (2023) state that open access available information is incomplete, outdated, or simply not recorded. Without data, the planning and implementation of CDW management are unfeasible.

Finally, the lack of coordination and collaboration between the Government, regulatory authorities, industry, commerce, and the community represent another significant factor. The lack of environmental awareness among the population and the scarce reuse, recycling, and separation processes hinder any progress. Without the implementation of incentives, infrastructure built with technologies and innovation, and without collaboration, CDW management in the country will continue to be an unfulfilled objective.

6.3. Improvement Opportunities and Proposals Based on Local and International Experiences

In Colombia, it is necessary to strengthen collaboration among all the above-mentioned actors. Establish deep relationships between CDW producers and the competent environmental authorities to develop sustainable integrated management projects that benefit the community and the environment.

Likewise, public and private universities can research various aspects of CDW management. From the design of new reverse waste management plans for different cities in the country to the analysis of existing plans and even experimental studies on improving mixes between natural and recycled aggregates of concrete, brick, and masonry waste, among others. All of this is to reduce the extraction of natural resources and promote the use of recycled materials as raw materials in new infrastructure projects.

The National Government and private entities must provide financial support to student and academic projects so that ideas do not remain on paper and can be implemented with current regulations.

In this same sense, authors like GIZ (2024) emphasize that it is essential to strengthen logistical operations for better functioning of the management system. The above implies implementing control mechanisms and exerting pressure on public cleaning companies or any certified entity in each municipality, requiring timely collection of CDW, establishing defined routes, reducing service costs, improving customer service, conducting awareness campaigns, and generating incentives for companies to prefer using these services.

Concerning the above, the National Government, in search of adapting to the era of industrial digitalization, established in Resolution 0111 of 2020 the voluntary use of electronic tools such as BIM in infrastructure projects to gradually prevent the generation of waste, starting with between 10% and 25% in 2022, 35% to 50% in 2023, 60% to 75% by 2024, and finally, in 2025, achieving a usage rate of 85% to 100%, along with the obtaining of construction licenses for new works (DNP, 2020). However, this resolution was in effect until 2021, representing a setback in strengthening and promoting sustainable CDW management. The failure to incentivize digital tools for construction processes becomes a legal gap for improving control, mitigation, prevention, and raw material usage rationing processes in the sector.

Building Information Modeling (BIM) is a team-working methodology applied to the construction sector, which collects geometric, environmental, maintenance, time, and cost information on processes. This model facilitates project management throughout its life cycle, helping to prevent CDW between 4% and 15% during the construction phase (CAMACOL, 2019).

Regarding the in-force regulations, it is essential to identify improvement opportunities in its application and control. Resolution 1257 of 2021 updates Resolution 0427 of 2017 because the government identified barriers in its implementation; however, these are considered opportunities for improvement. One of its modifications refers to establishing a symbiosis between the use of CDW by public entities and the industry, promoting the country's CE. Duque Rúa (2023) proposes in his research the dynamization of the market by incorporating potential exchanges of reusable materials between real estate projects and the sale of scrap metal to steel mills. Additionally, the regulation could include, as has been achieved in successful management cases in Mexico (Aguilar Maldonado, 2023), a classification system for generators based on the volume of waste produced per project or by periods of execution, for example, semi-annually or annually, to ensure compliance regardless of the size of the project.

Among the opportunities to strengthen the prevention of waste generation and its proper management in the initial stages of infrastructure projects is the inclusion of the Deconstruction method, which reduces production and simultaneously increases opportunities for later uses of those materials. Another opportunity could lie in categorizing CDW in each phase of the project, previously establishing the generation of waste and the corresponding activities that allow source separation, as is the case of successfully managing these materials in Chile (Aguilar Maldonado, 2023).

On the other hand, although national public entities, such as the Ministry of Environment and Sustainable Development and the DNP, have proposed incentives and financing methods mentioned in Chapter 4.4.1, no specific regulation promotes and controls the reintegration of CD materials back into the industrial production chain. Therefore, it is necessary to establish such criteria both in environmental management plans and in public and private contracting processes. In this context, one of the recommendations introduced by Duque Rúa (2023) is to provide technical certifications for recycled CDW.

Properly using CDW positively impacts the environment and can generate significant economic advantages in the industry and the community. In this way, Zapata et al. (2022) state that the commercialization, transformation, and reintegration of these materials into the production chain would boost emerging markets, reduce expenses in all stages, and generate more employment as long as quality is ensured in the processes and longer useful life is granted to products manufactured from recycling.

As mentioned in Chapter 4.4.3, the Sustainable Public Purchasing Model implemented in Medellín represents a relevant opportunity. When the state and companies in the industrial sector prioritize reusing CDW in their contracts, a demand would be created to boost and incentivize the recycling production chain. The above would help materials known as "waste" to be recognized as recyclable materials and, even better, assign their corresponding value in the market.

Another opportunity for improvement lies in strengthening standardized information systems that facilitate data collection, organization, and analysis. For example, Duque Rúa (2023) proposes developing technological platforms to digitalize all processes related to CDW management in the country. According to the available literature, the mentioned above would allow tracking of materials, optimize logistics and volume monitoring, enable projecting and visualizing waste from the early stages of the project, and companies would have stricter management control throughout all stages, among other benefits (Aguilar Maldonado, 2023; Suárez Silgado, 2019).

Additionally, as a reference for strengthening information, Chile has implemented an information system aimed at CDW managers about the technologies available in the market to treat their waste (Aguilar Maldonado, 2023). the above stimulates selective design and demolition because, from the beginning, waste is classified according to whether it can be treated later or not, avoiding the use of materials that cannot be utilized in their final stages.

It is crucial to prepare environmental and cultural education strategies, where information about the issue of inadequate CDW management and its consequences is shared while encouraging continuous and active participation. Authors such as Alzate Rodríguez

(2022) and Benavides Lozano et al. (2021) propose creating awareness campaigns, training on source separation, conscious use of waste, and the creation of newsletters, manuals, guides, and videos so that both company staff and the community understand and take ownership of the issue presented in this work.

Finally, in the European context, this continent has led the advancement in methodologies that could be adapted and reproduced in Colombia as long as they are adjusted to the country's reality.

Implementing the European CDW Management Protocol (European Commission et al., 2024a) in the country would boost selective demolition, encourage the competent authorities to conduct better audits before the demolition of buildings, strengthen traceability along with the previously mentioned opportunities for improving logistical operations, and guarantee quality standards through certifications.

Similarly, specific successful cases, such as Horizon 2020 (ran from 2014 to 2020), the financial instrument implementing the European Union’s research and innovation program, funded projects to address significant societal issues (Veugelers et al., 2015). Under this framework, projects such as BAMB, FISSAC, ICEBERG, and CIRCuIT have improved CDW management and promoted a circular approach in the EU construction sector.

The Building as Material Bank (BAMB) project in Belgium and Super Circular Estate in the Netherlands could be adapted to the country to implement new large-scale CDW reuse practices to achieve the reintegration of 100% of materials into new construction projects, as was achieved in these countries. These new practices include dismantling instead of demolishing, designing buildings in such a way that the materials used can be easily recovered once their useful life has ended, creating material banks where involved actors can borrow waste to incorporate into their projects, creating urban circular projects, creating the Materials Passport in which the characteristics of the materials are described, giving them value for recovery and reuse, creating platforms for buying and selling recycled materials, and proposing infrastructure designs by parts, meaning the manufacturing of standardized parts to be assembled later (BAMB, 2015., and UIA Initiative, 2018).

Furthermore, Fostering Industrial Symbiosis for a Sustainable Resource Intensive Industry Across the Extended Construction Value Chain (FISSAC) could also be adapted to the country to develop an innovative industrial symbiosis model seeking a zero-waste approach and circular economic practices as the EU did. To fulfill these objectives, a digital platform was developed to ensure collaboration between industries such as steel, aluminum, natural stone, chemicals, and demolition and construction sectors (European Commission, 2020).

Moreover, The Innovative Circular Economy-Based Solution for the Building Industry (ICEBERG) is a project aimed at creating innovative tools and novel technologies to enhance waste management and the reuse of End-of-life Building Materials (EBM) in order to boost the circular economy practices in the construction sector. Those advanced technologies could improve specific projects implemented in Colombia, which focuses on recovering high-purity secondary raw materials such as concrete, wood, plasterboard, glass, polymeric insulation foams, and inorganic superinsulation material (European Commission, 2024b).

Finally, the Circular Construction in Regenerative Cities (CIRCuIT) could be implemented in the country to boost industries seeking to move away from conventional construction practices into a more circular, eco-friendly, and regenerative construction approach, as was achieved in European cities such as Hamburg, Helsinki, Copenhagen, and London. The main objectives of this project were to extend building life through transformation and refurbishment, dismantle buildings to reuse and recycle materials, and increase the regenerative capacity within the cities mentioned above (Kuchta et al., 2019).

It also highlighted the importance of the implementation of the CINDERELA project, which was incorporated in 2020 in Slovenia, Italy, Serbia, Spain, Poland, the Netherlands, and Macedonia (CINDERELA Consortium, 2018), because it would strengthen the integration of digital technologies and circular business models, such as BIM, which, due to not being mandatory, no company would choose to integrate into their operations for reasons of time, practicality, and cost, and the Sustainable Public Purchasing Model, respectively.

Depending on the use of recycled aggregates from CDW in road construction could be an important opportunity to strengthen the country's more efficient and sustainable waste management. International experiences such as the one presented by Casale et al. (2025) in their study on the performance evaluation of recycled aggregates for road embankments demonstrate that recycled aggregates can achieve the technical performance required to implement road infrastructure. For example, implementing technologies such as sensor-based sorting systems and precision screening has improved the quality and homogeneity of recycled aggregates so they can be used in road construction. Likewise, using techniques such as adding cementitious binders, like quicklime, improves the mechanical behavior of these materials. Investment and implementation of these technological solutions in the country could represent a significant step toward a circular economy in the construction sector.

The incorporation of recycled aggregates into Colombian road infrastructure, in the same way as explained by Casale et al. (2025), would allow for the strengthening of the life cycle of materials and, at the same time, reduce the extraction of natural aggregates to minimize the adverse environmental effects that this entails, always moving towards more sustainable and resilient road construction practices.

Although there are no records in Colombia regarding the use of large volumes of waste from excavation, mining, and quarrying activities (Geomaterials), it is important to begin to have an international perspective on their proper management. Oggeri and Vinai (2020), in their research on the characterization of geomaterials and unconventional waste flows for their reuse as engineering materials, propose how effective management for the reuse and utilization of these materials could be achieved, which would involve:

- Planning from the preliminary stages of the project, meaning conducting early characterization (physical, chemical, and mechanical) of the excavated materials well before the start of construction works to help determine the environmental compatibility of the waste and its necessary properties for reuse.
- Implementation of material flow to manage the use of excavated soil and rocks, meaning to manage the waste in a planned manner, considering all stages, from extraction to reuse or disposal, always focusing on early characterization and the suitability of the material for different potential uses.
- The application of the Multicriteria Management Method, which the authors developed to determine how to manage and what final destination to assign to the waste based on interrelated parameters (geological conditions of the site, adopted excavation techniques, in-situ treatments of the excavated material, final destination of the material, and the interference of groundwater).
- Apply appropriate treatments to prepare the material according to its destination. For example, in-situ treatments improve the quality of the discarded geomaterials by implementing washing, screening, classification, drying,

dehydration, crushing, stabilization with lime or cement, and compaction.

In the same context, these authors emphasize how such waste could be reused depending on its quality, which makes it suitable or not for reintegration. The quality is determined by the combination of physical and mechanical properties, durability characteristics, chemical composition and environmental aspects, and material behavior, which are identified in the early stages of the project, ideally at the beginning of excavation works. If the evaluated waste is classified as a high-value material, it could be reused as raw material for industrial production; if it has intermediate value, it could be used as material for embankments; and if it has low value, it could be used as material for land recovery.

By implementing the MultiCriteria Management Method, Colombia could improve decision-making regarding CDW management since it would provide a broader view of recycling methods, recovery, and necessary treatments to achieve the required quality for a specific final destination.

To carry out adequate management of CDW, it is necessary to focus on the valorization of waste in the early stages of the project. Authors such as Oggeri et al. (2014) and Oggeri et al. (2017) present methodologies to classify excavated materials from tunnel construction to avoid, as far as possible, considering them as waste and to promote their valorization from the feasibility study phase. The above is achieved by implementing the Tunnel Muck Classification (TMC) system proposed by the authors from the early stages of the project, according to the excavation technique and the type of soil encountered. First, it is necessary to correlate the type of soil, the possible destination of the material, and the type of treatment required. Subsequently, using tables that associate each type of waste, the required treatments, and the characterization tests that must be carried out to evaluate recovery alternatives are obtained.

Incorporating this classification system into the management in Colombia could transform CDW into valorized resources through early planning, detailed and rigorous classification, promoting its reuse and recovery to obtain environmental (waste reduction and lower need for virgin material extraction), economic, and technical benefits. Effective management requires decisive decision-making that involves successful international cases.

7. Conclusions

In conclusion, the generation of CDW in Colombia is highly concentrated in the most relevant cities of the country, which highlights their urban dynamism, as well as the significant impact and scale of the activities carried out by the construction and demolition sector. Bogotá leads with an approximate generation of 15 million tonnes annually, followed by AMVA with 2 million tonnes annually. Other cities, such as Ibagué (448 thousand tonnes per year), Cali, and Barranquilla (each with approximately 321 thousand tonnes annually), also show significant amounts. Manizales (108 062 tonnes/year), Cartagena (67 097 tonnes/year), Valledupar (100 000 tonnes/year), and Pasto (53 713 tonnes/year) register lower but still relevant volumes in the regional context. It is essential to clarify that although the issue also involves other cities in the country, their CDW generation record was not included due to the unavailability of information.

Since 1994, the management of CDW in the country has raised interest from the corresponding environmental authorities, who have progressively expanded the implementation of policies and regulations in this sector. Still, it was not until 2005 that the emerging issue began to be taken seriously with the creation of Decree 4741/2005, which initiated the categorization of waste, the obligations for generators, requirements for management plans in all projects, and the establishment of responsibilities for each national and district environmental authority. However, the last update was in 2021; some legislations or standards lost their validity this year.

Although all regulations are aimed at the categorization, source separation, recovery, recycling, and final disposal of CDW, their focus is mainly on the construction stage, ignoring the initial stages of the project, such as design, coordination, and planning. It was also found that, in general, there are no references to the early prevention of such waste, which is why it is essential to begin evaluating the possibility of including in the legislation terms such as Deconstruction, selective demolition, and practices like Modulation (or construction by parts), which allow for better use of materials and reduction of their generation.

The literature review evidenced that although the regulation requires monitoring the disposal and generation of CDW, there is a widespread lack of public records on the amount of this kind of waste generated in the country.

Even though there are approximate data on the volumes of CDW generated in some main cities of Colombia, most of them are outdated amounts; these measurements were carried out approximately nine years ago, they are not reliable, they are variable and fragmented, meaning that such data may change depending on the document in which they are consulted, which makes it difficult to measure the magnitude of the national issue truly. It is also essential to highlight the concern shared by most Colombian researchers regarding the negligence of the sector entities, which usually do not measure the amount of CDW generated by their projects. When they report them, these data are not traditionally categorized, meaning they do not include the type of materials produced or their actual volume.

It is possible to conclude from the literature review that the causes of the lack of data on generation are the cultural and educational shortcomings of all the actors involved (citizens, government, and companies), logistical deficiencies, and limited monitoring and control by the competent authorities. The above limits the capacity for optimal planning and evaluation of CDW management strategies in the country.

It was also possible to highlight the lack of digitization systems in the construction industry, where there is no national registry system that allows the visualization of the traceability of CDW throughout its life cycle, the amount of materials used in civil infrastructure projects, the percentage of recovery for each type of waste, the technologies available for its subsequent treatment, informational forums, open-access databases where both the certified companies related to the management of such waste and the authorized sites for the proper disposal of CDW are registered.

Even though there have been regulatory efforts through resolutions such as 0472 of 2017 and 1257 of 2021 to promote more sustainable practices by following hierarchy strategies, final disposal remains the most common CDW management method. In areas such as the AMVA, the management of this type of waste is primarily focused on disposal in debris dumps or sanitary landfills despite having local regulations that promote the incorporation of recycled CD materials in new civil works.

This work also shows that the inadequate disposal of CDW in unauthorized sites such as illegal dumps, streets, vacant lots, and water sources, among others, is becoming a constant issue at the national level. For both citizens and companies in the sector, this practice becomes the most efficient, affordable, and practical alternative to eliminate this type of waste, regardless of the environmental consequences.

Government entities must start creating awareness programs aimed at all the actors involved, including public officials, citizens of all ages, and all workers from companies in the industrial sector, where they develop environmental awareness and take ownership of the issue. The lack of strategies focused on ecological awareness is a significant barrier to properly managing CDW. It is essential to achieve greater knowledge of the regulations and a national cultural shift, promote the training campaigns already established, and strengthen the divulgation of social and environmental impacts.

Regarding the recovery of CDW in the country, it was found that its rate is very low. Barriers such as the lack of source separation at different stages of the project, the correct classification of this type of waste, regulatory gaps, lack of control and monitoring by the competent authorities, the absence of training for company workers, limited and mostly low-tech infrastructure, and finally the lack of economic incentives were observed.

Despite all the challenges found in this work, there are several successful cases of initiatives and progress in some cities, such as Bogotá, Barranquilla, Medellín, and their surroundings. They are presented as opportunities and examples to follow, demonstrating that achieving the recovery objectives set for each city is possible, reducing the environmental and social impacts exposed in this work, improving sustainability, and reducing the final disposal of CDW.

Finally, the review of local and international experiences presented in this work shows that practices such as selective demolition, the development of digital traceability systems, the classification of generators, the implementation of environmental diagnoses before construction projects, the promotion and implementation of environmental awareness, and the incorporation of regulations focused on all stages of construction and demolition become strategic practices to improve the current management of CDW in the country. If Colombia incorporates these methods into its regulations, incentives, and activities, it will improve the management of this type of waste and move towards a circular construction model, leaving behind the current linear model.

8. Future Perspectives in Research

For future research, it is recommended to deepen the development of more accurate measurement methods for the quantification of CDW generated at the different stages of the project, having reliable and precise data with open access while at the same time reducing the number of materials used in civil works.

In addition, it would be appropriate to investigate the application of technologies such as artificial intelligence for decision-making and enhance, promote, and enforce the use of BIM and Blockchain methodologies to improve the traceability and monitoring of CDW management.

Research is also recommended in the country's intermediate cities and rural areas, where production, reuse, and disposal dynamics are evaluated. It is essential to highlight that experimental studies would need to be conducted in these cases, meaning generation measurements would need to be taken from scratch because the information is scarce.

Future research could focus on the economic advantages of using CDW in large urban centers, promoting circular business models.

Additionally, studies could be conducted on the quantities of CDW that are reused thanks to recyclers and how they operate within the construction industry environment.

Finally, it is necessary to explore options for implementing CDW recovery plants adapted to the current situations of each city in Colombia, focusing on municipalities that currently do not have the appropriate infrastructure and logistics.

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