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Urban Catalyst- Integration of Alternative Materials in Secondary Construction Systems for Enhancing Structural Lifespan in Transport Infrastructure

Dev Jeetendra Mirchandani¹, Ar. Abhijit Sahasrabudhe¹¹VESCOA

Abstract

The redevelopment of railway infrastructure in rapidly growing urban contexts such as Surat demands materials that can withstand aggressive environmental conditions while minimizing long-term maintenance. Conventional construction materials used in station facades and secondary systems often deteriorate due to high humidity, chloride exposure, thermal variations, and continuous public usage, leading to frequent repair cycles and increased lifecycle costs. Despite advancements in material technology, the integration of alternative materials in large-scale public transport infrastructure remains limited, highlighting a critical research gap (Favier, De Wolf, Scrivener & Habert, 2018). This study aims to evaluate the performance and applicability of alternative materials as secondary construction systems to enhance structural lifespan and operational efficiency. The research focuses on materials such as ultra-high-performance concrete (UHPC), geopolymer panels, fibre-reinforced polymers (FRP), ETFE membranes, and engineered bamboo. A structured methodology is adopted, including literature review, case study analysis of comparable transit infrastructure, environmental assessment of Surat's climatic conditions, and comparative evaluation of material properties based on durability, thermal performance, and maintenance requirements (Duxson, Provis, Lukey & Van Deventer, 2007; Provis & Van Deventer, 2009). The study proposes a material integration framework that aligns material selection with functional zones such as facades, concourses, platforms, and roof systems. Findings indicate that alternative materials, particularly self-healing geopolymer systems, offer significant advantages in terms of durability, reduced maintenance cycles, and environmental performance when compared to conventional materials. The research further demonstrates how strategic material deployment can improve user comfort, reduce operational costs, and enhance the overall resilience of transport infrastructure (Gagg, 2014). The outcomes of this study provide practical guidelines for architects and planners in selecting and integrating alternative materials within infrastructure projects. Future research can explore large-scale implementation, long-term performance monitoring, and advancements in material technology to further optimize sustainable construction practices in transportation systems. (De Belie et al., 2018).

Keywords; Alternative Materials, Climate-Responsive Design, Transport Infrastructure, Lifecycle Performance

INTRODUCTION

Transport infrastructure in rapidly urbanising cities is subjected to continuous environmental and operational stress, leading to accelerated material degradation and increased maintenance demands. In stations, particularly in coastal and humid regions such as Surat, commonly used construction materials in facades and secondary systems are highly vulnerable to moisture ingress, chloride exposure, thermal expansion, and repetitive user load. These factors result in microcracking, corrosion of reinforcement, surface deterioration, and frequent repair cycles, ultimately reducing the service life of the structure (Gagg, 2014).

Traditional repair methods, including surface coatings, patch repairs, and epoxy treatments, often provide only temporary solutions and contribute to increased lifecycle costs and embodied carbon. With the growing emphasis on sustainable and resilient infrastructure, there is a need to explore alternative material systems that

not only improve durability but also reduce long-term maintenance and environmental impact (Favier et al., 2018). Recent advancements in material technology have introduced high-performance and bio-based materials such as ultra-high-performance concrete (UHPC), geopolymer composites, fibre-reinforced polymers (FRP), ETFE membranes, and engineered bamboo. These materials offer enhanced strength, durability, thermal efficiency, and adaptability to complex environmental conditions (Van Tittelboom & De Belie, 2013)

Aim: *To evaluate and integrate alternative materials as secondary construction systems in transport infrastructure in order to enhance structural durability, reduce maintenance cycles, and improve lifecycle performance under specific climatic conditions.*

Objective:

- Evaluate structural, thermal, and durability performance of alternative materials such as UHPC, geopolymer systems, FRP, ETFE, and engineered bamboo in comparison to conventional construction materials (De Belie et al., 2018).
- To analyse the suitability of these materials under the climatic conditions of Surat, including high humidity, chloride exposure, thermal variations, and urban dust.
- To develop a comparative framework based on lifecycle performance, maintenance requirements, and environmental impact for material selection in infrastructure projects. (Favier et al., 2018).

Methodology:

1. Literature Review and Data Compilation

- A comprehensive review of academic literature, technical reports, railway manuals, and international case studies is conducted to understand the properties, performance characteristics (Provis & Van Deventer, 2009).

- Applications of alternative materials such as UHPC, geopolymer systems, FRP, ETFE, and engineered bamboo (Snoeck & De Belie, 2015).

2. Case Study Analysis

- Selected case studies of transport infrastructure, including projects with similar climatic and functional conditions, are analysed to understand real-world applications of alternative materials. (Gorgolewski, 2008).
- This stage focuses on benchmarking material performance, construction techniques, and maintenance practices.

3. Material Selection Framework

- The environmental conditions of Surat are analysed, including high humidity, chloride-laden air, temperature variations, monsoon exposure, and urban dust (Favier et al., 2018).

4. Field and Climate Suitability Assessment

- Evaluate the environmental issues of Analyse Surat, such as humidity, salt-filled air, exposure to monsoon winds, and urban dust.
- Evaluate the response of the materials to these parameters, such as accelerated ageing tests and service demands (De Belie et al., 2018).

5. Design Detailing and Integration Proposals

- Prepare prototypes and drawings (using other materials) of main areas of ticket counters, waiting halls, roofs, ramps and service ducts.
- Accountability conform to GDCR, UDCPR, code of accessibility and structural safety.

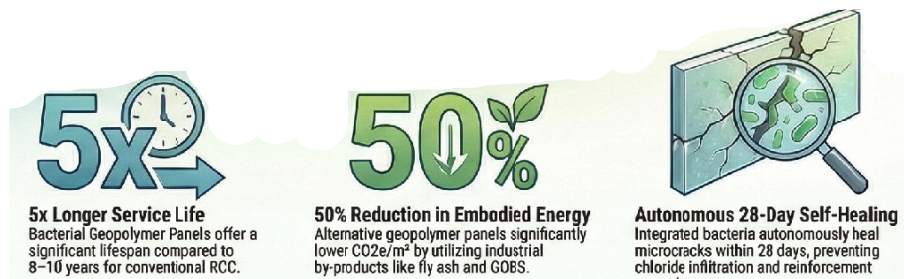


Figure 1: Usage of Green Material Adaptivity

Source: Author

6. Recommendations and Future Research

- Provide Supply maintenance procedures, pilot installation plans and possible mock-ups to confirm the performance of the material.
- Recommend where to do future research and cooperate with suppliers, universities and industry agencies.

Table 1: Comparison of Matrix with Other Traditional Materials

Source: Author

Parameter	Bacterial Self-Healing Geopolymer Panel	Geopolymer Terrazzo Flooring	Bio-PCM Roof Panel System	Conventional RCC + ACP Façade
1. Mechanical Strength & Stability	Compressive strength ~35 MPa, flexural ~5–6 MPa; maintains integrity post-healing (excellent structural retention)	35–60 MPa; suitable for high-traffic loads (very high surface hardness)	Structurally stable sandwich (shear strength 0.3–0.5 MPa, depends on skin material)	RCC 30–35 MPa but prone to cracking (moderate long-term stability)
2. Durability & Maintenance	Autonomous crack healing within 28 days; expected service life >50 years	Highly abrasion resistant; polish renewal every 15 years	25–30 years before PCM replacement; minimal corrosion	Frequent repair cycles every 8–10 years (high maintenance)
3. Thermal Efficiency	$U \approx 1.2\text{--}1.6 \text{ W/m}^2\text{K}$ (ventilated system)	$U \approx 2.0\text{--}2.5 \text{ W/m}^2\text{K}$ (non-insulated)	$U \approx 0.6\text{--}1.0 \text{ W/m}^2\text{K}$; reduces indoor temperature by 20–25% (excellent passive cooling)	$U \approx 2.8\text{--}3.2 \text{ W/m}^2\text{K}$ (poor thermal performance)
4. Embodied Energy (EPI / CO₂e)	~45–55 kg CO ₂ e/m ² (50% lower than ACP)	~30–40 kg CO ₂ e/m ² (60% lower than OPC terrazzo)	~35–50 kg CO ₂ e/m ² (depending on PCM core)	~100–120 kg CO ₂ e/m ² (baseline high impact)
5. Material Availability & Regional Sourcing	Fly ash & GGBS from Hazira / Ankleshwar; bacterial system prepared locally (readily regional)	Fly ash & GGBS locally available (high feasibility)	PCM & bamboo/FRP partially imported (moderate local availability)	Fully local but energy-intensive (no sustainability advantage)
6. Fabrication & Installation	Precast panels (1.2×1.2 m) with SS anchor system; requires curing & QC	Cast-in or tile-based; local fabricators skilled	Prefab modular panels; requires controlled encapsulation	Common cast & fix; high on-site labor (low precision)
7. Lifecycle Cost (30 yrs)	₹4,500–5,000/m ² (low maintenance frequency)	₹3,000–3,500/m ² (periodic polishing)	₹4,500–6,000/m ² (initial high cost, low running cost)	₹6,000–7,000/m ² (frequent repaint & repair)
8. Sustainability Impact & Waste Utilization	Utilizes industrial by-products (fly ash, GGBS) and biological systems (strong circular economy value)	Uses recycled aggregates and industrial waste (excellent environmental balance)	Employs natural PCM and bamboo FRP (biobased innovation)	High embodied energy, non-recyclable (environmentally unsustainable)
9. Railway Project Suitability	Ideal for humid, chloride-prone climates; maintenance-friendly (perfect façade system)	Excellent for passenger-heavy concourses; long life	Suitable for large roof spans; enhances passenger comfort	High corrosion & crack risk under vibrations (low durability)

Inference:

- The Bacterial Self-Healing Geopolymer Panel has better thermal properties, durability, and lifecycle sustainability in comparison to all locally available materials
- It can be locally produced, substituting the quarry stone or imported ACP with industrial by-products of Gujarat
- The heat and moisture control features of it render it much more fitting in the hot-dry salty climate of Surat, where the old-fashioned cement facades of buildings are being plagued with cracks and flakes.
- Stone is still applicable to base plinths, tactile edges, though on the scale of large wall and concourse facades, the hybrid panel is the most effective solution.

Integration Strategy:

Table 2: Application of the selected material for designated areas

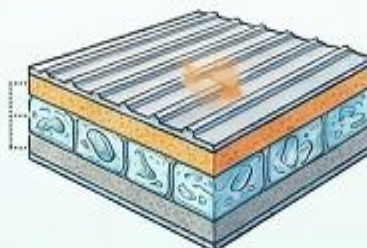
Source: Author

Orientation / Zone	Panel Type & Treatment	Reason & Benefit
South & South-West Façades	Bacterial Geopolymer Panels with ventilated back cavity + external fins	Reduces direct solar gain (peak afternoon sun); self-healing prevents thermal cracking
North Façade	Hybrid panels with punched openings or perforations	Allows uniform daylight without glare for concourse offices and retail zones
East Façade (platform side)	Semi-perforated panels with integrated louvers	Captures soft morning light; promotes cross-ventilation through platform area
Roof Envelope	Bio-PCM sandwich panels over waiting halls and ticketing zone	Controls heat gain and stabilizes temperature fluctuations inside halls
Platform Parapet and Balustrade	Geopolymer modules with open air-vents	Allows air flow and reduces hot air stagnation under canopy
Atrium / Concourse Core	Vertical stack vent with translucent geopolymer panels (fritted glass laminate)	Diffuses daylight deep into station; releases hot air by stack effect

ZONAL INTEGRATION STRATEGY



Climate-Responsive Facades
South/West facades use ventilated geopolymer panels and fins to reduce peak afternoon solar gain.



Bio-PCM Thermal Buffering
Roof envelopes utilize Bio-PCM sandwich panels to stabilize temperatures in waiting halls and ticketing zones.



High-Traffic Geopolymer Terrazzo
Used in concourses for its high surface hardness and 15-year polish renewal cycle

Figure 2: Zonal Integration Strategy in Different Design Parameters

Source: Author

Daylight and Ventilation Co-ordination:

- The highly albedo geopolymer panels reflect sunlight without causing glare and thus provide visual comfort on the inside.
- Intermediate platforms have a cross-ventilation shaft which passes the cooler air through the roof vents and exhausts it, which means it is the air brought between the store blocks (platforms).
- Daylight factor requirement: 2-3 per cent in the case of public areas and 5 per cent in the case of concourse areas.

Zonal Implementation for the Station:

Table 3: Zonal implementation of the material for the project
Source: Author

Station Zone	Panel Type / Finish	Function	Rationale for Placement
Main Concourse Façade	Self-healing geopolymer textured panels (1.2×1.2 m)	External cladding	High solar exposure area; requires long life and low maintenance
Ticketing & Retail Zone	Lighter panels with vent slots & louvers	Partial enclosure	Improves daylight and airflow; reduces HVAC load
Platforms & Service Walls	Plain panels with silicate sealant finish	Structural protection	Resists chloride attack from rail wash and humidity
Waiting Hall Roof & Atrium	Bio-PCM roof modules with geopolymer top skin	Roofing	Thermal buffer zone for large air volumes
Admin Block & Foot-Over Bridge (FOB)	Geopolymer panels combined with bamboo-FRP handrails	Hybrid design	Lightweight, aesthetic, and easy to install

Local Material Cost & Availability:

Table 4: Approximation costing of the material selected for project
Source: Author

Material Type	Local Source / Supplier Region	Approx Cost (₹/m²)	Sustainability Comment
Fly Ash & GGBS	Ankleshwar / Hazira industrial belt	500–700	Industrial by-product reuse (key eco-benefit)
Bacterial Culture & Microcapsules	Microbiology labs (Surat / Ahmedabad universities)	800–1,200	Locally produced; low mass impact
Geopolymer Panel Fabrication (Lab / Precast Yard)	Surat / Vadodara Precast Units	2,500–3,000	Transport ≤ 150 km reduces CO ₂
Stainless-Steel Fixings & Frames	Rajkot / Ahmedabad manufacturers	400–600	Recyclable metal; long service life

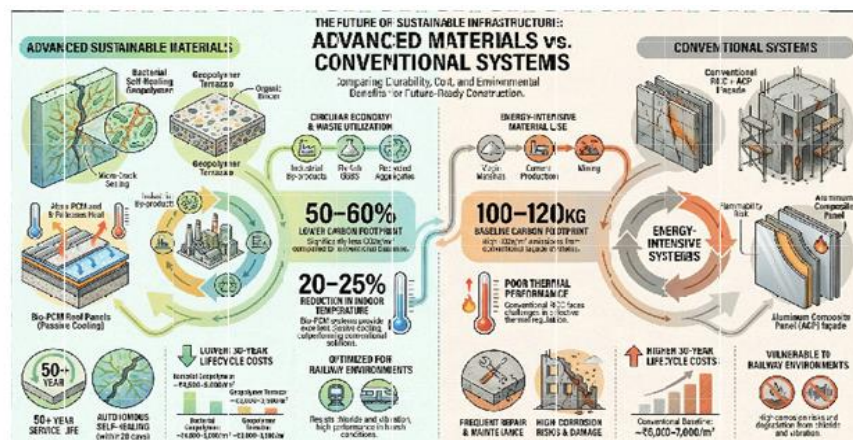


Figure 3: Comparison of Conventional vs. Advance Material
Source: Author

Production Strategies for the System:

Advantages:

- Reduce the cost of transporting as panels are manufactured at or close to the station.
- Prototyping in early stages and faster iteration in the experiment stage.
- Customisation of certain modules in case of a change in design.

Limitations (Major)

Inconsistent curing conditions:

Geopolymer binders must be subjected to controlled moisture and temperature; bacteria must have viable conditions. Premature death of spores at on-site conditions in Surat (40- 42 °C, dry air)

- **Higher risk of contamination and improper encapsulation**

Disproportionate machine powder quantities (mixing) means that batches are not made precisely.

- **Space constraints at the railway station**

Large mould beds, curing tents, and QC areas cannot be set up easily within a functioning urban station precinct.

- **Lack of precision for façade work**

Facade panels must be made to a very strict need (+2-3 mm tolerance). This is seldom done in on-site casting

- **Lab testing becomes harder**

Small test cubes would have to be delivered to a lab with each batch, and this would raise the variation in results.

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