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CHALLENGES, OPPORTUNITIES, AND CIRCULAR ECONOMY PATHWAYS FOR CONCRETE AND CONSTRUCTION WASTE MANAGEMENT: EVIDENCE FROM URBAN BUILDING PROJECTS IN KARACHI, PAKISTAN

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Abstract
The rapid expansion of urban construction activities in Karachi has led to a significant increase in construction and demolition waste, creating environmental, economic, and resource management challenges. In addition to conventional concrete debris, large volumes of secondary waste streams such as sewage sludge, plastic waste, waste glass, and tyre rubber remain underutilized despite their potential for value recovery. This study explores the challenges, opportunities, and circular economy pathways for integrated waste management in urban building projects in Karachi. Key challenges identified include the absence of effective waste segregation systems, limited recycling infrastructure, weak regulatory enforcement, and low market acceptance of recycled construction materials. However, these waste streams offer significant opportunities when incorporated into construction materials. Recycled concrete aggregates can replace natural aggregates, while processed sewage sludge ash can act as a supplementary cementitious material. Similarly, plastic waste, waste glass, and tyre rubber can be utilized to enhance concrete properties such as durability, thermal insulation, and crack resistance, contributing to sustainable material innovation.

The study proposes a circular economy framework that emphasizes waste-to-resource conversion, lifecycle extension, and reduction of virgin material consumption. By integrating multiple waste streams into construction practices, the approach not only minimizes landfill dependency but also reduces carbon emissions and promotes cost efficiency. The findings suggest that adopting such integrated circular strategies in Karachi requires coordinated policy support, technological advancement, stakeholder engagement, and increased awareness. This transition has the potential to transform the construction sector into a more sustainable and resource-efficient system while addressing the city's growing waste management crisis.

1. INTRODUCTION

The construction sector plays a pivotal role in urban development and economic growth; however, it is also one of the largest generators of solid waste worldwide, particularly concrete and construction waste (CCW)[1]. In rapidly urbanizing megacities, ineffective management of CCW contributes to environmental degradation, land scarcity, public health risks, and increased project costs[2]. Developing cities face additional challenges due to limited infrastructure, weak regulatory enforcement, and a high dependence on conventional construction practices that prioritize speed and cost over sustainability[3]. Karachi, the largest metropolitan city of Pakistan, is experiencing accelerated urban expansion driven by population growth, commercial development, and large-scale residential building projects. This growth has resulted in a substantial increase in concrete debris, demolition waste, masonry residues, and mixed construction materials. Much of this waste is disposed of through informal dumping, open landfills, or unauthorized sites, placing significant pressure on municipal waste systems and the urban environment. The absence of a structured construction and demolition waste management framework further exacerbates the problem. Many other waste supplementary materials production in Pakistan such as Sewage sludge, fly ash, metakaolin, sugar cane bagasse ash, corn cob ash, brick waste powder and rice husk ash[4], [5], [6], [7], [8]. The deterioration of concrete structures in Karachi is a serious issue caused by a combination of environmental, material, construction, and maintenance-related factors. One of the most important causes is the city's aggressive coastal environment. Because Karachi is located near the Arabian Sea, concrete structures are exposed to chloride-rich marine salts carried by sea breeze. These chlorides penetrate the concrete and reach the steel reinforcement, causing corrosion of reinforcing steel[9], [10]. This corrosion leads to cracking, spalling, rust staining, and gradual loss of structural strength, making chloride attack one of the most severe durability problems in Karachi. Another major environmental factor is high relative humidity (RH)[11]. The humid conditions in Karachi keep concrete surfaces damp for long periods and create favorable conditions for the movement of aggressive substances such as chlorides and sulfates into the concrete matrix. High RH also supports the electrochemical corrosion process of steel reinforcement[12], [13]. As a result, corrosion progresses faster, especially when the concrete is porous, poorly compacted, or already cracked. In this way, humidity works together with marine exposure to accelerate the deterioration process. High temperatures are also a critical factor[12]. Karachi's hot climate causes rapid evaporation of water from freshly placed concrete, and when curing is not properly maintained, the concrete develops shrinkage cracks, higher porosity, and lower long-term durability. In hardened concrete, repeated heating and cooling create thermal expansion and contraction, which generate internal stresses and surface cracks over time[14], [15]. These cracks then act as easy pathways for moisture and chlorides, further increasing the rate of deterioration. Apart from environmental exposure, poor material quality and improper mix design also contribute significantly to the problem[16], [17]. In many cases, incorrect proportions of cement, aggregates, and water produce low-strength and highly porous concrete. The use of unwashed aggregates, contaminated water, or low-grade cement makes the concrete even more vulnerable to external attack. Such weak concrete allows harmful agents to enter more easily and reduces the overall service life of the structure[18], [19]. Another important cause is lack of proper curing practices. Because of Karachi's hot weather, concrete loses moisture very quickly if curing is neglected. Without sufficient curing, hydration remains incomplete, resulting in weaker concrete with reduced durability[20]. This makes the structure more sensitive to chloride ingress, moisture penetration, and surface cracking from an early age. In addition, sulfate attack can occur in areas where soil and groundwater contain sulfates. Sulfates react with cement hydration products and cause expansion, internal cracking, and gradual loss of strength[21], [22], [23]. In industrial zones, the problem may become more severe due to chemical pollutants and acidic exposure, which further damage the concrete surface and internal structure. Poor construction practices and lack of supervision are also key reasons for deterioration. Inadequate compaction, improper placement, insufficient concrete cover over reinforcement, and poor finishing create voids, honeycombing, and weak zones in the concrete. These defects allow moisture, chlorides, and other harmful substances to penetrate more easily, thereby accelerating corrosion and deterioration.

Furthermore, lack of maintenance and inspection makes the situation worse. Many structures are not regularly checked, so early signs such as fine cracks, rust stains, damp patches, and surface damage are ignored. Over time, these minor defects grow into major structural problems that become more difficult and expensive to repair. Finally, overloading and design deficiencies also reduce the durability and service life of concrete structures. Buildings may experience loads beyond their original design capacity due to later modifications, poor planning, or misuse. This adds extra stress to already weakened structural elements and accelerates damage[24].

Overall, the deterioration of concrete structures in Karachi is mainly driven by the combined effect of Arabian Sea exposure, high relative humidity, high temperature, poor material quality, inadequate curing, sulfate attack, poor construction practices, and lack of maintenance. Together, these factors create a highly aggressive environment that reduces durability and shortens structural service life. Therefore, improving concrete performance in Karachi requires better material selection, proper mix design, adequate curing, sufficient cover thickness, improved workmanship, and regular maintenance.

Concrete waste, which constitutes a major fraction of construction debris, presents both technical and economic challenges. Over-ordering of ready-mix concrete, design changes, improper batching, and poor on-site handling often lead to unnecessary material losses[25]. At the same time, concrete waste offers opportunities for recycling into aggregates and secondary construction materials, supporting resource efficiency and reducing dependence on natural raw materials such as sand and gravel[26], [27]. In recent years, global emphasis on sustainable construction and circular economy principles has highlighted the need to minimize waste generation, enhance material recovery, and promote reuse and recycling within construction projects[28], [29]. While such practices are increasingly adopted in developed economies, their implementation in cities like Karachi remains limited and fragmented. Understanding the local context, constraints, and stakeholder perspectives is therefore essential for developing practical and scalable waste management strategies[30].

Construction and demolition (C&D) waste has sharply increased because of the fast urbanization of major Pakistani cities, particularly Karachi. Building construction, remodeling, and demolition projects frequently produce concrete waste, brick pieces, steel cuttings, wood, and packaging materials[22]. An estimated 12,000–14,000 tons of solid trash are produced daily in Karachi, Pakistan's main urban and economic center, with construction activity accounting for a sizable amount of this waste[31]. However, the lack of an organized framework for waste management has led to resource waste, degradation of the environment, and unlawful disposal. Road bases, recycled aggregates, geopolymer concrete, and sustainable building goods are all increasingly made from concrete and construction waste worldwide. Pakistan, on the other hand, continues to rely significantly on roadside or landfill dumping.

This study investigates the main obstacles and possible solutions for efficient C&D waste management in Karachi's urban construction projects[32]. The objective is to draw attention to workable ideas that can boost material efficiency, lessen environmental impact, and increase sustainability in the building industry. Against this backdrop, this study examines the challenges and opportunities associated with managing concrete and construction waste in urban building projects in Karachi, Pakistan[31]. By adopting a case study approach, the research aims to evaluate existing practices, identify key gaps, and propose actionable measures to improve waste management performance at the project and city levels, contributing to more sustainable urban development[32].

2. METHODOLOGY

This study adopts a case study–based qualitative and quantitative research design to examine the challenges and opportunities in managing concrete and construction waste (CCW) in urban building projects in Karachi, Pakistan. The methodology as shown in **Figure 1**, is structured to capture real-world practices, stakeholder perspectives, and measurable waste patterns at the project level.

Figure 1 Methodological framework adopted for assessing construction and concrete waste management in urban building projects in Karachi.

2.1 Research Design

A multiple case study approach was employed to ensure variability in project scale, type, and location[33]. Selected cases included mid- to high-rise residential and commercial building projects located in different urban zones of Karachi. This approach enabled comparative analysis across projects while maintaining contextual depth.

2.1.1 Data Collection Methods

Data were collected using a combination of primary and secondary sources:

1. Site Observations

I. Direct on-site observations were conducted to assess waste generation, handling, storage, and disposal practices.

II. Particular attention was given to concrete waste sources such as over-batching, rejected pours, demolition debris, and leftover materials.

2. Waste Stream Assessment

I. Visual audits and approximate quantification of waste streams were performed to identify dominant waste categories (concrete, masonry, wood, steel, packaging, and mixed waste).

II. Waste handling pathways (reuse, recycling, informal disposal, landfill) were documented.

3. Semi-Structured Interviews

I. Interviews were conducted with project engineers, site managers, contractors, supervisors, and informal waste handlers.

II. Questions focused on current waste management practices, perceived challenges, cost implications, regulatory awareness, and attitudes toward recycling and reuse.

4. Document Review

I. Project documents such as material procurement records, concrete pour logs, waste disposal receipts (where available), and site safety/environmental guidelines were reviewed.

II. Relevant local regulations and municipal waste management policies were also examined to understand the regulatory context.

5. Data Analysis

I. **Qualitative data** from interviews and observations were analyzed using thematic analysis to identify recurring challenges, behavioral patterns, and opportunity areas[34].

II. **Quantitative data** from waste assessments and records were analyzed descriptively to estimate waste proportions and identify high-loss activities[34].

III. Findings from different data sources were triangulated to improve reliability and validity.

6. Scope and Limitations

The study focuses on active urban building projects and does not include large-scale infrastructure works or post-disaster demolition waste. Due to limited formal record-keeping and reliance on informal waste systems, some waste quantities are estimated rather than precisely measured. Nevertheless, the methodology provides a realistic representation of on-ground practices in Karachi's construction sector.

Overall, this methodology enables a comprehensive assessment of CCW management practices while grounding the analysis in local operational and institutional realities.

The qualitative information used in this case study came from:

1. Site visits to mid-rise residential and commercial construction projects in Saddar Town, Gulshan-e-Iqbal, and the Defence Housing Authority (DHA).
2. Interviews with twelve stakeholders, including labor supervisors, contractors, project managers, and local officials.
3. Examining current Sindh Building Control Authority (SBCA), Karachi Metropolitan Corporation (KMC), and Sindh EPA environmental rules.
4. Comparison with global norms, such as those in Singapore, Japan, and the EU. The investigation focused on identifying:

I. Types and quantities of waste generated

II. Current disposal practices

III. On-site handling and segregation methods

IV. Challenges in recycling or reusing materials

V. Potential opportunities and strategies for improvement

Table 1. Summary of Data Collection Methods

Method	Description	Locations / Participants	Purpose
Site Visits	Observations of waste generation and handling	Saddar Town, Gulshan-e-Iqbal, DHA	Identify waste types and practices
Interviews	Semi-structured interviews	12 stakeholders (contractors, PMs, labor supervisors, municipal staff)	Understand challenges and perceptions
Policy Review	Review of local regulations	SBCA, KMC, SEPA	Analyze regulatory gaps
Global Benchmarking	Comparison with international models	Japan, Singapore, EU	Identify applicable best practices

Based on site observations, stakeholder inputs, and regulatory review, a conceptual framework for concrete waste management in urban construction projects was developed, as shown in **Figure 2**."

Figure 2 Conceptual framework of concrete waste management in urban construction projects (Karachi)

3. RESULTS AND DISCUSSION

This section presents and discusses the findings obtained from site observations, waste audits, stakeholder interviews, and document reviews conducted across selected urban building projects in Karachi. The results highlight prevailing waste generation patterns, key operational and institutional challenges, and feasible opportunities for improving concrete and construction waste management in the city. "A comparative overview of major challenges and corresponding opportunities in concrete waste management is presented in **Figure 3**, emphasizing the role of policy enforcement, recycling infrastructure, and stakeholder involvement.

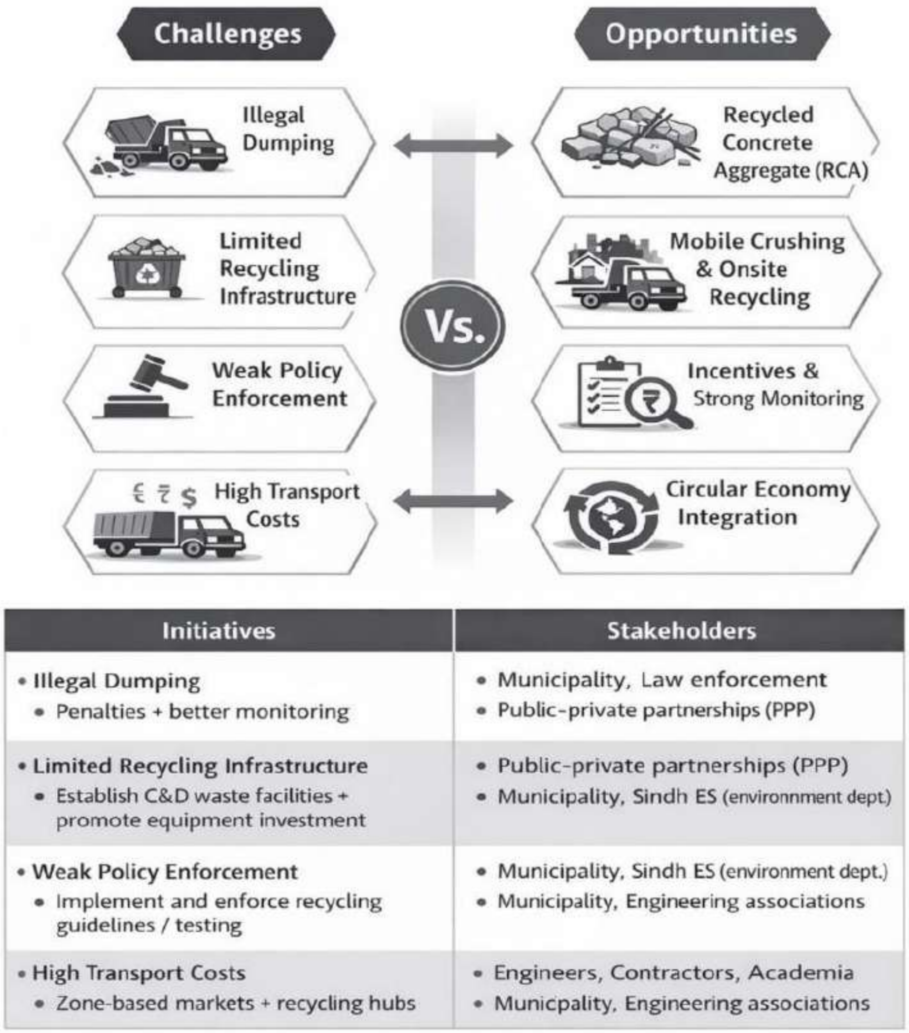

Figure 3 Overview of challenges and opportunities for concrete waste management in urban construction projects (Karachi)

3.1 Waste Generation Patterns in Karachi's Urban Projects

The analysis reveals that concrete debris constitutes the largest fraction of construction waste, accounting for approximately 35–45% of the total waste generated at urban construction sites. This is followed by brick and block waste (25–30%), steel scrap (8–12%), wood waste (6–10%), and miscellaneous materials such as plastics, cardboard, and tiles (10–12%).

The dominance of concrete waste is primarily attributed to activities associated with structural concrete works, including rejected concrete batches, over-ordering, formwork (shuttering) damage, cutting and dimensional errors, and changes in design during construction. Masonry works represent the second-largest source of waste due to brick cutting, breakage, and improper handling. Additionally, finishing activities such as false ceiling installation, plastering, and tiling—generate significant quantities of packaging waste and material offcuts. In redevelopment projects, excavation and demolition activities further contribute to mixed construction debris.

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Due to limited space availability at most urban sites, waste materials are often temporarily stockpiled on roadsides, footpaths, or nearby vacant plots. Such practices obstruct pedestrian movement, increase dust emissions, block drainage systems, and pose risks to public safety and the surrounding environment.

Table 2: Estimated Proportion of Waste Types

Waste Type	Estimated Share (%)	Major Sources
Concrete Debris	35–45%	Structural works, batching errors
Brick/Block Waste	25–30%	Masonry works
Steel Scrap	8–12%	Cutting, reinforcement adjustments
Wood	6–10%	Formwork, packaging
Plastics/Cardboard/Tiles	10–12%	Finishing works

Figure 4 Waste Composition Pie Chart

3.2 Key Challenges in Managing Construction and Concrete Waste

The findings of this study reveal a set of interconnected regulatory, infrastructural, operational, and socio-economic challenges that significantly hinder effective management of construction and concrete waste in Karachi's urban building sector. These challenges collectively contribute to inefficient resource utilization, environmental degradation, and unsustainable urban development, directly affecting progress toward Sustainable Development Goals (SDGs) 9, 11, 12, and 13.

Figure 5 Key challenges in construction waste management

3.2.1 Weak Regulatory Enforcement and Institutional Gaps

Weak regulatory enforcement remains one of the most critical barriers to sustainable construction waste management. Although construction waste handling and site cleanliness provisions are referenced in Sindh Building Control Authority (SBCA) guidelines and environmental regulations, enforcement at the project level is limited and inconsistent. Construction projects are generally not required to submit Waste Management Plans (WMPs), achieve minimum recycling or diversion targets, or undergo systematic compliance audits during construction activities.

The absence of monitoring mechanisms and penalties for non-compliance allows contractors to prioritize cost and schedule efficiency over environmental responsibility. In addition, limited coordination among SBCA, Sindh Environmental Protection Agency (Sindh EPA), and municipal authorities weakens institutional accountability. As a result, waste disposal practices remain largely informal and unregulated, undermining SDG 12 (Responsible Consumption and Production) and SDG 16 (Strong Institutions).

3.2.2 Absence of Dedicated Construction and Demolition Recycling Facilities

Another major challenge is the absence of large-scale, formal construction and demolition (C&D) waste recycling facilities in Karachi. The city currently lacks centralized plants capable of processing concrete waste into recycled concrete aggregates (RCA), manufactured sand, or other secondary construction materials. Consequently, even technically recyclable materials are disposed of in landfills or illegally dumped in open spaces, roadside areas, and drainage channels. The lack of recycling infrastructure discourages on-site segregation and material recovery, as contractors have no reliable downstream facilities to process segregated waste. This reinforces a linear construction model based on extraction, consumption, and disposal, increasing dependence on natural aggregate sources and conflicting with SDG 9 (Industry, Innovation and Infrastructure) and SDG 11 (Sustainable Cities and Communities).

Table 3. Challenge–Impact–Evidence (Karachi Context) Matrix

Challenge	Typical Site-Level Evidence	Primary Impact on Projects/City
Weak regulatory enforcement	No WMP documents, no disposal receipts, informal hauling	Uncontrolled dumping; weak accountability
Lack of recycling facilities	No reliable recycler linkage; waste sent to landfill/open plots	Loss of recyclable materials; higher landfill load
Mixed waste streams	Concrete, steel, and plastics stored together	Low recovery value; higher disposal cost
Low awareness and training	Poor batching, shuttering failures, damaged materials	Rework; increased waste and cost overruns
High transport costs	Contractors choose nearby dumping instead of distant landfill	Illegal dumping; increased pollution and flood risk
Space constraints at urban sites	Waste stacked on roadsides/footpaths	Safety hazards; blocked walkways and drainage systems

3.2.3 Limited On-Site Waste Segregation Practices

Limited on-site waste segregation is widely observed across urban building projects. Concrete debris, masonry waste, steel scrap, wood, plastics, and packaging materials are commonly mixed during collection and disposal. This practice results in contaminated waste streams, significantly reducing recycling potential and increasing handling and disposal costs.

The lack of segregation is primarily attributed to inadequate site planning, absence of designated waste zones, time-driven construction schedules, and insufficient supervision. Without source segregation, materials that could otherwise be reused or recycled lose their economic value and are treated as general waste, directly undermining SDG 12 and circular economy objectives.

3.2.4 Low Awareness and Insufficient Workforce Training

Low awareness and insufficient training among site engineers, supervisors, and laborers further exacerbate construction waste generation. Most site personnel lack formal training in sustainable construction practices, waste minimization strategies, and environmental compliance requirements.

Operational inefficiencies such as inaccurate concrete batching, poor shuttering quality, improper material storage, and careless handling of construction materials were frequently observed. These deficiencies lead to avoidable material losses, rework, and excessive waste generation, particularly during structural concrete works and finishing stages. This challenge highlights the importance of skill development and capacity building in achieving SDG 8 (Decent Work and Economic Growth) alongside environmental sustainability.

3.2.5 Transportation Constraints and Cost Pressures

Transportation of construction waste to authorized landfill sites presents significant economic and logistical challenges. Approved disposal facilities are often located far from active construction zones, resulting in increased fuel consumption, higher labor costs, and project delays. These additional costs place financial pressure on contractors operating under competitive and time- sensitive project conditions.

To minimize expenses, contractors frequently resort to illegal dumping in nearby vacant plots, roadside areas, and drainage systems. Such practices contribute to air and soil pollution, clog urban drainage networks, and increase the risk of flooding, imposing long-term environmental and social costs on the city. This challenge directly conflicts with SDG 11 and SDG 13 (Climate Action) due to increased emissions and environmental degradation.

3.2.6 Space Constraints at Dense Urban Construction Sites

Severe space constraints at urban construction sites—particularly in densely populated areas such as Saddar and Gulshan—further limit the feasibility of effective waste storage and segregation. High land values and compact site layouts leave little room for designated waste collection areas or temporary material storage. Congested site conditions lead to inefficient material handling, increased safety risks, obstruction of construction activities, and damage to stored materials. As a result, waste is often removed in an unplanned manner or disposed of externally without proper control, reinforcing inefficient and unsafe waste management practices. This challenge adversely affects urban livability and safety, directly impacting SDG 11.

3.2.7 Overall Implications

Collectively, these findings indicate that construction and concrete waste management in Karachi remains largely reactive rather than preventive, driven by short-term cost and schedule considerations rather than sustainability objectives. The persistence of regulatory gaps, lack of recycling infrastructure, weak operational practices, and limited workforce capacity highlights the need for integrated regulatory enforcement, infrastructure investment, and alignment with circular economy principles. Addressing these challenges is essential for advancing sustainable urban development and achieving relevant SDGs in rapidly growing metropolitan cities such as Karachi.

3.3 Opportunities for Sustainable Concrete & Construction Waste Management

3.3.1 Establishment of C&D Waste Recycling Facilities

Karachi presents strong potential for the development of centralized construction and demolition (C&D) waste recycling facilities due to its high and continuous generation of construction waste. Such facilities can play a critical role in converting waste materials into usable construction inputs. Concrete debris can be crushed and processed to produce recycled concrete aggregates (RCA) suitable for non-structural applications. Additionally, the production of manufactured sand (M- sand) from crushed concrete and masonry waste can help address the growing scarcity of natural river sand. Brick and block waste can be recycled into subbase and backfill materials, particularly for road and pavement construction, while steel scrap can be collected, processed, and reused through formal recycling channels. The establishment of these facilities would significantly reduce the volume of waste sent to landfills and illegal dumping sites. Moreover, it would lower the demand for natural aggregates extracted from environmentally sensitive areas such as the Malir and Hub River beds, thereby minimizing ecological degradation and supporting environmentally responsible construction practices. The circular life cycle of concrete waste, from demolition to recycling and reuse, is illustrated in **Figure 6**, and **Figure 7** highlighting the potential for reducing natural aggregate consumption.

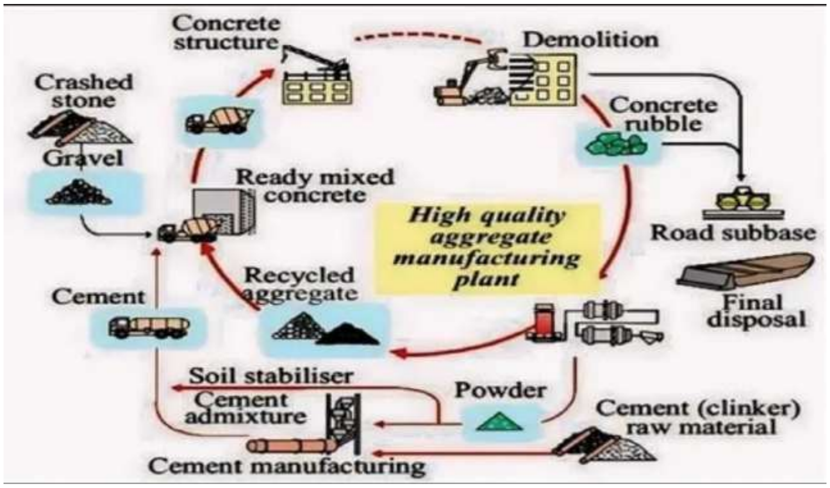

Figure 6 Key challenges in construction waste management

Figure 7 Key challenges in construction waste management in karachi, Sindh

3.3.2 Mandating Waste Management Plans (WMPs)

Introducing mandatory Waste Management Plans (WMPs) as part of the construction approval process can substantially improve waste control at the project level. Developers would be required to submit WMPs before commencing construction, ensuring that waste considerations are addressed during the planning stage rather than after waste is generated. A comprehensive WMP may include accurate material quantity estimation to prevent over ordering, defined on site segregation procedures, documentation of recycling and disposal routes, and clearly stated recovery or diversion targets. Such requirements would promote accountability among contractors and encourage systematic waste reduction and monitoring throughout the project lifecycle.

3.3.3 On site Segregation and Material Sorting

On-site segregation is one of the most effective and low-cost strategies for improving recycling efficiency. Separating concrete, steel, wood, plastics, and packaging materials at the source prevents contamination and increases the quality and value of recyclable materials.

Site management can be significantly enhanced through the introduction of basic color-coded containers, designated waste collection zones, and simple training sessions for workers. These measures reduce handling time, improve safety conditions, and facilitate direct transfer of segregated materials to recycling facilities or reuse channels.

3.3.4 Use of Recycled Aggregates in Construction

The application of recycled aggregates offers a practical pathway for closing the material loop in construction. Recycled aggregates can be effectively used in non-structural concrete, paver blocks, lean concrete, road sub-base layers, and landscaping works without compromising performance requirements. Utilizing recycled materials reduces the consumption of virgin aggregates, lowers transportation related emissions, and decreases overall material costs. Wider acceptance of Recycled aggregates through standards and pilot projects can significantly enhance their market confidence and adoption in Karachi's construction industry.

3.3.5 Government Incentives

Government agencies such as the Sindh Environmental Protection Agency (Sindh EPA) and Karachi Metropolitan Corporation (KMC) can play a decisive role by introducing incentive-based mechanisms. These may include tax reductions, reduced permit fees, or expedited approval processes for projects that incorporate recycled materials or implement sustainable waste management practices. Such incentives would motivate developers and contractors to move beyond minimum compliance and actively invest in waste reduction and recycling initiatives, thereby accelerating the transition toward sustainable construction practices.

3.3.6 Technology Integration

The integration of digital technologies, particularly Building Information Modeling (BIM), offers significant potential for minimizing construction waste. BIM enhances material quantity accuracy, enables early detection of design clashes, and improves construction sequencing and coordination. By reducing design errors, rework, and over ordering of materials, BIM can directly contribute to waste minimization. Additionally, digital tools can support waste tracking, reporting, and performance monitoring, enabling data driven decision making throughout the construction process.

3.3.7 Employment and Economic Opportunities

The formalization of the construction waste recycling sector can generate substantial employment and economic benefits. Recycling facilities, material sorting operations, transportation services, and processing plants can create thousands of jobs for sorters, recyclers, equipment operators, technicians, and logistics personnel.

This transition would also help integrate Karachi's informal waste workforce into safer and more regulated employment conditions, improving livelihoods while supporting the city's broader sustainability and economic development goals.

Table 4. Solution–Implementation Requirements–Expected Outcomes

Proposed Solution	Implementation Requirements	Expected Outcome
Mandatory WMPs + SBCA requirement at approval stage	Compliance audits, inspection checklist, traceability	Improved compliance
Centralized C&D recycling plant	Land allocation, crusher systems, licensing, supply contracts	RCA/M-sand production; reduced landfill dependency
Source segregation	Color-coded bins, waste zones, signage	Higher recycling rate; cleaner waste streams
Training & awareness	Toolbox talks, supervision routines, SOPs	Reduced rework; lower material wastage
Local recycling hubs	Ward-level collection points, transport scheduling	Reduced transport cost; reduced illegal dumping
Just-in-time waste removal	Timetabled pickups, small-footprint storage	Less congestion and safer

Table 5. Circular Economy Pathways for Major Waste Streams

Waste Stream	Current Practice (Linear)	Circular Economy Option	Possible End Use
Concrete debris	Dumped/landfilled	Crushing + grading	Road subbase, lean concrete, pavers
Brick/block waste	Dumped	Crushing/screening	Backfill, subbase, landscaping
Steel scrap	Sold informally	Formal scrap processing	Rebar reprocessing / steel industry
Wood/formwork	Disposed/burned	Reuse/repair	Temporary works, secondary use
Plastics/cardboard	Mixed disposal	Sorting + baling	Recycling supply chain

3.3.8 Stakeholder Perspectives

Stakeholder consultations revealed differing but complementary viewpoints. Municipal authorities emphasized the lack of recycling infrastructure and enforcement capacity, while contractors expressed concerns regarding increased costs, time pressures, and unclear regulatory requirements. Local residents, particularly those affected by illegal dumping, reported serious issues such as dust pollution, blocked drains, reduced walkability, and visual degradation of neighborhoods.

Despite these differences, a strong consensus emerged among stakeholders that a structured and enforced construction waste management system would improve both site efficiency and overall urban living conditions.

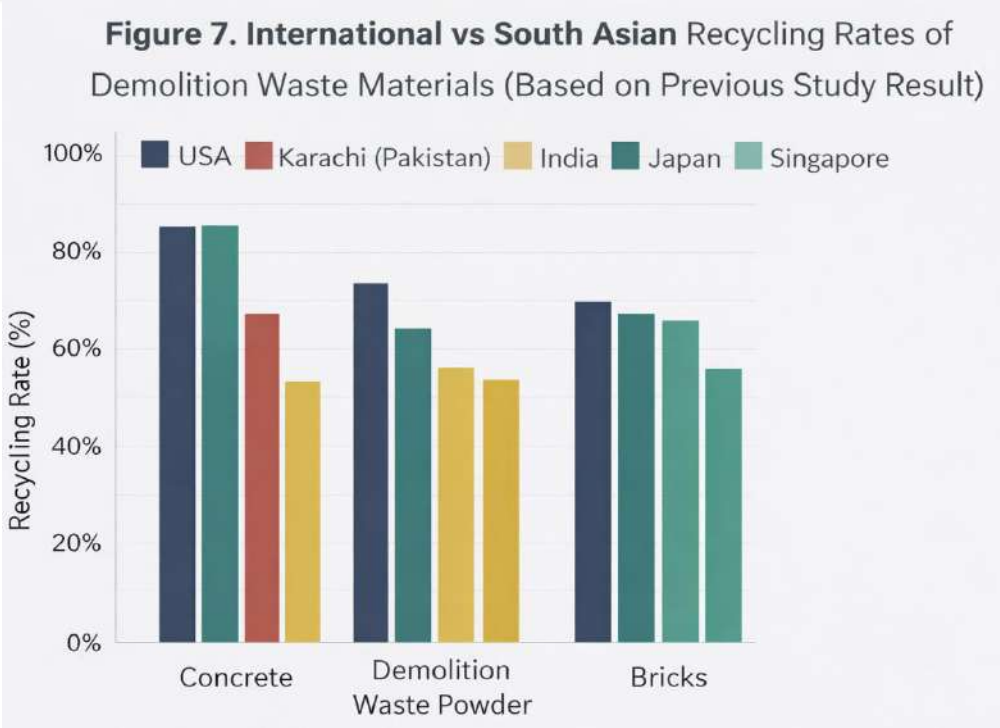

Figure 8 International vs Karachi Recycling Rates

Table 6 Problem–Solution Matrix for Construction and Concrete Waste Management in Karachi

Problem Area	Observed Impact	Underlying Cause	Proposed Solution / Intervention	Relevant SDGs
Weak regulatory enforcement	Unregulated dumping and non-compliance	Lack of mandatory Waste Management Plans (WMPs) and audits	Enforce mandatory WMP submission, introduce compliance audits and penalties	SDG 12, SDG 16
Absence of recycling facilities	Loss of recyclable concrete and masonry waste	No centralized C&D recycling infrastructure	Establish large-scale C&D recycling plants producing RCA and M-sand	SDG 9, SDG 11
Mixed waste streams	Low recycling efficiency, higher disposal costs	Lack of on-site segregation system	Implement source segregation with designated waste zones and bins	SDG 12
Low workforce awareness	High material loss and rework	Insufficient training and supervision	Conduct training programs for supervisors and laborers	SDG 8, SDG 12
High transportation costs	Illegal dumping and environmental pollution	Distant landfill locations and high fuel costs	Develop local recycling hubs and incentive-based disposal systems	SDG 11, SDG 13
Space constraints at urban sites	Safety hazards and inefficient handling	Congested site layouts in dense areas	Use compact segregation systems and scheduled waste removal	SDG 11
Overuse of	Environmental	Dependence on virgin	Promote use of recycled	SDG 12,

natural aggregates	degradation	materials	aggregates in non-structural works	SDG 13
Informal waste handling	Unsafe working conditions	Lack of formal recycling industry	Formalize recycling sector to create regulated employment	SDG 8, SDG 9

Table 1 presents the overall data collection framework used in the study. It shows that the research was based on four main methods: site visits, interviews, policy review, and global benchmarking. Through site visits in Saddar Town, Gulshan-e-Iqbal, and DHA, the study observed how construction waste is generated and handled in real project settings. Interviews with 12 stakeholders, including contractors, project managers, labor supervisors, and municipal staff, helped capture practical challenges and perceptions from the field. In addition, the review of local institutions such as SBCA, KMC, and SEPA helped identify policy and regulatory gaps, while comparison with international models from Japan, Singapore, and the EU helped identify best practices that could be applied in Karachi.

Table 2 provides a broad summary framework linking the main problem areas with their observed impacts, underlying causes, proposed solutions, and relevant SDGs. It shows that weak regulatory enforcement, absence of recycling facilities, mixed waste streams, low workforce awareness, high transportation costs, space constraints, overuse of natural aggregates, and informal waste handling are all major barriers to effective C&D waste management in Karachi. This table is important because it connects each problem directly to its cause and to a specific intervention, making the whole issue easier to understand in an integrated way.

Table 3 gives more detailed Karachi-specific field evidence for the challenges identified in the study. It explains how weak regulatory enforcement can be seen in the absence of waste management plan documents, disposal receipts, and formal hauling systems. It also shows that the lack of recycling facilities forces recyclable waste to be sent to landfill or open plots, while mixed waste streams lower the recovery value of materials. Similarly, poor awareness and training lead to damaged materials and rework, high transport costs encourage illegal dumping, and space constraints at urban sites create safety hazards and blocked drainage. Therefore, **Table 3** strengthens the study by showing the real site-level evidence behind the identified challenges.

Table 4 focuses on solutions by linking each proposed intervention with its implementation requirements and expected outcomes. It shows that mandatory waste management plans and SBCA requirements at the approval stage can improve compliance and accountability when combined with audits and inspection checklists. Centralized recycling plants require land allocation, crusher systems, licensing, and supply contracts, but they can reduce landfill dependency through RCA and M-sand production. Source segregation, training and awareness, local recycling hubs, and just-in-time waste removal are also presented as practical measures that can improve recycling rates, reduce waste, lower transport cost, and make sites safer. This table is especially useful because it moves the discussion from identifying problems to showing how solutions can actually be implemented.

Table 5 explains the circular economy pathways for the major waste streams. It shows that concrete debris, brick and block waste, steel scrap, wood or formwork, and plastics or cardboard all have reuse or recycling potential. For example, concrete debris can be crushed and graded for road subbase, lean concrete, and pavers, while brick waste can be used for backfill and landscaping. Steel scrap can enter formal reprocessing systems, wood can be reused for temporary works, and plastics and cardboard can be sorted and baled for recycling supply chains. This table demonstrates that materials currently treated as waste can instead become useful resources under a circular economy approach.

Finally, **Table 6** links the proposed interventions with the Sustainable Development Goals. It shows that waste management plans and enforcement support SDG 12 and SDG 16 through responsible material management and stronger institutions. Recycling facilities support SDG 9 and SDG 11 by promoting sustainable infrastructure and reducing landfill pressure. Recycled aggregates adoption contributes to SDG 12 and SDG 13 through resource conservation and emissions reduction. Training programs support SDG 8 and SDG 12 by improving productivity, reducing waste, and creating safer work conditions, while transport optimization supports SDG 11 and SDG 13 by reducing dumping, emissions, and urban pollution. Overall, Table 6 highlights that the proposed waste management framework is not only a technical response, but also a sustainability-driven strategy aligned with international development goals.

Taken together, **Table 1, Table 2, Table 3, Table 4, Table 5,** and **Table 6** form a complete logical flow of the study. **Table 1** explains how the data were collected, **Table 2** summarizes the main problem-solution framework, **Table 3** provides field evidence from Karachi, **Table 4** explains how solutions can be implemented, **Table 5** presents circular economy options for waste streams, and **Table 6** shows the sustainability significance of these interventions. As a result, the tables collectively support the argument that Karachi needs an integrated C&D waste management system based on stronger regulation, better recycling infrastructure, improved site practices, workforce training, and alignment with circular economy and SDG principles.

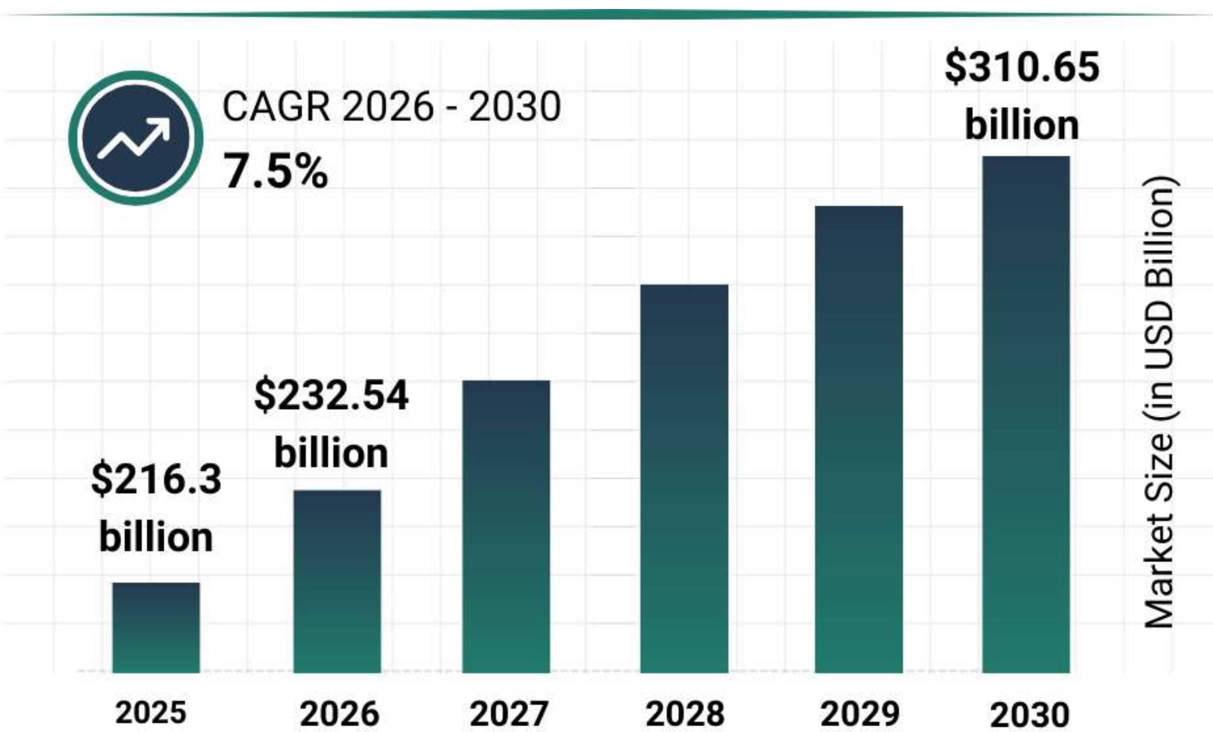

Figure 9. Projected Market Growth (2025–2030) with CAGR of 7.5%

This **Figure 9** illustrates the projected growth of the global market (in USD billion) from 2025 to 2030, highlighting a steady upward trend driven by a compound annual growth rate (CAGR) of 7.5% between 2026 and 2030. The market size increases from $216.3 billion in 2025 to approximately $232.54 billion in 2026, showing a clear initial rise. This growth continues consistently over the years, reaching around $250+ billion in 2027, followed by further expansion to nearly $270–280 billion in 2028, and about $290+ billion in 2029. By 2030, the market is expected to reach $310.65 billion, indicating significant long-term expansion.

The steady increase in bar heights reflects a stable and predictable growth pattern rather than sudden spikes, which suggests strong underlying demand, continuous investment, and sustained industry development. The presence of a consistent CAGR of 7.5% indicates that the market is not only growing but doing so at a reliable and manageable rate, making it attractive for investors, policymakers, and industry stakeholders.

Overall, the figure emphasizes a positive growth trajectory, showing that the market is expected to expand significantly over the next five years. This trend can be associated with increasing demand, technological advancements, and growing awareness of sustainable practices, depending on the specific industry context of the study.

4 CONCLUSIONS

1) This study confirms that concrete waste is the dominant component of construction and demolition waste in Karachi's urban building projects, primarily generated during structural concrete works, masonry activities, and finishing operations. Poor batching practices, design changes, and limited site control significantly contribute to material losses.

2) The findings reveal that ineffective regulatory enforcement, absence of dedicated recycling facilities, limited on-site segregation, and low stakeholder awareness are the major barriers to sustainable construction waste management. Space constraints and high transportation costs further encourage informal and illegal dumping practices.

3) Despite these challenges, Karachi possesses strong potential for sustainable waste management through the establishment of centralized C&D recycling plants, mandatory Waste Management Plans, adoption of recycled aggregates, and integration of digital tools such as BIM to minimize waste at the design and construction stages.

4) Implementation of structured waste management systems, combined with government incentives, industry training, and contractor accountability, can significantly reduce environmental impacts, improve construction efficiency, and support the transition toward a circular construction economy in Karachi.

5 FUTURE STUDY RECOMMENDATIONS

1) Future research should focus on quantitative life cycle assessment (LCA) of recycled concrete aggregates to evaluate their environmental and economic benefits compared to natural aggregates in Pakistan's construction context.

2) Detailed studies on the mechanical and durability performance of recycled aggregates in structural and non-structural concrete applications under local climatic conditions are recommended.

3) Further investigation is needed into the economic feasibility and business models of large-scale C&D waste recycling facilities in Karachi, including public private partnership (PPP) frameworks.

4) Future studies may explore the role of policy instruments and enforcement mechanisms, assessing how mandatory recycling targets and incentives influence contractor behavior and compliance.

5) Research integrating digital construction technologies such as BIM, AI based material optimization, and smart waste tracking systems could provide practical solutions for reducing construction waste at the project planning stage.

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