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Reimagining Solid Waste Management in India: A Case of Circular Approach in C&D Waste Management

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Abstract

Construction and demolition (C&D) waste, which accounts for an estimated 150–500 MT annually and approximately 10–20% of the nation's total municipal solid waste (MSW) generation, is a significant management challenge in India. Accelerated urbanization, population growth, infrastructural expansion, and urban redevelopment initiatives are the primary drivers of this rapidly expanding waste stream. In the absence of proper segregation and treatment, much of this waste is disposed of through uncontrolled dumping, encroachment on low-lying areas, and overburdened landfills, causing serious environmental degradation, public health hazards, and the loss of valuable land resources. With an emphasis on sustainable management techniques based on circular economic principles, this study explores the lifecycle environmental impacts of C&D debris, as well as its evolving role in modern urban development. There are notable differences between India and the United States in the frequency of demolitions, rehabilitation cycles, and construction practices. Unlike the United States, which has higher renovation-led waste generation and established recycling markets, India remains largely dependent on demolition-driven redevelopment, which frequently lacks institutional recovery and reuse systems. Life cycle assessment (LCA) frameworks are examined to highlight the potential for improved resource efficiency, reuse, and recycling. Case studies from Thilafushi Island in the Maldives and Kolkata, India, illustrate real-world challenges and context-specific solutions, including material substitution in building block production, decentralized processing, and biomining of legacy waste. The study examines how circularity in C&D waste management can reduce carbon footprints, mitigate urban heat island effects through material reuse, and support national initiatives such as SBM 2.0. This paper aims to examine the urgent need for robust governance frameworks to integrate C&D waste management into India's broader low-carbon urban growth trajectory.

Keywords: Construction and demolition waste, circular economy, waste management, urban sustainability, life cycle assessment (LCA), resource efficiency, carbon footprint, Swachh Bharat Mission 2.0, landfill overflow, waste-to-energy, urban heat island, recycling infrastructure, sustainable development, legacy waste, environmental impact, real estate sector, biomining, Thilafushi island, prefabrication, modular construction.

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INTRODUCTION

India faces significant challenges in waste management owing to its vast population and the staggering 1.751 million metric tons (MT) of waste in 2023–24, accounting for nearly one-third of the global total. Despite this immense volume, the country's recycling infrastructure remains underdeveloped, with only an average of 16–17%

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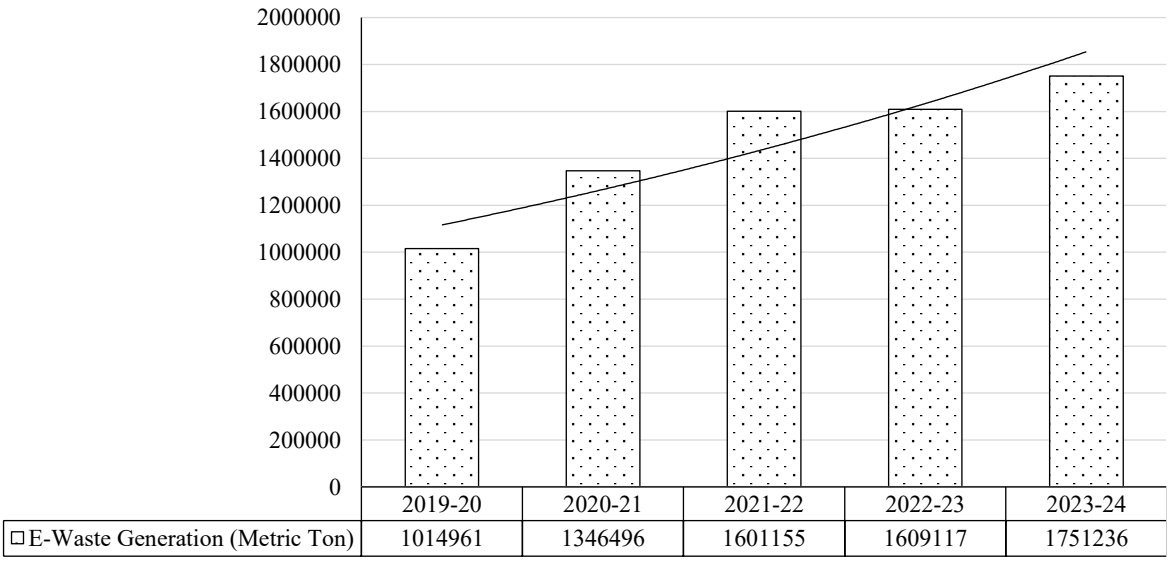
of recycled materials being effectively reused. Ten to twenty percent of MSW is comprised of construction and demolition (C&D) trash, which is a significant component of various waste streams. This study examines the effects of C&D waste on the environment, potential policies to mitigate these issues, and how the circular economy can advance sustainability [1]. India generates 150–500 million metric tons of C&D waste annually, leading to unauthorized dumping, lack of space for disposal, long-term waste logging in landfill sites, and improper mixing with biodegradable waste, which presents challenges during the waste-to-energy process.

In the last 5 years, waste generation in India has increased significantly because of factors such as an increasing population, tourism, and economic activities. C&D waste comprises both major and minor components, including cement, concrete, bricks, steel from reinforced cement concrete (RCC), roofing support systems, timber, and excavated soil, along with smaller elements like electrical fixtures, pipes, asbestos, plastic, glass, and packaging materials [2]. According to the Guidelines on Environmental Management of C&D Wastes [3], new construction should weigh between 40 and 60 kg per square meter, building repairs should weigh between 40 and 50 kg per square meter, and building demolition should weigh between 300 and 500 kg per square meter. The environmental impact of C&D waste is significant throughout its lifecycle, beginning with resource depletion and high carbon emissions during raw material extraction. Inefficiencies in construction lead to excessive waste generation, while demolition produces vast amounts of debris, including hazardous substances such as asbestos and silica dust. Improper disposal further contributes to air, water, and soil pollution, overburdens landfills, and intensifies the urban heat island effect, highlighting the urgent need for sustainable waste management practices (Figure 1).

Contributors Towards the Waste Sector and C&D Waste

India is on track to become a $1 trillion real estate economy by 2030, driven by rapid urbanization, infrastructure development, and government initiatives. The real estate sector, which includes residential, commercial, retail, and industrial projects, is expected to contribute nearly 13% to India's gross domestic product (GDP) by 2025. Economic growth and waste generation are deeply interconnected. As a country's GDP expands, so does industrial production, urbanization, and consumer spending, all of which contribute to increased waste. Policy interventions, technological innovations, and circular economy strategies can disrupt this pattern. Sustainable development requires responsible production, efficient waste management, and a shift towards a resource-efficient economy.



	2019-20	2020-21	2021-22	2022-23	2023-24
□ E-Waste Generation (Metric Ton)	1014961	1346496	1601155	1609117	1751236

Figure 1. E-waste generation.

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Table 1. Comparative data on C&D waste generation between India and the USA.

Type of C&D waste	Generated in India	Overall waste generated by the C&D category (India)	Generated in the USA	Overall waste generated by the C&D category (USA)
New construction	8%	300 million tons	8%	600 million tons
Renovation	6.25%		44%	
Demolition	62.50%		48%	

Note: Analyzed w.r.t Guidelines on Environmental Management of Construction & Demolition (C&D) wastes [3].

The Guidelines on Environmental Management of C&D Wastes state that sources that produce more than 20 metric tons per day or 300 metric tons per month are included in the quantum of waste generation. Major cities as the contributor includes Chennai (2500 TPD), Mumbai (2500 TPD), Kolkata (1600 TPD), etc. Comparative data from a typical type of C&D activity between India and the USA is shown in Table 1.

Based on these data, both countries generate 8% waste from new constructions; the U.S. produces a significantly higher amount of 44% waste from renovations compared with 6.25% in India. This disparity suggests that the U.S. has frequent renovation cycles, driven by stricter building codes, higher maintenance standards, and modernization trends, whereas in India, buildings are often used for extended periods with minimal alterations. Conversely, India generates 62.5% of its C&D waste from demolitions, compared with 48% in the U.S., indicating a greater reliance on redevelopment projects, unplanned urban expansion, and informal demolition practices, which tend to produce more waste. The U.S. likely focuses more on adaptive reuse, controlled demolition techniques, and sustainable building management, resulting in a lower percentage of demolition waste. These differences highlight the need for improved renovation practices in India to extend building lifespans and better demolition waste management strategies to minimize environmental impact [3–5].

ROLE OF C&D WASTE IN AN URBAN ENVIRONMENT

The United Nations Environment Programme (UNEP) states that waste management includes both waste disposal and prevention. The waste management hierarchy emerged when the environmental movement began to criticize the disposal-based waste management approach in the 1970s. It argued that "waste" composed of various materials should be handled differently, as recommended. Minimize production, investigate the potential for recycling and reuse, and dispose of it finally. The same is either directly or indirectly reflected in India's waste management handling regulations, which cover C&D wastes. By 2050, it is anticipated that 877 million people, or more than 50% of India's population, will reside in cities and towns due to the country's current urbanization patterns. This will drastically impact waste production in every sector. It is prevalent in today’s practice that landfills are filling up, which implies a demand for more space for landfills. Landfills comprise storage, reuse, and incineration or waste-to-energy transformation; however, for C&D waste, reuse is limited to a certain extent.

As the urban population increases in existing cities, new towns/cities may emerge as counter magnets to major cities, with an increase in population. New central business districts (CBDs) would be proposed, which would create new demand for housing and commercial spaces. Considering this effect, renovation and demolition activities would increase to a peak, followed by the new construction of high-density regions. This mass change is expected by the target year 2050, which inspired the 1950s and 1970s in North America and Europe on the early trends of urbanization. This provides the country with an estimated 25-year preparation period. This demands a study on the life cycle analysis from generation to reuse period, including measures for residue [4].

LIFE CYCLE ANALYSIS OF C&D WASTE

Life cycle analysis (LCA) is a method for the environmental assessment of products and services, covering their life cycle from raw material extraction to waste treatment [6]. LCA can be categorized into three types:

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1. *Cradle-to-gate:* Before a product is shipped to the customer, cradle-to-gate evaluates its environmental impact up to the point where it exits the manufacturing plant.
2. *Gradle-to-grave:* All five life stages are included in the footprint measurements from birth to death. This displays the entire footprint from beginning to end.
3. *Cradle-to-cradle:* This is similar to cradle-to-grave; however, instead of using garbage, it uses a recycling or upcycling process that turns it into a product that can be used again, thereby "closing the loop.

For recycled products, the cradle-to-grave method is implied. The "circular economy" concept, which is the emphasis of Swatch Bharat Mission 2.0, is connected to the cradle-to-cradle strategy. It suggests reducing the use of virgin construction raw materials in various building projects and expanding tax rebates on recycled C&D products [7].

CIRCULAR ECONOMY AND CARBON FOOTPRINT

According to the United Nations Environment Programme's 2022 Global Status Report for Buildings and Construction, presented at COP27 in Egypt, the industry was responsible for more than 34% of energy consumption and almost 37% of CO_2 emissions related to energy and processes in 2021. This raises the alarm regarding decarbonizing the building sector by 2050 to reduce the effects of climate change due to rising temperatures. The circular economy (CE) plays a crucial role in promoting sustainability across various sectors, particularly in construction, by emphasizing recycling, reuse, and decentralized waste management to reduce landfill pressure, mitigate pollution, and generate employment in waste management and renewable energy. In urban areas, CE aligns with initiatives such as Swachh Bharat Mission 2.0, contributing to cleaner cities and improved public health. Within the construction industry, CE principles enhance material efficiency, minimize waste, and lower the carbon footprint by advocating for designing buildings for deconstruction and allowing material repurposing at the end of their lifecycle. Given that cement production alone accounts for approximately 8% of global CO_2 emissions and the construction sector contributed 37% of energy- and process-related CO_2 emissions in 2021, as reported at COP27, decarbonizing the industry is imperative. C&D activities further exacerbate urban heat island (UHI) effects owing to heat-absorbing materials, such as concrete and asphalt, dust emissions, and vegetation loss, whereas heavy machinery and energy-intensive construction processes contribute to rising urban temperatures. Implementing sustainable solutions, such as urban greening, reflective materials, dust suppression, and C&D waste recycling, can counteract these effects and make cities more livable [1, 7]. Research by Servadei et al. highlights the potential of C&D waste-based geo-polymers for green building applications, providing good thermal and acoustic insulation and mechanical strength suitable for non-structural uses, with its breathability making it ideal for historic building restoration [8–11]. Furthermore, emerging CE-aligned strategies, such as prefabrication, modular construction, and adaptive reuse, enhance efficiency while minimizing waste and fostering environmentally resilient urban development.

CASE AND ANALYSIS

Selected cases representing landfill overflow in Kolkata, West Bengal, India, and waste-to-energy plants in the Thilafushi Island of the Maldives are discussed below.

Kolkata Landfill at Dhapa

The Dhapa landfill is situated in the western part of Ward No. 57 within the administrative boundaries of the Kolkata Municipal Corporation (KMC), with 144 wards, located at coordinates 22°38'53.3"N, 88°23'42.3"E along the Belghoria Expressway. Covering an approximate area of 35 ha, the landfill is surrounded by residential zones and water bodies. Serving as the city's primary waste disposal site since 1987, Dhapa had accumulated approximately 7 million metric tons of municipal waste by the end of 2009. Geometrically, the landfill is divided into two unequal sections: a closed dump and an active dump, separated by a privately operated composting plant. Of the total area, 12.14 ha comprises the closed dump, which was operational from 1987 until its closure in 2009. The remaining 23 ha constitute

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the active dump, which began operations concurrently and continues to receive waste. In 2010, an additional 10 ha was annexed adjacent to the active dump to accommodate the increasing volume of municipal waste (Figure 2) [11–17].

The C&D waste concentration from the composition marks 10%-15%, which accounts for the daily average of 450 MT (out of a total estimate of 4500 mt @ 0.667 kg/capita) [16–18]. As per the set of data provided by the guidelines on environmental management of C&D wastes, Table 1. Comparative data on C&D waste generation between India and the USA. The city of Kolkata and the extended part of the municipal region are undergoing massive development, especially in the region of New Town, Rajarhat, and Madhyamgram; therefore, the proportion of waste could be high due to new development and renovation, which calls for a high priority to address the legacy waste and discard the garbage from buildings and demolition in the landfill.

Over the years, the landfill has presented several issues, such as surpassing its capacity, resulting in unregulated waste accumulation. The site emits methane and other pollutants, contributing to air quality degradation, which leads to environmental problems and rising temperatures. Proximity to densely populated areas raises concerns about respiratory and other health issues among residents. Decades of unsegregated waste have resulted in substantial legacy waste, complicating remediation efforts [11, 15, 16, 18]. To manage and minimize legacy waste at Dhapa, the Kolkata Municipal Corporation (KMC) has initiated biomining. The rubbish mound is expected to be removed in three years after over 4.5 lakh (450, 000) metric tons of waste have been treated. However, in April 2023, a C&D waste recycling plant was inaugurated in New Town, Kolkata. This 1,600-ton-per-day factory promotes circularity in the building industry by turning C&D debris into recyclable aggregates, bricks, and tiles [10, 19]. In 2025, it was observed that the landfill surpassed the capacity limit, and the biomining operation was temporarily halted; the local government issued a call for a new facility (73 ha) due to an incoming waste quantum exceeding 5000 metric tons per day, in which (New Town, Saltlake and Panihati contributes 500 metric tons per day while another 300 metric tons is contributed the Howrah Municipal Corporation), as per the Times of India. Addressing the concern in 2022, a C&D waste recovery plant has been in operation over a 20-ha site for recent developments in the adjoining area [17, 20].

Thilafushi Island Waste-to-Energy (WTE) Plant, Maldives

The Republic of the Maldives Archipelago is located between the Indian and Arabian Seas, between India and Sri Lanka. The geographical extent of the Maldives spreads over 90,000 sq. km, spanning 1192 small islands distributed among 26 administrative atolls. Greater Malé is centrally located in the Maldives and is the capital city of the nation. The Malé Island and its 32 inhabited islands are categorized as Zone 3 in the National Solid Waste Management Policy. The Greater Malé region (Zone 3) produces 774 TPD of mixed solid waste. This is expected to rise to 924 TPD due to rapid urbanization and tourist-based development. The national waste policy is built on the decentralized model with the establishment of the Island Waste and Resource Management Centres (IWRMC) in all inhabited islands (Figure 3) [21].

In addition to having a dedicated space for composting organic waste and another for storing hazardous waste and residuals, the independent wire rope core (IWMRC) is designed to separate and store recyclable materials, such as plastic and metal.

In accordance with the regional waste management planning, the atolls were divided into seven zones based on the following characteristics:

There is no adequate waste management system in the Greater Malé Region. Waste has been gathered, transported by sea, disposed of, and burned at an open disposal site at Thilafushi, an island six kilometers from Malé, for the past 30 years [20]. Zone 3 is the largest contributor of waste because it is home to the capital and a major source of tourism revenue; therefore, the rate of MSW production in this region is 3 kg/bed, equivalent to tourism, 610 grams per capita in the atolls, and 900 grams per capita in the capital region [22].

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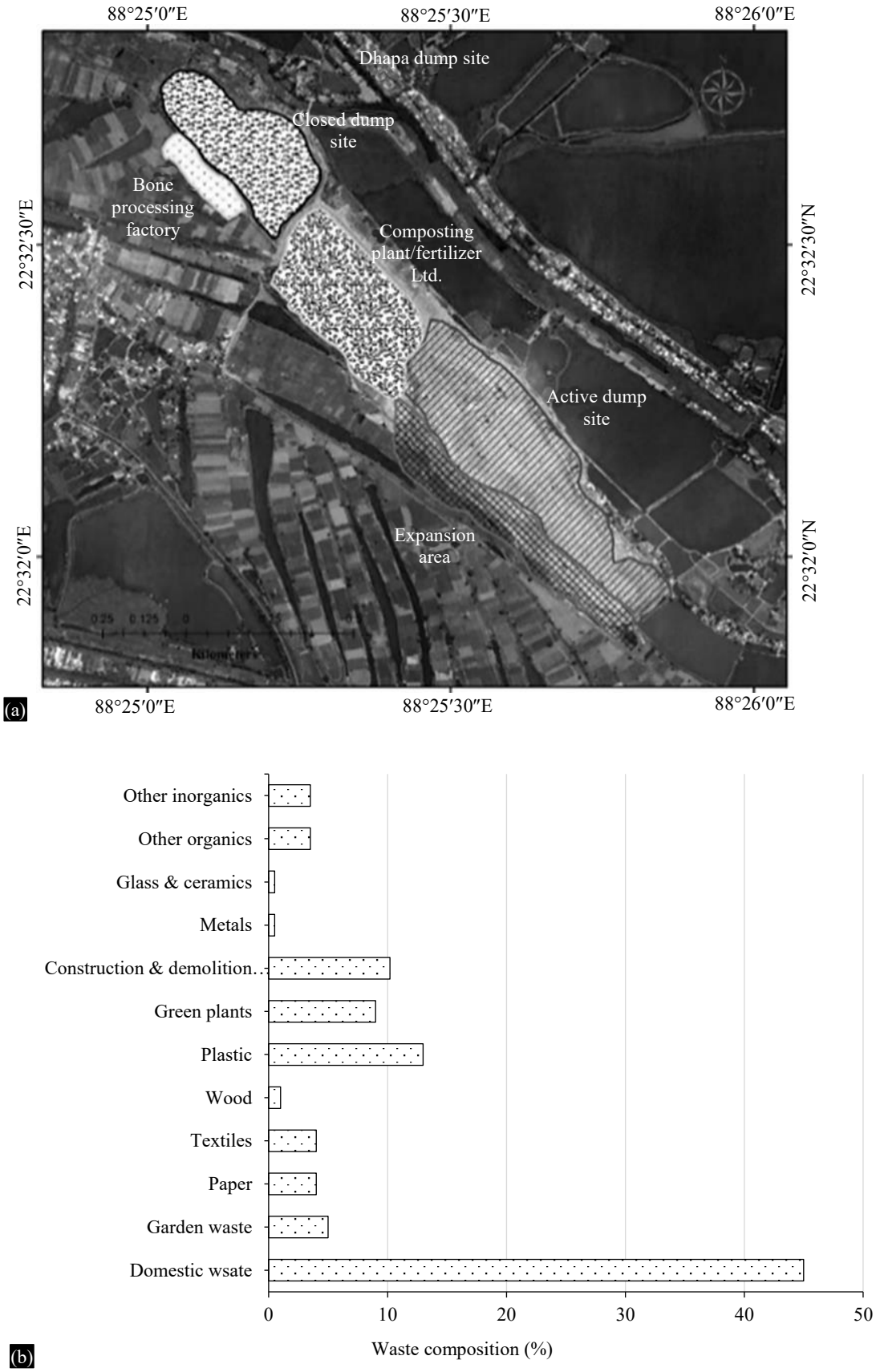

Figure 2. (a) and (b) Dhapa landfill (ward No. 57 of KMC) and waste type.
Source: Ali, et al., 2019.

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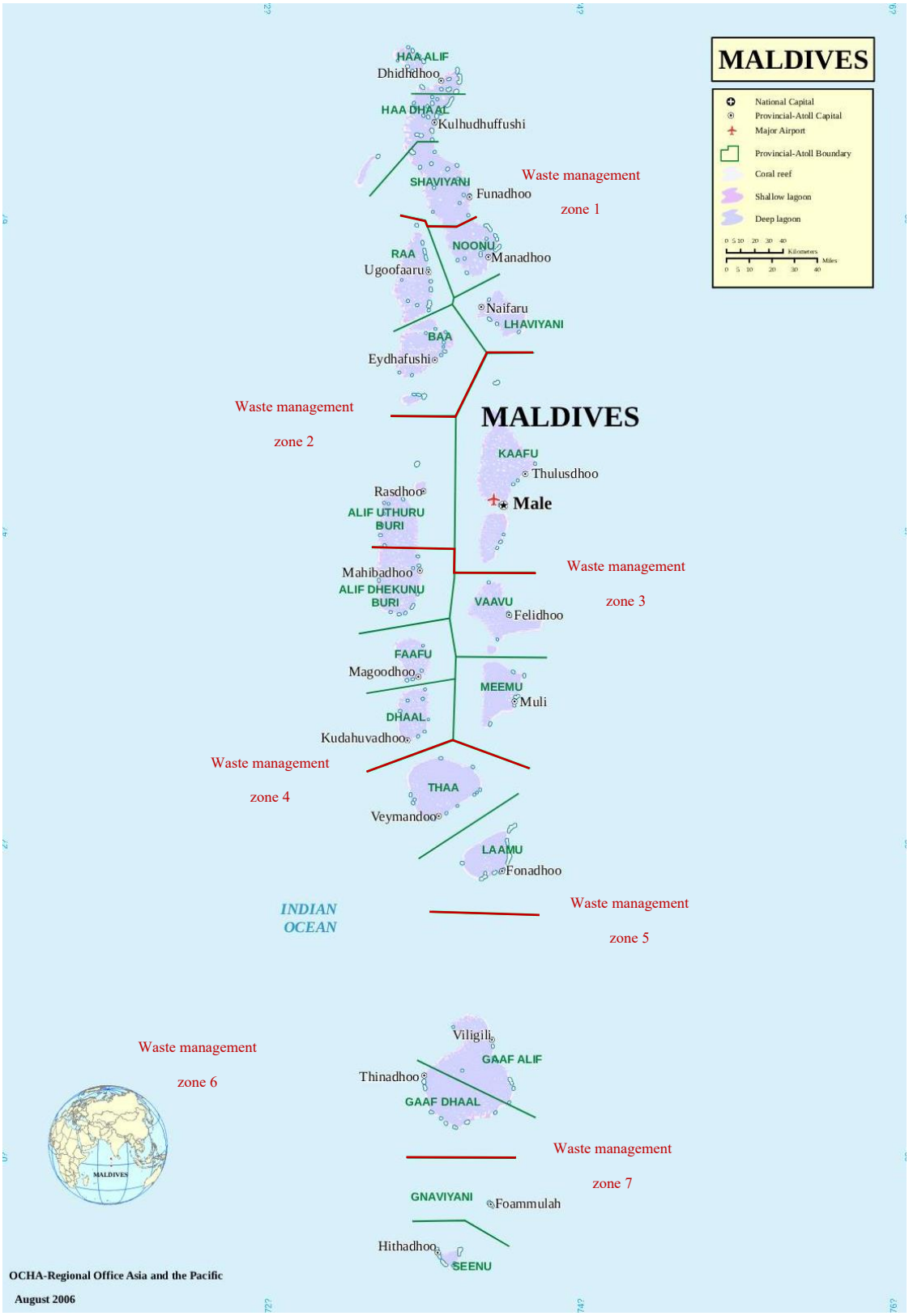

Figure 3. Regional waste management zones in the Maldives.

The construction of buildings and civil infrastructure (roads, airports, ports, etc.) and the demolition of buildings and civil engineering projects are the main sectors that include C&D waste in atolls influenced by tourism.

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Table 2. Regional waste management planning in the Maldives.

Waste management zones	Location of facility	Capacity and status
1, 2	R. Vandhoo Transfer Station (TS) in HDh. Kunburudhoo	40 TPD (Operational since 2023)
3, 4, 5	K. Thilafushi Transfer Station (TS) in Dh. Hulhuvehi	500 TPD (Expected operation end of 2025)
6, 7	Addu Transfer Station (TS) in GDh. Vaadhoo	50 TPD (Operational since 2023)

Source: National Waste Management Policy and preparation of a National Waste Management Strategy [23].

Every day, sea vessels transport C&D waste from Malé and Hulhumale to Thilafushi for disposal. The projected daily quantity. Sand and aggregates used in buildings are now imported. C&D trash is used for two purposes: to prevent coastal erosion or for backfilling. Building demolition is costly. In general, managing C&D waste is a challenging task. It is expected that the C&D waste plant, once operational, will enable construction waste to be transported to Thilafushi for proper disposal. This initiative is part of ongoing efforts to improve waste management in the Greater Malé area and reduce the environmental risks associated with dumping waste into the sea. A construction waste system and a waste-to-energy plant are also under development. This facility is expected to be completed and brought into operation next year, contributing to improved waste management by converting waste into usable energy. The circularity proposed by the Republic of Maldives involves the replacement of sand, a major component of block production. Block production in Malé and Hulhumale' requires about 291 TPD of sand. The current demand for sand (fine aggregates) in block production is slightly less than the generation of 205 TPD of recycled aggregates and 100–125 TPD IBA, out of which 58 metric tons (20% of 291 TPD) can be used for sand replacement [24].

OPERATION AND BANKABILITY OF C&D PLANT

The average generation case lies between 450 MT and 550 MT of C&D generation. The reusability denied in both cases is source-specific. The reusability of C&D waste in Kolkata is aimed towards substitute materials for road construction, whereas the Thilafushi C&D waste is targeted towards block production as a substitute for sand. From the bankability of projects related to C&D waste, it can be noted that this type of waste has direct applications, unlike non-biodegradable waste, which requires energy for change(waste-to-energy), including incineration. To highlight this characteristic, it is important to note the applicability of waste residues, apart from the solid fraction of C&D waste as follows:

1. Waste residue has a complex composition, relatively stable characteristics, and a particle size distribution similar to that of river sand. Dust powder, which is similar to silicate cement but has less reactive volcanic material, is mostly composed of calcium carbonate, calcium sulfate, and silica.
2. Natural sand may be replaced with waste residue. Particle size grading and waste residue addition affect mortar strength. Strength can be maintained by replacing less than 20% natural sand with well-graded water-resistant (WR). Alkali activation, especially with $Ca(OH)_2$, can increase mortar strength by refining pores and producing additional calcium silicate hydrate (CSH) gels; however, replacing cement with damp-proofing (DP) will significantly weaken it.
3. The current ideal composition for waste residue–dust powder mortar involves replacing 20% of regular sand with waste residue and adding 4% of $Ca(OH)_2$-activated dust powder as an additional binder to replace 30% of the cement content. The highest compressive strength can be obtained by water curing, which is followed by wet burlap curing [22, 25, 26].

With this attempt, a C&D plant can achieve 100% usability of the entire waste by adopting stages of segregation based on the size and availability of the waste. Separating the waste into coarse and fine particles can provide part of the waste that is ready to be sold, while the remaining waste can be

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compacted, which reduces the waste to residue and dust powder, finding applications in industry. This not only provides a revenue opportunity but also provides opportunities for startups in the field of building materials. This model will not be a solo revenue or profit-based source that can directly affect operations and SBM 2.0 and employability in the sector.

INFERENCE AND CONCLUSION

As India moves towards achieving its Net Zero 2070 goal, integrating circular economy strategies into national policies will be crucial in balancing economic growth with environmental responsibility. By embedding sustainability at the core of development planning, India can mitigate the adverse effects of waste generation, drive innovation, create large-scale green job opportunities, and strengthen its resilience against climate change. Ultimately, this holistic approach reinforces the vision of 'Sabka Sath, Sabka Vikas', ensuring that economic progress is equitable, sustainable, and beneficial to all sections of society. This study underscores the critical role of C&D waste in shaping sustainable urban futures. LCA reveals that C&D waste has severe environmental impacts from extraction to disposal, emphasizing the need for cradle-to-cradle strategies and circular economy principles. These principles advocate material reuse, design for deconstruction, and technological interventions, such as geopolymer concrete, modular construction, and prefabrication, to minimize the carbon footprint and promote resource efficiency. Case studies from Kolkata, India, and Thilafushi, the Maldives, demonstrate varying regional challenges and responses. While Kolkata grapples with overburdened landfills and legacy waste, it also showcases emerging solutions, such as biomining and C&D recycling plants. Meanwhile, the Maldives presents a decentralized, tourism-driven model that highlights the potential for C&D waste to substitute raw materials, such as sand, in block production, reinforcing circularity. To transition towards a sustainable and resilient waste management ecosystem, India must strengthen regulatory enforcement, promote innovation, and incentivize circular practices. Policy reforms under Swachh Bharat Mission 2.0 and the National Waste Management Strategy need to be aligned with localized solutions, stakeholder participation, and green financing models to ensure scalability. The path forward demands urgent action to transform waste from a liability into an economic and environmental asset, while preparing Indian cities for the challenges of 2050 and beyond.

CRediT Authorship Statement

Sayan Munshi: Writing, review and editing, formal analysis, data curation, and conceptualization. Aditee Prabhakar: Writing, review and editing, investigation, formal analysis, data curation. Rajarshi: Investigation, formal analysis, data curation. Sweta Rupapara: Investigation, formal analysis, data curation.

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