

Sustainable Organic Materials Used in the Construction Sector

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1. Introduction

The construction sector remains one of the largest consumers of raw materials and energy and, therefore, one of the most important fields for implementing circular-economy strategies and low-carbon technologies. Conventional infrastructure and building materials, such as fossil-based bituminous materials, cement-based materials, polymeric composites, fibers, natural aggregates, reinforcements and ancillary functional materials, have historically depended on non-renewable resources. Their production, processing, transportation, construction and maintenance impose substantial environmental burdens over the service life of civil infrastructure. In response, researchers and practitioners have increasingly focused on sustainable organic materials and organic-modified construction materials, including plant-derived products, bio-based additives, recycled polymers, waste-derived modifiers, rubberized materials, recycled carbon fibers, and hybrid material systems that combine mechanical performance with reduced environmental impact.

This Special Issue, ‘Sustainable Organic Materials Used in the Construction Sector’, was established to collect research-, development- and application-oriented studies dealing with sustainable solutions in civil engineering, material science and related domains. Its scope emphasized sustainable development, organic materials, infrastructure and building construction, organic plant-based materials, biomass-based bioproducts and biochemicals, and green products. The Special Issue also covered applications in buildings, roads, railways, bridges and other infrastructure systems, including asphalt concrete, cement concrete, fiber-reinforced composites and hybrid materials.

A total of 25 research articles were published in this Special Issue, collectively receiving 350 citations and 93,874 webpage views as of June 2026. These metrics demonstrate the strong academic impact, extensive international visibility, and broad readership of the Special Issue within the sustainability, materials science, and civil engineering communities. Several highly cited articles have substantially advanced the understanding and application of sustainable organic materials, particularly in machine-learning-based eco-friendly concrete design [1], with other highlights including the life-cycle sustainability assessment



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of an FRP composite footbridge [2], coal-ash sustainable brick study [3], eco-friendly structural concrete mix design study [4], urban heat island pavement study [5], and multiple papers on polyurethane-modified bitumen and plastic-waste-modified asphalt [6,7]. The scientific contributions presented in this Special Issue have not only enriched the current body of knowledge but also provided practical guidance for the development and implementation of low-carbon, resource-efficient, and circular construction materials and infrastructure systems. This implementation dimension is one of the key strengths of the Special Issue, as it bridges laboratory-scale material innovation with construction practice and infrastructure management.

2. Synthesis of the Contributions to the Special Issue

The 25 contributions can be organized into four interrelated themes. The first two themes focus on road materials, where organic and recycled constituents are used to improve the sustainability and performance of asphalt mixtures and binders. The third theme covers cementitious, geotechnical and railway materials, showing how waste-derived and low-carbon resources can be integrated into structural and non-structural construction components. The fourth theme highlights digitalization, life-cycle sustainability assessment, urban heat mitigation and multifunctional surface technologies, which expand the role of sustainable organic materials from material substitution to system-level infrastructure performance.

2.1. Recycled and Sustainable Asphalt Mixtures for Circular Pavement Construction

This theme reflects the increasing demand for pavement rehabilitation strategies that reduce the consumption of non-renewable materials while maintaining adequate workability, mechanical performance and long-term durability. The papers address plant, cold, and hot in-place recycling, permeable asphalt containing reclaimed asphalt pavement (RAP), high-content recycled SBS-modified asphalt mixtures, and the influence of blending behavior on recycled mixture performance.

Yang et al. [8] investigated the compaction characteristics of plant recycled hot-mix asphalt mixtures via a comprehensive experimental work. Their results indicated that finer gradation, higher gyration temperature, increased gyration number and higher RAP content improved compactability, and that RAP content up to 50% could contribute to achieving target void contents more efficiently.

Duan et al. [9] examined the initial anti-wear performance of emulsified asphalt cold-recycled mixtures via a case study in northern China. Cold recycling has significant sustainability advantages; however, early-stage surface wear and construction traffic resistance are critical. This study supports the practical use of cold recycled mixtures under regional environmental and traffic conditions.

Zheng et al. [10] focused on the viscoelasticity of recycled asphalt mixtures with high contents of reclaimed SBS-modified asphalt pavement. The study contributes to the understanding of viscoelastic response in mixtures containing reclaimed SBS-modified materials and helps define performance-related evaluation approaches for high-RAP applications.

Xiao et al. [11] studied permeable asphalt mixtures containing RAP. Permeable asphalt contributes to stormwater management, drainage and urban heat mitigation, while RAP incorporation improves material circularity. The work suggests that RAP can be used in permeable systems when mixture design is properly controlled, thereby extending RAP recycling beyond dense-graded asphalt layers.

Wang et al. [12] investigated the effect of blending behavior on the performance of hot recycled asphalt mixtures. By emphasizing blending behavior, this study advances the

mechanistic understanding needed for high-quality recycled asphalt mixture design rather than relying only on empirical RAP content limits.

Wang et al. [13] further extended this theme by evaluating hot in-place recycled asphalt mixtures, including RAP analysis, compaction characteristics and field evaluation. Their study demonstrates how recycled pavement technologies can be assessed using both material characterization and field performance indicators.

2.2. Organic, Polymeric and Waste-Derived Modifiers for Asphalt Binders

This theme addresses asphalt binders modified by organic, polymeric or waste-derived materials. Asphalt binder modification is a critical pathway for improving durability, lowering production temperature, using waste resources and tailoring performance for climate- and traffic-specific conditions. The papers under this theme cover polyurethane precursor-modified bitumen, stabilized rubber powder-modified asphalt, plastic-waste-modified binders, biodegradable waxes for warm mix asphalt, rubber asphalt and polymer asphalt under aging, polymer-modified asphalt at low temperature, high-modulus asphalt mixtures and high-viscosity modified asphalt prepared with a thermoplastic rubber.

Zhang et al. [6] studied the aging resistance of polyurethane precursor-modified bitumen and its modification mechanism. The work demonstrates how reactive organic modification can improve the aging resistance of bitumen and provides mechanistic insight into the interaction between polyurethane precursors and asphalt components.

Ma et al. [14] investigated the viscosity–temperature properties and thermal stability of stabilized rubber powder-modified asphalt. This study contributes to the practical implementation of rubber powder-modified asphalt by clarifying the relationship between temperature sensitivity and stability, which is essential for mixing, pumping, storage and field construction.

Veropalumbo et al. [7] examined the chemical, thermal and rheological performance of asphalt bitumen containing plastic waste. This paper assessed the material response from multiple perspectives, including chemical, thermal and rheological behavior. Promising elasticity and strength properties were observed in the mixture with 20% waste plastic content by weight of bitumen.

Sigwarth et al. [15] explored a biodegradable wax to modify asphalt binder for warm mix asphalt. The introduction of biodegradable wax provides an organic and potentially more environmentally compatible additive option. The study contributes to the development of temperature-reduction technologies that are not only energy efficient but also aligned with sustainable material selection.

Jin et al. [16] compared rubber asphalt and polymer asphalt under long-term aging conditions in Michigan. By evaluating long-term aging behavior, the authors provided useful information for selecting modifiers that can maintain performance during service. The paper also links waste-rubber utilization with durability-based pavement design.

Huang et al. [17] investigated the low-temperature viscoelastic properties of polymer-modified asphalt using gray relational analysis. Low-temperature cracking is a major distress in cold and seasonal climates. The paper contributes an evaluation framework for understanding the relationship between multiple viscoelastic indicators and low-temperature performance.

Huang et al. [18] analyzed modulus properties of high-modulus asphalt mixtures and proposed a new evaluation index for rutting resistance. The proposed evaluation index provides a performance-oriented tool for mixture design and contributes to the broader objective of designing durable, resource-efficient pavement structures.

Wang et al. [19] developed high-viscosity modified asphalt with a novel thermoplastic rubber. This work provides another example of organic/polymeric modification aimed

at improving pavement functionality and resistance to damage. Together with the other binder-related papers, it shows the diversity of organic modifiers that can contribute to more sustainable asphalt systems.

2.3. Sustainable Concrete, Brick, Soil and Railway Materials

The third theme broadens the scope of the Special Issue beyond asphalt pavement and demonstrates the relevance of sustainable organic and waste-derived materials in concrete, bricks, soils and railway infrastructure. These studies are important because buildings, geotechnical works and railway systems also consume large quantities of raw materials and require durable, low-carbon solutions.

Jena and Kaewunruen [2] presented life-cycle sustainability assessments of an innovative FRP composite footbridge via a case study in the UK. Their results show that if the FRP footbridge surpasses its original estimated lifespan, the economic savings can be increased, and the environmental impacts can be reduced substantially.

You et al. [20] compared environmentally friendly production methods for railway prestressed concrete sleepers and bearers. By comparing alternative production methods, the study provides useful evidence for reducing environmental burdens in railway infrastructure while maintaining structural performance and manufacturing feasibility.

Mobili et al. [21] investigated the effect of gasification char and recycled carbon fibers on the electrical impedance of concrete exposed to accelerated degradation. Electrical impedance can provide information about concrete condition and degradation, and the inclusion of recycled carbon fibers may enhance multifunctionality.

Ashiq et al. [22] assessed the suitability of marble powder, glass powder and polypropylene fibers for improving Siwalik clay. This study contributes to sustainable geotechnical engineering by showing how industrial and construction-related waste streams can be repurposed for subgrade or foundation improvement, leading towards sustainable solutions of the serviceability problems.

Li et al. [23] studied crack propagation in time-dependent concrete degradation of prestressed concrete sleepers. By assessing crack propagation under degradation, this study contributes to service-life prediction and the management of concrete railway components. Its relevance lies in connecting material degradation mechanisms with infrastructure safety and sustainability.

Mukhtar et al. [3] evaluated the feasibility of using coal ash for the production of sustainable bricks. Coal ash utilization can reduce waste accumulation, lower demand for natural clay resources and provide alternative construction products. Such work is especially relevant in regions where brick production remains material- and energy-intensive.

Gerges et al. [4] proposed an eco-friendly optimum structural concrete mix design. The optimum eco-friendly structural concrete mix was determined, and the identified mixes can be potentially used for structural applications. It also shows how sustainability can be embedded in conventional structural concrete practice without requiring entirely new construction systems.

Milani et al. [24] examined the effect of partial sandy soil replacement by construction waste on the mechanical behavior and microstructure of cemented mixtures. By combining mechanical testing with microstructural analysis, the authors clarified how waste replacement affects performance and material structure for ground improvement.

2.4. Digital, Environmental and Multifunctional Technologies for Sustainable Infrastructure

The fourth theme captures studies that extend sustainable material development toward digital design, environmental performance and multifunctional infrastructure. Sus-

tainable construction materials must increasingly satisfy not only mechanical requirements but also climate-adaptation, serviceability, monitoring and functional-performance needs.

Lavercombe et al. [1] applied machine learning to eco-friendly concrete design for decarbonization. This was the most cited paper identified from publicly accessible citation snippets. The study reflects the increasing role of artificial intelligence in navigating complex material-design spaces, identifying that machine learning can accelerate the identification of concrete mixtures that balance mechanical performance, embodied carbon and material availability. This paper also illustrates a broader trend: digital tools are becoming essential for sustainable material optimization because they can extract design rules from large datasets and support decision-making under multiple constraints.

Moretti et al. [5] investigated parking lot pavements as a strategy to counteract urban heat islands. Parking lots occupy extensive urban surfaces and can contribute substantially to heat storage and surface-temperature increase. By studying pavement alternatives for heat mitigation, the paper connects material selection with urban climate adaptation.

Li et al. [25] developed sustainable superhydrophobic and photothermal coatings for anti-icing applications on concrete using a simple CNTs/SiO₂ modification method. The integration of super hydrophobicity and photothermal behavior provides a passive or semi-passive route to winter maintenance, and the simple preparation method supports potential engineering implementation.

3. Future Research Horizons

The contributions in this Special Issue demonstrate substantial progress, but they also reveal several research horizons that should guide future work on sustainable organic materials in the construction sector.

First, future studies should place greater emphasis on long-term durability and service-life prediction. Many sustainable organic modifiers and waste-derived materials show promising short-term performance, but their aging behavior, compatibility, moisture sensitivity, freeze–thaw durability, ultraviolet aging and fatigue resistance must be understood over realistic service periods. Accelerated laboratory testing should be linked with field monitoring and mechanistic modeling so that performance benefits can be translated into reliable design inputs.

Second, the field requires more integrated life-cycle and techno-economic assessment. Sustainable materials should not be evaluated only by the amount of waste reused or the reduction in virgin materials. Full life-cycle impacts, including raw material collection, processing, transport, construction, maintenance, end-of-life treatment and potential emissions or leaching, should be quantified. Economic feasibility and supply-chain availability are also essential for implementation. Studies such as the FRP footbridge assessment and concrete mix optimization illustrate this direction, but more harmonized assessment frameworks are needed across asphalt, concrete, soil and railway applications.

Third, digitalization and artificial intelligence should be expanded. Machine learning can assist concrete mix design, asphalt binder formulation, pavement performance prediction, recycled material classification and maintenance planning. However, reliable models require high-quality datasets, transparent feature selection, uncertainty quantification and domain-informed interpretation. Future work should combine laboratory data, field data, life-cycle data and material inventories to create trustworthy digital tools for sustainable construction-material design.

Fourth, field implementation should become a central component of sustainable material research. Laboratory studies are essential for screening and mechanism identification, but field sections, pilot projects and long-term monitoring are necessary for demonstrating constructability and durability. The Special Issue includes several implementation-relevant

studies, particularly in recycled asphalt and pavement surface technologies. Future Special Issues and research programs should encourage papers that combine laboratory testing, field trials, environmental evaluation and stakeholder feedback.

Finally, future research should address policy, procurement and industry adoption. Sustainable organic materials can only generate large-scale impact if public agencies, designers, contractors and material suppliers are able to specify, produce, verify and maintain them. Performance-based procurement, carbon-accounting requirements, circular-economy targets and open databases can accelerate adoption. Collaboration between academia, industry and government will be essential for moving sustainable organic materials from innovative research products to routine construction practice.

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