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Editorial

Ceramics in the Circular Economy for a Sustainable World

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1. Introduction to the Field of This Special Issue

The transition toward a circular economy is one of the most pressing challenges and opportunities of our time, requiring fundamental shifts in how we produce, consume, and manage materials [1]. Within this context, the ceramics industry, a sector traditionally associated with high energy consumption and significant raw material extraction, is undergoing a remarkable transformation [2,3]. This Special Issue, "Ceramics in the Circular Economy for a Sustainable World", showcases cutting-edge research that demonstrates how ceramic materials can become key enablers of sustainability through waste valorisation, resource efficiency, and innovative processing technologies.

The global ceramics industry faces mounting pressure to reduce its environmental footprint while meeting growing demand for construction materials, refractories, and functional ceramics [4,5]. Traditional ceramic production relies heavily on virgin raw materials such as clays, feldspars, and quartz, alongside energy-intensive firing processes that contribute substantially to CO_2 emissions [6,7]. Simultaneously, modern societies generate vast quantities of industrial, agricultural, mining, and construction waste that pose environmental and economic burdens. The convergence of these challenges has catalysed a new research paradigm: transforming diverse waste streams into valuable ceramic feedstocks and products [8,9].

Recent advances in this field reveal several converging research directions. First, there is a systematic effort to replace virgin clays and minerals with industrial and biological residues in traditional ceramic formulations. Second, researchers are developing alternative consolidation routes, e.g., alkali-activated materials and geopolymers, that reduce or eliminate high-temperature firing requirements, thus saving energy and fuels. Third, the field is moving toward engineered porous and lightweight ceramics that serve multiple functions in insulation, filtration, and environmental remediation [10,11]. Fourth, life cycle assessment (LCA) methodologies are increasingly being applied to quantify the environmental benefits of waste-derived ceramics, although standardisation still remains a challenge [12].

The scope of waste materials being valorised in ceramic applications is remarkably diverse. Industrial wastes include foundry sand, ceramic shell waste, glass cullet, metallurgical slags, and bottom/fly ash from waste incineration. Mining residues encompass bauxite tailings, granite powder, ornamental stone fines, and phosphate mine waste rocks [13]. Agricultural and biogenic waste ranges from rice husk ash and coffee grounds to sunflower

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shell ash and banana fibres. Construction and demolition waste [14,15] provides another significant feedstock stream, including crushed concrete, brick fragments, and gypsum waste [16,17].

This Special Issue brings together 23 original research articles that exemplify the breadth and depth of current innovations in circular ceramic production. The contributions span multiple continents and address diverse waste streams, ceramic applications, and sustainability dimensions. Collectively, these papers advance both fundamental understanding and practical implementation pathways for ceramics in the circular economy. They demonstrate that waste valorisation in ceramics is not merely about disposal (landfilling) reduction but it represents a strategic opportunity to create high-performance materials with reduced environmental impact, lower production costs, and enhanced functionality.

2. Overview of the Contributions Collected in This Special Issue

This Special Issue collects 4 comprehensive reviews and 19 research articles. We would like to present here a small selection of the highly significant papers included in this Special Issue, which well summarise its key topics and scientific areas.

Six papers focus on the utilisation of glass cullet/waste glass as well as the vitrification of bottom ash/fly ash to obtain functional products, such as porous glasses for thermal insultation in buildings or glass-ceramics. Glass in an exceptionally versatile material but its recycling or reuse pose several challenges, predominantly associated with the heterogeneity in the chemical composition of various glass types and the glass particle size distribution, both things that dramatically affect the efficiency and feasibility of recycling procedures. Tameni and Bernardo [18] comprehensively discuss the emerging trends in the recycling and upcycling of waste glass through the utilisation of glass in the production of geopolymers and alkali-activated materials, thereby efficiently converting waste into high-value products.

Six other papers focus on the use of waste ceramics or recycled materials in the production of cement, concrete, mortar, and masonry, which are all key elements in construction. Santos Nascimento et al. [14] investigates the use of gypsum waste from civil construction as a partial substitute for cement in soil–cement formulations in an effort to produce eco-friendly bricks, which aligns with the paradigms of the circular economy. Strategies like this one, which aim at reducing cement usage, are key from the viewpoint of sustainability as cement production greatly contributes to greenhouse emissions (e.g., primarily as a consequence of carbon dioxide derived from the thermal decomposition of limestone).

The challenges associated with the use of ceramics in the circular economy are important not only on the Earth but also… in space! In a highly interesting paper, Ellery [19] discusses the strategies that can be adopted on for full industrialisation of the Moon, based on a circular lunar industrial ecology, and examines the contribution of ceramics, with a special focus on additive manufacturing technologies applied using these inorganic materials. Popular and relatively affordable 3D printing methods, such as direct ink writing, are less suitable on the Moon compared to the Earth as they typically require polymers, which are scarce on the Moon, for the production of printable inks. This suggests that full industrialisation of the Moon cannot be completed until the problem of ceramic manufacturing is resolved, most likely in conjunction with polymer synthesis from potential carbon sources.

Sustainable approaches applied to ceramics are also highly appealing with regard to improving the quality of life and wellbeing of humans. Torre et al. [20] propose the use of polyphenols from grape pomace to impart antibacterial and anti-inflammatory properties to calcium phosphate bioceramics to be implanted in bone defects, potentially accelerating tissue healing and regeneration.

3. Invitation to the Readership

The continuous industrial growth and demand for ever more products that come as consequences of growing populations worldwide have led to the over-exploitation of natural resources and are associated with the generation of huge amounts of waste, pollution, and carbon dioxide introduced into the atmosphere. Traditional economic models are linear—i.e., resources are consumed, goods are fabricated, and waste is produced and eventually disposed of—resulting in an obvious impact on the environment and on human health. In an attempt to avoid these criticalities, a new paradigm has emerged based on the circular economy, which implies a change in mindset and the implementation of fundamental changes throughout the value chain, including new approaches to product design and manufacturing technologies, new business models, novel strategies to preserve natural resources and turn waste into new (secondary) resources, as well as new behaviours, common practices, and education. Ceramics can indeed play a vital role in such a change in paradigm, and this Special Issue demonstrates that once more. As Editors, we hope that the valuable contributions gathered together in this Special Issue can stimulate the discussion among various stakeholders involved in the ceramics community and in sustainable development, including researchers from academia, industry, and government. This exchange of ideas, methods, and results will be key to coping with the needs of a world that has finite resources but (almost) infinite desires.

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References

1. Davies, M.L. Introduction to the circular economy themed collection. *RSC Sustain.* **2025**, *3*, 1036–1038. [CrossRef]
2. da Silva, S.B.G.; Barros, M.V.; Radicchi, J.Â.Z.; Puglieri, F.N.; Piekarski, C.M. Opportunities and challenges to increase circularity in the product's use phase. *Sustain. Futures* **2024**, *8*, 100297. [CrossRef]
3. Vázquez Calvo, V.L.; Korzeb, Z.; Alonso-Fariñas, B.; Morillo Aguado, J. Circular economy transition under the revised Industrial Emissions Directive: A review of challenges and enablers. *J. Clean. Prod.* **2025**, *533*, 146779. [CrossRef]
4. Furszyfer Del Rio, D.D.; Sovacool, B.K.; Foley, A.M.; Griffiths, S.; Bazilian, M.; Kim, J.; Rooney, D. Decarbonizing the ceramics industry: A systematic and critical review of policy options, developments and sociotechnical systems. *Renew. Sustain. Energy Rev.* **2022**, *157*, 112081. [CrossRef]
5. Nasare, R.; Shah, V.; Joshi, T.; Dave, U.; Ghaffar, S.H. Exploring sustainable utilization of ceramic waste in heat-resistant concrete: A comprehensive review. *Int. J. Appl. Ceram. Technol.* **2025**, *22*, e15021. [CrossRef]
6. Almeida, M.; Simões, F.; Dias, F.; Amado, A. Ceramic industry contribution to a circular economy. In Proceedings of the Congress of Innovation on Sustainable Construction CINCOS, Lisbon, Portugal, 3–4 November 2016.
7. Muthaiyan, U.M.; Lankapalli, C.; Thangavel, B.; Arumugam, K. Integrating ceramic wastes into concrete: Sustainable disposal and resource optimization strategies. *Environ. Prot. Eng.* **2025**, *51*, 53–72. [CrossRef]
8. Peng, X.; Jiang, Y.; Chen, Z.; Osman, A.I.; Farghali, M.; Rooney, D.W.; Yap, P.-S. Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: A review. *Environ. Chem. Lett.* **2023**, *21*, 765–801. [CrossRef]
9. Srivastava, A.; Pandey, S.; Shahwal, R.; Sur, A. Recycling of waste into useful materials and their energy applications. In *Microbial Niche Nexus Sustaining Environmental Biological Wastewater and Water-Energy-Environment Nexus*; Springer: Berlin/Heidelberg, Germany, 2025; pp. 251–296.

10. Aguiar, M.C.d.; Gadioli, M.C.B.; Sant'Ana, M.A.K.; Almeida, K.M.d.; Vidal, F.W.H.; Vieira, C.M.F. Red Ceramics Produced with Primary Processing Fine Waste of Ornamental Stones According to the Circular Economy Model. *Sustainability* **2022**, *14*, 12887. [CrossRef]
11. Terrones-Saeta, J.M.; Domínguez, V.; Ramos, D.; Romero, E.; Asensio-Lozano, J. Analysis of the Mechanical Properties of Structural Ceramics Made from Aggregate Washing Sludge and Manganese Mining Waste. *Materials* **2024**, *17*, 4427. [CrossRef] [PubMed]
12. Ünsal, Z.; Ekinci, M.Ö.; İlcan, H.; Şahin, O.; Selçuk, S.; Şahmaran, M. Life cycle assessment of geopolymer materials utilizing construction and demolition waste. *Environ. Res.* **2025**, *285*, 122359. [CrossRef] [PubMed]
13. Almendro-Candel, M.B.; Jordán Vidal, M.M. Glasses, Frits and Glass-Ceramics: Processes and Uses in the Context of Circular Economy and Waste Vitrification. *Coatings* **2024**, *14*, 346. [CrossRef]
14. Nascimento, E.S.S.; Oliveira, H.A.d.; Santos, C.P.d.; Gomes, M.d.A.; Valerio, M.E.G.; Macedo, Z.S. Sustainable Use of Gypsum Waste for Applications in Soil–Cement Bricks: Mechanical, Environmental, and Durability Performance. *Ceramics* **2025**, *8*, 83. [CrossRef]
15. Murali, G.; Hassas, N.; Abdelgader, H.S. Ceramic waste as a sustainable cementitious resource: Pathways to cleaner and high-performance concrete. *Clean. Mater.* **2025**, *18*, 100352. [CrossRef]
16. Marín Cortés, S. Towards a More Sustainable and Circular Ceramic Tile Industry Through the Valorization of Construction and Demolition Waste. Ph.D. Thesis, Autonomous University of Madrid, Madrid, Spain, 2025.
17. Allaoui, D.; Majdoubi, H.; Haddaji, Y.; Nadi, M.; Mansouri, S.; Oumam, M.; Tamraoui, Y.; Alami, J.; Hannache, H.; Manoun, B. Valorization of ceramic sanitary waste into Resilient phosphoric acid-based geopolymers for sustainable construction: Thermal, mechanical, and microstructural properties. *Ceram. Int.* **2024**, *50*, 8875–8889. [CrossRef]
18. Tameni, G.; Bernardo, E. Alkali Activation of Glass for Sustainable Upcycling: An Overview. *Ceramics* **2025**, *8*, 108. [CrossRef]
19. Ellery, A. Ceramics—The Forgotten but Essential Ingredients for a Circular Economy on the Moon. *Ceramics* **2025**, *8*, 107. [CrossRef]
20. Torre, E.; Morra, M.; Cassinelli, C.; Iviglia, G. Anti-Bacterial and Anti-Inflammatory Effects of a Ceramic Bone Filler Containing Polyphenols from Grape Pomace. *Ceramics* **2024**, *7*, 975–988. [CrossRef]

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