Environmental performance of wastes incorporation in concrete mixtures

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The building sector contributes to 39% of the annual global CO_2 released (Ali et al., 2020), from which 11% are embodied in building materials. The concrete production is estimated in 12 billion tons per year, which makes it the second most consumed substance on the planet. Thus, remarkable volumes of natural resources are needed by the concrete industry, with significant environmental challenges. The current linear economy and the global population growth are responsible for an expressive release of wastes to the environment. To revert this burden, the European Commission targeted to decrease 90% of the emissions from the building sector until 2050 (European Commission, 2019) and promote resource efficiency and circular economy models. This will imply the reformulation of several building materials and products, where conventional materials could be replaced by reused or recycled ones, with economic, technical, and environmental benefits, also in line with the United Nations Sustainable Development Goals (Mancini et al., 2019).

Indeed, the use of wastes as secondary construction materials can channel by-products back into the value chain (Bonoli et al., 2021). This potentially decrease waste, landfill disposal, and primary resources exploitation, resulting, at the same time, in promising cleaner production routes and an increase market competitiveness. In this context, several by-products from different industries, that are currently disposed of as waste, have been the focus of research into reuse opportunities in concretes (Naran et al., 2022). Advances in solid waste management and product development resulted in innovative construction materials such as new concrete blends, blocks, tiles, aggregates, and binders (Pappu et al., 2007). To boost innovative methods for high-value advanced recycling, it is essential to demonstrate both environmental and economic advantages from life cycle thinking and sustainable assessment approaches. For instance, an effective recycling process starts from the material design, when the real impact of sustainability-oriented solutions can be triggered. The quality and quantity of recycled materials are straightly dependent on end-of-life planning and management. In this context, life cycle assessment (LCA) can determine environmental benefits and compare solutions that differ in terms of materials, processes, components, or applications (Bonoli et al., 2021).

The interest in LCA within the construction sector has been increasing during the past decades. Nevertheless, there is a lack of studies that focus on mapping the research of the LCA in particular topics of the construction industry, with a comprehensive understanding (Yılmaz & Seyis, 2021). Thus, this work aims to synthesize the existing knowledge on the potential benefits of different wastes incorporation in concrete mixtures, considering an LCA perspective and current challenges.

Multiple studies have analyzed the functional performance and potential environmental benefits of using recycled aggregates (RA) from construction and demolition wastes (CDW) to replace natural aggregates in new concrete blends. Some challenges associated with product functionality and LCA studies have been highlighted. For instance, the varying characteristics of different recycled aggregates, and their generally inferior surface properties when compared to virgin aggregates. The difficulty to compare the results of LCA studies was also identified due to dissimilar approaches followed by different authors (Xing et al., 2022), namely regarding the system boundaries, functional units, allocation procedures (*i.e.*, if the avoided landfilling is considered, physical, or economic allocation), transport distances among RA and concrete producers (Göswein et al., 2018), and including (or not) the carbon uptake during the concrete life cycle or its end-of-life stage (Zhang et al., 2019).

Some LCA studies assessed the impact of using conventional and alternative materials (*e.g.*, recycled asphalt, concrete, bitumen, fly ash residues, tire rubber granulates, ground-granulated blast-furnace slag, and polymers) in road pavements. The most assessed impact categories were primary energy and global warming, whereas the most studied road types were high-traffic ones (Balaguera et al., 2018). Most studies conclude that a wide variety of solid wastes (urban, industrial, CDW, etc.) can be successfully used in road construction taking different roles: aggregates, fillers, fiber reinforcements, and additives. Studies taking advantage of waste material properties and the chemical reactions achieved among different types of materials (Gravina & Xie, 2022), may result in blends with not only environmental benefits but also improved durability and performance (Vishnu & Singh, 2021).

Another trend identified is the reuse of mining wastes into innovative alkali-based materials for lightweight construction products (Kastiukas et al., 2018). Geopolymers, which are a combination of an activator, aluminosilicates, and water, also demonstrated advantages in stabilizing hazardous compounds in mixtures with mining residues (Ahmari et al., 2012). The development of innovative polymer-based composite materials from non-contaminated mining residues appears to have suitable properties and potential for conservation, restoration, and/or rehabilitation of historic monuments, sculptures, decorative and architectural interventions, or as materials for building coatings (Castro-Gomes et al., 2012). Ceramic tiles can also be produced taking advantage of mining residues, namely with iron ore residues, due to their red/orange color. They can be used as aggregates in the manufacturing of unfired bricks (*e.g.*, adobe), extruded or compacted earth blocks (Chen et al., 2011).

Summing up, environmental assessments as supporting decision tools, particularly oriented to wastes incorporation in concrete production, can support further developments and promote circular economy models in buildings and construction while providing a reliable strategy to perform a comparative analysis of materials and products. These findings are valuable for stakeholders to evaluate the cost-effectiveness of alternative green concrete materials in their construction projects.

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References

Ahmari, S., Ren, X., Toufigh, V., & Zhang, L. (2012). Production of geopolymeric binder from blended waste concrete powder and fly ash. *Construction and Building Materials*, *35*, 718–729. https://doi.org/10.1016/J.CONBUILDMAT.2012.04.044

Balaguera, A., Carvajal, G. I., Albertí, J., & Fullana-i-Palmer, P. (2018). Life cycle assessment of road construction alternative materials: A literature review. *Resources, Conservation and Recycling*, *132*, 37–48. https://doi.org/10.1016/j.resconrec.2018.01.003

Bonoli, A., Zanni, S., Serrano-Bernardo, F., & Pereira, S. (2021). *sustainability Review Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal. The Contribution of Concrete Recycling*. https://doi.org/10.3390/su13042139

Castro-Gomes, J. P., Silva, A. P., Cano, R. P., Durán Suarez, J., & Albuquerque, A. (2012). Potential for reuse of tungsten mining waste-rock in technical-artistic value added products. *Journal of Cleaner Production*, *25*, 34–41. https://doi.org/10.1016/J.JCLEPRO.2011.11.064

Chen, Y., Zhang, Y., Chen, T., Zhao, Y., & Bao, S. (2011). Preparation of eco-friendly construction bricks from hematite tailings. *Construction and Building Materials*, *25*(4), 2107–2111. https://doi.org/10.1016/J.CONBUILDMAT.2010.11.025

European Commission. (2019). *Going climate-neutral by 2050. A strategic long-term vision for a prosperous, modern, competitive and climate-neutral EU economy*.

Göswein, V., Gonçalves, A. B., Silvestre, J. D., Freire, F., Habert, G., & Kurda, R. (2018). Transportation matters – Does it? GIS-based comparative environmental assessment of concrete mixes with cement, fly ash, natural and recycled aggregates. *Resources, Conservation and Recycling*, *137*, 1–10. https://doi.org/10.1016/j.resconrec.2018.05.021

Gravina, R. J., & Xie, T. (2022). Toward the development of sustainable concrete with Crumb Rubber: Design-oriented Models, Life-Cycle-Assessment and a site application. *Construction and Building Materials*, *315*. https://doi.org/10.1016/j.conbuildmat.2021.125565

Kastiukas, G., Zhou, X., Asce, M., Kai, ;, Wan, T., & Gomes, J. C. (2018). Lightweight Alkali-Activated Material from Mining and Glass Waste by Chemical and Physical Foaming. *Journal of Materials in Civil Engineering*, *31*(3), 04018397. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002610

Mancini, L., Vidal-Legaz, B., Vizzarri, M., Wittmer, D., Grassi, G., & Pennington, D. W. (2019). *Mapping The Role Of Raw Materials In Sustainable Development Goals*. https://doi.org/10.2760/026725

Naran, J. M., Gonzalez, R. E. G., del Rey Castillo, E., Toma, C. L., Almesfer, N., van Vreden, P., & Saggi, O. (2022). Incorporating waste to develop environmentally-friendly concrete mixes. *Construction and Building Materials*, *314*, 125599. https://doi.org/10.1016/J.CONBUILDMAT.2021.125599

Pappu, A., Saxena, M., & Asolekar, S. R. (2007). Solid wastes generation in India and their recycling potential in building materials. *Building and Environment*, *42*(6), 2311–2320. https://doi.org/10.1016/J.BUILDENV.2006.04.015

Vishnu, T. B., & Singh, K. L. (2021). A study on the suitability of solid waste materials in pavement construction: A review. *International Journal of Pavement Research and Technology*, *14*(5), 625–637. https://doi.org/10.1007/s42947-020-0273-z

Xing, W., Tam, V. W., Le, K. N., Hao, J. L., & Wang, J. (2022). Life cycle assessment of recycled aggregate concrete on its environmental impacts: A critical review. *Construction and Building Materials*, *317*. https://doi.org/10.1016/j.conbuildmat.2021.125950

Yılmaz, Y., & Seyis, S. (2021). Mapping the scientific research of the life cycle assessment in the construction industry: A scientometric analysis. *Building and Environment*, *204*, 108086. https://doi.org/10.1016/J.BUILDENV.2021.108086

Zhang, Y., Luo, W., Wang, J., Wang, Y., Xu, Y., & Xiao, J. (2019). A review of life cycle assessment of recycled aggregate concrete. *Construction and Building Materials*, *209*, 115–125. https://doi.org/10.1016/j.conbuildmat.2019.03.078