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REVIEW

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From plastic use in the construction and built environment to state-of-the-art circular economy solutions to combat microplastic pollution

Katja Turk[1,2], Gabriela Kalčikova[2,3], Anita Jemec Kokalj[4] and Branka Mušič[1*]

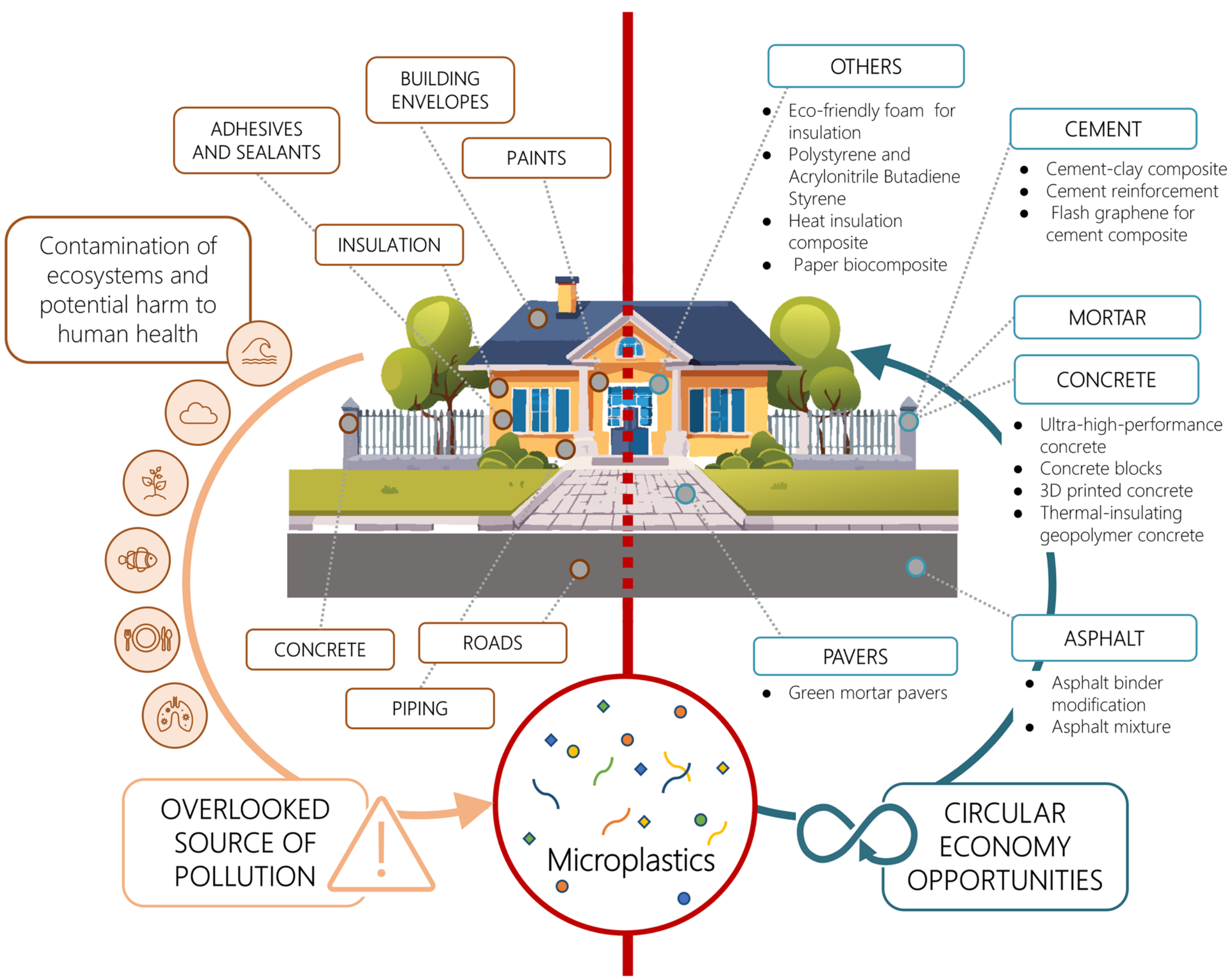
Abstract

Plastics are widely used in the construction and building industry, accounting for 23.5% of European plastic consumption. They can replace traditional materials in various applications, including building insulation, piping, paints, adhesives, sealants, roofing, flooring, etc., serve as key components in various composites, and are indispensable for packaging materials and elements that facilitate the construction process itself. Despite their long lifespan, building materials inevitably degrade over time, releasing microplastics (MPs) that contribute to environmental pollution. According to some estimates, annual emissions of MPs in the European Union range from 0.7 to 1.8 Mt, with building paints identified as a dominant source, contributing between 231,000 and 863,000 tons per year. However, reported numbers vary significantly across studies, reflecting the substantial uncertainties still present in quantifying MPs. Now ubiquitous across ecosystems worldwide, MPs have become one of the most pressing concerns of the scientific community, leading to a rapid expansion of research in recent years. Yet less than 0.6% of studies focus on their presence in the construction and building sector, leaving this major industry largely overlooked. This review consolidates scattered knowledge by examining the applications of plastics in the construction and built environment and their role in microplastic generation throughout the materials' life cycle, from production and application to use and end-of-life management. It also examines MPs within the broader framework of sustainable development, particularly in the transition from a linear to a circular economy, where MPs could potentially be repurposed as secondary raw materials for new products. Particular emphasis is placed on recent research exploring the incorporation of MPs into construction materials, while highlighting state-of-the-art solutions that demonstrate their potential commercial viability. Moreover, this article raises awareness of the potential risks associated with such practices, offering authors' critical perspective on existing research and emphasizing the need for a comprehensive evaluation of their impacts. By synthesizing the current state of knowledge, this review lays the groundwork for advancing future research, developing mitigation strategies, and fostering more sustainable material management in the construction and building sector.

Keywords Microplastics, Building, Construction, Pollution, Circular economy

*Correspondence:
Branka Mušič
branka.music@zag.si
Full list of author information is available at the end of the article

Graphical abstract



Introduction

The widespread use of artificial materials has transformed modern life, influencing everything from everyday products to advanced technologies. Plastics have long been indispensable and omnipresent due to their remarkable versatility, with properties such as durability, lightweight, water resistance, and, above all, cost-effectiveness [1]. These properties, along with their durability in corrosive environments and ability to be formed into complex shapes, make plastics an important component of many sectors, including the construction and built environment, which, in addition to buildings and urban areas, also includes other infrastructure, transport networks, public spaces, as well as management of wildlife and cultivated lands [2]. In modern construction, plastics often replace traditional materials and also serve as a polymer additive to other materials, forming composites that improve the properties of final products while significantly reducing weight and cost [3–7].

This growing reliance on plastics is reflected in broader production trends. Global plastic production has increased enormously over the past decades, rising from 2 million metric tons (Mt) [8] in 1950 to 413.8 Mt in 2023 [9], with no indication of slowing down in the future. Projections by The Organization for Economic Cooperation and Development (OECD) indicate that even with the greater use of recycled plastics, the annual production of virgin plastics will exceed 1,000 Mt by 2060 [8]. The construction and building sector is one of the largest consumers of plastics, accounting for 23.5% of plastics consumed in Europe in 2022, second only to the packaging industry [10]. While mass production has led to unprecedented plastic waste accumulation, the lifespan of plastic products varies significantly based on their application, where the construction and built environment stand out for its extended material lifespan [11]. Despite their durability, these materials generate waste throughout their life cycle, from raw material extraction, processing, production, distribution, usage, demolition, and disposal or recycling [12]. Since the construction and building sector represents the largest global industry [13], addressing the use of so-called construction plastics and the management of construction waste containing plastics is of paramount importance for mitigating environmental impacts.

In addition to their substantial presence in construction waste, these materials remain in use for extended periods, during which they interact with environmental factors and undergo weathering, wear, and degradation, leading to the release of fragments into the surrounding environment. These fragments may be classified as microplastics (MPs), which have emerged as a central topic in scientific and regulatory discussions due to their persistence, widespread presence, and potential effects on ecosystems and human health [14–18]. Demolition and renovation of buildings also contribute significantly to microplastic pollution through activities such as breaking, cutting, and grinding plastic-containing materials such as paints, insulation, flooring, roofing, pipes, sealants, windows, etc. [19], releasing MPs into the environment.

Once emitted, MPs remain in the environment for long periods, as the degradation of plastics is an extremely slow process, with an average degradation time of more than 50 years [20]. The rate of degradation depends not only on environmental conditions, but also on the intrinsic properties of the material, making durable construction products particularly problematic. For example, plastic pipes commonly used in the building sector may have a half-life of up to 1200 years [21]. These MPs can be easily spread through air [22] and water [23, 24], accumulate in soil [25], and pose a negative impact on the environment and human health [26–28]. Research by the Irish Environmental Protection Agency (EPA 2017) [29] suggests that MPs from construction activities may be among the most hazardous, highlighting the importance of recognizing this source in microplastics research.

Despite the scale of the construction and building sector, its heavy reliance on plastic-based materials, and the potential hazards associated with them, remarkably little systematic attention has been paid to its role in the generation of MPs. To advance the field, it is necessary to collect and critically assess the available knowledge, which remains fragmented across different disciplines and case studies. The review addresses this need by summarizing current findings. The aim is to inform future research directions, support efforts to mitigate the problem, and promote more sustainable practices that are in line with circular economy principles.

Microplastics research trends in building and construction industry

Methodology of literature review (2004–2024)

Although the presence of small plastic debris in the environment was recognized as early as the 1970 s [30], significant research efforts have only gained momentum in recent years. However, research development has not progressed evenly across all fields. Despite the construction and building sector's critical role as one of the largest consumers of plastic [31], research on MPs in this area remains significantly underexplored [18].

We evaluated the number of studies published in the scientific database Web of Science [32], which was chosen for its selectivity and reputation as one of the highest-quality databases featuring peer-reviewed content. We first searched the studies specifically linking MPs to the construction and building sector over the period between 2004, when the term "*microplastics*" was first used to describe small plastic particles [33], and the end of 2024. The latter were identified using the keywords "*microplastics*" AND "*construction*" as well as "*microplastics*" AND "*building*", with irrelevant and duplicate entries removed. The selection process of relevant studies is shown in Fig. 1.

Descriptive analysis

An analysis of publication trends provides insight into how attention to MPs in the construction and built environment has evolved in comparison to the broader field of microplastics research. The data gathered from our search are illustrated in Fig. 2, which contrasts the total number of publications on microplastics research with those specifically focused on MPs in the construction and building sector, based on a search in the Web of Science database [29]. Since there are significantly fewer studies on MPs from the construction and building sector, the data for these studies are presented on a secondary axis that is 100 times smaller. The search revealed that the first studies on MPs in the construction and built environment appeared in 2018, at a time when microplastics research in general was already expanding at an exponential rate.

For the comparison, we also conducted a broader search of all studies investigating MPs using the keyword "microplastics". In this case, duplicates were not removed, as the aim was to illustrate the scale of research interest rather than generate a refined dataset. Over the past 20 years, 22,722 studies on MPs have been published,

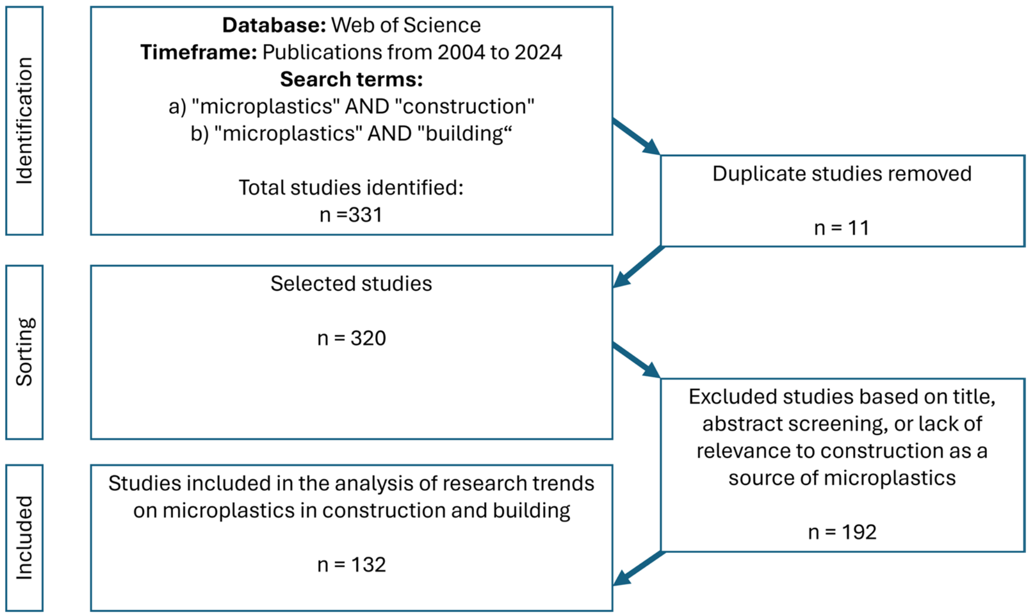


Fig. 1 Selection process for determining the number of scientific studies on MPs related to construction

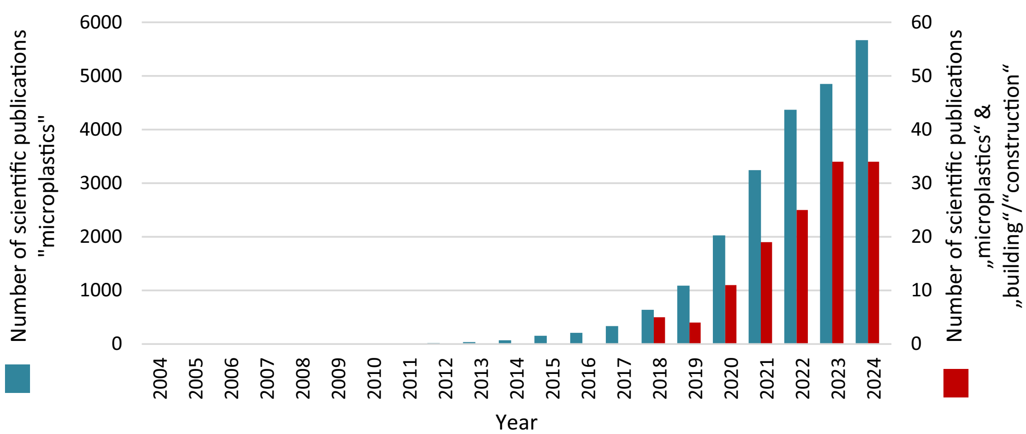


Fig. 2 Publication trends: MPs overall vs. MPs in construction and building

yet only 132 are linked to construction and building as a source of microplastic pollution, representing less than 0.6% of total publications. The most notable increase in studies within this field occurred between 2019 and 2020, with a 175% surge, followed by a gradual slowdown to 73% and 32% growth in the next two years, respectively. By 2024, the number of published studies remained stable, matching the total from the previous year. This is further illustrated in the Supplementary materials (Figure S1 and Figure S2), which present the data from slightly different perspectives.

While some studies merely cite the construction and built environment as one of many sources of microplastic pollution [34, 35], others specifically focus more on construction-related microplastic emissions, particularly in relation to indoor pollution [36], road-derived MPs [37, 38], and MPs on construction sites [39–42]. Beyond research on microplastic detection and environmental contamination, a growing number of publications also explore the potential incorporation of MPs into construction materials, such as asphalt and cement-based composites [43, 44].

The use of plastic materials in building and construction as a potential source of microplastic pollution

Plastics play a crucial role in modern construction, accounting for approximately 10% of the total materials used in residential buildings [45]. The most widely used plastics in the construction and building sector include polyvinyl chloride (PVC), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polystyrene (PS), polypropylene (PP), and polyurethane (PUR) [10, 46]. However, as the use of plastics increases, the release of MPs into the environment also escalates [18]. When shaping an overview of construction materials and products that could be potential sources of MPs, we relied on the list of product families from the European Commission report [47] and created the eight sub-chapters below. Each sub-chapter outlines the general use of plastics within the respective product family, followed by a discussion linking these applications to MPs, including studies that identify the product as a source or assess its environmental impact. A concluding separate paragraph then summarizes key challenges and research gaps and, given the considerable differences between the studies reviewed, provides an overview of the detection and analytical methods used, highlighting the difficulties this poses for cross-study comparisons.

Concrete and other cement-based materials

While concrete, as the most widely used material in the world, is known for its exceptional compressive strength, its low tensile strength presents a significant challenge [48]. To overcome this limitation, various reinforcement elements can be incorporated, with the market generally divided into polymer, steel, glass, and other categories. Among these, polymer fibers have gained the largest share, as they offer advantages such as high flexibility, effective shrinkage control, and compatibility with sustainable construction practices [49]. Compared to other materials, plastic fibers, such as PP, HDPE, and polyethylene terephthalate (PET), are particularly effective in preventing cracks and improving concrete's post-cracking behavior [50]. Moreover, a life cycle assessment comparing virgin PP fibers with steel-reinforced mesh, which is traditionally used to prevent shrinkage cracks in concrete, found that the use of PP fibers reduces water consumption, fossil fuel use, and greenhouse gas emissions (CO_2 equivalent) by 28%, 78%, and 50%, respectively. One study even showed that these reductions are even more pronounced when using recycled PP fibers, reaching 99%, 91%, and 93%, respectively [51]. To enhance strength and prevent cracking, fibers are also added to other cement-based materials, such as mortar [52, 53]. On the other hand, plastic particles can partially replace traditional aggregate, significantly reducing both the weight and construction costs while at the same time enhancing properties such as thermal and acoustic insulation [48]. Aggregates constitute most of the concrete, accounting for 85% of its weight [48] or 65–80% of the volume [54], having a significant impact on concrete properties. However, data on the proportion of plastic aggregate that can replace traditional aggregate without significantly affecting mechanical properties vary depending on specific applications and final product requirements. For example, in a study incorporating plastic aggregate from electronic waste (E-waste), compressive strength was maintained with up to 30% aggregate replacement, flexural strength, Young's modulus, and split tensile strength remained stable with up to 10% replacement, while impact strength decreases regardless of the replacement percentage [55]. The optimal replacement ratio depends largely on the characteristics of the plastic aggregate, such as aggregate gradation (fine or coarse) and material composition (e.g., PET, LDPE, E-waste, PVC, PP, HDPE), as well as concrete mixing parameters [56]. Beyond their use as aggregate substitutes and fiber reinforcement, plastics can also be incorporated into concrete mixtures in the form of plasticizers and additives to enhance workability and improve mechanical properties [57, 58].

Despite their functional role in concrete, plastics embedded within these composites can become a source of MPs over time. During use, mechanical wear and surface erosion gradually lead to microplastic emissions, for example, from concrete paving blocks, which are a significant source of MPs that enter the environment through urban stormwater runoff [59]. At the end of its life cycle, demolition processes can also further accelerate microplastic release, as crushing and fracturing of concrete cause MPs to detach in the form of leachates or airborne dust [18]. Demolition generates high levels of particulate matter, which far exceed those produced during regular use and have well-documented negative health effects [60].

Insulation materials

Plastics such as PUR, expanded polystyrene (EPS), and extruded polystyrene (XPS) are essential for the thermal insulation of walls and roofs. These materials play a significant role in addressing climate adaptation, conserving raw materials, and improving energy efficiency [61]. For example, the installation of plastic insulation can save 16% of energy and contribute to a 9% reduction in greenhouse gas emissions compared to conventional insulation materials such as mineral wool and glass foam [62]. Their advantages include low thermal conductivity and high water–vapor diffusion resistance factor, making them effective vapor barriers. On the other hand, their biggest disadvantage is high flammability, which is why flame retardants are added during the manufacturing process [63]. In parallel with these performance considerations, the global market for insulation materials was valued at $65.11 billion in 2023 and is expected to see continued growth, driven by rising awareness of energy conservation, regulatory policies, and increased infrastructure investments in emerging markets [64]. The construction and building sector represents the largest share of this market, accounting for $26.87 billion in 2024, with an anticipated 5.9% growth by 2030, with plastic insulation, particularly EPS, emerging as the fastest-growing segment [65].

The role of insulation materials in microplastic pollution has often been overlooked. This issue was highlighted in a study by Gao et al. [66], which found that more than half of the PS MPs in the environment originated from construction foam waste. Due to its low density and high buoyancy, this material is more susceptible to environmental influences and fragmentation, leading to its widespread distribution in ecosystems [67]. Insulation materials can contain highly problematic substances, such as hexabromocyclododecane (HBCD), which has been listed under the Stockholm Convention as a persistent organic pollutant (POPs). However, despite its classification, HBCD is still permitted for use as an exception in EPS and XPS insulation in buildings in some countries [68]. Although the source does not explicitly address MPs, the hazardous nature of the bulk material becomes even more concerning once it fragments into MPs. The reduction in size not only increases bioavailability but also enhances leaching potential, as smaller MPs release additives and associated chemicals more readily. This leaching is further influenced by environmental factors such as UV radiation, temperature, mechanical agitation, and biofilm formation [69, 70].

Piping

Plastics are important for ensuring safety and hygiene, as they are used to manufacture pipes that supply buildings with water and gas while also facilitating wastewater drainage. They are particularly valued for their high corrosion resistance and ability to be molded into various shapes [61]. PVC is the dominant material in this category, and although it is often described as durable and slow to degrade, real-world data indicate that it can develop severe defects and deteriorate faster than expected [71]. The production of pipes and fittings represents the largest market for PVC, accounting for 40% of total PVC consumption [72]. The biggest consumers of PVC pipes, aside from agriculture, are municipal and building water supply and drainage systems [73]. Data show that 25.9 million tons of PVC pipes were produced globally in 2024, and production is expected to increase to 36.3 million tons by 2032, despite concerns that PVC is one of the most toxic plastics [74].

Degradation of PVC pipes and generation of MPs is often accompanied by the leaching of (volatile) organic compounds, raising further concerns about water quality [75]. The release of MPs from pipes is highly dependent on the material used, with PVC pipes producing substantially more MPs than polyethylene (PE) pipes. The same study found that once these MPs enter the water, they increase turbidity, raise dissolved oxygen levels, accelerate chlorine decay, and promote the growth of heterotrophic bacteria [76].

Paints

Plastics play a crucial role in interior cladding, including wall linings, floor coverings, ceiling panels, and tiles [18, 77], as they are key components in surface protection coatings and paints, ensuring proper adhesion, enhancing durability, providing resistance to chemicals, weathering, and wear. They also help protect and extend the lifespan of coated surfaces [78]. Paints are composed of various ingredients, including pigments, dyes, solvents, fillers, additives, and binders. More than 90% of commonly used binders are made of synthetic polymers, including PUR, PS, polyester (PES), polyacrylates (PAA), vinyl, alkyds, and epoxies [79]. They consist of polymeric nanoparticles that form a suspension that is applied to surfaces. Upon curing, these particles bind together, creating a polymeric structure in the dried paint.

Over time, as these coatings degrade, they release secondary MPs into the environment [80]. In addition to generating secondary MPs, some paints also contain primary MPs [18]. MPs in paints are added to reduce density for easier application, enhance hardness, improve durability and scratch resistance, and create various surface effects, such as texture, matte finishes, and glitter [80].

However, paint losses occur throughout the entire material life cycle: during production, application, use, and end-of-use life. According to OECD estimates, approximately 1.5% of conventional decorative wall paint is washed into water merely from cleaning brushes after application, while over the entire life cycle around 40% of the material eventually leaks into the environment, with 63% of this already in the form of MPs [81]. The rate of microplastic release during use is highly dependent on the quality of the paint, the texture of the coated surface, cleaning methods, weather conditions such as precipitation and wind, as well as the location and orientation of the painted surface [82]. For building coatings, the main mechanisms of microplastic release include UV degradation of the binding polymer and mechanical wear from damage, regular use, and renovations, where sanding old layers removes previous coatings before new ones are applied [83]. Paints used in road markings represent another major source of MPs, where the primary mechanism of the release is tire abrasion against the road surface [84]. Both exterior building paints and road markings contribute substantially to environmental microplastic pollution, particularly because MPs are easily transported into surrounding ecosystems. Since emissions from painted surfaces are often discharged directly into the environment, without interception or treatment, data on MPs originating from paints are extremely inconsistent, with reported values varying widely across studies [85]. For instance, the Eunomia final report [86] estimates that each year between 21,100 and 34,900 tons of MPs from building paints enter European surface waters, accounting for around 3% of all environmental MPs, while road markings contribute an additional 94,358 tons per year, or about 12% [85]. By contrast, the Impact Assessment Report [87] provides much higher figures, estimating an annual release between 231,000 and 863,000 tons of MPs from building paints in the EU, making paints the single largest source of MPs, contributing approximately 43% of total emissions.

Adhesives and sealants

Adhesives and sealants are an integral part of the construction and built environment, used in virtually every phase of the building process. Plastics are a fundamental component of many adhesives, as they provide bonding strength, flexibility, and fatigue resistance while also making adhesive bonding a simple and cost-effective technique [88]. The selection of a suitable adhesive depends on various factors, including working properties, expected stress, chemical compatibility, and environmental conditions [89]. The same applies to sealants, which are composed of synthetic elastomers that can be applied as a paste, and once cured, form a flexible material that prevents the infiltration of air, water, or dust. The main types of sealants rely on polymers such as PUR, PAA, silicones, polysulfides, and others [88, 90].

Over time, adhesives degrade when exposed to environmental conditions, leading to the formation of MPs. In fact, up to 5,570 fragments of MPs have been shown to be released from just 1 cm^2 of degraded adhesive vinyl film [91]. Similarly, sealants used in the construction and built environment undergo weathering and mechanical stress, further contributing to microplastic pollution. Fang et al. [92] demonstrated that the degradation of polymer-based sealants results in the release of MPs, highlighting their role as an overlooked source of environmental contamination.

Building envelopes

Plastics also form other integral components of buildings, such as roofing, flooring, curtain walling, windows, and doors, which also contribute to microplastic pollution.

Roofing

In roofing systems, plastic is typically used in the form of impermeable membranes, such as those made from PVC, thermoplastic olefins, and chlorinated PE, which prevent water leakage and reduce heat loss. The energy efficiency of roofing systems can be further enhanced with foamed sheets made from materials like polyisocyanurate and PS [3]. Due to constant exposure to environmental factors, such as sunlight, rain, hail, snow, wind, atmospheric contaminants, and temperature fluctuations, roofing materials undergo gradual degradation [93]. Research on the degradation of polymer roofing membranes, like those made from PVC, often focuses on the mechanisms behind this degradation, particularly in relation to the loss of waterproofing properties [94], whereas their role in microplastic generation has received far less attention, despite evidence from some studies identifying roofing rainwater as a significant carrier of MPs [95, 96]. In addition to the degradation of the plastic materials themselves, MPs are also deposited on roofs through atmospheric deposition, which is frequently washed into rainwater collection systems, posing both ecological and health risks [95].

Flooring

Laminate planks and vinyl tiles are one of the most commonly used flooring applications due to their excellent wear and chemical resistance, low-maintenance requirements, and tolerance to moisture [97]. Floors are subjected to foot traffic, friction from furniture, cleaning processes, and environmental degradation, all of which lead to material damage and the formation of MPs. Jo et al. [98] highlighted the risk of microplastic contamination from flooring materials in schools, noting that the material hardness and age played significant roles in the release of MPs. They observed that older floors released a higher quantity of MPs. Floors can also be covered with carpet tiles, which have often been identified as a significant source of fibrous MPs in indoor environments [99–101]. In a study investigating microplastic generation due to human gait, carpeted floors produced 4.5 and 5.8 times more MPs compared to marmoleum (i.e., linoleum flooring) and laminate flooring, respectively [102].

Doors and windows

Plastic has increasingly replaced materials like aluminum, steel, and wood, including in door and window profiles, with PVC being the dominant material due to its economic advantages, design flexibility, energy efficiency, and low maintenance [103]. On top of that, the development of transparent plastics, such as polymethyl methacrylate, polycarbonate, and glass-fiber reinforced PES, has also led to replacing glass in many applications, due to cost benefits, lighter weight, improved mechanical properties, and superior thermal insulation [104]. While there is a lack of studies linking doors and windows directly to microplastic pollution, researchers [105] have examined the degradation of window frames in terms of their lifespan and material integrity. In a study on the degradation of window frames made from various materials, PVC was found to be highly sensitive to UV radiation and heat, showing severe discoloration. This degradation was also linked to the release of large amounts of toxic chemicals throughout the window's lifecycle [105].

Road construction

The construction and building sector also includes road infrastructure, where plastics are becoming an increasingly common component. Due to the rising volume of traffic and the impacts of climate change, there is a growing demand for more durable road surfaces that require less maintenance. This is often achieved through fiber reinforcement, which can include the use of plastic fibers. When incorporated into asphalt, plastic fibers strengthen the asphalt matrix, improving its mechanical stability and durability [106, 107]. Additionally, workability, as well as fatigue and deformation resistance, can be achieved via polymer-modified bitumen. For that, polymeric materials are added to bitumen, an oil-based material that serves as a binder in asphalt mixtures, which ultimately extends the lifespan of road surfaces [108]. Like concrete mixtures, plastics have shown potential as a substitute for traditional aggregate, particularly as a solution for managing large volumes of plastic waste. The substitution reduces asphalt density, improves flow properties, and enhances stability [109, 110].

However, roads are constantly exposed to different weather conditions and mechanical wear, leading to the release of MPs into the environment [111]. Tire and road wear have been identified as one of the largest sources of MPs in urban environments. These MPs generated through the abrasion process are often difficult to differentiate, and while past research has primarily focused on tire wear MPs, the contribution of road surface wear has often been underestimated [59, 112]. In colder climates, this problem is further worsened by the use of studded tires and anti-skid aggregates, which are commonly employed for safety reasons. Both contribute to increased abrasion of road surfaces, accelerating the release of MPs into the environment [113]. Once generated, the dispersion of MPs depends on precipitation, wind, and local infrastructure characteristics, which determine whether MPs accumulate in a specific area or spread into other ecosystems. The largest wash-off of MPs from road surfaces occurs during street cleaning and rainfall, which typically carries them into sewage systems [114]. Estimates indicate that roughly one-third of road MPs are removed by direct friction from traffic, while the remaining two-thirds are washed away by rainfall [115].

In addition to road traffic surfaces, pedestrian and recreational surfaces also contribute to MP pollution. Artificial turf, used not only in sports facilities, but also in other urban landscapes, is a notable example [116]. According to the European Chemicals Agency, an estimated 16,000 tons of MPs from granular infill are released into the environment annually, making it the largest single source of microplastic pollution [117]. This issue is further aggravated by the presence of hazardous chemicals, such as heavy metals and polycyclic aromatic hydrocarbons [118].

Other materials facilitating construction process

Plastics are often used to make consumable elements that play a crucial role in the construction process itself. Some of them can become permanent components of the built environment, contributing to functionality, durability, and protection. Examples include waterproofing and vapor membranes [119], geotextiles for soil stabilization [120], and facade anchors [121], as well as materials essential for electrical wiring within buildings [122]. In electrical applications, polymeric materials protect and insulate cables that carry electricity, due to their high electrical resistance. While PVC is the most used material for this purpose, other plastics such as PE, PES, polytetrafluoroethylene, nylon, and rubber are also widely utilized. To meet specific performance requirements, these materials are often modified with various additives, including stabilizers, flame retardants, fillers, lubricants, and smoke suppressants [3].

In addition to permanent components, plastics are extensively used in temporary construction elements that facilitate the building process but are later removed. These include polymeric membranes that retain moisture and regulate the curing and hardening of concrete [123], plastic molds for precast elements [124], and spacers that ensure the correct placement of individual components [125]. Such materials enhance precision, efficiency, and ease of installation, ensuring a smooth and controlled construction process.

Another important category of consumables is packaging, which is especially relevant in the context of transporting building components to construction sites. The increasing use of prefabricated materials, along with the need for enhanced protection of traditional materials, has led to a sharp rise in plastic packaging consumption [126]. Gonzales et al. [126] estimated that constructing 100 houses requires approximately 1,700 kg (or 35 m^3) of plastic packaging materials, primarily in the form of protective films.

The materials mentioned can contribute to microplastic pollution through wear and gradual degradation. For example, dust-proof nets used to cover bare land in China have been recognized as significant sources of MPs, contributing to their accumulation not only through the degradation of the nets but also by trapping MPs from other sources. Soil covered with plastic nets at construction sites contained 5.8 times more MPs compared to uncovered soil [127]. Geotextiles are another important source, with fibrous MPs released at levels comparable to those from the breakdown of fishing nets or industrial laundry [128, 129]. Their degradation is primarily driven by photooxidation, but exposure to water further enhances the breakdown, increasing the risk of microplastic release from such materials [129]. Additionally, the issue of MPs can be linked to the presence of POPs, such as Dechlorane Plus, used in the coating of electrical cables and wires [130].

Detection and analytical methods for construction-derived microplastics

A thorough review of the literature on the use of plastics in different product families in the construction and built environment and their contribution to the formation of MPs reveals that the available information often varies in terms of presentation, methodology, or scope, making comparisons between studies difficult. The information given by the authors differs from each other to the extent that they cannot be unified or directly compared, making in-depth comprehensive qualitative and/or quantitative analysis impossible. In fact, in some cases, studies on specific applications are entirely absent. Although it is evident from empirical observation that plastic materials gradually degrade and generate MPs, there is, for instance, not a single study explicitly addressing microplastic release from window or door profiles. This lack of more detailed, consistent, and critical data significantly hinders efforts to assess the actual extent and pathways of microplastic release from the construction industry, which limits the possibility of a broader understanding of the issue.

One of the key challenges in managing and limiting MPs from the construction and built environment is the extreme heterogeneity of particles that fall under this category. As emphasized by Hartmann et al. [131], the term "*microplastics*" encompasses a wide spectrum of particles that differ in polymer type and chemical additives, size, shape, color, structure, and origin of formation. This diversity complicates the selection of appropriate analytical approaches and detection methods.

These challenges emerge already at the first stage of environmental studies: sampling. Sampling strategies can be classified as selective (targeted collection of suspected MPs), bulk (non-selective collection of an environmental sample volume), or volume-reduced (partial separation during collection to retain only the most relevant fraction) [132]. For example, in aquatic environments, MPs originating from construction materials have been collected using devices based on mechanical filtration, such as mesh drift nets and manta trawls [66]. Terrestrial samples, by contrast, were obtained with soil drills [91], while atmospheric fallout was passively captured either in large containers placed on rooftops in populated urban areas [99] or in Petri dishes indoors [100]. After sampling, MPs must be separated from often complex environmental matrices using techniques such as density separation, sieving, filtration, or visual sorting [132]. An alternative approach is to investigate the release of MPs directly from the building or other objects by analyzing the changes occurring in the bulk material. For instance, Burghardt et al. [84] evaluated wear and material loss from road markings, a known source of MPs through abrasion.

Subsequent characterization depends on the properties of the MPs and the research objectives, and in the context of construction MPs, a variety of analytical techniques have been employed. For example, X-ray fluorescence (XRF) has been used to determine elemental composition [66], Fourier-transform infrared spectroscopy (FTIR) to identify polymer types [66, 67, 91, 100], Raman spectroscopy to characterize polymer structures and pigments [92, 133], and scanning electron microscopy (SEM) often coupled with energy-dispersive X-ray spectroscopy (EDS) to assess surface morphology and elemental composition [67, 101, 113]. In addition to MPs characterization, some studies focused also on chemical additives embedded in construction plastics. For instance, to analyze brominated flame retardants leaching from insulation materials, high-performance liquid chromatography coupled with mass spectrometry (HPLC–MS) was applied after dissolving EPS samples [67].

Several studies have also simulated microplastic generation under controlled laboratory conditions. For example, Temam and Mortula [75] investigated leaching from PVC pipes under varying pH, chlorine concentrations, and retention times, analyzing the resulting water samples with total organic carbon (TOC) measurements, and made ATR-FTIR and SEM–EDS analyses on filtered MPs. Sheng et al. [76] compared different pipe materials, employing flow cytometry to quantify MPs, SEM for surface characterization, and genetic analyses of biofilms colonizing the MPs. Others prepared innovative set-ups that include devices for accelerated friction testing, simulating pedestrian traffic and monitoring the release of MPs using particulate matter (PM) sensors [101, 102].

Due to the great variability in the properties of MPs and, more importantly, the different scenarios in which they occur, no single standardized protocol can be applied universally. Researchers must therefore adapt existing methods to specific cases, often relying on empirical experience. Nevertheless, ISO 24187:2023 [134] provides valuable overarching principles for sampling in different environmental matrices, sample preparation, and subsequent analysis, which is a crucial step toward greater harmonization. It is therefore crucial for researchers in this field to align their methods with these guidelines to improve the comparability of data and enable more robust conclusions.

Sustainable development in construction and building industry and potential use of microplastics

Eco-friendly progress and transition to circular economy

Human activity has significantly harmed the natural environment through resource overuse and excessive waste generation. Concerns about these impacts were raised as early as the 1960 s, when scientists began warning about the consequences of rapid development [6]. Today, the construction and building industry alone consumes approximately 40% of all raw materials globally [135]. Additionally, rapid urbanization and economic growth have intensified construction and demolition activities, resulting in a steady increase in waste production. In 2020, the activities associated with the construction and building sector accounted for 37% of all waste generated within the European Union [136].

Recognizing its scale and environmental footprint, several studies [137, 138] have highlighted the construction and building sector's essential role in achieving sustainable development, revealing its direct and indirect connections to multiple Sustainable Development Goals [139, 140]. For example, the goal related to *Industry, Innovation and Infrastructure* emphasizes the importance of adopting innovative technologies; *Sustainable Cities and Communities* focus on reducing environmental impacts and building resilient urban environments; *Responsible Consumption and Production* further emphasizes the need to optimize resources and reduce waste.

A key pathway toward achieving these goals is the transition from a linear to a circular economy, a model that utilizes innovative technologies to seek economic progress while simultaneously delivering positive environmental impacts. Circular economic principles focus on extending the lifespan of materials, ensuring they remain in use for as long as possible. This approach not only reduces waste generation, but also minimizes the need for extracting primary resources [141–143]. In the construction and building sector, circularity can be advanced through innovative design practices, the use of recycled or renewable materials, and continuous monitoring of material conditions throughout their lifecycle. It also involves identifying opportunities for material reuse and refurbishment after demolition, responsibly managing generated waste, and adopting a range of other strategies to minimize environmental impact and maximize resource efficiency [144].

To measure and track the effectiveness of the transition, the European Union framework employs 11 statistical indicators to monitor each phase of a product's life cycle, providing a comprehensive assessment of progress toward circularity [143, 146]. These indicators are divided into five thematic sections: production and consumption, waste management, secondary raw materials, competitiveness and innovation, and global sustainability and resilience, all of which also relate to the construction and building industry. Efforts aligned with this framework have already yielded positive results. For instance, the recovery rate of construction and demolition waste in the European Union has significantly improved, reaching an average of 88% in 2020 [147]. Despite advances in the recycling and recovery of construction and building materials, the impact of MPs on the environment and humans, released during the use, demolition, and processing of these materials for reuse within the circular economy, remains largely unexplored [18].

Following the direction set by the European Green Deal, MPs are increasingly being considered for integration into both open-loop and closed-loop circular economy systems. While this represents a promising step toward more sustainable material management, the field remains in its early stages. There is currently a lack of data and systematic studies on how MPs are released from individual building products, how to effectively capture/reduce them, how embedded MPs behave when incorporated into new material matrices, whether they are immobilized there or further contaminated, how they are released from recycled material, what their fate is at the end of their useful life, whether they are released during recycling stages and to what extent, and whether this impacts the environment, etc.

Incorporation of microplastics into new materials

According to the principles of the circular economy, the reuse and recycling of materials are the highest priorities in end-of-life material management, followed by composting, then incineration, with waste disposal ranking the lowest [148]. In primary recycling, where the material's properties must remain unchanged so it can be reused for its original purpose, the material has to be inherently recyclable and pure. This is often challenging for plastics, as the diverse polymer types along with various additives result in a vast array of combinations. As a result, secondary recycling is more commonly applied to plastic waste and also holds potential for utilizing MPs [149]. This approach presents an opportunity for the inclusion of such MPs in new materials, where they serve as a novel component that can significantly influence mechanical properties and durability, largely depending on their interaction with the surrounding matrix of the base material [150].

The incorporation of MPs into materials as a part of the circular economy is currently primarily focused on developing innovative strategies to manage the vast amounts of plastic waste generated worldwide. This approach is commonly applied in the construction materials industry, where they serve either as a (partial) replacement for aggregate or as reinforcing elements in cementitious and asphalt mixtures. Typically, MPs are produced by cutting or grinding larger pieces of plastic [151–154], whose properties are sometimes further enhanced through additional treatments [155, 156]. The most common sources include mixed plastic waste, PET bottles, discarded PVC products, textiles of various origins, rubber, etc. Table 1 presents state-of-the-art studies on the integration of MPs into new materials, providing information on the basic properties of the MPs used and highlighting their potential applications.

Some studies have also explored the use of secondary MPs, which are not intentionally produced for incorporation into new materials (e.g., fibers captured by filters in the textile industry [157] or generated during the manufacture of PVC products [158, 159]). Recycling and refurbishing facilities also produce MPs, often in the form of powders or fibers, which can be repurposed for use in new materials [160, 161]. However, due to the small size and complex behavior of MPs in the environment, technologies for their capture from environmental matrices are still in their infancy [162]. Consequently, our literature review did not identify a single study in which MPs obtained directly from natural ecosystems were used for incorporation into construction materials as part of environmental remediation efforts.

In the construction and built environment, MPs can replace traditional aggregates in varying proportions, thereby affecting the physical, mechanical, and durability characteristics of construction materials [163]. Beyond the positive environmental impact of reducing waste generation and minimizing the exploitation of natural resources, the use of MPs is also associated with the lower density of plastics. This results in the reduced weight of the final product and can provide economic benefits [159]. Generally, plastic particles can substitute both coarse and fine aggregates. However, it is important to note that most published studies focus on particles larger than 1 mm, which applies not only to coarse aggregates, but also to many studies investigating fine aggregates. In accordance with the definition of MPs according to the ISO 24187:2023 [134] standard, in the following article, we focused primarily on smaller plastic particles, up to 1 mm in size.

Understanding how they interact with construction matrices is essential, as the mechanical properties of construction materials with incorporated MPs vary considerably. In most cases, reductions in flexural, tensile, or compressive strength are reported [159, 160, 164], although some studies indicate no significant changes in strength [165]. These differences result both from the properties of the MPs themselves and from the conditions under which the composites are produced. Since MPs comprise a wide range of particles with different chemical compositions, shapes, and sizes, their effects on material properties are inherently inconsistent. The concentration of MPs also plays a decisive role: a higher replacement of traditional aggregates by MPs generally leads to a greater loss of strength. The lower strength is primarily due to poor interfacial bonding between the MPs and the cementitious matrix, which increases the void content and weakens the strength of the material [160, 165]. However, strength reduction needs to be interpreted in the context of practical applicability. Mendonca et al. [160] showed that, despite a decrease in compressive strength, concrete containing up to 7.5% MPs still complied with established standards. Moreover, the negative impact on strength can sometimes be offset by co-incorporating other types of waste, such as fibers, which enhance bonding, and in some cases, restore or even improve strength compared to the reference sample [165].

Although many studies report a decline in mechanical strength, certain other properties may benefit from the incorporation of MPs. For instance, Bahmani et al. [164] observed that incorporating PET and tire wear MPs reduced thermal conductivity, leading to improved insulation properties. This effect is attributed to the inherently lower conductivity of MPs compared to sand, as well as the increase in porosity, as trapped air pockets act as thermal barriers. Beyond conventional mixes, the replacement of fine aggregates has also been explored in advanced applications, such as 3D-printed concrete. However, the incorporation of MPs in these mixtures has resulted in reduced mechanical properties of the final product [166].

Table 1 Current research on the integration of MPs into new materials

Original material	Preparation/treatment	Type of MPs used in final product/material	Particle size	Final product/material	Source (author and title)
Waste plastic shreds (mostly PET)	Milling Bio-oil and graphene-coating treatment	Carbon-coated PET granules	297–595 µm	Asphalt mixture	Sadat Hosseini et al. 2024 [156]
Waste plastic shreds (mostly PET)	Milling Oil treatment	PET powder	Dimensions not specified	Asphalt mixture	Hajikarimi et al. 2022 [155]
Waste plastics	Shredding, melting, extruding, milling	Pellets	< 1 and < 5 mm	3D-printed concrete	Oosthuizen et al. 2023 [166]
Mixed plastic waste	Cutting	Mixed powdered MPs	1—2 mm	Flash graphene for cement composite	Algozeeb et al. 2020 [170]
Industrial and domestic waste (PET foam, PET bottles, EPS waste)	Grinding	PET and EPS powder and flakes	30–110 µm	Eco-friendly foam	Caniato et al. 2021 [176]
Waste plastic bottles	Crushing and milling	Waste plastic powder	200 µm	Concrete	Najaf et al. 2022 [190]
Recycled PE bottles	Milling	PE powder	50—500 µm	Geopolymer	Xie et al. 2024 [154]
Waste plastic bottles	Grinding	PET flakes	0.45–0.5 mm	Asphalt binder modification	Mashaan et al. 2022 [108]
Micronized PET from plastic bottles (recycled)	Without modifications	PET powder	Dimensions not specified	Concrete blocks	Mendonca et al. 2023 [160]
Waste plastic bottle shreds synthetic and polymer powder used for fillers for structural paints	Without modifications	Waste plastic flakes (WPF) and synthetic polymer powder (SPP)	WPF: 0.28 and 0.45 mm SPP: 0.65 mm	Ultra-high-performance concrete	Ahn et al. 2023 [191]
Recycled tire and PET powder	Not specified	Tire and PET powder	50–150 µm	Thermal-insulating geopolymer concrete	Bahmani et al. 2024 [164]
Waste tires	Milling and grinding	Rubber powder	1.18 mm (90% of particles)	Concrete	Steyn et al. 2021 [192]
Waste tires (tire recycling plant)	Shredding, sieving	Rubber powder	0.1–0.84 mm	Cement–clay composite	Al-Subari et al. 2021 [193]
Waste truck tire tread rubber	Waterjet grinding process	Waterjet-produced rubber powder	90–300 µm	High-value applications of waste rubber	Hao et al. 2023 [194]
Devulcanized rubber (used automobile tires)	Crumbing, ultrasonic devulcanization process	Devulcanized rubber powder	Dimensions not specified	Heat insulation composite	Hittini et al. 2021 [195]
Waste rubber powder	Graft modification	Modified rubber powder	0.18 mm	Asphalt binder additive	Wang et al. 2021 [167]
Textile waste microfibers from textile finishing plant	Without modifications	Fibers (61% cotton, 29% cotton blend, and 10% synthetics)	Length: 3.65 ± 2.57 mm Diameter: 17.28 ± 1.68 µm	Cementitious composite	Malchiodi et al. 2022 [157]
Disposable medical mask	Shredding	PP fibers	Dimensions not specified	Cement reinforcement	Chen et al. 2023 [153]
End-of-life fishing nets	Cutting and grinding	Nylon fibers	4 mm	Polystyrene and Acrylonitrile Butadiene Styrene	Liotta et al. 2023 [174]
Waste PVC from industrial pipe cutting for commercial application	Without modifications	PVC in the form of fibers and powder	Fibers: 0.2—5 mm; Powder: 0.08—2 mm	Green mortar pavers	Guzman et al. 2024 [159]
Waste PVC	Not specified	PVC powder	Dimensions not specified	PVC/paper biocomposite	Ye et al. 2023 [175]
Electrical cable waste	Cutting and sieving	Powder and fibers	Powder: 0.15–1.18 mm Fibers: L = 3 cm, d = 1.3 mm	Sustainable Mortar	Hasan et al. 2023 [165]

Table 1 (continued)

Original material	Preparation/treatment	Type of MPs used in final product/material	Particle size	Final product/material	Source (author and title)
Redundant wind turbine blades	Cutting, shredding, sieving)	Powder (glass fiber, resin (epoxy, butyral), and auxiliary materials)	Powder: below 0.075 mm Fibers: 0.075–9.5 mm	Asphalt mixture	Lan et al. 2023 [151]
PE particles (industrially produced)	Without modifications	PE particles	297, 147, and 25 μm	Composites with electromagnetic shielding properties	Xiang et al. 2023 [177]
PE (not specified in which form)	Milled	PE powder (irregular flakes)	2–16 μm	Carburized-FeCoNiMn high-entropy alloys	Liu et al. 2024 [178]

Ultimately, the successful incorporation of MPs requires their careful selection and preparation, as well as adjustments to the material preparation process. Compatibility issues between MPs and the matrix can be partially mitigated through surface treatment, which enhances the bond between components [155, 156]. Without such adaptations, the hydrophobic nature of MPs affects the cement hydration process, leading to increased porosity and higher water absorption, which typically results in reduced mechanical performance [160]. Furthermore, some researchers have focused on using MPs to modify asphalt binder [108, 167]. The incorporation of waste MPs into bitumen during asphalt preparation is reported to improve rutting and fatigue cracking resistance [108].

As previously mentioned, another common application of MPs in the construction and built environment is their use as reinforcing elements. Due to their structure and geometry, fibrous particles are typically utilized for this purpose. The incorporation of fibers modifies the material's microstructure and influences properties such as shrinkage, workability, and mechanical performance. The overall effect depends on several factors, including the polymer type, fiber geometry and size, and the quantity of fibers added to the final material. Generally, the elongated shape of fibers facilitates crack bridging and load redistribution, effectively dissipating energy. Beyond improving impact resistance and crack control, fibers can positively affect strain capacity, toughness, and strength [168, 169]. Typically, raw fibers used for this purpose are made from materials such as PP, PE, polyamide, and polyvinyl alcohol, with their lengths usually exceeding 5 mm [169]. However, researchers are exploring sustainable alternatives to traditional fibers, including the use of fibrous MPs as secondary raw material.

MPs replacing conventional fibers are most frequently incorporated into cement and asphalt mixtures [151, 153, 157, 170]. When integrating MPs as reinforcing elements, researchers focus primarily on whether secondary fibrous MPs can be effectively incorporated into the matrix and how their inclusion impacts the material's properties. In some cases, the addition of MPs improves specific material characteristics, such as ductility, deformability, and crack propagation control [151, 158]. Randomly distributed fibrous MPs act as bridges within the matrix and improve cohesion and resistance to crushing or splitting. Under load, these composites deform more plastically and exhibit greater ductility, with the fibrous MPs preventing sudden failure. Acting as crack-bridging elements, fibrous MPs also delay crack initiation and propagation, thereby improving post-cracking behavior. However, not all mechanical properties respond equally to their incorporation. The flexural strength depends strongly on the fiber length, their distribution, and experimental conditions. Short fibers, including fibrous MPs, exhibit weak interfacial bonding with the cementitious matrix and tend to increase porosity, which can create weak points that ultimately reduce flexural strength. In contrast, this negative effect is not observed with longer fibers, which are more effective at maintaining load transfer across the matrix. Interestingly, multimodal reinforcement that combines both short and long fibers has been shown to markedly enhance flexural strength by improving crack control and increasing the overall load-bearing capacity of the composite [171]. In the case of compressive strength, the reduction is not only linked to the weaker bonding of MPs with the cement matrix but also to their intrinsic material properties. Since most MPs possess lower mechanical strength compared to the surrounding cementitious phase, their presence reduces the overall load-bearing capacity of the composite. Nevertheless, the fibrous MPs help to maintain the structural integrity of the specimens by reducing the likelihood of complete disintegration, which can be seen as an advantage for long-term durability. To address these challenges, fibrous MPs are sometimes further processed to modify their surface properties, which results in enhanced bonding with the matrix [153, 157].

Although fibers are the predominant reinforcing element in construction mixtures, the mechanical properties of the final product can also be enhanced by incorporating MPs with superior properties. For example, waste MPs can be converted into flash graphene using the flash Joule heating method. This upcycling process produces highly durable graphene particles that, even at minimal concentrations (0.035%) in a cement matrix, have been shown to significantly improve the compressive strength of Portland cement [170].

Researchers have also explored the integration of MPs into alternative materials, such as geopolymers, which serve as substitutes for traditional cement and offer a considerably lower carbon footprint, given that cement production accounts for at least 8% of global CO_2 emissions [172]. Geopolymers can exhibit comparable or even superior mechanical and durability properties relative to conventional cement while being synthesized from industrial by-products such as fly ash, slag, or even construction and demolition waste, thereby diverting large waste streams from landfills and supporting circular economy principles [173, 145]. By adjusting preparation conditions, such as MPs size, quantity, and curing temperature, they investigated the optimal conditions for enhancing mechanical properties and thermal resistance [154]. In the context of addressing marine plastic waste, another study has focused on preparing polymer composites by embedding discarded fishing nets into post-consumer

PS or acrylonitrile–butadiene–styrene matrices [174]. Additionally, some researchers have developed bio-composites from waste PVC powder and paper, which exhibit promising mechanical characteristics [175]. Beyond wood–plastic composites, which have a wide range of applications also in the construction and building sector, MPs can be incorporated into other bio-based matrices. For instance, it is possible to create sustainable foam for thermal and acoustic insulation from finely ground industrial waste and an alginate matrix [176]. Finally, MPs also hold potential for specialized applications, such as the development of composites with electric shielding properties [177] or high-entropy alloys [178].

The literature review shows that the integration of MPs into new materials is technically viable and can in some cases contribute to improved performance characteristics of the final product. However, our current understanding of the true potential and constraints of such approaches remains limited. Research on the incorporation of MPs into new products mostly contains data on the technical processes of incorporation and the characterization of the final properties and rarely provides data on the consumption of resources for recycling, such as energy, water, and additional raw materials. Information on the fate of MPs after incorporation into recycled products and on the potential impacts on the environment and human health is often missing in those articles. When finding a way for new products with incorporated MPs to reach the market, a comprehensive life cycle assessment (LCA) or European product declaration (EPD) would be essential for making decisions regarding their production and large-scale implementation.

Challenges, research gaps and further directions

A review of the literature and closer examination of the field make it evident that research on MPs from the construction and built environment is still in its infancy and lags significantly behind other sectors. One of the primary obstacles in understanding MPs from construction materials (as well as from other sources) lies already in their detection and analysis, as also outlined in Sect. 3.9. Because of their small size, MPs are difficult to detect and properly sample, and the currently available methods for reliable quantitative and qualitative assessment remain limited. Environmental samples typically contain MPs dispersed within large volumes of material, which require pre-concentration or separation of MPs during sampling. These procedures also increase the risk of contamination and misleading results. In addition, the term "*microplastics*" encompasses a very broad group of particles with diverse morphologies and polymeric structures, surface coatings, and a large surface area prone for the adsorption of chemicals. Simple density-based separation is often ineffective, as many polymers have densities close to that of water. Over time, MPs fragment into even smaller particles and interact with the environment, becoming embedded in matrices such as soil or sediment, or colonized by microorganisms that form biofilms, which further mask the MPs [179, 180]. This adds to the difficulty of identifying and isolating MPs even for research purposes, while remediation projects face an even greater challenge, as MPs are virtually impossible to remove on a large scale once they have entered the environment [181]. In this context, ISO 24187:2023 [134] provides an important first step by outlining general principles for sampling, sample preparation, and analysis across different environmental matrices, yet its practical impact is still limited. Harmonized methodologies have not been broadly adopted so far, and the continued reliance on diverse, non-standardized methods hinders comparability between studies and prevents the development of robust, universally applicable conclusions.

The same applies to studies on the effects of MPs on human health, where the current scientific consensus remains divided. Some argue that environmental concentrations are still sufficiently low not to pose immediate risks to human health [182], while others highlight well-documented negative impacts on various parts of the human body, including the digestive, excretory, respiratory, and nervous systems, as well as internal organs and even the placenta [183]. These effects may result from (1) the MPs themselves, which can cause physical damage; (2) chemical additives incorporated during plastic production and subsequently leached out; or (3) pollutants and pathogenic microorganisms that attach to MPs in the environment, turning them into vectors [184].

Despite these observations underscoring potential risks and the strong emphasis on safety in the construction and building sector, the inconsistency of research findings and the mixed conclusions drawn from available studies hinder progress in policymaking. Yet harmonized legislation is precisely what is needed to improve the management of MPs and to protect both environmental and human health [185]. In recent years, MPs have gained recognition in European policy, prompting the development of concrete initiatives. In line with the Green Deal, the Zero Pollution Action Plan [186] has set a target to reduce microplastic emissions by 30% by 2030. For the construction and building industry, given its scale and its frequent neglect as an important source of MPs, progress toward these goals remains even more challenging.

To tackle this problem in the construction and building sector, priority must be given to both the development of durable materials with lower degradation potential and the proper management of plastic-based products throughout their life cycle in order to minimize microplastic emissions. In addition, sources of pollution must be accurately identified and collection systems set up as close as possible to the point of release. Over time, MPs become even smaller and are increasingly difficult to distinguish from natural particles, making them even harder to remove. Strengthening monitoring systems is also essential to provide reliable data on actual environmental concentrations of MPs and to track progress following the implementation of mitigation measures. Special attention should be given to large-scale construction activities, which can significantly accelerate microplastic generation and release. Examples include major renovation projects or building demolitions, where clear guidelines are needed to limit emissions of MPs into air, water, and soil. In this context, requiring plastic manufacturers to systematically report the microplastic generation potential of their products would be an important action in achieving greater transparency and supporting more effective long-term mitigation strategies. One promising approach in this direction is also the use of the MicroPlastic Index (MPI), a metric that reflects how prone different polymers are to break down into MPs under mechanical stress [189]. It might also be worthwhile to investigate the link between the MPI and CO_2 emissions (as part of an LCA or EPD analysis), which would support a more comprehensive environmental assessment. Consistently reporting results of the analyses linking the mechanical and physical properties of polymers to microplastic pollution and the greenhouse gas emission indicator (as CO2 equivalent) would provide a comparable and useful tool for identifying materials with a lower environmental impact and promote sustainable alternatives.

In this context, the use of plastics in construction and building should be reduced and replaced with sustainable alternatives wherever feasible to prevent the formation of MPs in the first place, rather than simply mitigating the outcomes of plastic use. One promising example is the use of bio-based insulation materials produced from wood fibers, hemp, wool, cellulose flakes, or other natural feedstocks [187]. Nevertheless, it must be acknowledged that plastics are often selected for their capacity to enhance energy efficiency, improve safety, and reduce maintenance requirements of buildings [61]. As highlighted earlier, decisions regarding substitution require a careful life cycle perspective that considers the overall environmental footprint.

Another critical aspect concerns the widespread use of disposable plastic products in construction. Large amounts of packaging materials are used to protect raw materials or prefabricated elements during storage and transport. Reducing this dependency on single-use construction plastics and promoting biodegradable alternatives would represent an important step forward.

Ultimately, overcoming these challenges requires not only scientific and technological progress, but also socioeconomic feasibility. The successful implementation of measures such as material substitution, improved collection systems, and large-scale monitoring depends on adequate political support, financial incentives, and the commitment of industry stakeholders. Raising awareness among industry, policymakers, and the general public is crucial. Only through concerted efforts can meaningful progress be made in reducing microplastic pollution from the construction and building sector and protecting the environment and future generations.

Conclusion

Plastics are widespread in the construction and built environment, whether as packaging for construction materials, building elements, components that support the construction process, or within composite materials to enhance the properties of the final material. While plastics in the construction and building industry generally have a longer lifespan compared to other sectors, the sheer scale of their use is immense. Combined with population growth and increasing infrastructure demands, this has led to an ever-growing dependence on plastics. To put this in perspective, in 2022, the total global building floor area reached 201 billion square meters, with projections estimating an increase to 298 billion square meters by 2030 [188]. As a result, the generation of MPs during construction, use, and demolition is also increasing, making it a pressing environmental concern.

Despite the exponential growth of microplastics research in recent years, their role in the construction and built environment remains largely underexplored. Standardized methods for detecting and quantifying MPs in construction materials are lacking, and the mechanisms by which they are released are still poorly understood. Our in-depth review further reveals that obtaining reliable data for meaningful quantitative and qualitative assessment is extremely challenging. Available information is often limited, incomplete, or so specifically tied to individual case studies that meaningful comparisons are difficult to make. As a result, a comprehensive understanding of the issue, regarding also the environmental and human health impacts of construction-derived MPs, remains unclear. Advancing data comparability and promoting consistent reporting practices would represent a crucial step toward supporting impact assessments and better control of microplastic emissions from construction materials.

On the other hand, within the framework of sustainable development, researchers are exploring ways to incorporate MPs into new materials. In the context of the circular economy, this approach typically repurposes plastic waste by incorporating it into construction materials, either as a partial replacement for traditional aggregates or as reinforcement in cementitious and asphalt mixtures and immobilizing it there. In addition to reducing waste, these methods can enhance material properties and lower costs. However, it is important to note that most MPs used in these applications are derived from larger plastic pieces that have been mechanically processed, while the direct incorporation of pre-existing MPs remains rare. Reuse efforts are currently limited to MPs sourced from industrial processes, as recovering MPs from natural ecosystems remain constrained by challenges in detection and capture technologies.

While these practices extend the functional lifespan of plastics, they also raise concerns about unintended consequences. Potential risks include the creation of materials that are difficult or impossible to recycle and the increased release of MPs due to long-term environmental exposure. In attempts to solve one issue, there is a risk of creating another, potentially even greater and more difficult to manage, especially as MPs fragment into smaller sizes, their capture and removal from the environment becomes increasingly challenging. Therefore, before the use of MPs in building practices is widely adopted, it is crucial to thoroughly evaluate their environmental, economic, performance-related, social, and health impacts [149]. That said, addressing MPs in the construction and building sector requires a multidisciplinary approach, bringing together scientific research, industry innovation, and regulatory action to develop effective and responsible solutions.

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Declarations

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Author details
[1]Slovenian National Building and Civil Engineering Institute, Dimičeva Ulica 12, 1000 Ljubljana, Slovenia. [2]Faculty of Chemistry and Chemical Technology, University of Ljubljana, Večna Pot 113, 1000 Ljubljana, Slovenia. [3]Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, 61669 Brno, Czech Republic. [4]Biotechnical Faculty, Department of Biology, University of Ljubljana, Jamnikarjeva 101, 1000 Ljubljana, Slovenia.

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