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Harnessing Cactus Mucilage as a Natural Binder for Sustainable and Circular Brick Innovation

- **Key Concepts-** Paper-based bricks, Natural binders, Low-carbon materials, Thermal insulation, Waste valorization, Bio-based adhesive, Non-structural and structural materials

Central Problem

The production of conventional bricks is often considered as a highly unsustainable industry. This process heavily relies on the extraction of virgin raw materials such as clay, sand, and stone, leading to significant environmental degradation, soil depletion, and the accelerated loss of natural resources. In addition, brick manufacturing often requires energy-intensive processes like kiln firing, which generate substantial greenhouse gas emissions. The use of cement further exacerbates this issue, as it is one of the largest contributors to the carbon footprint in the construction sector.

At the same time, there is an inefficient management of solid waste, both urban and construction-related. Materials such as paper, glass, and demolition debris—despite their potential for reuse—are commonly disposed of in landfills or dumped into the environment.

Moreover, conventional construction materials often fail to meet the needs of vulnerable communities, particularly in regions exposed to extreme climatic conditions. These areas require building solutions with improved thermal performance, lower costs, and greater accessibility. However, the limited adoption of innovative and sustainable inputs restricts the development of more efficient, low-impact, and socially inclusive construction alternatives.

Bio-Based Solutions for Sustainable Construction Materials

The proposed solution is based on the development of a sustainable and circular model for brick manufacturing, in which waste materials are reintroduced into the production cycle as valuable inputs. Instead of relying on virgin raw materials, this approach incorporates recycled resources such as paper, glass, and construction debris, significantly reducing environmental impact while promoting resource efficiency.

10 kg. of paper brick mixture	
Solid material	**Percentage**
Cement	8%
Mashed glass	10%
Paper	16%
Local natural ground	20%
Recycled Concrete Fine Aggregate	16%
Recycled Concrete Coarse Aggregate	20%
Gypsum	10%
Cactus Mucilage	100 grams
Water	5 Liters

A key aspect of this solution is the use of bio-based additives, particularly cactus mucilage, as a natural binder. This plant-derived material partially replaces conventional binders, reducing dependence on carbon-intensive inputs while enhancing cohesion, durability, and moisture resistance. By integrating naturally sourced compounds, the process aligns with the design of safer and lower-impact materials, minimizing toxicity and environmental footprint.

This is complemented by a carefully engineered matrix of recycled materials that work synergistically to enhance the overall performance of the paper brick. The use of paper pulp as a primary component provides intrinsic thermal and acoustic insulation, while the incorporation of crushed

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glass and recycled concrete aggregates contributes to improved machanical strenght and durability. This hybrid composition allows the material to balance lightness and strenght achieving structural properties suitable for non-load-bearing applications while maintaining a significantly lower weight compared to conventional masonry units.

Volcanic tuff - based brick

A second type of brick emerged as a response to the challenges caused by the landslides that occurr in Arequipa, where materials from demolitions such as concrete debris, bricks, and ceramics are often disposed of in ravines or landfills without proper management. In addition, in “sillar” quarries, a regional emblematic volcanic rock, extraction residues are neither reused nor properly treated, increasing environmental risk as they are carried by rainfall into urban areas.

The components are introduced into a mechanical mixer, where they are homogenized under controlled conditions to ensure a consistent distribution of materials and proper moisture content. This stage is critical to guarantee the cohesion and structural integrity of the bricks.

Once a uniform mixture is achieved, the material is transferred to a hydraulic press for molding. The compaction process applies controlled pressure to shape the bricks and reduce internal voids, thereby increasing density and mechanical strength. The molds are designed to produce standardized units, ensuring dimensional consistency and facilitating their application in construction. In some cases, interlocking geometries may be incorporated to improve assembly efficiency and reduce the need for additional binding materials during construction.

After molding, the bricks are carefully demolded and subjected to a curing and drying phase. This process typically lasts up to 28 days, with the first week being critical for strength development. During this period, the bricks may be cured under controlled humidity conditions or in open-air environments, depending on operational capacity and climate conditions. Proper curing allows for the hydration of cementitious components, enhancing the compressive strength and durability of the material.

10 kg. of sillar brick mixture	
Solid Material	**Percentage**
Recycled Concrete	20%
Local natural ground	25%
Cement	10%
Sillar Fine Aggregate	15%
Sillar Coarse Aggregate	25%
Mashed glass	5%
Water	4 Liters

The article was developed by Grupo Gea in Peru, the national implementing partner of the United Nations Industrial Development Organization's project 'Global Green Chemistry Innovation and Networking Programme' (GreenChem), funded by the Global Environment Facility. The program is implemented by the Center for Green Chemistry and Green Engineering at Yale University, USA.