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Sustainable Use of Construction and Demolition Waste in Urban Infrastructure: A Path Toward Circular Construction Practices

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ABSTRACT

The construction and demolition (C&D) waste is one of the biggest forms of waste in the world and it accounts for almost 30-40% of the total solid waste. The rising demands on the natural resources, urbanization and climate change have led to the cities adopting the linear model of consuming their resources to the circular construction of the cities. In this paper, the author includes a detailed overview of the global and regional practice on sustainable management and valorization of C&D waste, particularly in terms of urban infrastructure. It examines new models that combine recycling, industrial symbiosis, and life cycle assessment to bring about circularity in construction. The methodology of the study is a synthesis of the results of the empirical case studies and systematic literature reviews that were performed in 2018-2025. Findings reveal that successful segregation, implementation of controls and collaborating with stakeholders are key facilitators to material recovery and reuse. Energy recovery processes, re-use aggregates and geopolymer technologies are highly promising to decrease the embodied carbon and dependency on landfills. The analysis also indicates geographical voids especially in developing countries where informal sectors prevail in waste streams. Finally, sustainable C&D waste management makes materials more efficient, minimizes emissions of greenhouse gases, and increases the resilience of urban infrastructure, thus achieving the United Nations sustainable development goals (SDGs) 11 and 12.

Keywords—Construction and demolition waste, circular economy, urban infrastructure, recycling, sustainability, resource recovery.

1. INTRODUCTION

The construction industry is one of the greatest consuming industries of the world and the producer of waste. Nowadays, as global estimates show, more than 2.5 billion tonnes of waste is generated during construction and demolition (C&D) activities every year, which is almost 40 percent of all solid waste (Cudecka-Purina et al., 2024) [1]. The sources of this waste are demolition, renovation and new building projects and materials used include, concrete, bricks, steel, wood and plastics. The inefficient disposal methods, the dominance of the linear models of take, make and dispose, have contributed to the degradation of the land, depletion of resources and the upsurge in greenhouse gas emissions (Islam et al., 2024). [2]

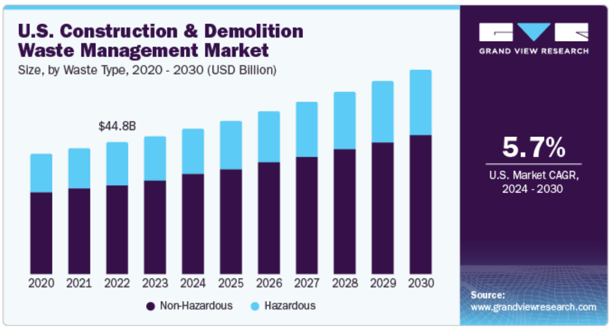

FIGURE 01: US CONSTRUCTION & DEMOLITION WASTE MANAGEMENT MARKET [3]

(Source: https://www.grandviewresearch.com/industry-analysis/construction-demolition-waste-management-market-report)

Circular construction is a relatively new paradigm of C&D waste management by creating a new cycle in the management of C&D waste and encouraging reuse, recycling, and recovery of materials (Gherman et al., 2023)[4]. The strategy is to be environmentally friendly and to create economic value as much as possible. A number of nations currently are creating policies and technologies to seal the

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material loop with selective demolition, digital waste tracking, and design to deconstruct (Al-Raqeb et al., 2023) [5].

The informal waste management, absence of regulations, and awareness of contractors and cities among municipalities are specific to India and other developing economies (Kanagararaj et al., 2022)[6]. At the same time, there is experience from abroad, including Europe, the Gulf, and Latin America, with replicable strategies that focus on the principles of extended producer responsibility (EPR), public-private collaboration, and the design of the product lifecycle.

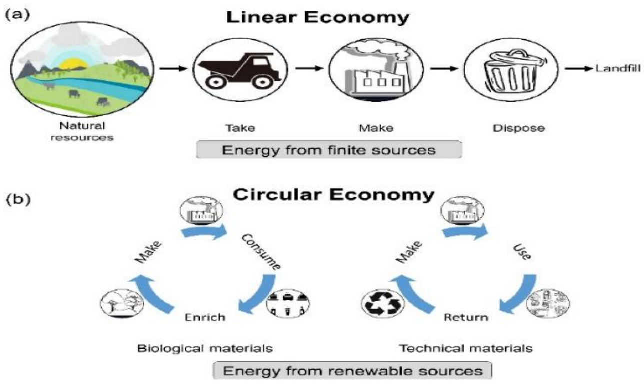

FIGURE 02: CONSTRUCTION AND DEMOLITION IN LINEAR AND CIRCULAR ECONOMY [7]

(Source: https://www.mdpi.com/1996-1944/15/1/76)

The objective of the review paper encompasses international practices, issues, and advancements in the management of construction and demolition waste towards ensuring the principles of the circle of the economy in the development of urban infrastructure. The review summarizes the recent results on the sustainable use of C&D waste in urban structures. It outlines material recovery routes, circuit breakers of the circular economy, and technological advances that facilitate the process of sustainable cities. The originality of the work is that it combines engineering, policy, and sustainability views on the basis of a cross-regional literature of 2021-2025.

2. OVERVIEW OF CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT

2.1. Global Trends and Challenges

Globalisation is a phenomenon that has gained momentum in contemporary society because of the emergence of modern technologies and global communication. The method of managing C and D waste is different in different parts of the world with regards to the economic development, maturity of the policy and technological ability. Recycling and reusing more than 70 percent of non-hazardous C&D waste is achieved in the European Union to a large extent thanks to rigorous regulatory frameworks (Díaz-López et al., 2021) [8]. But numerous developing neighborhoods, and South Asia and the Middle East in particular, have challenges of disconnected supply chain and inadequate infrastructures to collect the materials (Alite et al., 2023) [9].

Al-Raqeb et al. (2023) [5] found that some of the identified obstacles to the influencing C&D waste management in Kuwait comprised a weak coordination between stakeholders, inadequate recycling markets, and a lack of standardized data on waste makeup. On the same note, Nadazdi et al. (2022) [10] pointed out institutional failures in the Western Balkan region that are stopping the adoption of the circular economy although sustainability frameworks are present.

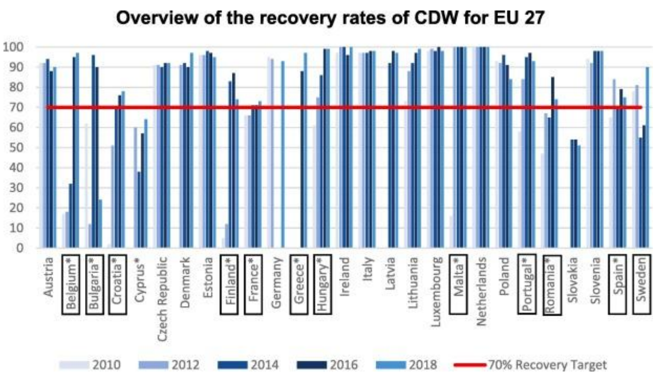

FIGURE 03: RECOVERY RATE OF CDW OF EU [11]

(Source:https://www.sciencedirect.com/science/article/pii/S0956053X23003616)

2.2. Material Composition and Recovery Potential

The common C&D wastes include 40-60 percent concrete, 20-30 percent masonry, lesser amounts of wood, metals, and plastics (Cudecka-Purina et al., 2024) [1]. Recycled concrete aggregates (RCA) and reclaimed asphalt pavement (RAP) have already shown their technical applicability in the sub-base layers, embankments, and new concrete mixtures (Ding et al., 2016; Pereira and Vieira, 2022) [12] [13]. According to the research conducted by Pessoa (2025a, 2025b) [14] [15], recycled materials in permeable pavements may be used to increase the urban drainage and decrease the effects of heat-islands, which result in the attainment of both environmental and functional values.

2.3. Regulatory and Institutional Frameworks

Policies are very vital in facilitating circular construction. Elena et al. (2022) [16], Rayra Brandão and Verissimo (2024) [17] highlighted the correspondence of C&D waste management to UN SDG 11 Sustainable Cities and Communities. The incorporation of extended producer responsibility, compulsory recycling goals, and green-procurement criteria have boosted the achievements in most of the states in the EU. On the other hand, the construction industry in India continues to have in place no extensive

FIGURE 04: SOLID WASTE COLLECTION AND MANAGEMENT [19]

(Source: https://www.hippyinasuit.org/videos/sdg11) implementation schemes, even though the national guidelines are present (Rahigude et al., 2022) [18]

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TABLE 01: LITERATURE-REVIEW MATRIX

Author(s) & Year	Key Findings / Results
Al-Raqeb et al., 2023 [5]	Identified poor coordination, lack of recycling markets, and weak data as main barriers. Illustrates Middle-East challenges in developing circular construction policy.
Alite et al., 2023 [9]	Limited recycling infrastructure and high institutional desire towards circularity. Lays emphasis on barriers in the same manner as in the Indian context.
Claudia Calle Müller et al., 2024 [20]	Compared international decarbonization strategies in the construction (higher-education sector) sector and observed the inclusion of material passports and low-carbon binders. Gives the background between circularity and design-for-reuse.
Cudecka - Purina et al., 2024 [1]	C&D flow Systematic review and data mapping. Propose energy recovery and industrial symbiosis of streams that cannot be recycled and offer quantitative EU information on the valorization potential.
Díaz-López et al., 2021 [8]	C&D research has grown exponentially post-2015; policy drivers are key.
Elena et al., 2022 [16]	Developed an urban circular economy (CE) management model. Emphasized the need for governance integration and multi-actor collaboration; supports municipal coordination.
Gherman et al., 2023 [4]	Synthesizes “circularity outlines” for C&D waste loops. Frames theoretical foundations of CE in construction.
Islam et al., 2024 [2]	Identified research gaps: digitalization, informal-sector integration. Rreinforces digital & social dimensions of C&D circularity.
Kanagaraj et al., 2022 [6]	Proposed roadmap for application in India’s construction.
Nadazdi et al., 2022 [10]	Provided indicators for CE adoption in C&D waste.
Pereira & Vieira, 2022 [13]	Rebates on recycled concrete aggregate (RCA) to use in pavements. Realized RCA practicable to layers of unbound gradation. Gives technical justification to recycled materials.
Pessoa, 2025a [14]	Recycled C&D waste in permeable pavements cuts costs & emissions. LCA case study of recycled C&D in permeable pavements reduces costs and emissions. Measures two environmental-economic benefits.
Pessoa, 2025b [15]	Demonstrated hydraulic and mechanical performance of recycled permeable pavements. Recycled permeable pavements that have been experimentally evaluated are hydraulically/mechanical. Assesses the functional viability of C&D reuse.
Prin Boonkanit & Suthiluck, 2023 [21]	Developed smart DSS for C&D circular transition. AI-powered decision support paradigm for the circular transition of C&D. created a smart DSS that showcases waste analytics' digital innovation.
Rahigude et al., 2022 [18]	Emphasized IoT, BIM, & AI integration for C&D waste tracking.
Rayra Brandão & Verissimo, 2024 [17]	Adoption key for achieving SDG 11 (Sustainable Cities).
Vara & Smol, 2023 [35]	Proposed resource-efficiency indicators for Green Deal compliance. Places C&D circularity within EU Green Deal framework.
Acikök, 2018 [22]	FA & GGBS improved strength of concrete pavements. It Illustrates industrial -byproduct reuse potential.
Ahmadinia et al., 2012 [23]	PET addition increased rutting resistance. It Demonstrates polymer waste utilization.
Akbarnezhad et al., 2013 [24]	Developed acid-treatment technique to determine RCA mortar content. It gives technical contribution for quality control of RCA.
Boominathan & Kumar, 1996 [25]	Lime-treated fly ash effective as embankment material. It is an early example of industrial waste valorization.
Chong & Wang, 2017 [26]	Showed pavement design choices affect life-cycle energy use.
Ding et al., 2016 [12]	Recycled-aggregate concrete reduced impacts vs. virgin concrete.
Du, 2018 [27]	GGBS-activated asphalt improved moisture resistance.
El-Naga & Ragab, 2019 [28]	PET waste improved asphalt binder properties.
Gallardo et al., 2016 [29]	Connected environmental assessment with highway management.

Hayat, 2023 [30]	Applied AI & geospatial tech in urban waste systems.
Hoy et al., 2016 [31]	Developed RAP–fly-ash geopolymer for road material.
Huang & Pauli, 2008 [32]	Studied crumb-rubber particle-size effects on asphalt.
Karimipour et al., 2021 [33]	Urban-scale GHG-reduction toolkit.
Kaza et al., 2018 [34]	Projected waste growth → need for resource recovery.
Kuenzel et al., 2013 [36]	Related metakaolin traits to geopolymer strength.
Kumar & Shankar, 2022 [37]	Used RCA index in agriculture; methodological note.
Laville & Taylor, 2018 [38]	Highlighted plastic overproduction crisis.
Lee et al., 2023 [39]	Studied aged RAP bitumen rejuvenation using waste oil.

3. PATHWAYS TOWARD CIRCULAR CONSTRUCTION

3.1. Circular Economy Principles

Circular construction aims at keeping the materials in productive cycles by designing to reuse and be modular and having reverse logistics (Gherman et al., 2023) [4]. Claudia Calle Muller et al. (2024)[8] found several important ways to decarbonize, such as recycled aggregates, low-carbon binders, as well as material passports. According to Varas and Smols (2023) [35], the combination of digital twin and material tracking technologies provides the basis of transparency in the resources and enables collaboration across sectors.

3.2. Material Valorization and Industrial Symbiosis

One of the suggestions by Cudecka-Purina et al. (2024) [1] is to include energy recovery of non-recyclable C&D fractions in industrial symbiosis networks. The emissions can be offset by matching the construction waste to the cement or energy industries and creating the circular value chains. The geopolymer and fly ash concretes achieve even greater circularity because the carbon-intensive cement is replaced with industrial by-products (Acikok, 2018; Hoy et al., 2016) [22] [31].

3.3. Technological Innovations

They include emerging technologies that enhance traceability and material optimization like automated sorting, artificial intelligence, and Building Information Modelling (BIM) (Prin Boonkanit and Suthiluck, 2023) [21]. Decision systems that make use of AI allow making predictions on waste quantity and assist the construction industry to implement data-based recycling policies. The applications of Industry 4.0, including drones and digital sensors, can help monitor the demolition process in real-time and minimize contamination and increase the recovery levels (Rahigude et al., 2022).

4. APPLICATIONS OF RECYCLED C&D MATERIALS IN URBAN INFRASTRUCTURE

4.1. Road and Pavement Construction

Urban roads have been successfully incorporated with recycled aggregates of demolition debris in their sub-base and base layers. Pereira and Vieira (2022) [13] showed that unbound pavement implementation relying on RCA satisfies the mechanical and durability criteria under the conditions of incorporating stabilizers, including lime or fly ash. Pessoa (2025b) [14] [15] also confirmed that porous pavements made using recycled C&D waste improves infiltration rates as well as alleviates urban flooding.

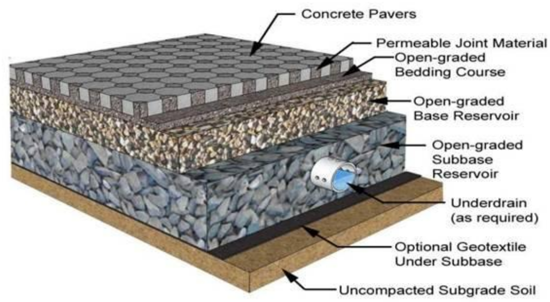

FIGURE 05: PAVEMENT DESIGN IN ROAD CONSTRUCTION

(Source: https://civildigital.com/pavement-design-road-construction-design-parameters/) [40]

4.2. Building and Structural Materials

To a structural concrete, up to 40 percent of natural coarse aggregates can be substituted with recycled aggregates with no deterrence to strength (Akbarnezhad et al., 2013; Ding et al., 2016) [24] [12]. The authors made a significant analogy of the impact of pre-demolition audits and sorting of materials on producing high-quality recycled products (Alite et al. 2023) [9]. Low-carbon concrete is ever-growing in the application of innovations in geopolymer binders and GGBS-fly ash composites (Du, 2018) [27].

4.3. Energy Recovery and Secondary Utilization

Waste materials that cannot be recycled, e.g., contaminated wood and polymer composites, can be recycled to recover energy by co-processing in cement kilns (Cudecka-Purina et al., 2024) [1]. The practice promotes symbiosis in the industry and dependence on fossil fuels. Hayat (2023) [30] emphasized the possibility of optimizing the urban waste-to-energy systems with AI to guarantee the maximum good to the environment.

5. RESULTS AND DISCUSSIONS

5.1. Environmental and Economic Impacts

The reviewed literature has been consistent that sustainable management of the construction and demolition (C&D) waste can greatly decrease the emission of greenhouse gases, energy utilization, and depletion of natural resources in the urban infrastructure development. The study of Life Cycle

Assessment (LCA)-based has revealed that the replacement of the virgin construction materials with the C&D materials (recycled) could lead to the significant environmental advantages. Indicatively, Chong and Wang (2017) [26] and Karimipour et al. (2021) [33] found that pavement systems that used recycled aggregates led to a reduction of about 30-50 percent in greenhouse gas emissions compared to the old-fashioned pavement designs.

On the same note, economic appraisals published in the literature reveal that there are significant cost savings that are linked to the use of recycled material. Pessoa (2025a) [14] found that the recycled construction and demolition waste as permeable pavements resulted in cost reductions of about 25 percent, which were mainly attributed to lower costs in procuring materials, cost of transportation, and disposal of waste at landfills. These results show that circular construction practices do not only make the urban infrastructure development economically feasible, but also make it more environmentally friendly.

It should be noted that the numerical values in this section are obtained purely by using the past published Life Cycle Assessment (LCA) studies, and experimental research that is reported in the literature. The authors in this review did not conduct any new LCA modelling, mathematical formulation, or experimental analysis. This Results section aims to summarize and analyze the confirmed data of the research that exists, and all the values of emission-reduction and cost-saving are referred to the sources of the original data to prevent the appearance of the hypothetic or self-created findings.

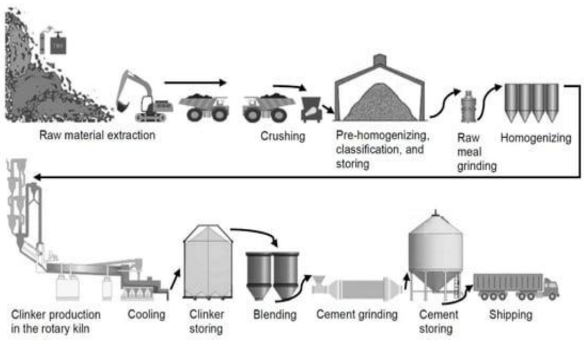

FIGURE 06: CONSTRUCTION AND DEMOLITION WASTE (Source: https://www.mdpi.com/2071-1050/16/2/585) [41]

5.2. Policy and Governance Gaps

Although the world is embracing circular economy policies, the developing nations are yet to enjoy the benefits due to weak implementation and minimal funds. Kanagararaj et al. (2022) [6] suggested a national roadmap of incorporating principles of the circular design in the construction codes in India, by means of digital waste registries. Nadazdi et al. (2022) focused on the necessity of regionalized sustainability assessment frameworks that should be flexible to local circumstances.

5.3. Future Prospects

The following decade will see more smart technologies, digital twins, and blockchain systems that will be integrated to guarantee material traceability throughout the construction value chain. Gherman et al. (2023) [4] and Claudia Calle Müller et al. (2024) [8] predict that this association between the circular construction and net-zero aims will transform the way urban infrastructure planning is planned. Future studies should be done within the domain of hybrid recycling plants, certification of the secondary material, and the socio-economic modelling of the transitions to the circle.

6. CONCLUSION

This review indicates that circularity in building urban infrastructure development requires that sustainable management of construction and demolition waste forms an important part of the process. The review of literature shows that recycling, industrial symbiosis, and recycled materials may be used as secondary materials like recycled aggregates, fly ash, and geopolymer binders, and they can significantly decrease environmental effects and save natural resources. The studies analyzed in this paper are based on Life Cycle Assessment and they all note significant savings in greenhouse gas emissions and material costs when the construction input of recycled materials are used instead of traditional ones. It is important to note that the conclusions made in this paper are made based only on the findings indicated in peer-reviewed literature and not on new experimental results, mathematical models, and Life Cycle Assessment that was performed by the researchers. The stated environmental and economic gains are based on the established LCA research and case studies that are mentioned in the paper.

7. ACKNOWLEDGMENT

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