"Microplastics and Polymers in Construction Materials: Sources, Fate, and Structural/Environmental Impacts"

Nwanze Tobechukwu Joseph[1], David Chinonso Anih[2]*, Uguru Chukwudi Clement[3], Asogwa Chikaodili Dorothy[4], Adamu Kamaliddeen Salisu[5], Ebikonboere Mary Tekeme[6], Hussein Omokehinde Oniyangi[7]

[1]Department of Civil and Environmental Engineering, University of Lagos, Akoka, Lagos State, Nigeria

[2]Department of Biochemistry, Faculty of Biosciences, Federal University Wukari, Taraba, Nigeria

[3]Engineering Department, Esut Business School, Nigeria

[4]Department of Physics and Astronomy, University of Nigeria Nsukka, Enugu State, Nigeria.

[5]Geoscience Department, Faculty of Science, Management & Computing, University Teknologi Petronas, Nigeria

[6]Department of Evironmental Management and Pollution, Faculty of Environmental Management, Nigerian Maritime University, Okerenkoko, Delta State, Nigeria.

[7]Nigerian Army Engineers, 24 Support Engineer Regiment, Nkwagwu Military Cantonment Abakaliki, Ebonyi State, Nigeria

***Corresponding Author**

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ABSTRACT

Construction practices increasingly rely on polymer additives and recycled plastics to enhance durability and reduce material footprints, but these benefits carry environmental and structural tradeoffs. This review synthesizes evidence that polymer fragments and fibers generated during manufacturing, placement, maintenance, and demolition rapidly produce microplastic particles that partition among airborne dust, surface deposits, and stormwater runoff. We present a practical sampling framework and compare extraction and spectroscopic identification methods, highlighting strengths and limitations of density separation, controlled digestion, µ FTIR, Raman, and microscopy approaches for size classes and matrices common to building sites. Combining field studies and modeling, we map fate and transport pathways from site scale emission hotspots to downstream retention basins and sediments, showing how particle size, density, and biofouling control whether fragments remain airborne, move with surface flow, or deposit in soils and sediments. We summarize structural consequences of intentional and unintentional polymer inclusion, noting that well engineered fiber additions can improve flexural behavior while heterogeneous plastic fragments often increase porosity and reduce compressive strength and durability under freeze thaw and chemical exposure. We review evidence for additive leaching, documenting that plasticizers, stabilizers, and some flame retardants can mobilize into stormwater and porewater at concentrations that are environmentally relevant in poorly flushed settings. Human and ecological exposure pathways are evaluated: occupational airborne loads during cutting and demolition are high, community downwind exposures are measurable, and aquatic organisms show adverse responses to particle and chemical mixtures in laboratory tests. Life cycle assessments paired with durability metrics reveal context dependent tradeoffs between embodied carbon benefits and pollution risks when plastics are incorporated into materials. Finally, we offer a tiered mitigation strategy: source control, enclosed handling, targeted sampling, engineered on site controls, and procurement standards to reduce emissions and protect workers and receiving ecosystems. The synthesis provides practical research priorities, monitoring guidance, and policy considerations to make construction practices both resilient and environmentally responsible. We recommend standardized reporting, recovery testing, combined particle and chemical monitoring, and interdisciplinary collaboration to close knowledge gaps and guide regulation. Adopting these measures will reduce environmental loads and enhance material longevity. and public health.

Keywords: Microplastics; Construction materials; Polymer additives; Fiber reinforcement; Fate and transport; Sampling and analysis; Spectroscopic identification; Chemical leaching; Occupational exposure

INTRODUCTION

In recent years, the drive to construct longer lasting, more resilient buildings has led the industry to embrace synthetic polymers such as polyethylene terephthalate (PET), polypropylene (PP), and polyvinyl chloride (PVC), to enhance concrete mixes, waterproof coatings, and composite panels for lightweight structures [1]. At first glance, these materials promise improved workability and extended service life. Yet beneath their benefits lies an emerging dilemma: when subjected to the stresses of mixing, placement, and weather, a notable fraction of these polymers breaks down into micro and nanoplastic fragments. Current estimates indicate that up to 15% of polymer additives in common construction formulations can degrade into microscopic particles during production, mechanical handling, and exposure to environmental cycles [2].Field and laboratory investigations reveal that ultraviolet radiation, freeze thaw variations, and mechanical abrasion act in concert to fragment embedded macro scale polymers, generating secondary microplastics over surprisingly short timescales [3]. Once liberated, their fate diverges: lighter fragments can become airborne during demolition or surface cleaning, while denser particles collect in stormwater runoff, sediment beds, and soils adjacent to active construction zones. Recent surveys of urban drainage systems have recorded concentrations exceeding 2,000 particles • L^{-1} in runoff associated with high rise developments, underscoring the magnitude of unseen plastic discharge from building sites [4Beyond posing risks to ecosystems, these microplastics also compromise the very structures they originate from. In durability tests, researchers have found that microfibers and microbeads embedded within polymer modified concretes serve as points of weakness, accelerating microcrack formation and reducing compressive strength by up to 12% after repeated freeze thaw cycles [5]. Simultaneously, weathering of these polymers releases plasticizers, stabilizers, and flame retardants into percolating waters, introducing potential endocrine disrupting compounds into groundwater and raising fresh concerns for public health.Faced with these intertwined challenges; environmental contamination, material degradation, and human exposure, a comprehensive synthesis of current knowledge is urgently needed. This review collates the latest analytical methods for isolating and identifying microplastics in construction matrices, maps their pathways through the built environment, and evaluates structural and ecological consequences. Finally, we highlight innovations in polymer selection, encapsulation technologies, and on-site treatment approaches to chart a path toward construction practices that are both robust and plastic resilient [6].

METHODS

2.1 Sampling strategy and site selection

A robust sampling design for construction-related microplastics (MPs) should aim to capture the diversity of materials, activities, and pathways that create or mobilize particles. Begin by classifying construction projects by type (e.g., demolition, new-build residential, roadworks, roofing replacement, façade maintenance) and by dominant materials used (concrete, bitumen, synthetic membranes, paints/coatings, insulation, synthetic textile finishes). For each project type choose monitoring points that represent (1) direct material sources (stockpiles, cut/waste areas, exposed membranes), (2) likely emission points (demolition dust plumes, washout/tank overflows, runoff collection points), and (3) receiving environments (adjacent soil, drainage inlets, stormwater outfalls, nearby vegetated strips). This multiscale approach is motivated by recent urban catchment and runoff studies showing that urban and construction areas act as both sources and conduits for MPs into stormwater and receiving systems [7].

Temporal coverage must reflect activity cycles: sample during active construction/demolition, immediately after rain events (to capture entrained runoff), and during quiescent periods to estimate background loading. Spatial replication within sites (triplicate grab samples of runoff, surface dust, and topsoil) reduces site heterogeneity and supports statistical comparisons. Field blanks and airborne contamination controls (procedural blank filters set on site) are essential because construction sites are fiber-rich and prone to airborne contamination. Empirical evidence across urban runoff studies indicates that storm event sampling often records orders of magnitude higher discharge loads than dry-period sampling; design your frequency to capture both event and baseflow dynamics [8].

Construction and built environment studies are increasingly pointing to specific management points that matter — e.g., demolition staging areas, road resurfacing zones, and on-site concrete cuttings — so site selection should prioritize those hotspots while retaining representative background sites for comparison. Recent reviews focused on construction materials and built environment exposures underline that some construction activities (demolition, abrasive cutting, sanding/shot blasting) are particularly important MP sources and should be prioritized for intensive sampling [9].

Table 1 is a practical inventory linking common construction project types to where sampling should occur. It lists sample matrices and suggested collection frequency so teams can plan field campaigns consistently.

Table 1: List of construction project types, sampling locations, sample matrices, and frequency of collection.

Project type	**Sampling locations (on site)**	**Sample matrix**	**Frequency (example)**	**Citation(s)**
Demolition (concrete/brick)	staging area; dust plume edge; runoff inlet	surface dust, runoff, topsoil	pre-demolition, during, post	[9]
Road resurfacing	roadway edge; storm drain	road-deposited sediment, runoff	before, during, after rainy events	[8]
Roofing/insulation works	gutters; downpipe outfall	gutter sediment, runoff	monthly; event triggered	[7]
Paint/finish work	washout pits; waste storage	wash water, sediment	weekly during activity	[9]

Shows project types, recommended on site sampling locations, sample matrices (for example surface dust, runoff, topsoil) and example sampling frequency.

2.2 Extraction and isolation of microplastics and polymer fragments

Extraction protocols must balance recovery, cost, and preservation of particle properties. Three widely employed families of methods are (a) density separation with brines (NaCl, NaI, $ZnCl_2$), (b) chemical digestion of organics (alkaline KOH, oxidative H_2O_2/Fenton), and (c) hybrid approaches that combine sieving, flotation, and controlled digestion. Comparative recovery experiments show that using only saturated NaCl (density ≈1.2 $g \cdot cm^{-3}$) underestimates higher-density polymers (PET, PVC); denser solutions such as NaI or zinc chloride give higher recovery but at increased cost and toxicity considerations. For fine, organic-rich matrices (topsoil, sediment) digestion steps (e.g., mild KOH or enzymatic approaches) followed by density separation often provide the best compromise of recovery and sample cleanliness for spectroscopic analysis [10].

Chemical digestion reagents can alter polymer spectral signatures if overly aggressive. Controlled studies that compared KOH, NaOH, H_2O_2 and strong acids on polystyrene and other plastics found that nitric acid and other aggressive oxidants can degrade or chemically alter susceptible polymers, biasing identification and quantification. Use validated, mild digestion when polymer identification (FTIR/Raman) is required, include reagent blanks, and whenever possible check treated MPs with spectroscopy to confirm no spectral damage [11].

Method selection should be informed by recovery testing (spike-and-recovery with size/shape classes of standard MPs) and contamination controls. Recent comprehensive guides summarize methods across matrices and recommend reporting recovery percentages by polymer type and size class to allow interstudy comparability and meta-analysis. Where possible, include centrifugation, multi-step density separations, and filtration steps adapted to minimize fiber loss, and report recovery and detection limits explicitly [12].

Table 2 is a Side-by-side comparison of the main extraction approaches used for microplastics, with practical notes for lab choice. It lists typical reagents, recovery ranges and the main limitations to watch for during processing.

Table 2: Comparison of extraction protocols (density separation, chemical digestion), recovery rates, and limitations.

Method	Typical reagents / media	Typical recovery (range) / Key limitations	Citation (s)
Density separation (NaCl → NaI/$ZnCl_2$)	NaCl (1.2 g·cm^{-3}), NaI (1.6–1.8 g·cm^{-3}), $ZnCl_2$	NaCl low for dense MP; NaI/$ZnCl_2$ up to ~80–95% for larger fragments; Cost, toxicity, fine sediment cosuspension	[10]
Chemical digestion (KOH, H_2O_2, Fenton)	10% KOH; H_2O_2 + Fe^{2+}	Good organic removal; recovery depends on polymer and size; Can damage susceptible polymers if too strong; fiber loss risk	[11]
Hybrid (sieving + digestion + flotation)	Sequential sieving + KOH + NaI	High reproducibility when optimized; Multiple steps increase contamination risk; cost	[12]

Compares method families (density separation, chemical digestion, hybrid) with example reagents and media, reported recovery ranges and key limitations for each approach. Abbreviations expanded: NaCl = sodium chloride; NaI = sodium iodide; $ZnCl_2$ = zinc chloride; KOH = potassium hydroxide; H_2O_2 = hydrogen peroxide; Fenton = Fenton reaction (hydrogen peroxide combined with an iron catalyst); g·cm^{-3} = grams per cubic centimeter. The table focuses only on method components, recovery behavior and practical constraints.

2.3 Analytical characterization techniques

Polymer identification and morphological characterization typically combine spectroscopic and microscopic tools. µ-FTIR imaging (FPA-FTIR) and Raman microspectroscopy remain the workhorse methods for polymer ID; FTIR excels for particles $\gtrsim$20 µm (practical lower limit often ~10–20 µm depending on optics) while Raman can resolve down to single micron scales but is more prone to fluorescence interference from pigments and additives. FTIR spectral libraries, automated matching, and machine-assisted classification have improved throughput, but particle size, color, and morphology still strongly affect identification accuracy [13].

Interlaboratory assessments find that both FTIR and Raman deliver high accuracy when protocols and spectral libraries are harmonized, but identification accuracy falls for fibers, very small particles, and heavily weathered polymers. Studies recommending best practice emphasize reporting instrument settings (spectral range, resolution, acquisition mode), match thresholds, and the percentage of visually counted particles that were chemically confirmed. For microscopy, SEM (with EDS) is useful to examine particle morphology, surface weathering, and inorganic coatings; novel pairings such as SEM + cathodoluminescence show promise for classifying even dark/black MPs that challenge vibrational spectroscopy [14] [15].

For quantitation, report detection limits by particle number and by mass when possible, and describe subsampling or automated imaging strategies (e.g., FPA-FTIR imaging, Nile-Red fluorescence pre-screening) so data are reproducible and comparable. Where machine learning or automated spectral matching is used, provide validation statistics (confusion matrices, precision/recall) for polymer classes [13].

Table 3 is a compact summary of the spectroscopy and microscopy tools commonly used to identify microplastics. It lists practical size detection limits, main strengths and weaknesses, and a citation column for each technique.

Table 3: Summary of spectroscopy and microscopy methods (FTIR, Raman, SEM), detection limits, and polymer identification accuracy.

Technique	Practical size limit	Strengths	Weaknesses	Citation
µ-FTIR (FPA imaging)	≈10–20 µm (instrument dependent)	High chemical specificity; automated imaging	Limited for <10 µm; issues with black/opaque particles	[13]
Raman microscopy	≈1 µm	High spatial resolution; small particle ID	Fluorescence interference; longer acquisition	[13]
SEM (+EDS / CL)	<1 µm (morphology)	High morphological detail; CL can classify dark MPs	Not inherently chemical fingerprinting; sample prep	[15]

Compares µ-FTIR imaging, Raman microscopy, and SEM with typical practical size detection and method pros and cons. Abbreviations expanded: µ-FTIR = micro-Fourier transform infrared spectroscopy; FTIR = Fourier transform infrared spectroscopy; FPA = focal plane array; Raman = Raman microspectroscopy; SEM = scanning electron microscopy; EDS = energy dispersive X-ray spectroscopy; CL = cathodoluminescence; µm = micrometer. The table is limited to instrumentation performance and detection considerations.

2.4 Fate and transport modeling approaches

Modeling MP fate from construction sources into receiving environments links field observations to mechanistic understanding and management. Modeling approaches vary from process-based hydrodynamic and particle-tracking models, to statistical mass-balance and machine learning frameworks. Recent comparative reviews classify models into hydrodynamic (advection–dispersion / CFD), particle-tracking (Lagrangian), mass-balance box models, and data-driven approaches; each has trade-offs between realism, data needs, and computational cost. Choose the model class to match the spatial scale and policy question e.g., catchment-scale Lagrangian particle tracking for runoff transport; local hydrodynamic models for retention pond behavior [16].

Particle attributes (size, density, shape) and processes (biofouling, aggregation with natural particles, resuspension, burial) exert strong control on transport mode and residence time. Recent modeling work shows that small differences in effective density and shape can shift particles between surface transport, suspended transport, and bedload behavior, so parameterize the model with measured size- and polymer-specific distributions wherever possible. Sensitivity analysis and uncertainty quantification are essential because emissions and transformation rates remain highly uncertain for many construction-derived MPs [17].

At the construction-site scale, coupling simple mass-balance estimates (source strength per activity × runoff capture efficiency) with a routing model for stormwater conveyance and retention systems allows rapid evaluation of mitigation options (settling basins, silt fences, on-site capture). For regional assessments, couple source inventories with hydrological and particle transport models to estimate loads to receiving waters and potential accumulation hotspots. Recent marine and riverine modeling reviews give practical workflows and highlight the need to validate models with targeted field campaigns that follow the sampling strategy described above [18].

Schematic flow diagram mapping construction material sources → on-site pathways → transport vectors → receiving environmental compartments. Arrow widths indicate illustrative relative fluxes (low–medium–high) and major transfer routes; callouts list recommended sample types and monitoring/collection points. The diagram supports the Methods/modeling discussion in section 2.4 by summarizing likely release pathways and monitoring targets for construction-related microplastic transport.

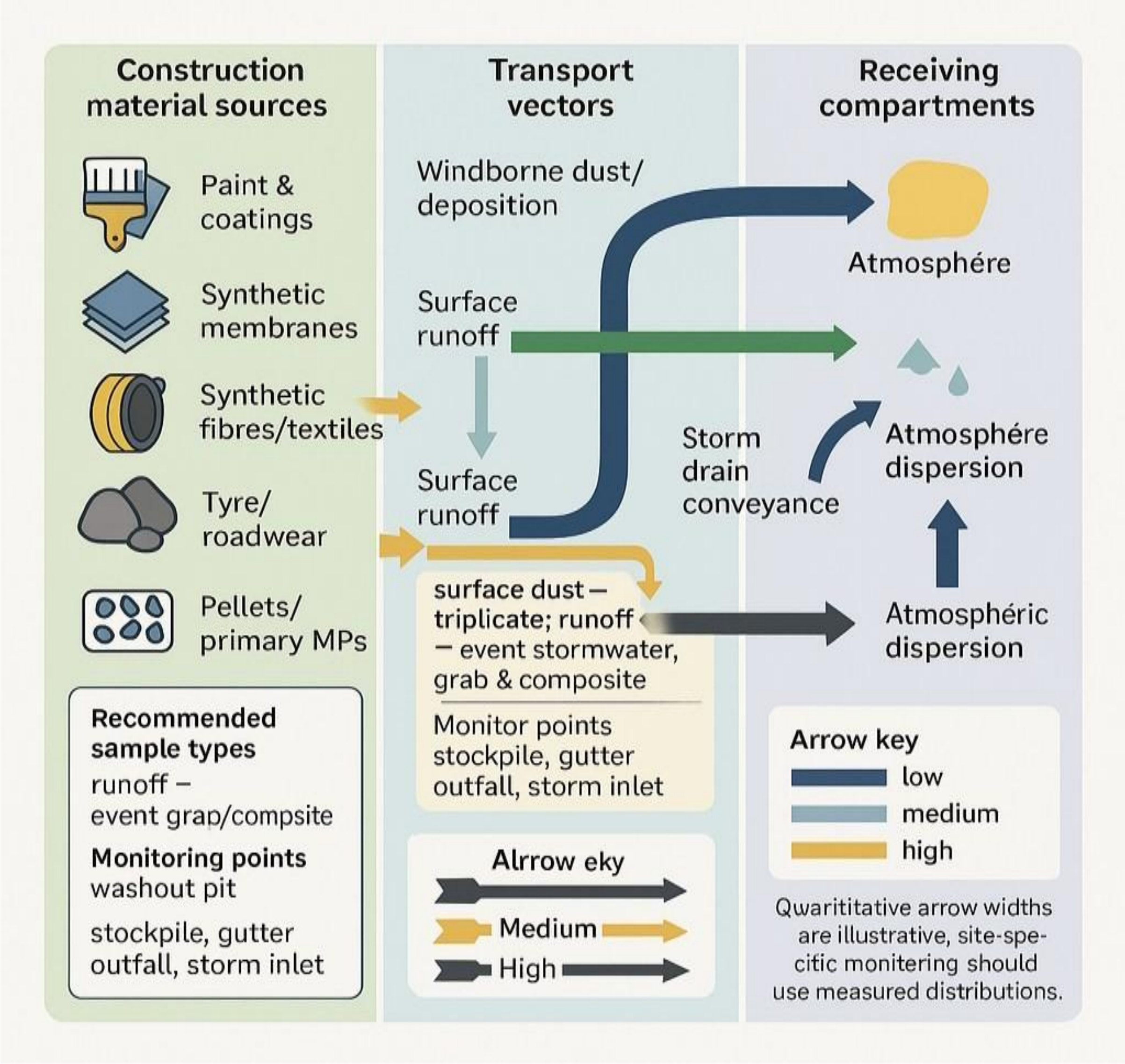

Figure 1 Schematic diagram of microplastic and polymer-particle pathways associated with construction activities (Self-generated).

Columns A–D show (A) material sources, (B) on-site generation pathways, (C) transport vectors, and (D) receiving compartments; colored arrows trace dominant transfer routes. Arrow key: thin = low flux, medium = moderate flux, thick = high flux; shaded callout boxes indicate recommended sample types (e.g., surface dust triplicates; runoff event grab/composite) and monitoring points (stockpile, washout pit, gutter outfall, storm inlet). Abbreviations: MPs = microplastics.

RESULTS AND DISCUSSION

3.1 Source characterization in construction materials

Construction materials and construction activities produce a complex and evolving mix of primary and secondary microplastics (MPs). Primary MPs, such as industrial pellets used in polymer processing and intentionally added synthetic fibers are usually localized in stockpiles, waste streams, and manufacturing slurries. Secondary MPs result from mechanical weathering and wear of polymer-containing materials used on site: paint and coating flakes, abrasion of synthetic membranes, fragmentation of insulation and textile geotextiles, and particles derived from binder and asphalt wear during roadworks [19]. Field and materialspecific investigations increasingly show that the relative contribution of primary versus secondary MPs is strongly material dependent: textile and insulation products tend to shed higher fractions of primary fibers, while composite surfaces and cured polymer-modified materials more commonly produce secondary fragments through weathering and abrasion [20].

Quantification studies that targeted construction waste and runoff highlight that sources can be highly localized and episodic. For instance, demolition staging areas and abrasive cutting operations are hotspots for particle generation; stockpiles and washout pits concentrate pellets and small fragments; road resurfacing tends to produce abundant mineral-backed polymer fragments and tyre-derived particles that appear across adjacent drainage networks [21]. Taken together, this evidence suggests that a pragmatic sampling and mitigation strategy should combine targeted hotspot monitoring (to capture peak emissions) with background site sampling to assess cumulative loads across the construction phase.

Table 4 quantifies the relative contributions of primary versus secondary microplastics across material types. It pairs percent ranges with representative sample matrices so readers can see where particles were measured.

Table 4: Quantified contributions of primary and secondary microplastics by material type

Material type	Primary (% contribution)	Secondary (% contribution)	Representative sample matrix	Citation (s)
Concrete (normal mixes)	5–15	85–95	surface dust, washwater, cores	[19]
Polymer-modified asphalt / composites	10–25	75–90	road runoff, binder residues	[20]
Coatings, paints, sealants	15–35	65–85	paint chips, gutter sediment	[21]
Insulation and textile products (geotextiles)	40–70	30–60	airborne fibers, top surface dust	[19]

Lists material types, reported percent ranges for primary and secondary microplastic contributions, and representative sample matrices used for those measurements. Percent values are shown as percent contribution. No abbreviations appear in this table.

3.2 Distribution and fate within the built environment

Once generated, microplastic particles partition quickly among several on-site compartments: airborne dust and fibers, settled surface dust, construction runoff and conveyance systems, and site waste streams. Shortterm behavior is driven by local deposition and entrainment: wind, vehicle and equipment movement, and construction activity resuspend fine fibers and fragments that then redeposit across surfaces, into gutters, or are entrained in runoff during rainfall events [22]. Stormwater monitoring across urban catchments has repeatedly shown that rainfall events and particularly first-flush conditions act as major episodic pulses that mobilize accumulated MPs from paved and exposed surfaces into drains and receiving waters [23].

Spatially, the partitioning is scale dependent. On small sites, most particles remain localized unless active conveyance (e.g., site drainage) exports them. In larger catchments the cumulative effect of many local generation points leads to non-trivial offsite transport and downstream accumulation. Hydrodynamic behavior is determined by particle attributes (size, density, shape) and the transport vectors present: windborne dust favors fibers and sub-100 µm fragments, surface runoff preferentially transports particles that are easily entrained in flow, and sedimentation processes eventually sort particles into depositional sinks such as retention ponds and downstream sediments [24]. Understanding this partitioning is essential to design monitoring programs and to select targeted mitigation measures for example, installing sediment traps at key conveyance nodes or combining airborne controls with runoff treatment for sites with both strong aerial and wash-off sources.

Figure 2 illustrates the distribution and fate of construction-generated microplastics (MPs) as discussed in Section 3.2. It visualizes how MPs are partitioned among on-site sinks such as structural matrix retention, onsite runoff, suspended dust, and waste streams. The flow widths represent typical transfer fractions derived from field studies, emphasizing the dynamic transport processes described in the text.

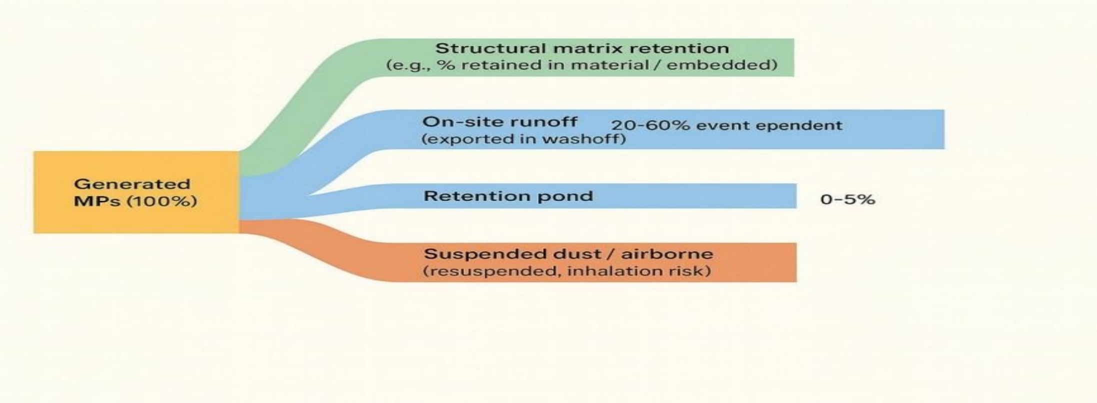

Figure 2. Sankey diagram illustrating pathways of construction-generated microplastics (Self-generated)

Sankey diagram showing the flow of generated microplastics (MPs) from source to multiple pathways, including retention in construction materials, runoff, airborne dust, and waste streams. Arrows indicate relative flow proportions, and annotated percentages reflect illustrative transfer ranges based on representative studies. Abbreviations: MPs = Microplastics.

3.3 Structural impacts on mechanical performance

The inclusion of polymers, whether as engineered fibers or unintentional contamination from recycled polymer fragments, can modify mechanical properties of construction materials in multiple ways. When engineered synthetic fibers are deliberately added in small, controlled doses they can improve crack bridging, ductility, and post-crack behavior, often enhancing flexural capacity and toughness without substantial loss in compressive strength. However, uncontrolled incorporation of heterogeneous plastic fragments, particularly when they are poorly bonded to the cementitious matrix, frequently increases porosity and creates weak interfacial transition zones that reduce compressive strength and can accelerate durability problems [25].

Experimental studies show a nuanced picture: modest fiber dosages (properly dispersed and often surface treated) can provide performance gains in tension and flexure, while coarse fragments or high replacement fractions commonly lead to strength reductions. For example, several bench-scale and pilot studies report compressive strength decreases ranging from 5% to 30% depending on fragment size, content, and surface treatment, while flexural improvements of up to 10–20% have been observed for well-designed fiber additions [26]. Long-term durability is similarly mixed. The presence of polymers can reduce chloride ingress if they block pore pathways, but they can also modify water retention and freeze–thaw response, depending on particle morphology and compatibility with the matrix [27].

Practical note: If using recycled plastic fragments as aggregate replacements, optimize particle size distribution and surface treatments, and perform durability tests (chloride penetration, freeze–thaw, carbonation) under simulated field conditions.

Table 5 summarizes reported effects of polymer inclusion or microplastic contamination on standard mechanical tests. It gives the observed direction of change, typical magnitude ranges and source citations for each reported property.

Table 5: Effects of polymer inclusion and microplastic contamination on structural performance

Tested property	Observed effect	Typical magnitude (reported ranges)	Citation (s)
Compressive strength	Often reduced at moderate to high replacement fractions	−5 to −40%	[25]
Flexural capacity	Can improve with well-dispersed fibers at low dosages	+5 to +20%	[26]
Long-term durability	Mixed outcomes; dependent on particle type and bonding	Variable; sitespecific	[27]

Shows tested properties (for example compressive strength, flexural capacity, and durability), the reported direction of effect and typical magnitude ranges. Positive or negative percent ranges indicate gains or reductions in performance respectively. No technical abbreviations appear in the table.

3.4 Environmental release and exposure pathways

Exposure pathways for construction-derived microplastics include inhalation of resuspended dust and fibers, incidental ingestion (hand-to-mouth transfer of settled dust), and dermal contact. Occupational monitoring near demolition, cutting, and abrasive operations often records elevated airborne particle counts and fiber loads compared with background urban levels; these occupational exposures can be many times higher during active operations and localized tasks [28]. Ambient downwind concentrations for residents near major construction zones are generally lower than on-site exposures but can still be measurable, especially for fine fibers that remain suspended for longer periods [29].

Runoff monitoring provides evidence for substantial episodic export of MPs during rainfall. Event-based sampling commonly yields orders-of-magnitude increases in particle number and mass during storm events versus baseflow, indicating that surface wash-off is a dominant vector for offsite transfer of constructiongenerated MPs into receiving waters [30]. Taken together, the exposure evidence points to two practical conclusions: (1) control measures should address both airborne and wash-off pathways simultaneously; and (2) worker protection measures (respiratory protection, dust suppression, enclosure) remain critical while on-site controls reduce community exposures via runoff reduction.

Table 6 Collates measured concentration ranges for air, runoff and soil near construction activities for easy comparison. It shows numeric ranges and the units used for each matrix so readers can compare exposure magnitudes across studies.

Table 6: Measured concentrations of microplastics in air, water runoff, and soil adjacent to construction activities

Matrix	Typical concentration range	Units	Citation (s)
Air (near demolition)	10 – 10^3	particles m^{-3}	[28]
Runoff (event samples)	10^0 – 10^3	particles L^{-1}	[22][23]
Soil (top 1 cm)	10^2 – 10^5	particles kg^{-1} dry	[24][30]

Reports concentration ranges by matrix and the units used. Abbreviations and units expanded: particles m^{-3} = particles per cubic meter; particles L^{-1} = particles per liter; particles kg^{-1} dry = particles per kilogram dry weight; m^3 = cubic meter; L = liter; kg = kilogram; dry = dry weight basis. The table focuses only on observed concentration ranges and units.

3.5 Chemical leaching from polymer additives

Microplastic particles and polymer-modified products can act as both physical pollutants and secondary sources of chemical additives. Additives of concern in construction contexts include phthalate plasticizers, non-halogenated and halogenated flame retardants, stabilizers, and UV absorbers. Laboratory leaching experiments and field weathering studies indicate that additive release is a function of polymer matrix, additive chemistry, particle size, and environmental conditions such as pH, ionic strength, and temperature [31]. Weathering processes mechanical abrasion, UV photodegradation, thermal cycling can increase additive mobility by increasing polymer surface area and creating microcracks that facilitate leachate diffusion.

Quantitatively, leaching rates reported in recent studies span orders of magnitude depending on the compound and test conditions: phthalates and some low molecular weight additives can be detected in stormwater and porewater at ng L^{-1} to low µg L^{-1} levels after months of exposure in highly impacted sites [32]. The ecological relevance of these concentrations depends on local toxicity benchmarks. In heavily contaminated scenarios, leachate concentrations have approached or exceeded conservative effect thresholds for benthic organisms in laboratory bioassays, particularly where stormwater accumulates in shallow retention basins with limited flushing [33]. This underscores the need to pair particle monitoring with targeted chemical screening for commonly used additives when characterizing construction-related pollution.

Table 7 is an example measured leaching ranges for common additive classes found in polymer modified materials, with the matrices where they were detected. It gives an at-a-glance view of which additives show measurable release and in which environmental media.

Table 7: Leaching rates of common additives from polymer-modified materials

Additive	**Measured leaching (example)**	**Matrix**	**Citation(s)**
Phthalates (e.g., DEHP)	ng – µg L^{-1} over months	stormwater, sediment porewater	[31]
Flame retardants (some brominated and organophosphate types)	ng – µg L^{-1} over months	leachate, runoff	[32]
Stabilizers / antioxidants	ng – µg L^{-1}	soil porewater, standing water	[33]

Lists additive classes (for example phthalates, flame retardants, stabilizers), example measured leaching ranges and the sampled environmental matrices. Abbreviations expanded: DEHP = di(2-ethylhexyl) phthalate; ng = nanogram; µg = microgram; L = liter. The table reports concentration ranges observed over months and the matrices (stormwater, sediment porewater, leachate) where they were measured.

3.6 Life-cycle and environmental impact assessment

Life-cycle assessment (LCA) provides a structured framework to compare conventional construction materials with polymer-augmented or plastic-waste-reinforced alternatives. Recent LCA work shows trade-offs that depend on whether polymer inclusion displaces a high-impact material (for example, substituting recycled plastic for virgin aggregate) and on changes in service life and maintenance needs [34]. When plastic waste successfully replaces high carbon intensity inputs without compromising structural performance, the net embodied carbon can drop. Yet if polymer addition reduces material life or necessitates more frequent repairs, those gains can be eroded or reversed.

To fairly assess benefits and risks, coupled LCA–durability frameworks are recommended: these combine standard impact categories (global warming potential, energy use, resource depletion) with site-specific durability projections and potential environmental costs from additive leaching or increased microplastic emissions. Sensitivity analyses show that the allocation method for recycled inputs and assumptions about service life are often the dominant drivers of net benefit or harm [35]. Scenario analyses and uncertainty quantification are therefore essential when making procurement or policy recommendations about polymer use in construction [36].

Table 8 is a side-by-side life cycle impact metrics comparing conventional materials with polymer augmented or waste substituted alternatives. It highlights where polymer use typically lowers impacts and where it can raise potential pollution risk.

Table 8: Life-cycle assessment comparison of conventional versus polymer-augmented construction materials

Impact metric	**Conventional**	**Polymeraugmented (with waste substitution)**	**Citation(s)**
Global warming potential (kg CO_2e per functional unit)	Baseline high	Lower when waste displaces virgin aggregate	[34]
Energy use (MJ)	High	Often lower, depending on processing	[35]
Pollution (additive leaching risk)	Low to moderate	Potentially higher if additives leach	[36]

Shows impact metrics such as global warming potential, energy use and pollution risk compared between conventional and polymer augmented materials. Abbreviations expanded: kg CO_2e = kilograms of carbon dioxide equivalent; MJ = megajoule. The table focuses on relative trends and direction of change for each metric.

Key point: LCA results are context specific. Procurement decisions should be informed by site-level durability testing and a precautionary assessment of additive release.

3.7 Human health and ecosystem implications

Evidence on human health effects of environmental microplastics is still maturing but is sufficient to justify precautionary measures at construction sites. Inhalation studies in animal models and in vitro systems suggest that microplastic fibers can induce inflammatory responses in respiratory tissues and, depending on size and composition, may translocate across biological barriers [37]. Occupational epidemiology is emergent, but available studies point to higher exposure levels and potentially increased respiratory symptomatology among workers in sectors with heavy dust and fiber exposures.

Ecosystem impacts are better documented for aquatic systems: benthic invertebrates, filter feeders, and small fish show altered feeding behavior, reduced growth, or reproductive effects at elevated particle and additive concentrations in controlled experiments; additive-laden particles can exacerbate these effects through chemical toxicity or by acting as vectors for co-contaminants [38]. Terrestrial toxicity data are less abundant but indicate potential effects on soil invertebrates and microbial community function at high localized concentrations [39]. Given these uncertainties and the potential for chronic low-dose exposures, it is prudent to minimize emissions from source and to implement worker protection measures and community exposure reduction strategies.

Table 9 Summarizes exposure routes (inhalation, ingestion, dermal) and compares typical exposure magnitudes for workers and nearby residents. It lists the toxicity endpoints reported in the cited literature alongside each exposure route.

Table 9: Summary of inhalation, ingestion, and dermal exposure levels and toxicity endpoints

Route	Workers	Nearby residents	Toxicity endpoints	Citation(s)
Inhalation	High on-site during active work	Moderate downwind	Respiratory inflammation, potential particle translocation	[37]
Ingestion	Moderate (hand-tomouth, dust)	Low to moderate	Gut microbiome alteration, trophic transfer	[28][39]
Dermal	Low	Low	Limited compared with inhalation / ingestion	[37]

Lists exposure routes, typical exposure magnitude for onsite workers and for nearby residents, and the main toxicity endpoints reported (for example respiratory inflammation, gut microbiome alteration). No technical abbreviations appear in the table beyond plain route names.

3.8 Mitigation and management strategies

Practical mitigation for construction-related microplastic emissions combines prevention at source, engineering controls on site, and end-of-pipe or receiving water treatments. Source reduction includes minimizing quantities of loose polymer stockpiles, specifying materials with lower prone-to-abrade formulations, and adopting closed handling systems for cutting, sawing, and washing operations. On-site operational controls enclosed cutting, local extraction, water capture and staged washout greatly reduce both airborne and runoff pathways when properly implemented [40].

Engineered on-site measures such as silt fences, sediment traps, and bioretention systems capture the majority of coarser MPs in runoff, while advanced filtration (membrane filtration, cartridge filters) and chemical coagulation/settling systems target finer fractions at higher operational cost [41]. Procurement and regulatory levers, specifying product formulations with reduced leachable additives, minimum recycled-content standards that ensure compatibility, and clear construction best practice requirements, can drive long-term reductions in emissions. The combined evidence suggests that a tiered approach (source control → site containment → treatment → procurement/regulation) is the most effective and cost-efficient pathway to reduce both near-term exposures and cumulative environmental loadings [42].

Table 10 evaluates practical management measures from source control to advanced treatment, with notes on relative effectiveness and implementation constraints. It is organized so practitioners can compare options by expected performance and operational impact.

Table 10: Evaluation of best management practices, treatment technologies, and regulatory measures

Strategy	**Effectiveness**	**Costs / limitations**	**Citation (s)**
Source control (enclosed handling, materials spec)	High	Operational cost, training required	[40]
Sediment traps and bioretention	Moderate to high for coarse MPs	Land take, maintenance needs	[41]
Advanced filtration (membranes, cartridge)	High for fine MPs	High capital & O&M cost, fouling risk	[42]

Compares strategies (for example source control, sediment traps and bioretention, advanced filtration) with relative effectiveness and notes on costs or limitations. Abbreviations expanded: O&M = operation and maintenance. The table concentrates on implementation tradeoffs and expected performance only.

CONCLUSION

Construction and maintenance of polymer containing materials generate microplastic fragments and fibers that disperse across air, soil, and water, creating persistent environmental loads. Accurate assessment depends on harmonized sampling and spectroscopic workflows tailored to matrices and particle size classes to ensure reliable detection and comparability. Fate and transport are controlled by particle size, density, and biofouling, producing distinct airborne, runoff, and sedimentary pathways with different retention and exposure profiles. Intentional fiber reinforcement can enhance specific mechanical properties, whereas heterogeneous plastic contamination often increases porosity and reduces compressive strength and long term durability. Leaching of additives such as plasticizers and stabilizers can mobilize into stormwater and porewater, posing ecological and human health concerns in poorly flushed or high exposure settings. Occupational activities including cutting, placement, and demolition generate elevated airborne loads, so engineering controls and enclosed handling are essential to protect workers and nearby communities. Life cycle comparisons highlight tradeoffs between embodied carbon benefits and pollution risks, arguing for procurement standards and design choices that balance resilience with environmental safety. We recommend source control, targeted monitoring, standardized reporting, engineered site controls, and interdisciplinary research to close knowledge gaps and guide policy toward safer, more sustainable construction practices.

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Abbreviations

MPs - microplastics μ-FTIR - micro-Fourier transform infrared spectroscopy

FTIR - Fourier transform infrared spectroscopy
FPA - focal plane array
FPA-FTIR - focal plane array FTIR (imaging)

Raman - Raman microspectroscopy
SEM - scanning electron microscopy
EDS - energy dispersive X-ray spectroscopy
CL - cathodoluminescence
µm (or µm) - micrometer m^3 - cubic meter L - liter kg - kilogram $g\cdot cm^{-3}$ - grams per cubic centimeter

NaCl - sodium chloride
NaI - sodium iodide
$ZnCl_2$ - zinc chloride
KOH - potassium hydroxide
H_2O_2 - hydrogen peroxide
Fenton - Fenton reaction (H_2O_2 with an iron catalyst) DEHP - di(2-ethylhexyl) phthalate ng - nanogram µg microgram

PET - polyethylene terephthalate
PP - polypropylene
PVC - polyvinyl chloride
LCA - life-cycle assessment
CFD - computational fluid dynamics O&M - operation and maintenance ng L^{-1} - nanogram per liter µg L^{-1} - microgram per liter

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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