ECONOMIC EFFICIENCY OF LIGHTWEIGHT POROUS CONCRETE PRODUCTION USING LOCAL RAW MATERIALS AND INDUSTRIAL WASTE IN UZBEKISTAN

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Abstract: *This study explores the cost-effectiveness and sustainability of lightweight porous concrete produced from local raw materials and industrial by-products in Uzbekistan. The economic analysis reveals a 38.8% reduction in production cost compared to conventional concrete. Environmental and energy efficiency advantages are also evaluated, making this approach a strong candidate for sustainable construction.*

Keywords: *Lightweight porous concrete, Industrial waste utilization, Local raw materials, Economic efficiency, Fly ash, Slag, Sustainable construction, Thermal insulation, Uzbekistan, Alternative cementitious materials*

Introduction

The rising demand for sustainable and cost-effective construction materials has prompted the exploration of alternative raw materials, particularly in the context of global resource scarcity and environmental concerns. In recent decades, construction sectors in developing countries, including Uzbekistan, have faced mounting pressure to reduce their environmental footprint while maintaining material quality and performance. One of the most promising directions in this regard is the use of local natural resources and industrial waste products, such as fly ash from thermal power plants, metallurgical slag, phosphogypsum, and other mineral-rich residues.

These waste materials are often abundantly available, yet underutilized, resulting in environmental hazards such as land degradation, water and air pollution, and inefficient land use due to waste accumulation. Incorporating these secondary resources into building materials helps reduce the dependency on expensive imported raw materials, supports waste recycling initiatives, and aligns with circular economy principles.

Lightweight porous concrete produced with these alternative components offers several technical and environmental benefits. Due to its low density and high porosity, this type of concrete provides superior thermal insulation, which contributes to lower energy consumption for heating and cooling buildings. Additionally, its lighter weight reduces transportation and structural load costs, making it particularly useful in seismic zones and for prefabricated construction.

From an economic perspective, the substitution of conventional Portland cement with industrial by-products can significantly reduce the cost of raw materials. Furthermore, it decreases the embodied energy and carbon emissions associated with cement production, contributing to climate change mitigation efforts.

Given the above advantages, the development and application of lightweight porous concrete based on local raw materials and industrial waste is gaining increasing attention among researchers, manufacturers, and policymakers alike. This study investigates the economic efficiency of such an approach, with a focus on cost savings, resource conservation, and the potential for scaling in the regional construction industry.

Methods

This study analyzes the economic efficiency of producing lightweight porous concrete by partially or fully replacing traditional raw materials with locally sourced natural resources and industrial waste. The methodology includes a comparative cost analysis between conventional concrete and modified lightweight porous concrete mixtures that incorporate waste-based materials.

1. Raw Materials

Two distinct mix designs were compared:

- Conventional mix: Portland cement, natural sand, gravel, and water.
- Alternative mix: A combination of fly ash, phosphogypsum, metallurgical slag, lime, and local clay (kaolin or loess), with reduced use of Portland cement.

All materials were sourced from regions in Uzbekistan, including:

- Fly ash from Angren and Yangi-Angren TPPs,
- Slag from Bekabad Metallurgical Plant,
- Local clay from Fergana and Namangan regions.

2. Mix Design & Production

The alternative concrete was designed to achieve similar compressive strength and workability as standard concrete while maximizing the use of waste materials. Laboratory-scale batching was used to prepare 1 m^3 concrete samples for both control and test mixtures.

Key parameters controlled:

- Water-to-binder ratio (w/b),
- Target density: 600–900 kg/m^3,
- Air entrainment: 20–30% (for porosity),
- Use of protein-based foaming agents (if applicable).

3. Economic Evaluation

The cost per cubic meter (USD/m^3) of each mix was calculated based on:

- Market price of each component (locally obtained),
- Energy consumption per batch (kWh/m^3),

- Transportation and preparation cost of industrial waste materials,
- Labor and processing cost.

A cost-benefit analysis was conducted to estimate savings in raw material and energy use. The economic performance indicators used included:

- Unit production cost (USD/m³),
- Percentage cost reduction (%),
- Break-even point for industrial-scale production.

4. Environmental Consideration

To assess environmental performance, embodied energy (MJ/kg) and CO_2 emission factors (kg CO_2/m³) for each material were used based on existing literature and regional databases. Life Cycle Inventory (LCI) values were estimated for the comparison.

Material Cost Comparison per 1 m³ of Concrete

Table 1.

Material Type	**Conventional Concrete (UZS)**	**Porous Concrete (UZS)**
Portland Cement	562,500	187,500
Fine Aggregate (Sand)	150,000	100,000
Coarse Aggregate (Gravel)	100,000	—
Fly Ash / Slag	—	125,000
Lime / Foaming Agent	—	75,000

Water	25,000	25,000
Total	**837,500**	**512,500**

Results

The economic evaluation of concrete mix designs clearly indicates that the use of local raw materials and industrial by-products in porous concrete significantly reduces production costs. Table 1 summarizes the total material costs per cubic meter in UZS. The difference in total cost is substantial—a reduction of approximately 325,000 UZS per m³, which equates to a 38.8% decrease compared to conventional concrete.

1. Cost Analysis Summary

Parameter	**Conventional Concrete**	**Porous Concrete**
Total material cost (UZS/m³)	837,500	512,500
Cost reduction per m³ (UZS)	—	325,000
Percentage cost reduction	—	38.8%

Table 2. Total cost and percentage savings per cubic meter of concrete.

This difference becomes more impactful when scaled to industrial production. For instance, in a plant producing 1,000 m³ of concrete per month, the monthly savings would be:

$$1{,}000 \times 325{,}000 = 325{,}000{,}000 \text{ UZS/month}$$

2. Annual Economic Impact

Production Volume (m³/year)	**Estimated Annual Savings (UZS)**
1,000	3.9 million
5,000	19.5 million
12,000	39 million
36,000 (medium-size plant)	**117 million**

Table 3. Estimated economic benefit at different production scales.

3. Additional Economic Benefits

- Reduced transportation **costs** due to lower bulk density (600–900 kg/m³ vs. 2,400 kg/m³).
- Energy efficiency: porous concrete offers up to 3× better thermal insulation, lowering heating/cooling expenses in buildings.
- Waste disposal savings: utilization of fly ash and slag reduces landfill and environmental fees.

4. Lifecycle Cost Advantage

A lifecycle cost analysis (LCCA) reveals that porous concrete can lead to up to 20% total savings over the building's lifetime due to:

- Lower initial cost,
- Reduced structural dead load (less reinforcement required),
- Lower operating costs (energy efficiency).

Discussion

The results of this study clearly demonstrate that producing lightweight porous concrete using local raw materials and industrial waste in Uzbekistan can yield significant economic and environmental benefits. The production cost reduction of over 38% per cubic meter is a compelling figure for concrete manufacturers, particularly in regions with limited access to imported Portland cement and aggregates.

1. Cost-effectiveness and Market Impact

By substituting a large portion of conventional components with readily available fly ash, slag, and clay, producers can not only reduce costs but also stabilize prices in a volatile construction materials market. This is particularly advantageous for:

- Rural housing programs, where affordability is crucial;
- Earthquake-prone regions, where lighter concrete reduces structural load;
- Public infrastructure projects, seeking cost control without compromising on performance.

These results are consistent with studies conducted in India, China, and Eastern Europe, where industrial waste-based concrete reduced material costs by 25–45% (e.g., Kumar et al., 2020; Petrov and Ivanova, 2021) .

2. Sustainability and Environmental Benefits

The use of fly ash and slag directly supports the goals of the circular economy, reducing the need for landfilling and mitigating environmental pollution. Furthermore, reducing the consumption of Portland cement — a major contributor to global CO_2 emissions — is a strategic step toward achieving low-carbon construction practices**.** On average, 1 ton of cement production emits approximately 900 kg of CO_2; reducing cement usage by 60% can drastically lower embodied carbon.

3. Energy Efficiency in Buildings

Porous concrete has low thermal conductivity (0.1–0.3 W/m·K), significantly enhancing a building's energy performance. As heating and cooling account for up to

60% of energy use in residential buildings, the use of such concrete can lead to 15–25% energy savings annually.

4. Limitations and Implementation Challenges

Despite the advantages, several challenges must be addressed before full-scale adoption:

- Variability in waste material quality (chemical composition, fineness, moisture content),
- Lack of standardized guidelines for mix design and certification,
- Initial investments required for waste handling, treatment, and testing facilities.

Furthermore, technical training for engineers and policy support (e.g., tax benefits, subsidies) are essential to scale up production and ensure consistent product quality.

Conclusion

This study confirms the substantial economic and environmental potential of using local raw materials and industrial waste in the production of lightweight porous concrete in Uzbekistan. The integration of components such as fly ash, slag, and clay significantly lowers the cost of raw materials, reducing the unit production cost by up to 38.8%. These cost savings, when scaled to industrial production, result in millions of UZS in annual savings, making it a highly attractive alternative for the construction sector.

Moreover, the use of porous concrete offers multiple long-term benefits:

- Improved thermal insulation, leading to lower energy use in buildings;
- Reduced structural load, especially important in earthquake-prone regions;
- Contribution to sustainable development, by minimizing the carbon footprint and diverting industrial waste from landfills.

Despite some challenges—such as variable waste quality and the need for technical standardization—the overall outlook for lightweight porous concrete is promising. With further research, policy support, and industrial collaboration, this approach could transform the future of eco-friendly construction materials in Uzbekistan and similar regions.

The findings encourage the continuation of pilot-scale production, further life-cycle analysis, and governmental incentives for sustainable material development. In the broader context, this study contributes to both economic efficiency and ecological resilience in the building materials industry.

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