Advanced Low-Carbon High-Performance Mortars for Retrofitting of Heritage Buildings

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The structural retrofitting of 20th Century built heritage presents unique challenges due to the materials and construction techniques applied. Reinforced concrete and masonry structures require specific approaches for repair and restoration. Advanced high-performance mortars are required to ensure both durability and compatibility with the original structure.

RESHEALIENCE HORIZON 2020

The restoration of the 1930 Civil Abattoir Water Tower in Marsa, Malta, is an example of a conservation-led approach that carefully respects the structure's authenticity while addressing extensive material and structural deterioration. Through advanced assessment methods and the introduction of innovative, high-performance materials, including ultra high performance and textile reinforced concrete, the project achieved a balance between preserving historical integrity and ensuring long-term structural durability.

SINCERE Project - HORIZON Europe

The conservation and adaptive reuse of heritage buildings present critical challenges in balancing historical preservation with modern energy and structural requirements. This research presents a comparative study of five pilot interventions from the EU-funded SINCERE project, each employing innovative mortar technologies tailored to the climatic, structural, and regulatory contexts of heritage structures in Israel, Spain, Czech Republic, Greece, and Malta.

Across the sites, mortars incorporating hempcrete, textile reinforcement, and phase-change materials among other constituents are evaluated for their performance in thermal retrofitting, environmental resilience, and heritage compatibility. For the data on thermal performance, the network of sensors is applied. The mechanical performance, durability and compatibility of repair mortars are critical factors in the successful retrofitting of heritage buildings and application in buildings and infrastructure.

Objectives

→ Lower energy consumption during the operation of restored CH buildings by improving their thermal performance and extending the durability of repair mortars and building structures

→ Test and validate SINCERE technologies through pilot projects at five demonstration sites and evaluate their societal, economic, and scientific impact

→ Decrease the environmental footprint of restoration and maintenance by developing low-energy, low-carbon restoration mortars that are highly compatible and have an extended lifespan, while maintaining architectural authenticity

DemoPark buildings at Algete, Marid, Spain

The technologies that will be developed within the SINCERE project, following the designing and the laboratory-testing, will be evaluated and validated outdoors at a larger scale, on building prototypes (test cells) located in the Demopark at Algete (Madrid) managed by ACCIONA. The prototypes will serve as testbeds of the developed materials exposed in real environmental conditions and will provide useful information, regarding the practical issues arising, but also will give an insight for the overall response of the applied solutions. Four experimental test cells have been made available to apply the materials and technologies and to analyze the thermal performance of the different refurbishment solutions (thermal mortars, radiative cooling coatings) and compare them with non- refurbished conventional old solutions.



1. First mock-up, serving as a reference, includes baseline hempcrete blocks (K = 0.071 W/mK) and commercial mortar (K = 0.68 W/m·K)
2. Second mock-up incorporates baseline hempcrete blocks and hempcrete mortar
3. Third mock-up includes baseline hempcrete blocks and ternary mortar (lime-white cement-pozzolan, incorporating phase change materials (PCMs)
4. Fourth mock-up includes baseline hempcrete blocks and textile reinforced mortar (TRM), consisting of the same matrix and both incorporating phase change materials.

Neoclassical school building in the Medieval city of Rhodes, Greece

This pilot is a 19th century neoclassical school building, in the Medieval city of Rhodes. The building is in front of the Grand Master Palace, the most visited site in Rhodes, and forms a typical example of the Ottoman period architecture. The building was in operation until the late 1980s, when it was abandoned, due to serious static problems on its foundation. The building covers approximately 650 m2 and is developed around a central atrium with a perimeter gallery, with a total area of approximately 350m2. To enhance occupant comfort and ensure equipment stability, the building requires improved passive regulation of internal temperatures and thermal buffering of interior wall surfaces to reduce fluctuations. These upgrades must align with heritage conservation constraints, while improving the environmental performance of the envelope.



These needs are addressed through the application of lime-based thermal insulating mortars incorporating phase change materials (PCMs) and lightweight hemp shives. Three 6–7 mm-thick thermal retrofitting renders are applied across three 2 m² test areas on the south façade:

Area 1: Ternary mortar enhanced with PCMs
Area 2: Reference (standard) mortar
Area 3: Thermal retrofitting mortar with hempcrete

The monitored test zones are internally enclosed within an insulating box (Dow Styrofoam, 2.70 × 1.30 × 0.30 m) to control boundary conditions and evaluate performance.

Holon Institute of Technology, Israel

The Holon Institute of Technology was founded in 1969 in an existing site with workshop buildings, built in 1953. The pilot site at HIT is building no. 3. A four-story structure of a total floor area of 2200 m2, constructed in 1972. It was renovated and enlarged in 1992 and in 2009, when an elevator core was added for accessibility. The building provides today a mixed-use of spaces for administration (offices, meeting rooms), laboratories, conference hall, and synagogue. The building is built of exposed reinforced concrete frame in the Brutalist style of exposed concrete surfaces. Other materials include aluminum windows and uninsulated corrugated metal panel roof (a later addition).
HIT as an academic institution is open throughout the day, and accessible to the wider public, ensuring accessibility to the public and organized visits. The educational context will also provide opportunities to study the pilot in real-time and engage students and faculty in the monitoring and evaluation process, reporting and dissemination.



Application and monitoring of insulating mortars, including hempcrete and PCM-enhanced mixes, on exposed concrete wall surfaces and radiative cooling paint on aluminum roof to reduce energy loads, especially during the hot season. Energy use impact can be tracked via the building's dedicated electricity meter.
Roof Interventions:
Test Area 1 Radiative-cooling paint-coated aluminum sheets
Test Area 2 Unpainted aluminum sheets
Concrete Wall Interventions Wall Test Areas (70 × 80 cm each):
Area 1: Exposed concrete (no mortar)
Area 2: 2 cm hempcrete mortar layer
Area 3: 2 cm PCM-enhanced hempcrete mortar

MUSEum+ Industrial Heritage Building, Ostrava, Czech Republic

MUSEum+ aims to revitalize Blast Furnaces 4 and 6 and the casting hall in Lower Vítkovice, Ostrava, transforming this brownfield into an innovative industrial museum while preserving its cultural significance. After the plant closed in 1998, the furnaces, built in 1962 and 1971, were declared a national cultural monument, yet they continue to deteriorate despite earlier restorations on the site. This pilot stands out as the only industrial case, offering a unique opportunity to test structural and thermal retrofitting mortars in a colder northern climate unlike the Mediterranean pilots. The rehabilitation of the cultural monument with sustainable materials and methods, combined with its new use, of cultural and educational nature, encompasses a symbolism, which highlights the transition from a structure previously belonging to a plant with increased negative environmental impact, to a considerably eco-friendly, greener building with cultural and educational qualities.



Since some legal conservation restrictions were faced, 5 panels of 2cm thickness will be installed on the external building walls for the demonstration of materials (Textile Reinforced Mortar TRM, Phase Change Material PCM, Ultra High Performance Concrete UHPC) and technologies.

Panel 1: TRM + PCM + Sensors
Panel 2: TRM
Panel 3: UHPC + Welded Wire Mesh
Panel 4: UHPC + Self healing Agent + Welded Wire Mesh
Panel 5: UHPC + Corrosion Inhibitor + Welded Wire Mesh

Searchlight Post, Inwadar Park, Malta

The surviving searchlight post within Il-Park Nazzjonali tal-Inwadar represents a significant element of Malta's coastal defense infrastructure during World War II. Constructed as part of a network of visual tracking installations, this structure was specifically designed to support anti-aircraft and coastal defense operations by illuminating aerial or maritime targets during night-time raids. It is a compact two-storey structure built from local limestone masonry and reinforced concrete. The interventions aim to stabilize and adaptively reuse the building as a compact, low-impact astronomy observation lab. This enhances the building's structural performance, ensures its conservation, and supports educational and recreational use linked to dark-sky heritage and coastal observation.

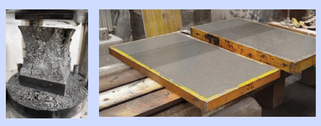
- Protection of floor surfaces from wear and moisture ingress
- Strengthening of horizontal structural elements
- Reinforcement of slab undersides to control cracking and enhance flexural performance
- Stabilization of cantilevered components
- Increased durability of external walls
- Passive internal temperature regulation
- Thermal buffering of internal walls and improved environmental performance of envelope



To strengthen and preserve the concrete slabs, a 20 mm layer of ultra-high-performance concrete (UHPC) with crystalline admixtures will be applied to the floor surfaces on both levels. This layer increases durability, water resistance. The slab undersides will be reinforced with textile-reinforced concrete (TRC) using AR-glass mesh to increase structural integrity, limit deflection, and control cracking. The same TRC will be applied to the cantilevered beam and exposed reinforced-concrete walls, improving resistance to environmental degradation from wind, salt, and thermal stress. Interior walls will be treated with cement-based TRC integrated with phase-change materials (PCMs) to act as a passive thermal buffer, reducing temperature fluctuations and providing a stable environment for astronomical instruments. The method maintains breathability, respects the heritage fabric, and improves energy performance.

Mix design	CEMIV, kg/m3	Fine aggregates, kg/m3	Natural pozzolan, kg/m3	Water, kg/m3	Super plastisizer, kg/m3	Amorphous Alloy Fibers, kg/m3	PCM, kg/m3
UHPC UoM	794	1333	-	190	29,6	45,58	18,57

Mix design	7d compression strength, MPa	7d flexural strength, MPa	28d compression strength, MPa	28d flexural strength, MPa
UHPC UoM	87,57	11,82	104,75	12,64



Marsa Water Tower, Malta

The comprehensive restoration and conservation of the 1930 Civil Abattoir Water Tower in Marsa, Malta, is in conformity with the original physical state of the structure and conservation principles and values, while taking into account the severe degradation of the structure (shell elements & slender columns). To address severe structural degradation, the project involved advanced appraisal techniques, including numerical structural modelling and materials testing, to optimize repair and strengthening interventions.

Advanced Materials and Mortars

Development and then the application of advanced ultra-high performance materials applied for the first time, including ultra-high performance self healing nano-additive based concrete (UHPC) and carbon textile reinforced high performance concrete (TRC) for the strengthening of the structure. Ultra-high strength concrete to enable interventions using restricted thin sections instead of large cross-sectional new elements which would detract from the appearance and elegance of the original structure. (180MPa compressive Strength, 35MPa Flexural Strength. The intervention integrated advanced restoration techniques, such as electro-chemical chloride extraction, alkalization, and epoxy injection, adhering to principles of legibility and re-treatability.

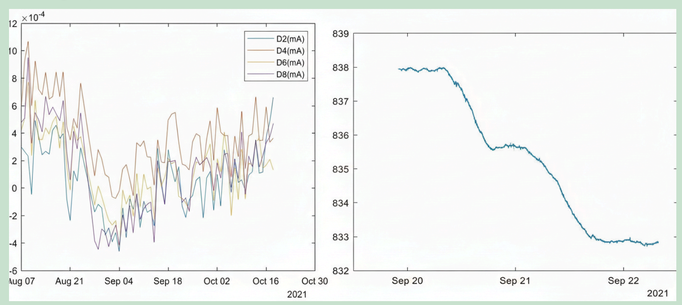




The intervention was conducted on the basis of scientific restoration methodology: assessment of the materials and the structure and the development of new materials (high performance mortars) & application of new materials and monitoring in the laboratory and on site for compatibility and performance.

Structural Health, Durability and Environmental Monitoring

The long-term monitoring approach is based on an advanced structural health and Durability monitoring system together with environmental monitoring. The system is based on 150 sensors embedded in the structure, the data collection and processing in real time, to validate performance of materials and interventions and to monitor long-term performance of the structure in service during operation.





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