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Construction Waste Management In India: Status, Challenges And Pathways To A Circular Construction Economy

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Abstract: **I**ndia's building sector is one of the fastest growing in the world due to rapid urbanization, infrastructure investment and housing demand. However, construction and demolition (C&D) waste has remained poorly quantified and weakly regulated as a consequence of this expansion. The construction sector contributes about 25% of the total solid waste stream. When demolition, redevelopment and infrastructure works are fully accounted for, the annual C&D waste generation may reach hundreds of millions of metric tonnes. In India, only a small proportion of C&D waste is converted into secondary raw material. Most construction debris is informally dumped along roadsides, in drains, on riverbanks, or co-disposed with municipal solid waste at open dumps and landfills, leading to dust emissions, urban blight, traffic disruption and encroachment on ecological assets. To address this, the Ministry of Environment, Forest and Climate Change has created a dedicated national regulatory framework.

This paper provides a structured, narrative review of construction waste management in India based on peer-reviewed articles, technical reports, guidelines and fact sheets published up to February 22, 2022. Evidence on the magnitude and composition of C&D waste, the evolution of the regulatory and institutional framework, existing practices and technologies, and the socio-economic and behavioural barriers that limit effective management are synthesised. The paper proposes an integrated set of interventions to move Indian construction towards a circular economy, in which waste prevention, reuse and high-quality recycling are systematically embedded into planning, design and execution.

Index Terms **-** Construction and demolition waste, C&D waste, recycling, circular economy, India, environmental regulation, urban infrastructure.

I. INTRODUCTION

A. Background and context

About 8% of India's GDP is contributed by the construction sector, which provides employment to a large section of the skilled and unskilled workforce [4]. Large investments in national highways, metro rail projects, airports, industrial corridors and urban housing, together with the push for schemes such as "Housing for All" and various state-level infrastructure missions, have substantially increased the demand for building materials. This expansion creates huge quantities of construction and demolition (C&D) waste, which remain far less visible in public discourse and policy debates than construction outputs themselves [7].

C&D waste arises from a wide range of activities in India, including greenfield building construction, road and bridge construction, demolition and renovation of old structures, regularisation of informal settlements, infrastructure maintenance, and routine repair and refurbishment. The debris generated typically contains broken concrete, bricks and blocks, masonry mortar, plaster of Paris, sand and aggregates, excavated soil and stone, steel, non-ferrous metals, wood, plastics, glass and bituminous paving fragments [3]. Most of this material has historically been treated as inert waste that simply needs to be removed from construction sites, with little attention to its potential as a secondary resource or to the environmental costs imposed by dumping.

Most Indian cities focus their waste management efforts on household and commercial waste. Construction debris has either been left to the informal sector or treated as a low-priority stream to be handled through ad hoc dumping. C&D waste has contributed to multiple problems. Dumping in lakes, wetlands and riverbanks reduces the buffering capacity of natural ecosystems [5]. Roadside dumping generates high levels of dust and particulate matter. The conversion of agricultural land and peri-urban open spaces into informal dumping grounds has serious implications for livelihoods and local environments.

B. Emergence of C&D waste as a policy concern

In the late 1990s and early 2000s, the Centre for Science and Environment (CSE) in India began to examine the scale of C&D waste generation and its impact on the urban environment, and the environmental significance of C&D waste started to receive more systematic attention [3]. The 2001 study *Utilisation of Waste from Construction Industry* was one of the first attempts to quantify C&D waste composition and explore technological options for recycling [3]. It showed that more than 85% of typical C&D waste is potentially reusable, and that low recovery is mainly a result of policy neglect rather than technical impossibility [5].

Large-scale demolition and renovation projects in major metropolitan areas brought the issue into sharper focus. Expansion of city road networks, flyovers and metro systems, together with slum clearance and high-rise redevelopment, dramatically increased demolition waste volumes in cities [4]. The Burari plant was commissioned in Delhi in 2009 under a public–private partnership as a dedicated C&D waste recycling facility. There was growing recognition within the Ministry of Urban Development that a separate set of rules and guidelines was needed to regulate C&D waste. The notification of the Construction and Demolition Waste Management Rules, 2016 explicitly defined C&D waste and assigned responsibilities to generators, local bodies and state agencies [1]. The Rules, supplemented by technical guidelines prepared by the Central Pollution Control Board and other agencies, marked a significant step towards recognising C&D waste as a distinct policy domain within Indian environmental regulation [2].

C. Research gap and objectives

Over the past decade, regulatory and technical attention to C&D waste has increased, but practice on the ground still lags behind policy intent. Review documents by Faruqui and Siddiqui highlight this gap [7]. Many urban local bodies have not established comprehensive systems for source segregation despite the notification of the C&D Rules [6]. Recurring issues include unreliable data on waste generation and incomplete records, limited processing capacity, weak enforcement of regulatory responsibilities, poor awareness among contractors and site managers, and underdeveloped markets for recycled C&D products. Within this context, the present paper has four interrelated objectives. It seeks to compare estimates of C&D waste generation and composition in India with other studies; to re-examine the structure and content of the Indian regulatory framework for C&D waste; to synthesise evidence on current management practices in Indian cities; and to outline a set of practical, context-sensitive recommendations for moving towards a circular construction economy in India.

D. Structure of the paper

The remainder of the paper is organised as follows. The methodology used for this review is described in Section II. Section III discusses estimates of C&D waste generation and typical material composition in India, and presents a comparative table of major national-level studies. Section IV focuses on the C&D Rules 2016 and associated guidelines and toolkits. Section V reviews prevailing practices in collection, transport, processing and recycling of C&D waste. Section VI summarises key barriers and challenges. Section VII highlights emerging good practices and case examples. Section VIII proposes an integrated set of interventions to support a transition towards circular construction, and Section IX summarises the main conclusions and policy implications.

II. Methodology of the Review

A narrative review of secondary sources is the approach used in this paper. This choice is motivated by the nature of the subject, where a significant portion of relevant knowledge is contained not only in peer-reviewed journal articles but also in government notifications, technical guidelines, conference documents, fact sheets and reports produced by national and international organisations. Many of these documents provide rich contextual information on policy processes, institutional arrangements and implementation constraints, which are not easily captured through purely quantitative metrics. Key search terms included "construction and demolition waste India", "C&D waste management India", "construction waste management in India", and combinations of these phrases. To identify peer-reviewed articles and conference papers, searches were conducted in academic databases. Rules, guidelines, toolkits and fact sheets were obtained from the websites of the Centre for Science and Environment and the Ministry of Housing and Urban Affairs [1].

Only sources published up to 23 February 2022 were included in the core analysis. Later documents were occasionally consulted to cross-check earlier information, but they are not cited as primary references. The inclusion criteria emphasised relevance to the Indian context, clarity of methodology, and explicit discussion of at least one of the following topics: generation and composition of C&D waste, regulatory and institutional frameworks, and technologies and practices for collection and management.

Quantitative estimates of waste generation and composition were taken from each source and compared in line with the objectives outlined in Section I-C. The allocation of responsibilities in the regulatory framework was analysed qualitatively. Observations reported in review papers by Faruqui and Siddiqui [7], Jain et al., and Hariprasad and Dayananda [6] were cross-validated across multiple sources. The synthesis does not claim to be exhaustive, but rather reflects the most widely cited and policy-relevant contributions in the Indian literature up to early 2022. The review aims to provide a robust and nuanced picture of construction waste management in India by triangulating multiple sources.

III. Magnitude and Composition of Construction and Demolition Waste in India

A. National-level estimates of C&D waste generation

Estimating the total amount of C&D waste in India is challenging because of differing methodologies and assumptions. An indication of the likely order of magnitude is provided by the indicative values reported in several influential studies. One of the earliest structured attempts was the 2001 study *Utilisation of Waste from Construction Industry* [3]. It suggested that, in the early 2000s, the Indian construction industry generated more C&D waste than any other industrial sector. This figure is considered a conservative lower bound because it did not fully account for the large volumes of informal construction, dilapidated housing, and dispersed infrastructure and demolition activities.

More advanced approaches have since been used to refine these estimates. Some studies link construction activity data with material intensity coefficients and demolition rates in order to improve resource efficiency assessments [4]. One such study estimated total C&D waste generation to be around 716 million metric tonnes in 2015 [4]. The higher value highlights the need for updated, periodically revised national inventories.

At the city level, Jain et al. proposed an approach to estimating C&D waste generation using a combination of building permit data, land-use information and building inventory records [9]. The methodology used to derive per capita C&D waste generation rates in selected Indian cities showed that demolition and renovation cycles can cause sharp peaks in waste quantities. The results indicate that the age distribution of the building stock, land values and redevelopment policies have a major influence on C&D waste generation patterns, which cannot be captured adequately by simple national average factors [9]. National and city-level estimates are also summarised in fact sheets [5]. According to a synthesis of multiple sources, C&D waste accounts for roughly 25–30% of the total solid waste generated in Indian cities [5]. There is broad agreement across recent studies and reviews that C&D waste in India represents a very large and growing material stream, with significant implications for resource conservation, land use and environmental quality. Table 1 presents a comparison of national-level C&D waste generation figures reported in Indian studies.

Table 1: Selected Estimates of Construction and Demolition Waste Generation in India

Source	Year(s) considered	Methodology / Basis	Estimated annual C&D waste (approx.)
TIFAC [3]	~2000–2001	Per capita and activity-based factors for construction industry	12–14.7 million tonnes
CSE (factsheet) [5]	Various, up to 2014	Synthesis of studies; share of total solid waste 25–30%	Not a single number; indicates undercount
Sekhar (GIZ) [4]	2013, 2015	Material flow analysis for construction sector	530 million t (2013); 716 million t (2015)
Jain et al. (cities) [9]	Selected years	City-level MFA and building stock analysis	City-specific; extrapolation implies very large national totals
Jain et al. (review) [6], [8]	Up to 2020–2021	Mini-review of multiple Indian studies	Concludes that earlier national estimates are gross underestimates

Source: Compiled by the author based on [3]–[6], [8], [9].

Differences in methodology and genuine changes in underlying construction activity are reflected in the wide spread between early and recent estimates. The key conclusion is the recognition that C&D waste is a major material stream that can no longer be treated as a marginal issue within urban solid-waste management.

B. Typical material composition of C&D waste in India

The material composition of C&D waste is very important. It determines which fractions can be easily separated, which require more complex processing, and which may pose environmental or health risks if handled incorrectly. The first quantitative breakdown of C&D waste in India was provided in 2001 [3]. Indian C&D waste consists of approximately 36% soil, sand and gravel, 31% brick and masonry, 23% concrete, 5% metals, 2% wood, and 3% other materials. This composition reflects the dominance of masonry- and concrete-based construction in India, as well as the significant contribution of excavation and

site-preparation activities. Fact sheets highlight the high share of mineral fractions that are technically suitable for reuse [5].

Similar patterns are reported by both project-level and city-level studies. Surveys of construction-site waste in multi-storey residential projects show a high proportion of concrete, mortar, brick and plaster of Paris during structural and finishing stages, while demolition waste from older load-bearing masonry buildings may contain proportionally more brick and lime-based mortar. Large infrastructure projects, such as road and bridge construction, add substantial quantities of bituminous paving waste, sub-base material and other aggregates. When waste from different sources is mixed together, it creates challenges for downstream processing. A large portion of C&D waste is composed of non-hazardous mineral fractions. Under appropriate quality-control conditions, crushed concrete and masonry can be recycled into aggregates suitable for road sub-base, embankment works and non-structural concrete and masonry products. Excavated soil can be used as backfill. Wood, glass and plastics can also be recycled [4]. The main barrier is not inherent material unsuitability, but the lack of systematic segregation, collection and processing infrastructure.

C. Sources of C&D waste and activity profiles

Understanding activity profiles is important for designing effective C&D waste-management systems. India has a wide spectrum of generating activities. Large-scale infrastructure projects generate substantial quantities of excavation spoil, concrete and bituminous paving waste. These projects typically involve formal contractors and are subject to some environmental-clearance conditions, but C&D waste-management provisions are not consistently enforced [1]. In many cities, low-rise load-bearing structures have been replaced by reinforced-concrete high-rise buildings. This has led to specific zones where demolition debris is concentrated. Jain et al. highlight that renovation and redevelopment cycles are key drivers of city-level C&D waste generation and need to be explicitly considered in urban planning [9]. Significant contributions also come from routine repair and redevelopment activities. These are often carried out by small contractors or through self-help arrangements, generating many small, dispersed waste streams that are not linked to any formal collection or recycling system [6].

India thus has a very large number of small and dispersed generators alongside a smaller number of large projects. While large projects can, in principle, be required through contractual clauses and environmental clearance conditions to prepare C&D waste-management plans, local bodies often lack the capacity and incentives to enforce regulations at this level. Successful city-level initiatives tend to address this diversity of generators by combining regulatory measures, convenient service models and economic incentives.

IV. Regulatory and Policy Framework for C&D Waste in India

A. Construction and Demolition Waste Management Rules, 2016

The notification of the *Construction and Demolition Waste Management Rules, 2016* by the Ministry of Environment, Forest and Climate Change marks an important milestone in the governance of C&D waste in India [1]. Prior to these Rules, there was no explicit legal obligation on waste generators to manage C&D waste systematically. The 2016 Rules define what constitutes C&D waste, allocate responsibilities across multiple actors, and specify management requirements for different stages of the waste stream. C&D waste is defined in the Rules as building materials, debris and rubble resulting from any civil construction, as well as desilting of waterbodies and excavation works [1]. The Rules apply to all types of waste generators, including individual homeowners, bulk generators, real-estate developers and infrastructure agencies. They require the setting up of dedicated systems for collection and processing of C&D waste.

A key feature of the 2016 Rules is the clear enumeration of responsibilities for bulk generators. Large projects above specified thresholds are required to submit a C&D waste-management plan as part of their project-approval process [1]. These provisions aim to ensure that the most significant point sources of C&D waste are brought within a formal regulatory framework. The Rules mandate that urban local bodies identify suitable sites for C&D waste processing and disposal, frame by-laws specifying collection mechanisms and user charges, and integrate C&D waste considerations into their overall solid-waste management plans [1]. State Pollution Control Boards and Pollution Control Committees are tasked with granting authorisation to C&D waste-processing facilities, monitoring compliance with environmental standards, and compiling data on quantities generated and processed. This multi-level allocation of responsibilities is intended to create a coordinated governance framework. The distribution of responsibilities is presented in Table 2.

Table 2: Indicative Allocation of Responsibilities under C&D Waste Management Rules, 2016

Actor / Institution	Key Responsibilities
Waste Generators (individuals and bulk)	Segregate C&D waste at source; store within premises; submit waste management plan for large projects; pay user charges; deliver waste only to authorised collection/processing sites.
Urban Local Bodies (ULBs)	Identify and notify collection points and processing/disposal sites; frame bylaws and user charges; integrate C&D into SWM plans; ensure regular collection and transport; create awareness.
State Government / Urban Development Dept.	Facilitate land allocation for processing plants; issue policy directions to ULBs; integrate C&D waste management into state-level urban development programmes.
State Pollution Control Boards (SPCBs)	Authorise C&D waste processing facilities; monitor compliance; collect data on quantities handled; include C&D in annual environmental reporting.
MoEFCC and Central Agencies	Notify and periodically revise national rules and guidelines; coordinate with central ministries; promote research and pilot projects.

Source: compiled from [1], [2].

The fundamental interactions between actors are best understood as a web of planning, regulatory and operational functions. Local and national regulatory functions shape the relationship between waste generators and urban local bodies. The institutional arrangement for waste management in India is shown in Figure 2.

Figure 2: Institutional arrangement for construction and demolition (C&D) waste management in India

B. Technical guidelines and manuals

Technical guidelines and manuals for the C&D Rules have been prepared by the Central Pollution Control Board (CPCB) [2]. These documents provide guidance on estimating C&D waste quantities, designing collection and storage systems, selecting technologies for processing, and identifying suitable end uses for recycled products.

They offer step-by-step recommendations for the planning and implementation of C&D waste management facilities [2]. Technological options are described for primary segregation at construction sites, secondary sorting at transfer stations, mechanical crushing and screening of concrete and masonry, metal recovery, and quality assurance for recycled aggregates and manufactured products. Control of dust emissions at crushing plants is highlighted as an important environmental safeguard. The CPHEEO manual recommends that C&D waste be treated as a separate stream with its own collection routes, fee structure, and processing technologies [13]. These guidelines can be used by municipal engineers, consultants and private operators.

C. Green building frameworks and standards

The concept of construction waste management has also been mainstreamed through voluntary green building rating systems and professional bodies. The Indian Buildings Congress has published a compilation titled *Waste Management in the Built Environment* [13]. The authors in this volume advocate standardised dimensions, modularity, and provisions for future alterations and deconstruction as key strategies to reduce waste generation [14]. Green building rating systems in India award credits for measures such as on-site

segregation, high reuse and recycling rates, and the use of certified recycled materials in non-structural components. Presentations at national green building summits highlight projects that have successfully used paving blocks, kerb stones and concrete products manufactured from recycled C&D aggregates [15]. Although these frameworks are voluntary, they can encourage early adoption of good practices that may eventually inform regulatory standards.

V. Current Practices and Institutional Arrangements

A. Collection and transport

Informal and semi-formal arrangements continue to dominate the collection and transport of C&D waste. For small-scale construction and renovation activities, it is common for waste generators to hire local transporters to remove debris from the site, often without any record or requirement that the waste be taken to an authorized location [5]. Political pressure and limited staffing make it difficult for urban local bodies to consistently enforce anti-dumping regulations.

Where urban local bodies have attempted to implement the 2016 Rules, designated C&D waste collection points have been introduced. Some cities have experimented with differential user charges, imposing higher penalties for unauthorized dumping and lower fees for delivering waste to authorized sites. However, the coverage of such systems remains uneven. When monitoring is weak, transporters have an incentive to dump waste at unauthorized locations because disposal sites are often distant from central areas. Practical barriers to compliance include the absence of convenient service options for small generators [6].

B. Processing and recycling infrastructure

Only a limited number of Indian cities currently operate formal C&D waste recycling plants, and even in these cities the proportion of waste processed remains small relative to the total generated. Delhi is often cited as a pioneer, having commissioned a C&D waste recycling plant at Burari in 2009, followed by additional facilities under public–private partnerships [4]. These plants typically receive mixed C&D waste, which is then sorted, crushed and screened to produce a range of recycled products. Facilities in other cities often operate below capacity because of inconsistent inflows and limited market demand for recycled products.

The overall recycling rate for C&D waste in India is low, often estimated at around 1% of total generation [5]. A significant share of C&D waste is informally disposed of through unauthorized land-levelling and encroachment activities rather than being channelled into controlled recycling processes. Such informal reuse does not fully exploit the resource potential of the material and may have negative environmental and land-use implications. Table 3 presents an illustrative summary of typical performance parameters of C&D waste recycling facilities.

Table 3: Indicative Characteristics of Selected C&D Waste Recycling Initiatives in India

City (example)	Approx. year of first plant	Indicative capacity (TPD)*	Ownership / Model	Typical output products
Delhi	2009	500–2000	Public–private partnership	Recycled aggregates, paving blocks, kerb stones, precast tiles
Ahmedabad	Mid-2010s	300–500	Municipal concession	Aggregates for road sub-base, non-structural concrete
Bengaluru	Late-2010s	300–500	PPP / municipal operator	Aggregates, blocks, pavers
Hyderabad	Late-2010s	300–500	PPP	Aggregates for public works, fill material

*TPD: tonnes per day. Source: compiled from [4], [5], [6], [8], [11].

The table is indicative, but it shows some common features, such as capacities in the range of a few hundred to a couple of thousand metric tonnes per day, reliance on public–private partnerships, and a focus on non-structural applications where performance requirements are easier to meet with recycled aggregates.

C. Role of the informal and secondary materials sector

The informal sector plays a significant role in waste management in India. The lack of formal services and the desire to reduce costs make informal contractors and labourers responsible for a large share of dumping. Second-hand materials traders and informal networks recover many reusable items from demolition sites, including doors, windows, sanitary fittings, structural members, timber components and even intact bricks [10]. These activities extend the useful life of materials and reduce the demand for new products, but are rarely documented or integrated into official statistics. Informal recovery can be strengthened and formalised through appropriate policy instruments. Municipalities could provide guidelines, registration procedures and technical support for safe deconstruction practices. Informal actors can then be more systematically integrated into formal C&D waste management systems.

VI. Barriers and Challenges

A. Data and information gaps

In the Indian literature, the lack of reliable data is a recurring theme. Many urban local bodies do not maintain separate records for C&D waste, and when they do, the information is often limited to the quantities delivered to a few authorised facilities or temporary dumping sites [5]. National-level estimates, such as those derived from early studies or GIZ's material flow analysis, provide useful benchmarks but are not updated regularly, and methodological differences make it difficult to compare figures across sources [3]. This lack of robust, disaggregated data has multiple consequences. Policymakers cannot accurately plan processing capacity, identify suitable locations for facilities, or design realistic financial models. They also cannot easily track whether waste generators are complying with their obligations. Effective C&D waste management requires systematic data collection and reporting mechanisms [6].

B. Economic and market barriers

The use of processing facilities is constrained by economic factors. Virgin aggregates and natural sand are relatively inexpensive in many regions, whereas recycled products may be more costly once transport and processing expenses are included [4]. Structural engineers and contractors often prefer conventional

materials, even where standards permit the use of recycled products, because of uncertainty about the performance of recycled aggregates. Technical standards for C&D-derived materials remain limited. Although research shows that concrete made with recycled aggregates can meet performance criteria [9], this knowledge is still being translated into codes and specifications. Demand for recycled products is therefore confined to a narrow set of applications, such as road sub-base layers and minor landscaping works, which may not provide a sufficiently large or stable market to justify substantial investment in processing capacity.

C. Institutional fragmentation and weak enforcement

Multiple institutions are involved in C&D waste management, including municipal corporations, development authorities, State Pollution Control Boards, urban development departments and central ministries. Responsibilities are distributed across these actors, but coordination mechanisms are often weak. Urban local bodies may be tasked with providing land and services for C&D waste collection and processing [1]; however, if agencies do not work together, policy mandates may not translate into effective operational systems. Enforcement of the 2016 Rules also faces practical constraints. C&D waste violations may not be prioritised by municipal inspectors and engineers. Penalties for illegal dumping are often too low to be a meaningful deterrent. In the absence of visible enforcement and meaningful sanctions, waste generators may treat compliance as optional.

D. Behavioural and awareness-related obstacles

Lack of awareness and risk-averse attitudes are major obstacles to the adoption of sound C&D waste management practices [6]. Many contractors and site managers are unfamiliar with the provisions of the 2016 Rules and may perceive waste management as an additional cost and administrative burden. Safe handling and reuse-oriented practices are rarely incorporated into training for construction workers. Design choices often do not explicitly consider waste minimisation or flexibility. These cultural and behavioural dimensions are critical for long-term change, yet harder to address than purely technical issues. Shifts in professional practice and norms are more likely to produce sustained improvements than regulatory mandates alone.

VII. Case Examples and Emerging Good Practices

A. Delhi's C&D waste recycling initiative

Delhi illustrates how a large city can begin to systematise C&D waste management. In response to severe dumping problems, the city partnered with a private operator to establish a C&D waste recycling plant at Burari in 2009 [4]. The private concessionaire invested in processing equipment and assumed responsibility for plant operations, while the municipal corporation provided land and guaranteed a minimum supply of C&D waste.

At the Burari facility, mixed C&D waste is delivered, then sorted, crushed and screened. The resulting aggregates are used to manufacture paving blocks, kerb stones, tiles and other non-structural concrete products. These products have been used in footpaths, parking areas and selected public buildings, thereby creating assured demand and demonstrating the practical suitability of recycled materials. Delhi's experience offers several lessons. Long-term access to land is critical for the financial viability of C&D plants. Market hesitancy can be mitigated through public procurement policies that prioritise recycled products. However, significant quantities of C&D waste can still bypass formal systems if enforcement and service coverage are incomplete.

B. Resource efficiency pilots in other cities

C&D waste recycling measures have also been piloted in other Indian cities. These pilot projects have used recycled aggregates in road sub-base layers and as partial replacements for natural aggregates in non-structural concrete [4]. Where quality control is maintained, the performance of recycled materials in such applications is comparable to that of conventional materials, while offering potential environmental benefits. The pilots underscore the importance of early coordination. When C&D waste flows are planned and contracted in advance, project timelines can integrate waste collection and product supply. Ad hoc arrangements, by contrast, often lead to underutilised processing capacity.

C. Design-oriented waste minimisation practices

In addition to end-of-pipe recycling, there is growing recognition in India that design and planning choices at the outset of projects have a profound influence on subsequent waste generation. Measures such as modular design, standardisation of component dimensions, and the use of flexible and adaptable layouts are advocated by the Indian Buildings Congress and other professional forums [13]. Careful alignment of structural grids, partition systems and façade modules can significantly reduce off-cuts and material wastage. Some innovative projects are experimenting with design-for-deconstruction principles, in which building components are assembled with reversible connections and documented in ways that facilitate future disassembly and material recovery. Such approaches can help shift C&D waste management from a downstream disposal problem to an upstream design challenge.

VIII. Towards a Circular Construction Economy: Recommendations

The classical waste management hierarchy emphasises interventions that prevent waste generation over those that merely treat or dispose of it. In the context of construction and demolition waste in India, design and planning measures to avoid waste, followed by reuse and high-quality recycling, should take precedence over end-of-pipe options such as low-value recovery or disposal. Figure 1 illustrates the construction and demolition waste management hierarchy.

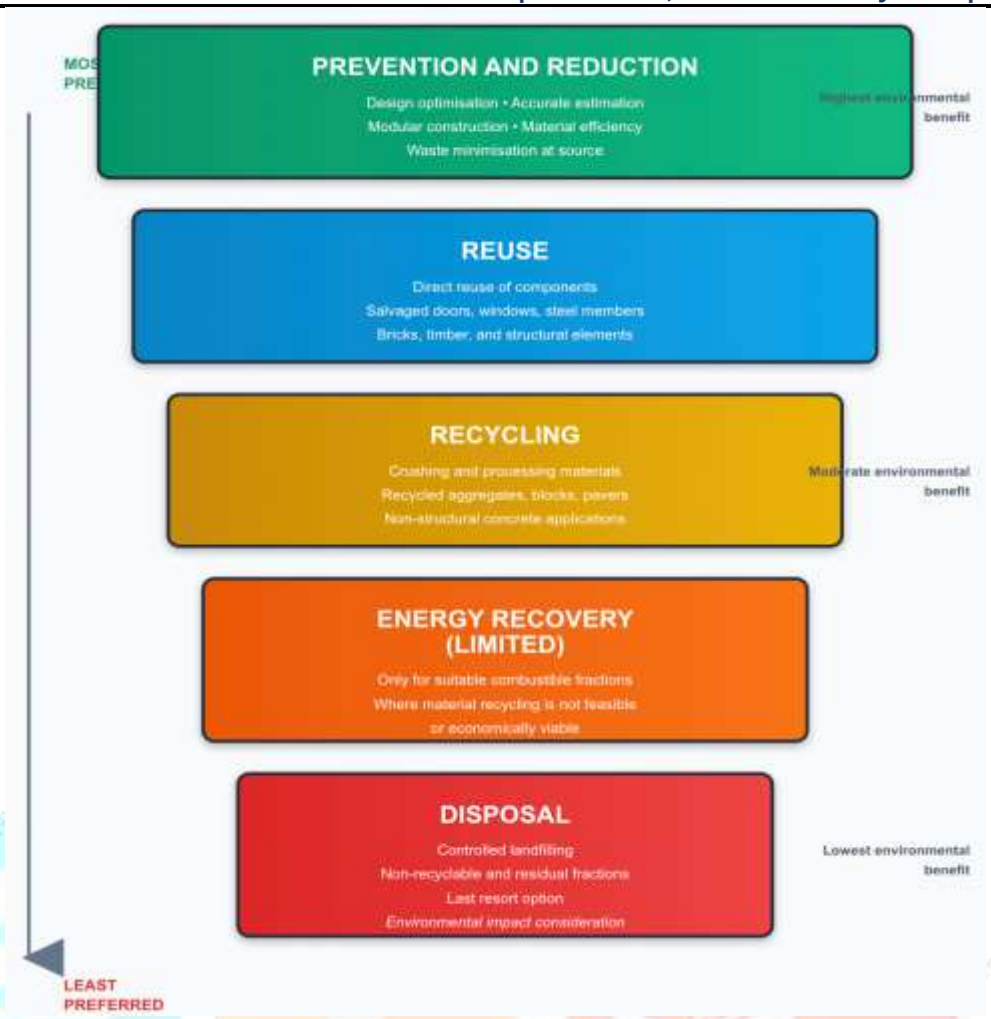

Figure 1: Hierarchy of construction and demolition waste management in India

A. Strengthening data systems and planning

The first measure towards better C&D waste management is the development of robust information systems. The records of C&D waste collected, processed and dumped should be disaggregated by source and geographic area. Updating estimates of generation rates and composition can be done through surveys and audits. Material-flow-based assessments could be refined and institutionalised as part of regular environmental reporting [3]. Accurate data will allow more realistic planning of processing capacity, appropriate siting of facilities, and development of financial models that reflect actual waste flows. Integrating C&D waste considerations into city-level master plans and infrastructure plans will help avoid situations where processing plants are added merely as an afterthought.

B. Expanding infrastructure and service coverage

Both large and small waste generators need convenient and reliable service models. This includes the identification and notification of accessible C&D waste collection centres, provision of clear information on collection schedules and user charges, and establishment of multiple processing facilities strategically located to minimise transport distances. A hub-and-spoke model is appropriate for large metropolitan regions. Public–private partnerships can be an effective vehicle for mobilising investment and operational expertise if contracts are designed with realistic performance indicators and revenue structures. Minimum waste quantities or tipping-fee guarantees may need to be provided by the city during an initial transition period while markets for recycled products are still being developed.

C. Aligning economic incentives and procurement policies

Economic instruments can help shift behaviour. It becomes more attractive to deliver waste to authorised facilities if user charges are structured appropriately. Fiscal incentives can help create demand for certified recycled materials. Public procurement is a particularly powerful lever. Government agencies responsible for roads, buildings and other public works can include minimum recycled-content requirements in their tender specifications. Standard clauses mandating the use of recycled aggregates can provide a steady market for recycling plants.

D. Developing standards and technical guidance

National and state standards bodies should continue to develop technical standards and design guidelines for the use of C&D-derived materials. This includes guidelines for quality control and testing, as well as specifications for recycled aggregates in different classes of concrete. Clear standards will increase contractor and engineer confidence. Practical design and construction details can be captured in technical guidance documents. Training modules should be incorporated into professional development programmes.

E. Addressing behavioural and institutional dimensions

Technical and economic measures need to be complemented by actions that address institutional barriers. Awareness campaigns can highlight the importance of proper C&D waste management. Professional bodies can promote waste minimisation and circular construction principles. Municipal departments and pollution control boards need to be strengthened. Nodal officers can help maintain focus on C&D issues. Regular training and platforms for exchange can support the sharing of experience and solutions.

F. Integrating the informal sector

Strategies for a circular construction economy in India need to acknowledge the contribution of informal actors. With appropriate support and regulation, small-scale recyclers can make their activities safer and more effective. Simple registration procedures, access to information on upcoming demolition projects, and recognition in city-level planning processes can help bridge the gap between informal practices and formal policy.

IX. CONCLUSION

India's rapid urbanisation and infrastructure expansion has created a major by-product in the form of construction and demolition waste. Early estimates placed annual C&D waste generation at a few tens of millions of tonnes, but more comprehensive, material-flow-based analyses suggest the true figure is likely in the hundreds of millions of tonnes per year. This enormous material flow, dominated by mineral fractions, represents both a significant environmental challenge and a major opportunity for resource recovery. The adoption of the Construction and Demolition Waste Management Rules, 2016, together with associated technical guidelines and voluntary initiatives, marks an important step towards recognising C&D waste as a distinct policy domain. However, implementation is uneven according to the literature reviewed in this paper. The effectiveness of C&D waste management in Indian cities is hampered by data gaps, economic disincentives and institutional inertia.

It is technically feasible to establish C&D waste recycling systems that produce quality-assured secondary materials and integrate them into mainstream construction and public works. Design-for-deconstruction and waste-prevention approaches offer pathways to reduce waste generation at source. Strengthening data systems, expanding infrastructure and service coverage, aligning economic and procurement incentives, developing technical standards and guidance, and addressing behavioural and institutional barriers are all

necessary measures for moving towards a circular construction economy in India. If these elements are pursued in a coordinated manner, construction waste can be transformed from a poorly managed liability into a valuable urban resource.

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