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REVIEW

Rehabilitation of Urban Parks with Recycling of Construction and Demolition Waste in Mexico City

Hugo Alberto Quintero-Navarro [1], María Neftalí Rojas-Valencia [1*], Alfredo Martínez-Cruz [2]

[1] *Institute of Engineering, National Autonomous University of Mexico, Mexico City 04510, Mexico*

[2] *National Technological Institute of Mexico, Gustavo A. Madero Technological Institute, Mexico City 07470, Mexico*

ABSTRACT

Mexico City has experienced a rapid urbanization process, which has led to a socio-environmental crisis characterized by the generation of construction and demolition waste (CDW). The generation of CDW has been favored by the growth of the construction industry, the decrease in the useful life of buildings and an increase in the number of new buildings. To reduce the environmental impacts of CDW, recycling initiatives have been developed, offering alternatives for sustainable urban development. This study examines the use of recycled materials from CDW for urban park rehabilitation, focusing on the production of sustainable urban furniture. CDW as recycled material can be useful because it reduces the need for new resources, preserves land for future urbanization, protects the environment, and reduces transportation costs and energy needs A bibliographic analysis explored urban growth trends, CDW management methods, and the benefits of urban green spaces. As part of the project, urban furniture such as benches and planters was manufactured using recycled aggregates from CDW. The results demonstrate the functionality and sustainability of these elements, while providing recommendations on optimal aggregate sizes and compaction techniques. The urban furniture built using CDW (to manufacture benches, planters, jogging tracks and gabions), turned out to be totally functional, meeting the expectations of use This approach represents a viable alternative to natural fine aggregates, contributing to sustainable city development.

Keywords: Construction and Demolition Waste; Urban Parks; Recycling; Sustainable Development; Park Management

*CORRESPONDING AUTHOR:

María Neftalí Rojas-Valencia, Definitive Academic Technician, Full Professor C, SNII Level II, Researcher, Institute of Engineering, National Autonomous University of Mexico, Mexico City 04510, Mexico; Email: mrojasv@iingen.unam.mx

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1. Introduction

Mexico has experienced an accelerated process of urbanization. In Mexico City (CDMX) this phenomenon has caused a socio-environmental crisis. The growth and expansion of cities worldwide are drivers of environmental change. The increase in the generation of Construction and Demolition Waste (CDW) can be observed. The generation of CDW has been favored by the growth of the construction industry, the decrease in the useful life of buildings and an increase in the number of new buildings [1]. The construction sector is the largest contributor of urban solid waste worldwide, responsible for 50–70% of the total [2]. It is estimated that CDW generation worldwide exceeds 10 billion tons, with the United States producing around 700 million tons and the European Union more than 800 million tons [3].

CDW management initiatives consist mainly of the hierarchical waste management strategy of reduction, reuse and recycling, which are summarized in the "3R" principle [4]. Reusing CDW involves using the material more than once, even for different purposes. If CDW cannot be reused, then they must be converted into new materials through recycling, obtaining products belonging to various categories [5]. There are proposals for reusing CDW focused on reducing the use of natural resources (cement, sand, gravel, etc.): manufacturing blocks [6], bricks [7], prefabricated concrete pieces for the manufacture of urban furniture [8], recycled aggregates for the manufacture of sidewalks and curbs [9], and paving stones [10]. Despite these proposals for reuse, it is estimated that around 35% of CDW ends up in landfills [5]. Recycling CDW would reduce their environmental impact (reduce the overexploitation of material banks and decrease the amount of CDW deposited in landfills).

In 2021, the update of the Environmental Standard NACDMX-007-RNAT-2019 was published [11], which establishes the classification of CDW, as well as the specifications and technical requirements for its comprehensive management. It provides that all public and private jobs must use recycled materials and that small and large generators must submit a CDW management plan [12]. The Government of CDMX currently applies the CDMX Local Climate Action Strategy 2021–2050 to sustainably manage CDW [12]. This strategy is an instrument that defines the principles for the proper management of CDW through goals and actions established in accordance with the responsibilities of all the actors involved [13].

Public places are assets belonging to the community and are social creations that are continuously evolving [14]. Urban parks, as public areas, are considered an important part of the environmental system promoting sustainable urban development, adaptation to climate change and improving the quality of life [15]. Urban parks are green areas that are notable for their multifunctional design, including vegetation, walking and recreation areas, as well as spaces for play, sports, and leisure. The equitable distribution of urban park resources is considered a fundamental aspect of human rights [16]. It is estimated that 75% of the urban infrastructure that will be used in 2050 has not yet been built. This situation offers the opportunity to create functional urban spaces [17]. Green space and infrastructure in cities are crucial for any urban planning strategy aimed at promoting sustainability [15]. Shen et al. claim that urban parks in perfect condition establish a positive connection with various aspects of human well-being (civic health and quality of life) [18].

Urban park infrastructure should provide multigenerational use and include maintenance and cleaning. It is important to consider elements such as adaptability, vulnerability and resilience [19]. Sustainable development should emphasize long-term management to ensure that future generations can enjoy quality and social, economic, and environmental benefits [20]. Management and maintenance are essential in order to achieve services of better quality for users. Planning, design, and management of these projects should be included [21].

In the case of the rehabilitation of these spaces, the incorporation of new elements or the modification of existing ones could be included [21]. CDW as recycled material can be useful because it reduces the need for new resources, preserves land for future urbanization, protects the environment, and reduces transportation costs and energy needs. A CDW reuse proposal will reduce the amount of waste sent to landfills. This proposal will add an element of management to urban parks, including of course their rehabilitation. This case study proposes the feasibility of incorporating CDW as recycled material in the rehabilitation of urban parks, thus providing an alternative for the development of a sustainable city.

2. Methodology

Bibliographical research was conducted to learn about different areas of interest in the project: the trend and evolution of urban growth in Mexico City, including the urbanization processes that have encouraged the generation of CDW; the use of construction waste in Mexico City and the applicable regulations; the importance of green areas and their urban problems; urban planning of public spaces and urban parks; and the social and environmental benefits of urban parks. An analysis of the reuse of CDW in Mexico City was included as an element to reduce environmental damage caused by the inadequate management of CDW. Finally, the rehabilitation of a green area with the manufacture of urban furniture by including CDW as recycled aggregates in the facilities of the Engineering Institute of the National Autonomous University of Mexico in Mexico City was analyzed.

3. Results and Discussion

3.1. Mexico City and Its Urban Growth

In 2019, before the pandemic, 56% of the world's population lived in urban areas. This percentage is expected to increase to 80% in the next 25 years, with an even higher proportion (95%) in developing nations such as Mexico [22]. Mexico has experienced an accelerated process of urbanization, moving from a predominantly rural population to residents concentrated in urban areas [23]. Mexico has one of the most complex migration contexts in the world, characterized by high levels of emigration, although there is still no articulated policy to integrate this phenomenon. The lack of a migration policy generates conditions that favor the exclusion of those who settle in the country or transit through it, which puts social cohesion at risk and increases vulnerability [24]. In Mexico City, this urbanization phenomenon has caused a socio-environmental crisis [23].

People tend to migrate from places with few economic opportunities to places with greater prosperity. This generates a movement of population between regions with different demographic, social, cultural and economic characteristics [24]. This urbanization process has created urban peripheries in different cities in Mexico in the last decade. This creates a process of residential segregation that expresses new forms of urbanization in the area [25]. This segregation is explained by the location of resources, in terms of employment and services [26]. Although living in a large city presents challenges (housing prices, transportation costs and environmental degradation), these challenges can be overcome by taking advantage of the advantages of the agglomeration: labor market opportunities, and access to health and education services. One of the most notable trends in current housing models is coliving, a way of living that fits with the need to adapt to constantly changing work and family situations, housing shortages and the need for sustainable lifestyles [27].

3.2. Utilization of Construction and Demolition Waste in Mexico City

In Mexico City, the five most common types of urban solid waste are cardboard, food waste (vegetable and fruit scraps, eggshells, coffee and tea grounds, paper filters for coffee and tea, bread, tortillas, etc.), residual sludge from water treatment, plastics, and CDW. In 2022, CDW in Mexico City was generated by excavation activities (2,121,848.6 t/year) and demolition activities (1,864,012.4 t/year) [12]. Given this large amount of CDW, proposals for reuse have been made (**Table 1**) [28].

The proposal for recycling CDW has been successful in Mexico City. In 2022, 92.2% of the CDW generated was recycled, in contrast to 2021, when only 16.1% was recycled. Due to the problems associated with CDW, the Mexico City Government has implemented programs for its management and has increased investment in recycling infrastructure. **Table 2** shows the current CDW recycling infrastructure in Mexico City [12].

In Mexico City, CDW is used in three ways: a) Reuse in the compost plant located in Bordo Poniente, for maintenance of perimeter and interior roads and platform rehabilitation; b) On-site recycling to reuse waste as construction materials; c) Off-site recycling in recycling plants. As of 2022, 7.7% of the CDW generated in Mexico City was reused, 20.9% was recycled on-site, and 71.4% was reused off-site [12]. One of the main obstacles impeding the use of CDW, specifically those of household origin, is that

Table 1. Identification of Proposed Reuse of Construction and Demolition Waste.

Waste	Recycled Material	Application
Rubble mixed with concrete and mortar	Recycled aggregates	Hydraulic bases on roads and parking lots.
Asphalt scraps	Asphalt material mixtures	Asphalt bases; warm, hot and cold asphalts; roads.
Mixed debris	firm material	Embankments
Mixed debris	Recycled sand	Filling coverage, limestone substitute (tepetate); manufacturing of blocks, adopastos (available space for grass), tiles, posts, and curbs.
Mixed debris	Fine aggregates	Walkways and cycle paths.
Mixed debris	Recycled aggregates	Pipe beds, ribbing and filling, sedimentation fills, embankments, roof filling and landscaping, land shaping.
Concrete waste	Recycled gravel and sand	Curbs and sidewalks, concrete forms and wall construction.
Hydraulic pavement	Cold recycling	Hydraulic base and black base.

Source: CMIC [28].

Table 2. Infrastructure Available for Recycling Construction and Demolition Waste in Mexico City.

Municipality	Managed by:	Sector
Iztapalapa	Concretos reciclados S.A. de C.V.	Private
Nezahualcóyotl	Concretos sustentables Mexicanos S.A de C.V.	Public-Private
Miguel Hidalgo	Concretos sustentables Mexicanos S.A. de C.V.	Public-Private
Iztapalapa	ACCUBO S.A de C.V.	Private
Xochimilco	Dirección General de la Comisión de Recursos Naturales y Desarrollo Rural.	Public
Bordo Poniente (Nezahualcóyotl)	Secretaría de Obras y Servicios de la CDMX.	Public
Bordo Poniente (Nezahualcóyotl)	Concretos reciclados S.A. de C.V.	Private

source: SEDEMA [12].

citizens often do not have the capacity to properly manage this waste. In this sense, the Secretariat of Environment of Mexico City (SEDEMA) has implemented the program for the collection of CDW of household origin [12].

3.3. Importance of Green Areas and their Urban Impact

Climate change is a major challenge in the 21st century, representing a significant threat to health and sustainable development. Climate change is expected to cause several hundred thousand deaths per year by 2030 [29]. 88% of urban dwellers are exposed to levels of outdoor air pollution above the World Health Organization guidelines on air quality [30]. By 2023, seven million deaths worldwide were attributable to air pollution [31]. The world recently recognized the importance of climate change with the adoption of the 2030 Agenda for Sustainable Development, with which governments committed to ensuring progress on 17 Sustainable Development Goals (SDGs) and their 169 targets [32].

Rapid urbanization and population growth contribute greatly to climate change. Urban areas facilitate activity across multiple sectors where interventions can be made to generate positive and sustainable change [32]. One such intervention is green areas. In addition to the obvious benefits of climate change mitigation and air pollution reduction, green areas encourage physical activity [33]. Due to their size and composition, green areas provide social and physical benefits to citizens, as well as ecological and environmental benefits. The proximity of green areas is essential to increase the quality of life [34].

Mexico City, inhabited by almost nine million people, is a territory organized politically and administratively in 16 heterogeneous municipalities; there is a diversity of neighborhoods, towns and districts that make up an array of urban micro geographies that are poorly socially and spatially integrated [35]. Public spaces in Mexico City, including green areas, are scarce and low quality [36]. Green areas are defined by the Law as "any surface covered by natural or induced vegetation that is located in the city" and offer environmental services. Urban gardens are included in the category of green areas [37]. SEDEMA, in its Green Areas Inventory, indicates that the average per capita green area surface in Mexico City is 7.5 m2, while the World Health Organization (WHO) recommends at least 9.0 m2 of green area per inhabitant [37]. Incorrect management of green areas, including urban parks, can have a direct repercussion on the population, including deterioration of the urban image, proliferation of harmful fauna, and impacts on the health and safety of citizens [37].

Green areas in Mexico City are regulated by various laws ranging from general to specific. They include the General Law of Ecological Balance and Environmental Protection [38], the General Law of Human Settlements, Territorial Planning and Urban Development [39], the Environmental Law for the Protection of Land in the Federal District [40], and the Urban Development Law of the Federal District [41]; In addition, they include Standards such as NOM-001-SEDATU-2021 that regulates public spaces in human settlements [42]; NADF-006-RNAT-2016, which establishes the requirements, criteria, guidelines and technical specifications that must be met by the authorities, individuals or corporations that carry out activities to promote, improve and maintain green areas in Mexico City; and the Special Program for Green Infrastructure of Mexico City [43]. Besides their lack of specificity, it seems that these regulations are insufficient. Moreover, cooperation shortcomings between the Mexico City government and the local mayors' offices impair the fulfillment of these provisions.

3.4. Urban Planning in Public Spaces, Green Areas and Urban Parks

Mexico's urban population has undergone changes caused by various aspects, such as the overvaluation of land due to gentrification processes. These processes have caused the impoverished population to move from central areas to internal and external suburbs. In addition, certain sectors of the population are interested in being centrally located within cities to be closer to their workplaces and public services. However, the deficits and deterioration of these public services call into question their viability. Urbanization entails changes in occupation and lifestyles associated with lower levels of physical activity and greater use of cars [44]. In recent years, various popular neighborhoods located on the eastern outskirts of Mexico City have shown improvement in terms of housing conditions, access to infrastructure and basic equipment, especially as regards mobility and public transportation; however, their environmental and social surroundings continue to be challenging, as factors persist that contribute to their deterioration and precariousness (disordered legal land ownership, lack of public and private investment, workers' limited income, adverse orographic conditions, peripheral location, poor quality of vital goods such as water and lack of public spaces) [25].

Conventional forms of public space design have been consistent over time, especially since the conceptualization of modern urban perspectives: a one-way, uniform, outdated planning and management approach to sociocultural transformations, ignoring the diverse realities present in a single urban environment [45]. This is clearly visible in the appearance of cities, whose public areas, although well-established, do not have the desirable quality and characteristics, resulting in them being unattractive and unsuitable for their enjoyment and use [45]. The responsibility of the government is to build or renovate public areas in marginal neighborhoods to create the necessary conditions that enable the realization of social, sports, cultural and recreational activities, as a way of ensuring the right to enjoy the city and promoting a stronger community coexistence in the area [25].

Faced with this situation, public spaces are components of the urban structure valued for their potential to generate socialization processes that counteract the strong disintegrating tendencies that exist in society. The processes of creating or recovering different types of public spaces in the city (squares, parks, gardens, streets, cultural and sports areas) carried out with community participation, can activate the sense of identity and belonging, contributing to revaluing community life in urban peripheries in cities [25].

Urban parks offer solutions to the impact of rapid and unsustainable urbanization on health and well-being. The social and economic benefits of these spaces are equally important and must be studied in the context of issues of global interest such as climate change and other priorities established in the SDGs, including sustainable cities, public health and nature conservation [32]. The objective of sustainable development in a city is to improve the health of social, economic and environmental systems, which includes maximizing, balancing and maintaining social, financial and natural capital in the long term [46]. Urban parks offer multiple benefits to the population of cities. Inequitable access to these spaces for different socioeconomic groups of the population would represent a spatial injustice. There is a marked difference in favor of areas where the most socio-economically privileged population lives; this trend is clear, as the quality of green areas decreases as one goes down the socio-economic scale [47].

Disadvantaged groups often live in neighborhoods with little available green space, while socio-economically underprivileged people are often those who benefit most from improved access to urban green spaces. Therefore, reducing socio-economic inequalities as regards the availability of urban green spaces can help reduce health inequalities linked to income, minority status, disability and other socio-economic and demographic factors [48]. The goal of modern urban planning is to create a comfortable environment in cities with green spaces that support the continuity of the ecological functions provided by vegetation [49].

3.5. Benefits Generated by Urban Parks

Urban parks offer opportunities to generate positive changes and promote the development of urban centers. From a social and physical perspective, parks allow walking, cycling, playing and other outdoor activities. Moreover, they promote healthy movement and access to basic services for women, older people, children and low-income communities [32]. Evidence shows that interaction with nature could be associated with better mental health and greater well-being [22]. Access to urban parks improves health in the population, reduces cardiovascular morbidity and mortality, decreases obesity and the risk of type-2 diabetes, decreases stress, increases physical activity and reduces exposure to environmental pollutants [50], reduces depression, improves pregnancy outcomes, reduces rates of cardiovascular morbidity and mortality, obesity and diabetes [51–54]. Green spaces are healing spaces for communities because living near vegetation helps reduce stress and depression, promotes social coexistence, motivates residents to exercise and improves health [49].

In terms of environmental aspects, urban parks provide benefits including modulation of heat waves and extreme weather events [55], improved air quality through vegetation and oxygen supply [56], energy savings, reduction of greenhouse gas emissions, reduction of noise pollution, improved biodiversity, urban soil stabilization and climate change mitigation [57]. For every tree strategically planted to provide shade, about 10 kg of carbon emissions from power plants could be directly reduced by reducing air conditioning demand.

Urban shade trees provide substantial advantages in terms of reducing the need for air conditioning in buildings and enhancing the quality of urban air by reducing smog. Savings associated with these benefits vary depending on the climatic regions and can be as high as $200 per tree [32]. Investments in urban parks are therefore an efficient and cost-effective way to promote health and mitigate climate change [58]. Mexican cities often have inadequate urban planning, leading to haphazard development and scarce green spaces [49].

3.6. Urban Park Management

Urban park management must be sustainable; therefore, it must include environmental, social and economic aspects, and manage the relationships between these three elements. Human activity in the park should not affect its resources or reduce its capacity to continue serving future users [21]. Aly and Dimitrijevic state that urban parks are important spaces for any sustainable society as they provide environmental, social and economic benefits, and long-term maintenance and proper management of these spaces should be emphasized [59]. This means going beyond design and construction. Successful management involves understanding the conditions and characteristics of the park, the responsible agencies and determining the impact of interventions on the site; as well as setting improvement goals that promote environmental, social as well as economic benefits. This is possible by using sustainable materials or implementing better waste management processes [60].

By emphasizing decisions based on a true understanding of urban conditions, planners can use this information to increase the amount of public space and infrastructure that improves the well-being and quality of life of residents [61]. Some of the most relevant points in urban park management are: 1) Specific plans and planning instruments, 2) Increase in the size of green areas, 3) Experience in citizen participation, 4) Development of local standards, 5) Highlighting local conditions and needs, 6) Integrated system of green areas, 7) Horizontal coordination, 8) New forms of associative management, and 9) Knowledge of green areas and systematization of information and new standards [62].

Physical maintenance includes not only the prevention of new damage to city parks, but also the planning and routine processes to prevent serious damage (which is more expensive to repair). The maintenance of physical components includes cleaning, waste collection and management; maintenance of lighting systems; periodic inspection and repair or replacement of damaged components [63]. In Mexico, greater coordination between the state and civil society (universities, corporations, organized communities, foundations and interested persons) is necessary. This coordination will promote public-private alliances, strengthening and expanding participation in the management of urban parks. Another area of opportunity is the lack of public, transparent and updated information, which would promote the development of permanent participation instances and not be limited only to the design of the parks. The lack of maintenance of urban parks causes these spaces to be used as clandestine dumping sites (**Figure 1**).

Figure 1. Illegal Dumping Sites in Urban Parks in the Gustavo A. Madero Municipality, Mexico City.

Source: Authors and https://mexicocity.cdmx.gob.mx/e/about/about-mexico-city/geography-neighborhoods/?lang=es.

Ibarra classifies the problems of urban green areas according to different themes presented in **Table 3** [63,64]. For his part, Reyes classifies the problems identified in Mexico City parks as follows: (i) those common to all urban parks, and (ii) those exclusive to large urban parks [64]. **Table 4** presents this proposed classification.

Currently, urban park management involves the discussion of sustainability and governance criteria related to configuration and planning. However, other sociopolitical situations have joined this discussion, such as socio-environmental injustices, the regulatory gap for citizen participation in the establishment and development of green areas, the lack of professionalization in the design of urban parks, as well as the reduction of their areas. Therefore, it is necessary to link the socio-spatial analysis with proposals for the planning and management of urban parks [65].

Núñez carried out an analysis of the changes in urban green areas in Mexico City, considering the inventories published in 2002, 2010 and 2017 [66,67]; observing a loss of private and informal green areas, which represent approximately 40% of the total urban green areas of the city, caused by the change in residential land use. However, urban green areas managed by the government show a slight increase, mainly in forested areas. Section 8.6.2 of NACDMX-007-RNAT-2019 proposes the use of recycled CDW aggregates in non-structural elements [11]. **Table 5** shows these recycling proposals applicable to the case of urban parks.

Table 3. Problems of Urban Green Areas.

Theme	Problem
Legal system and planning	1) Green areas conceptualized and classified differently by various regulations.
	2) Lack of regulations related to the restoration of trees.
Management	3) Green areas not included in management programs.
	4) Absence of regulations of the Environmental Law for the Protection of Land in the Federal District.
	5) Lack of preparation of the municipalities for proper management of urban parks.
	6) Lack of budget and specialized personnel in the management of urban green areas.
Structure	7) Loss of green area surface.
	8) Uneven distribution of vegetation.

Adapted from Ibarra [63].

Table 4. Problems of Urban Parks in Mexico City.

Theme	Problem
Common	1) Low user traffic caused by lack of maintenance.
	2) Lack of lighting.
	3) Lack of surveillance.
	4) Compacted soil with low fertility.
	5) Reduction in its surface area due to the widening of streets.
Specific to large parks	1) Space Deterioration caused by inadequate distribution.
	2) Conflicts between authorities arising from the concurrence of combined facilities (museums, cultural areas, zoos, playing fields, etc.)
	3) Property regime problems.
	4) Concessions or permits free of charge or very expensive.
	5) Presence of informal trade.
	6) Existence of uncontrolled harmful fauna.
	7) Lack of budget.

Adapted from Reyes [64].

Table 5. Proposal of Durability and Resistance Tests to be Applied on Elements Manufactured from Recycled Materials.

Performed Tests	Procedure
Determination of Dimensions	NMX-C-038-ONNCCE-20013. Determination of the Dimensions of Blocks [69].
Apparent Dry Density	BS EN 772-13:2000 Determination of net and gross dry density [70].
Compressive Strength	NMX-036-ONNCCE-2013 Resistance to compression of blocks [71].
Initial Maximum Water Absorption	NMX-037-ONNCCE-2013 Determination of abortion of water [72].
Accelerated Weathering Test	NZS 4297. Accelerated weathering chamber. Standards New Zealand [73].

Source: Authors.

3.7. Recycling Proposal for Construction and Demolition Waste

The manufacture of urban furniture was carried out in the green areas of the Engineering Institute in CDMX, including benches, planters, jogging tracks and gabions (**Figure 2**). The urban elements have proven to be fully functional, meeting their design and use expectations (**Figure 2(a)–(d)**). The tests carried out when manufacturing this urban furniture found that the ideal granulometry for this type of element is 3/8” to fine; in addition, the use of vibratory compactors is recommended to obtain better resistance. The application of fine recycled aggregates from CDW is a sustainable alternative to natural fine aggregates, such as natural river sand, since the exploitation of this resource causes negative environmental impacts, so the search for alternatives to natural sand has become an urgent issue [67].

Figure 2. Elements Made from Construction and Demolition Waste at the Institute of Engineering, UNAM, Mexico City, **(a)** Benches, **(b)** Planters, **(c)** Jogging Tracks and **(d)** Gabions. Source: Authors.

Considering these results, it can be stated that the use of recycled CDW aggregates in elements that can be applied in urban parks is viable and technically possible. According to Cruz-Zúñiga and Ramírez-Picado [68], compression tests have been carried out where 30% of recycled CDW aggregates has been used in the manufacture of concrete, obtaining values higher than 210 kg/cm2. In another study, Sánchez shows the technical viability of recycled concrete for the manufacture of urban furniture [8], achieving compressive strengths greater than 35 MPa. The same study also mentions that the behavior of the manufactured concrete is better with coarse recycled aggregates than with coarse and fine aggregates together.

3.8. Tests on Recycled Materials Compressive Strength and Durability

Consideration of the details of compressive strength and durability tests for recycled materials is a very important element in developing construction elements that could be included in urban parks. **Table 5** shows a list of possible tests that can be applied to elements constructed from construction and demolition waste, considering international and Mexican standards [69–73]. In this way, the technical feasibility of elements made from these materials could be known.

In previous investigations of this working group, tests have been carried out on the strength and durability of elements constructed from recycled materials, including construction and demolition waste, and hardness and durability have been obtained which meet or even exceed the standards [74,75].

3.9. Two Emblematic Cases of Urban Park Rehabilitation in Mexico City

In Mexico City, Mexico, there have been documented some successful cases that have used construction and demolition waste in the rehabilitation of urban parks, such as the cases of Cuitlahuac Park and Bicentennial Park Ex-Refinery 18 de Marzo. A brief description of these cases follows.

3.9.1. Cuitlahuac Park

The Cuitlahuac Park, located in Iztapalapa of Mexico City, is a green space of 82 hectares that has been transformed with a strong focus on environmental sustainability. This rehabilitation project ended in 2021 and includes the recycling of 1.1 million tons of construction and demolition waste. The rehabilitation included the upgrading of 3 km of trapping (**Figure 3**), the creation of pedestrian paths (**Figure 4**), urban furniture (**Figure 5**), gabion walls and levelling of the ground. Recycled materials such as PET and HDPE were also used to stabilize the damaged soil, allowing a 90% survival rate for planted plant species. This park represents a prominent example of ecological restoration and waste management in the urban space of Mexico City (SOS, 2019).

Figure 3. Use of Construction and Demolition Waste in a Jogging Track in the Cuitlahuac Park, Mexico City, Mexico. Source: Authors and Google Maps.

Figure 4. Pedestrian Roads Including Construction and Demolition Waste in Cuitlahuac Park, Mexico City, Mexico. Source: Authors.

Figure 5. Urban Furniture Made from Construction and Demolition Waste in Cuitlahuac Park, Mexico City, Mexico. Source: Authors.

3.9.2. Bicentennial Park Ex-Refinery 18 de Marzo

The Bicentennial Park Ex-Refinery 18 de Marzo, located in the Miguel Hidalgo Mayor's Office of Mexico City, was inaugurated in 2010 on the site of the former "18 de marzo" refinery that operated until 1991. After 16 years of neglect, the remediation project was carried out in 2007 to transform this polluted space into an ecological park of 55 hectares (**Figure 6**). In a three-year process, advanced technologies including bioremediation and vapor extraction were applied to clean up the soil. In addition, during this process, 100% of the construction and demolition waste (**Figure 7**) was recycled "in situ" to build urban infrastructure within the park (**Figure 8**), including street furniture, walkers, flower boxes and more. Today, this park represents a natural space for family recreation and ecosystem conservation in Mexico City [76].

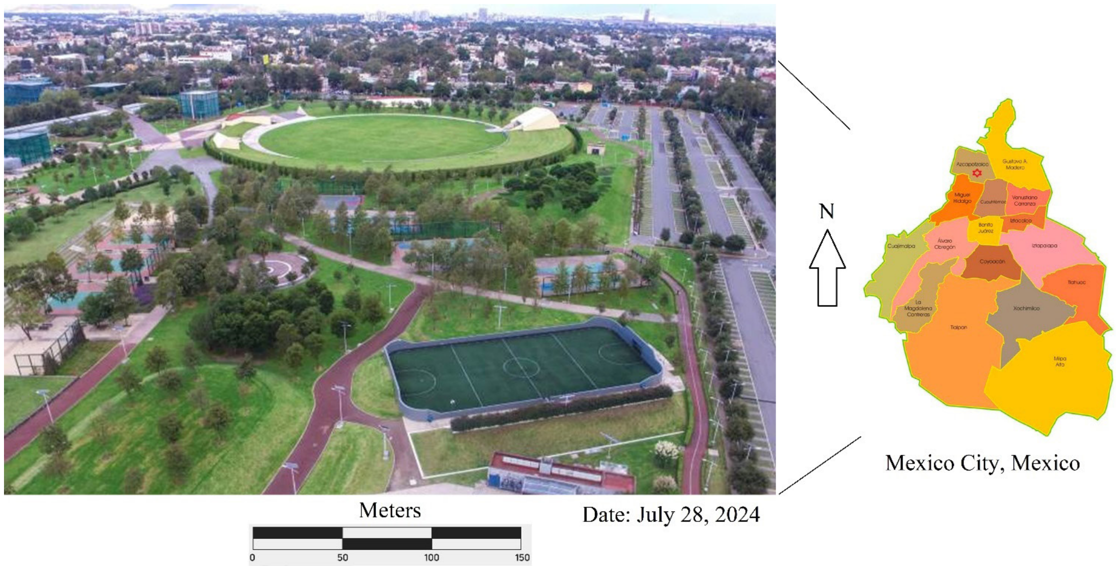

Figure 6. Aerial View of the 55 Hectare Bicentennial Park in Mexico City, Mexico.

Source: Authors and https://mexicocity.cdmx.gob.mx/e/about/about-mexico-city/geography-neighborhoods/?lang=es.

Figure 7. Recycling "In Situ" of 100% of the Construction and Demolition Waste Generated During the Project "Bicentennial Park Ex-Refinery 18 of March". Source: Authors.

Figure 8. Urban Infrastructure in the "Bicentenary Park Ex-Refinery 18 of March": Table Bases and Bases with Seating Functionality Using Construction and Demolition Waste as Fine Aggregates in Concrete Production. Source: Authors.

3.10. Regulatory Frameworks and Social Acceptance of Recycled Materials

In Mexico, solid waste legislation has focused mainly on municipal solid waste, while construction and demolition waste remain poorly regulated. In fact, Mexico City has been the only entity in Mexico to develop a specific standard for the management of construction and demolition waste: NACDMX-007-RNAT-2019 [11]. However, management of construction and demolition waste in Mexico remains limited, largely due to the lack of effective enforcement of regulations and laws, influenced by factors such as omission and institutional weakness.

Despite advances in the use of construction and demolition waste, there are still significant challenges for its implementation as a recycled aggregate in the construction sector. These include the lack of public policies to promote large-scale recycling [77], and low motivation for construction companies to adopt sustainable practices [78], and low efficiency in the processing of construction and demolition waste resulting from limited standards in waste classification and weak compliance mechanisms [79].

In contrast, European countries have made progress in managing construction and demolition waste through strong regulatory frameworks, extended producer responsibility policies, fiscal incentives and the creation of collaborative networks between governments and sector actors [80]. On the other hand, in countries such as Mexico, the integration of construction and demolition waste management is limited by a lack of infrastructure, public policies, financial resources and technology [81,82]. However, it has been shown that active government involvement through incentives such as tax reductions, subsidies and preferential contracting policies can drive circular practices in the management of construction and demolition waste [83,84].

3.11. Long-Term Durability and Maintenance of Recycled Materials in Urban Parks

Recycled coarse aggregates from construction and demolition waste provide a viable alternative for replacing non-renewable natural materials such as gravel and rock. Confirming the above statement, some research has been carried out on this subject. Francisco et al. developed a scheme for the production of concrete using mixed construction and demolition waste, given the difficulty involved in its precise classification [85]. They established that a mixture of waste concrete (50%), ceramic (35%) and mortar (15%) was suitable for partially replacing natural coarse aggregates, achieving a replacement rate of 20%. This ratio allowed the production of concrete with acceptable mechanical properties. However, in terms of long-term durability, it has been observed that this type of concrete may present a higher porosity and susceptibility to the entry of aggressive agents, which could affect its useful life. It is therefore essential to consider complementary design strategies, such as the use of additives, more rigorous curing treatments and a preventive maintenance plan, in order to ensure its structural and functional performance over time. In the cases of rehabilitation of the Cuitlahuac Parks and Bicentenary Ex Refinery 18 de Marzo Park, mentioned in this research paper, after more than a decade the elements that were made with construction and demolition waste have not suffered any damage.

In addition, construction and demolition waste has been used on other types of materials such as bricks and masonry blocks. Maldonado developed bricks, masonry blocks, walls and low walls [86]; testing the strength of these building elements based on Mexican regulations: Development and test of piles development and test of low walls NMX-464-ONNCCE-2010 and were found to comply with the regulations [87]. An additional example of the durability of urban furniture using construction and demolition waste is a small park rehabilitated within the facilities of the Institute of Engineering of the National Autonomous University of Mexico; the construction and demolition waste was used to manufacture urban furniture, and in a period of seven years only preventive maintenance of waterproofing has been carried out without any deterioration.

4. Conclusions

The results obtained in this project allow us to affirm that urban furniture built with CDW (benches, planters, jogging tracks, and gabions) turned out to be fully functional, meeting the expectations of use.

Tests carried out in the manufacture of street furniture built with CDW suggest that the ideal grain size for this type of element is 3/8”.

The results of this project suggest that the application of recycled CDW fine aggregates is a sustainable alternative to natural fine aggregates.

Given the results obtained, it was established that it is feasible and technically possible to use recycled CDW aggregates in urban areas that can be applied in urban parks.

Consequently, future research on the subject developed in this project should focus on improving the mechanical properties of finished products because the heterogeneous composition of CDW (waste from concrete, ceramics, glass, steel, wastepaper, wood, etc.) makes it difficult to classify them effectively.

Future projects should include the study of mechanical properties resulting from recycled CDW aggregates, such as compressive strength and flexural strength, to establish whether the requirements for direct structural use are met.

Author contributions

Conceptualization, M.N.R.-V.; methodology, H.Q-N.. and A.M.-C.; validation, M.N.R.-V.; investigation, M.N.R.-V.; resources, M.N.R.-V.; data curation, A.M-C. and M.N.R.-V.; writing—original draft preparation, H.Q.-N. and A.M-C.; writing—review and editing, M.N.R.-V.; supervision, M.N.R.-V.; project administration, M.N.R.-V. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

Data generated in this research is not available due to project privacy.

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Conflicts of Interest

The authors declare no conflicts of interest.

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