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Editorial

The materials science community is living a moment of extraordinary transformation. As global priorities shift toward sustainability, resilience, and the preservation of both built and cultural environments, our discipline continues to redefine itself—integrating advanced characterization, digitalization, and circular-economy principles. This issue of the journal reflects this vibrant evolution, showcasing research that expands our understanding of materials, their behavior, and their applications across modern engineering and heritage conservation.

A central theme emerging from the articles in this volume is **the increasing importance of multiscale analysis**. Today, materials are no longer examined solely through their mechanical or chemical properties; they are studied as complex systems. High-resolution imaging and spectroscopy allow us to see how microstructures, defects, porosity networks, and phase transformations influence large-scale performance. These methods do more than generate data: they contribute to predictive models, durability assessments, and the design of engineered surfaces with controlled functionality.
Complementing this micro-to-macro perspective is the clear progression toward digital workflows. Computational modelling, 3D/4D reconstruction, digital twins, and simulation-based material design are increasingly embedded in laboratory research. Several contributions demonstrate how digital techniques can accelerate innovation—whether by reconstructing ancient building technologies with exceptional accuracy, optimizing composite layups, forecasting degradation routes under environmental stress, or using virtual phantoms to validate analytical methods. This growing integration of digital tools reflects a broader shift in the field: materials science is becoming both more data-driven and more reproducible.

Another strong message conveyed through the studies in this issue is the need for sustainability and responsible material use. Researchers are exploring eco-friendly binders, recycled aggregates, bio-based coatings, energy-saving surfaces, and low-carbon composites. These developments are not simply technical improvements—they represent tangible contributions to climate mitigation and resource conservation. Importantly, many authors emphasize performance over simple substitution, demonstrating that sustainable materials can meet or exceed conventional expectations when their composition and microstructure are optimized.

The issue also highlights how heritage science and engineering increasingly intersect. Studies on ancient mortars, pigments, stone, ceramics, and conservation treatments illustrate that heritage objects behave like highly complex materials systems. Advanced analytical methods reveal how they degrade, how they were originally produced, and how modern interventions—such as hydroxyapatite-based consolidants or nanostructured coatings—interact with substrates at the nanoscale. Heritage research is not only about the past: it serves as a living laboratory for understanding long-term durability, weathering mechanisms, and sustainable design inspired by historical materials.
A major thread connecting many of the contributions is the urgent push toward **sustainability**. Researchers increasingly focus on greener binders, low-carbon composites, recycled aggregates, bio-based additives, and surface treatments designed for long-term performance with minimal environmental impact. This effort represents an essential pivot toward responsible materials engineering.

Within this broader sustainability agenda, **polymer circularity** has become one of the most challenging—and promising—frontiers. Polymers are ubiquitous in construction, packaging, transportation, electronics, and conservation materials, yet their end-of-life management remains a global concern. Several studies in this issue demonstrate how polymer circularity is moving beyond simple recycling to embrace a more holistic vision:

- **Design for circularity**: Engineering polymers with reversible bonding, tailored degradation pathways, and modular architectures that facilitate disassembly.
- **Advanced characterization**: Using spectroscopic and imaging techniques to understand polymer aging, contamination, and compatibility in recycling loops.
- **Chemical and mechanical recycling innovations**: New catalytic depolymerization strategies, purification processes, and compatibilizers that reintroduce polymer waste into high-quality production cycles.

- **Bio-based and biodegradable polymers**: Emerging systems that reduce dependence on fossil feedstocks while ensuring controlled end-of-life behavior.
- **Circular coatings and functional surfaces**: Smart polymers engineered for durability, reparability, and future reprocessing.

These developments show that polymer circularity is not merely an environmental requirement but an opportunity for scientific creativity—where chemistry, processing, and design converge to redefine the lifecycle of materials.
In parallel, this issue also illustrates how **heritage science and modern engineering** share common challenges: understanding long-term material behavior, mitigating degradation, and designing interventions that respect both functionality and sustainability. Insights from ancient mortars, pigments, and stones can inform future materials, just as modern analytical methods deepen our understanding of cultural heritage.
Finally, the collective strength of this issue lies in **interdisciplinary collaboration**. The most impactful studies emerge from teams that combine chemistry, physics, civil engineering, computational modelling, archaeometry, environmental science, and industrial practice. This diversity of perspectives is not optional—it is fundamental to solving the complex material challenges of our time.

Looking forward, the field continues to move toward:

- **Functional and adaptive surfaces** that respond to light, humidity, or pollutants
- **Nanostructured materials** that improve energy efficiency or offer protective capabilities
- **Circular material flows**, especially for polymers and composites
- **Machine-learning-assisted material design** for predictive properties
- **Digital twins for both infrastructure and heritage sites**, enabling real-time monitoring and risk assessment

Together, the contributions in this volume underscore the central message of materials science today: innovation is strongest when it is interdisciplinary, digitally informed, environmentally conscious, and grounded in a deep understanding of matter across scales.

We extend our sincere gratitude to the authors for their high-quality research, to the reviewers for their expert input, and to our readers for their engagement with this expanding field. We hope this issue inspires new collaborations, new questions, and new pathways toward materials that are not only high-performing, but genuinely sustainable—shaped with circularity and responsibility at their core.

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