RE-CAME STONE

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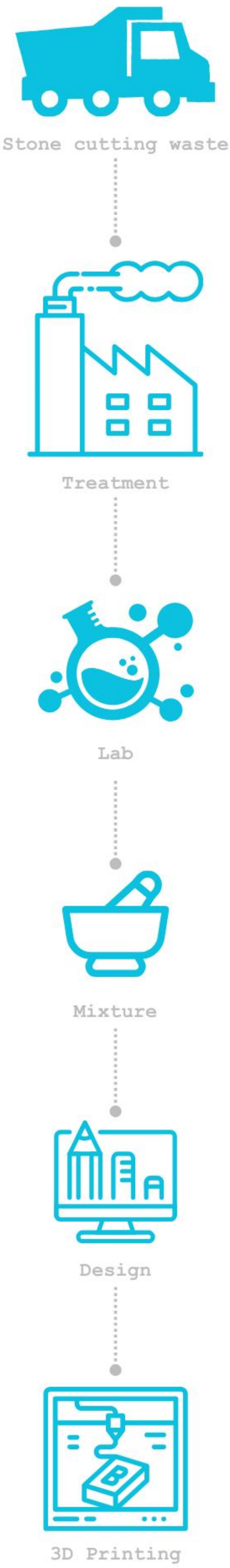
Executive summary

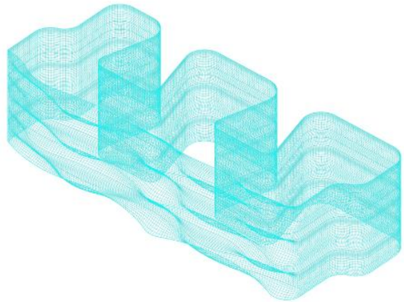
The construction industry alone accounts for 37% of global CO2 emissions, with cement production alone accounting for 8%. It is essential to propose a sustainable alternative capable of reducing the impact of this hard-to-abate sector. The Re-Came Stone project proposes an innovative solution: taking waste from stone cutting industry and transforming it into a building component through additive manufacturing (AM). To this end, laboratory tests were carried out to develop the optimal mix design and AM process, resulting in a stable, scalable and repeatable product. The strength of this project lies in the modularity of the product obtained, with sinusoidal shapes and cavities that improve aesthetics and provide a functional interpretation of this component, such as insulation or ventilation. The product life cycle analysis effectively showed a footprint of 0.475 kg CO_2eq/kg, lower than traditional cement and compliant with Italian CAM criteria.

The project embodies the concept of circularity, in which **today's waste can become tomorrow's product**.

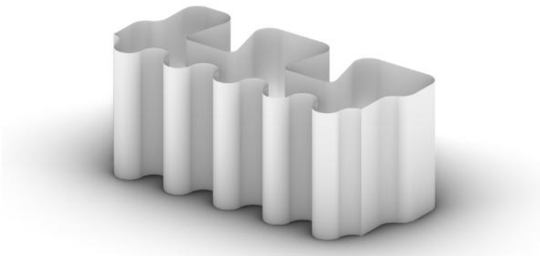
Key Words

Sustainability | Additive Manufacturing | Waste-To-Value | Circular Economy | Parametric Design.

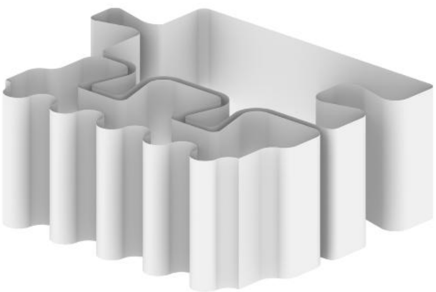




Form-finding



Prototype



Installation

Project description written by the Principal Academic Tutor

This project is based on the idea that stone, the oldest and most evocative building material, has now become waste rather than a resource.
In this context, previous research projects lead to obtaining innovative, sustainable materials like geopolymers. This involves activating aluminosilicates with alkaline solutions, and the results are encouraging. We are developing production processes for these materials as a viable alternative to cement-based products. This would enable the reuse of secondary raw materials (SRMs) from ornamental rock supply chains, while also reducing the energy impact, since the entire process can be carried out at room temperature or at temperatures not exceeding 80 °C.
The Re-Came Stone concept involves combining actual technologies with sustainable materials from local supply chains to reinterpret the cultural values of artefacts made from local materials in a contemporary way.
A transdisciplinary approach based on complementary skills was required to provide context-specific solutions. This methodological approach can be effectively applied in similar contexts involving secondary raw materials of a different mineralogical nature.
There must be constant and critical dialogue between the key construction disciplines of techniques, building physics, mechanics, acoustics, design, environmental engineering, computer science, geology and materials science, as well as engineering management.
The main aim of Re-Came Stone project is to develop technology that can combine the expertise of researchers in developing "geopolymers" from sawdust with the development of manufactured products created using parametric design and additive manufacturing techniques.

The Re-came Stone team was asked to address some key challenges.

- to finalize the development of geopolymer formulations currently used (increase the rate of substitution of natural resources with recycled alternatives) and to optimize the application with 3D printing technologies.

- to evaluate possible applications in the building sector, in particular for modular elements where design optimization is typically obtained through parametric design and multidomain indicators (e.g. shape, geometry, improved performance…).

- assess the advantage in terms of reduced environmental impact compared to the use of cement-based materials with reference to a prototype produced on a laboratory scale.

Team description by skill

The development of the *Re-CAME Stone Project* required a multidisciplinary *Team*, capable to approach the goal on the different identified fronts and to propose solutions, although always innovation-oriented, both technical and creative.

Fabio, an *MSc Material Engineering Student*, worked on optimizing the mixture and the 3D printing process, thanks to his strong knowledge and understanding of the raw material. Working alongside him was Veronica, an *MSc Mechanical Engineer Student*, who studied the properties of the material together, patented the most appropriate printing strategies and transformed a theoretical goal into a tangible product.

Alessandro and Umberto, both *MSc Building Architecture Students*, brought the creativity typical of their field of study to the technical approach required by the *Project*, defining an architectural application and an optimized shape for the component, which is both aesthetically and practically functional. Their contribution to the 3D printable design was made even more effective by attending masterclasses on the subject.

Caterina, an *MSc Building Engineering Student,* was responsible for the sustainability evaluation of the building component, both on a commercial scale and in terms of compliance with national construction standards. Working with her was Matteo, an *MSc Material Engineering Student*, who, thanks to his detailed knowledge of the material, made the overall evaluation a meticulously detailed practice, critically reviewed and benchmarked in its outputs.

Goal

Re-CAME Stone was designed to address one of the most pressing issues of the building industry: reducing its ecological footprint without compromising on material performance and design freedom. The construction sector is one of the main sources of CO_2 emissions globally, and cement production is one of the activities with the greatest impact in this area. The goal is to decrease the footprint of this hard-to-abate sector. Decarbonization strategies have so far been less than satisfactory, so it is crucial that new options were outlined that involve the circular economy.

The specific objective of this project is to transform stone-cutting sludge, an inert valueless industrial by-product, into a sophisticated building material. By chemical activation into a geopolymeric paste, the project produces a printable paste optimized for additive manufacturing (AM). The two objectives are: to valorize a locally available waste stream and to offer a reliable substitute for clinker-based cement.

To achieve this, the project defined clear technical and systemic objectives: offer adequate compressive and flexural strength, printability and dimensional stability, contain no less than 95% recycled content, and be suitable for use in modular architecture. The demonstrator produced— a sinusoidal façade element— fulfills these aims by combining structural efficiency with modularity and aesthetic value. Its form allows passive insulation, ventilation, or even biophilic inclusion, proving that materials from waste can be useful as well as beautiful.

In the end, the vision is not to create just one material, but to build a replicable process for transforming waste into value in building construction. By integrating advanced digital fabrication with sustainable materials innovation, Re-CAME Stone shows that circular economy strategies can be rendered actionable at architectural scale, facilitating carbon-neutral construction activities as well as opening the door for future uses in building envelopes and urban-scale applications.

Understanding the problem

The construction industry is considered one of the hardest to mitigate environmentally. Globally, it emits approximately 37% of CO_2 emissions, not only from energy consumed in use, but also from the material's embodied carbon. Cement is particularly problematic: its production alone emits approximately 8% of the world's CO_2 emissions (Figure 1), primarily due to clinker calcination and the combustion of fossil fuels. This cement reliance exposes a structural decarbonization bottleneck, since historical efficiency gains cannot address material embedded emissions.

Industrial supply chains, on the other hand, produce massive amounts of waste minerals globally. In decorative stone, stone-cutting sludge is among the notable by-products. Chemically inert and non-hazardous as it is, such waste is bulky, difficult to store, costly to transport, and typically beyond valorization streams. In practice, it becomes an economic and environmental cost. Its non-market worth is inversely related to its potential: rich in aluminosilicate, it can be reactivated and reintroduced into circular material flows.

The twin challenge, excessive dependence on high-carbon cement and squandered mineral assets, defines the core dilemma addressed by Re-CAME Stone. It is not just technical substitution that is sought, but systemic transformation: to rethink material flows so that waste becomes resource.

A second key dimension is that of construction practice itself. Historic practice relies on prefabricated, heavy elements with minimal adjustability. Additive manufacturing (AM) offers an alternative paradigm: layer by layer, AM facilitates material savings, complex geometries, and modular solutions that satisfy both functional and cosmetic requirements. Yet, the addition of non-traditional waste-derived materials into AM is fraught with challenges, including rheological control, flow stability, and curing uniformity.

Finally, stakeholders in the system - from waste managers like Marazzato Group, through builders, designers, and regulators - require solutions that are simultaneously sustainable, scalable, and compliant with prevailing regulations. Without these systems being addressed, even the most promising material innovation cannot be scaled up.

To understand the challenge is to behold an intertwining mix of environmental, technological, and societal challenges: reducing embodied carbon, valorizing industrial waste, and guaranteeing printability and performance while adhering to circular economy policy. Only by solving all these simultaneously can the building industry become genuinely sustainable and regenerative practice.

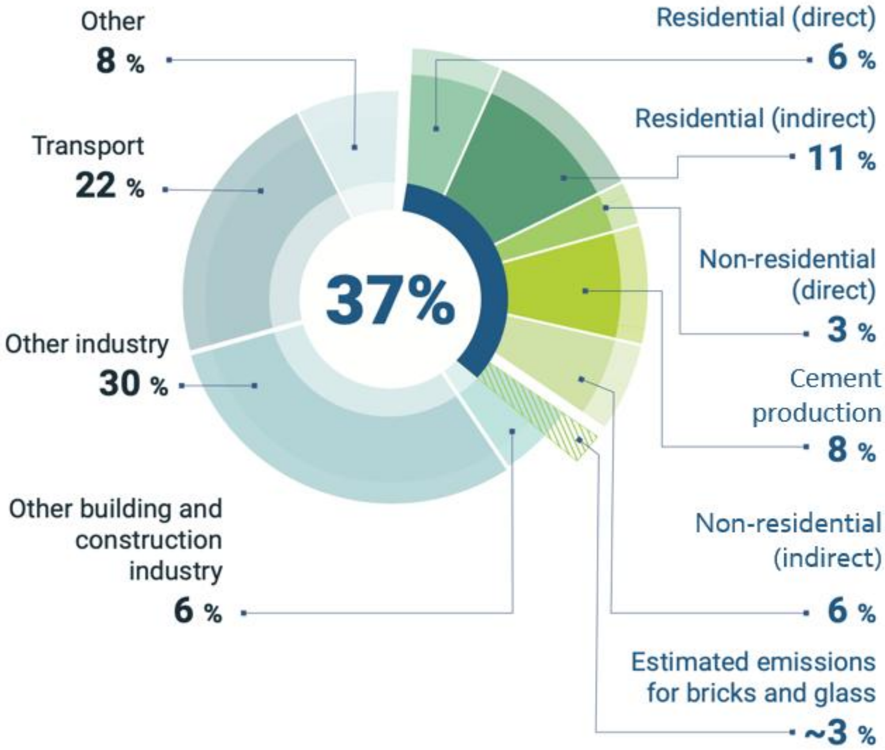


Figure 1 - Global share of buildings and construction operational and process CO2 emissions, 2021 by GlobalABC.

Exploring the opportunities

Re-CAME Stone opens a practical pathway from waste management to material supply, converting stone-cutting sludge into printable geopolymers that reduce embodied carbon while fitting existing logistics and circular-economy goals. For Marazzato, this shift enables a role at the center of a territorial value chain, sourcing, preprocessing, and certifying batches for distributed fabrication, rather than paying to store and transport low-value residues.

At product scale, the 3D-printed modular unit already demonstrates multiple functions beyond façade expression. Its internal cavity can host insulation, ventilation channels, technical conduits, or even vegetation, turning cladding into a performative, biophilic envelope. The brick-sized format supports interlocking assemblies, double-sided partitions, and scalable panels, while parametric control makes mass customization feasible without tooling costs—key advantages for renovations and bespoke urban furniture. Process learnings (gravity-fed screw extrusion, 8 mm nozzle, optimized flow and layer height) de-risk replication across printers and sites.

Market entry is strengthened by quantified impact and regulatory alignment. A cradle-to-gate LCA for Mixture 3 yields 0.475 $kgCO_2eq$ per kg, significantly lower than conventional cement and competitive with alternative composites, positioning the system for sustainability-driven procurement and certification roadmaps. Positive CAM compliance, thanks to high recycled content and modularity, unlocks Italian public works opportunities; early pilots in public space can showcase performance and aesthetics while building trust. Partnerships with large-format AM players and a distributed supply model near quarry districts can scale production with minimized transport impacts.

Near-term priorities include standardizing mixes across feedstock variability, formalizing QC and traceability, and developing EPDs and approval pathways with authorities. Strategically, Re-CAME Stone can serve design-led, mid-rise retrofit, and public-realm niches first, where customization, speed, and circularity are rewarded, then expand toward structural applications as codes and data mature.

Generating a solution

The solution delivers a repeatable, printable stone-sludge paste and a modular unit optimized for low-shear extrusion and single-path deposition. It is defined by three tight loops: a fixed mix protocol, an extrusion strategy matched to the material's rheology, and tuned print parameters that preserve geometry and bonding. Together, they form a clear recipe-method-module pipeline that can be replicated across operators and sites (Figure 2).

Mix protocol. To lock in homogeneity and printability, solids are dry-blended first; water is added incrementally; alkaline activation is delayed until after full wetting; then the paste rests briefly and is re-mixed to recover flow before printing. This sequence leverages the mix's thixotropy—stiff at rest, flowing after agitation—so the filament extrudes cleanly without premature setting. It also reduces segregation and delivers a stable open time for continuous jobs.

Extrusion strategy. Because the paste thickens under high shear, pressure-driven piston systems were rejected. A gravity-fed screw extruder minimizes shear, sustaining a stable bead through an 8 mm nozzle (narrower nozzles increased resistance and clogging). This pairing maintains cross-section shape and continuity, limiting pulsation and edge artifacts—essential for architectural-scale deposition and clean corner turns.

Print parameters and support. Systematic trials set the working window: screw rotation speed at 38 mm/s for consistent flow, and 4.5 mm layer height for adhesion and shape retention. First-layer reliability is achieved on EPS panels primed with the same paste, improving adhesion while limiting thermal and moisture sinks. Travel and extrusion are harmonized to bead width to avoid overfill and voids, yielding smooth strands and robust interlayer bonding.

Product definition. The outcome is a brick-sized module with extrusion-friendly geometry: a sinusoidal outer face for stiffness and light–shadow play, and an internal zig-zag cavity that doubles as structural interface and service space. Printed as a single continuous path, it enables clean joints, interlocking assemblies, and scalable panels—embracing visible stratification as a deliberate identity.

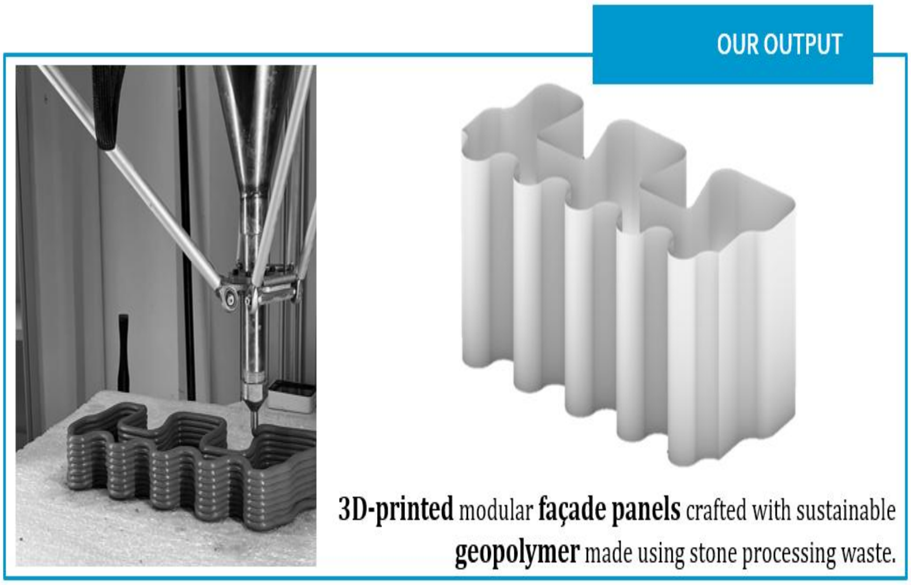


Figure 2 - Output of the project - 3D-printed modular facade panels by using geopolymers.

Main bibliographic references

Alessandro Severi, WASP. The first 3D printed bridge using waste materials from marble processing. s.l.: In News, Press Releases, Stories, Technology, 2024.

Cerutti, Palmero, Zerbinatti, Tulliani, Antonaci, Formia, Marian. Building material obtained from an alkaline activation of sawing sludge of stone materials and process for producing such building material. EP3371125, 2017.

Chen, Liu, Chen, Zhang, Ferrara, Li. Effect of raw materials on the performance of 3D printing geopolymer: A review: Journal of Building Engineering, Vol. 84, 2024.

ETH Zurich, SUPSI. Swiss project recycles waste marble as 3D printer feedstock, Arzo project on-site binder jetting using marble quarry waste. 2023.

Geopolymer Solutions, LLC, Environmental Product Declaration: Sequestered Red Mud Cement, EPD no. HUB-0575, EPD Hub. 2023.

Purton, M. World Economic Forum, Sustainable Development: Cement is a big problem for the environment. Here's how to make it more sustainable. 2024.

Ricciotti, Apicella, Perrotta, Aversa. Geopolymer materials for extrusion-based 3D printing: A review.15, Vol. 24, 2023.

United Nations Environment Programme, & Yale Center for Ecosystems + Architecture. Building Materials and the Climate: Constructing a New Future. 2023.