Harnessing secondary resources for sustainable and circular practices in the construction sector

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Introduction

The quest for sustainable practices in the construction sector has led in a new era of resource exploration, with a growing focus on secondary materials that were once deemed as waste. One such valuable resource is cellulose, abundantly present in diverse waste streams, including wastewater, urban refuse, and industrial byproducts. Researchers and industry experts are increasingly recognizing the potential of cellulose as a raw material for construction products, driven by its versatility, abundance, and eco-friendly characteristics (Elfaleh *et al*, 2023). Cellulose, derived from plant fibers, has found applications in various construction materials, such as insulation, fiberboards, and even as an additive to enhance the properties of concrete. The push towards sustainable construction has ignited interest in technologies and processes that can efficiently extract and utilize cellulose from waste streams (Nasir *et al*, 2022). This would not only reduce the environmental impact of waste but also contribute to the development of green and circular construction practices. In a parallel vein, the mining and metallurgy industries generate significant byproducts, including slags containing various minerals. Traditionally considered as disposal challenges, these slags are now emerging as valuable resources for the construction sector (Kurniati *et al,* 2023). Researchers have explored methods to extract and process minerals from slags, transforming them into components for concrete, road construction, and even soil improvement. This approach aligns with the broader goals of sustainable construction, where minimizing the use of primary raw materials is a key objective. Moreover, the escalating demand for clean energy technologies has brought attention to the recovery of critical minerals from industrial residues. Lithium, a crucial component in batteries for electric vehicles and renewable energy storage, is often found in residues from different industrial processes (Siekierka *et al*, 2022). The construction of lithium recovery processes not only addresses the supply chain challenges of these critical minerals but also aligns with the sustainability agenda by repurposing industrial residues. As the construction sector aims to transition to a more circular and sustainable model, the utilization of secondary raw materials becomes paramount. The exploration and development of technologies to extract, process, and incorporate these materials into construction products signify a paradigm shift in the industry. This shift not only mitigates the environmental impact of construction activities but also contributes to the creation of structures that are resilient, eco-friendly, and aligned with the principles of a circular economy.

However, despite these promising developments, challenges persist in effectively harnessing the benefits of these waste-derived materials. Economic feasibility, technological innovation, and regulatory frameworks pose significant barriers to their widespread adoption in construction processes. It is in response to these challenges that the ICARUS project emerges. The ICARUS project seeks to address and overcome these obstacles by pioneering innovative approaches to upcycling waste materials, focusing on lithium residues, cellulose waste, and steel slags from diverse industrial sectors. Through tailored technological solutions, ICARUS aims to bridge existing gaps and facilitate the seamless integration of secondary raw materials into the construction sector. This endeavor aligns with broader goals of achieving a circular and sustainable process industry, transforming waste materials into valuable resources and contributing to a resilient and environmentally conscious construction landscape.

This paper examines the current state of affairs related to the highlighted waste streams, underscoring their potential impact on the construction industry. Furthermore, an exploration of the challenges that hinder widespread adoption is conducted, and comprehensive strategies proposed by ICARUS are introduced to navigate these hurdles. This endeavor is aimed at paving the way for a more sustainable future in construction practices.

Technological innovations in ICARUS project

The ICARUS project (Figure 1) is set to transform the construction industry through the application of cutting-edge technologies that extract maximum value from waste-derived materials. To recover lithium from industrial residues, ICARUS will employ advanced hydrometallurgical techniques, utilizing environmentally friendly solvents in a process that ensures high extraction efficiency and minimal environmental impact. Additionally, innovative ion exchange resins will be used for selective lithium capture, enhancing the purity of the recovered lithium for applications in battery production. In the extraction of cellulose from waste materials, ICARUS will utilize enzymatic hydrolysis, breaking down complex structures to facilitate cellulose fiber extraction. This environmentally friendly process will yield high-quality cellulose suitable for various construction applications. Mechanical separation techniques, including sieving and centrifugation, will also be employed to isolate cellulose, ensuring its purity and quality. For the extraction of minerals from steel slags, ICARUS will leverage high-gradient magnetic separation, ensuring precise separation of minerals for direct incorporation into construction materials.

Selective leaching processes will be employed to target specific minerals within steel slags, providing a tailored approach to mineral extraction. In the realm of digitalization, ICARUS will integrate blockchain technology for Digital Product Passports, ensuring a secure and transparent record of the origin, composition, and processing history of construction materials. This technology, coupled with QR code integration, will enhance traceability, reduce fraud, and facilitate seamless data sharing across the supply chain. Furthermore, ICARUS explores the use of nanostructure super absorbents, which exhibit superior water absorption capabilities. These super absorbents will be incorporated into concrete formulations to reduce water usage, contributing to the sustainability of construction practices. By focusing on these specific and innovative technologies, ICARUS aims not only to overcome the challenges posed by waste-derived materials but also to establish new benchmarks for sustainable and technologically-driven construction processes.

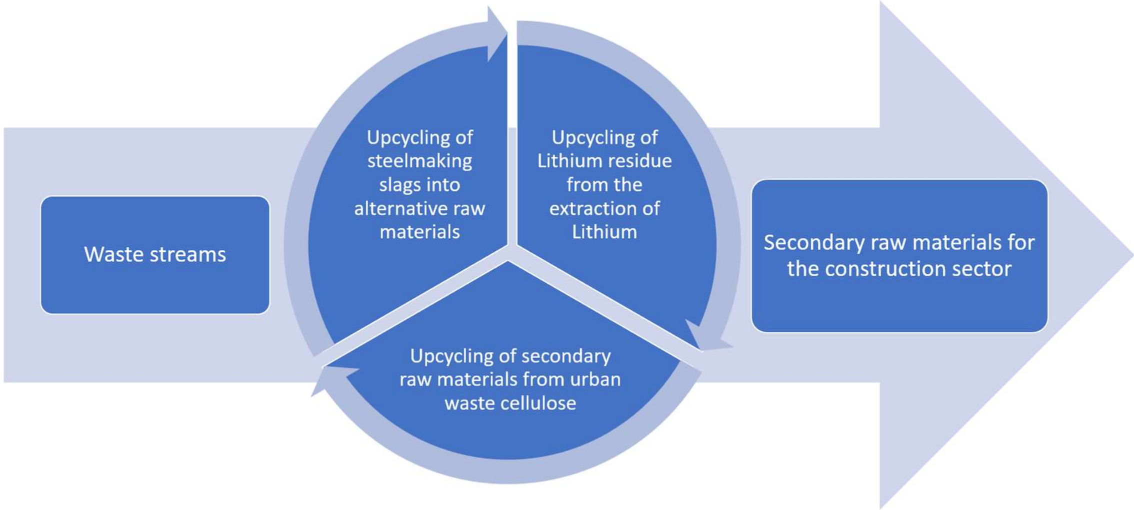

Figure 1. ICARUS concept.

Expected results

The anticipated outcomes of the ICARUS project are poised to revolutionize the construction industry and propel the green and digital transition through innovative solutions. With project results such as new concrete formulations, supplementary cementitious materials, and alternative aggregates, ICARUS aims to achieve substantial reductions in carbon emissions, waste sent to landfill, and resource consumption. For instance, focusing on cement replacement, it is expected to lead to a remarkable decrease in CO_2 emissions, potentially reaching up to 40% reduction. Concurrently, utilization of recycled cellulose fibers aims to demonstrate a 30% increase in the use of recycled materials and a notable improvement in concrete performance. The implementation of Digital Product Passports is anticipated to enhance traceability and efficiency in the supply chain, with an estimated 20% improvement in data sharing and interoperability. Furthermore, the project targets a reduction of 15% in water usage through the incorporation of recovered super absorbents in concrete formulations. Collectively, these expected results and figures underscore ICARUS's commitment to fostering a sustainable future in construction practices by significantly advancing circular economy principles, mitigating environmental impact, and promoting digitalization and innovation in the industry.

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