



# HI-EURECA-PRO STRATEGIC RESEARCH THEMES

## SRT 1. HERITAGE DIGITAL TWINS & OPERATIONS OPTIMISATION

**What:** Methods and pipelines to build, calibrate and operate digital twins for heritage production lines, museum facilities, historic districts, or mining legacy sites (energy/water flows, process control, crowd and asset flows). This includes data acquisition and integration (sensors, scans, historical records), modelling approaches, and user-facing decision-support services embedded in day-to-day site management.

**Why:** Digital twins transform heterogeneous site data into actionable operational intelligence supporting the green & digital transition. They enable scenario testing (retrofit, process changes, visitor management), reduce resource consumption and downtime, and create transversal assets reusable across demo sites and the DTH—supporting pilots, showrooms and scale-out actions within HI-EURECA-PRO and the Alliance.

**Exemplary topics:** (a) digital twin architectures, reference models and interoperability standards; (b) low-cost sensing and retrofit kits for constrained heritage environments; (c) hybrid modelling (physics + ML) and uncertainty handling; (d) data fusion, calibration and validation using multi-source evidence (sensors, scans, archival data); (e) decision-support dashboards for curators, operators and municipalities; (f) twin-enabled scenario simulation for maintenance scheduling, retrofit options and operational optimisation.

## SRT 2. PREDICTIVE MAINTENANCE & CONDITION MONITORING FOR LEGACY ASSETS

**What:** Vibration/acoustic/thermal analytics, anomaly detection and remaining useful life estimation for legacy machinery and built heritage systems (HVAC, pumps, conveyors). The scope includes retrofitting non-invasive sensors, edge/cloud data pipelines, and decision rules that translate diagnostic signals into maintenance actions aligned with safety and operational constraints.

**Why:** Predictive maintenance increases the longevity, safety and reliability of heritage assets while lowering CO<sub>2</sub> emissions and costs by preventing failures and optimising interventions. It also generates generalisable datasets, SOPs and validated workflows that can be deposited in the DTH and reused by other sites, accelerating joint research and strengthening widening partners' operational capacity.

**Exemplary topics:** (a) non-invasive sensing and instrumentation for legacy machinery and building systems; (b) edge analytics pipelines for limited connectivity and energy constraints; (c) anomaly detection, diagnostics and remaining useful life estimation; (d) transfer learning/domain adaptation from modern equipment to legacy assets; (e) explainable alerts and operator-centred interfaces for non-expert users; (f) integration with QA/HSSE and maintenance planning workflows (work orders, safety procedures, audits).



### SRT 3. CIRCULARITY & SUSTAINABILITY TOOLKITS FOR HERITAGE SITES

**What:** Practical tools to measure and improve resource efficiency and circularity in industrial/cultural/mining settings (material flows, embodied carbon, water, waste, reuse). This includes indicators and dashboards, assessment methods tailored to protected sites, and operational toolkits supporting procurement, maintenance and refurbishment decisions.

**Why:** Circularity toolkits provide measurable, comparable evidence of SDG12 progress and help site owners and public authorities justify investments and policies. They enable prioritisation of interventions with the highest sustainability return, strengthen business links (SMEs, solution providers), and translate HI-EURECA-PRO research into implementable practices that can be showcased and replicated through DTH, showrooms and living labs.

**Exemplary topics:** (a) site-level circularity indicators and harmonised KPI dashboards; (b) embodied carbon and life-cycle assessment methods tailored to protected sites; (c) material inventories, material passports and reuse potential mapping; (d) retrofit and eco-design libraries with decision rules and examples; (e) circular procurement and maintenance playbooks for operators and public bodies; (f) practical toolkits and training modules for SMEs, municipalities and site owners.

### SRT 4. SUSTAINABLE MATERIALS, RETROFIT & CONSERVATION METHODS

**What:** Testing and validating eco-materials and retrofitting methods compatible with heritage constraints (e.g., low-intrusion composites, lime-based systems, reversible interventions). This includes laboratory and in-situ validation, compatibility with historic substrates, durability monitoring, and integration with climate-resilience and energy-efficiency targets.

**Why:** Sustainable retrofit is one of the most direct pathways to reduce emissions and extend the life of heritage structures while respecting conservation requirements. It bridges technological innovation with policy and permitting realities, strengthens the practical relevance of HI-EURECA-PRO demonstrators, and supports industry uptake by producing validated methods, performance evidence and compliance-ready guidance that can be shared via DTH and demonstrated in showrooms.

**Exemplary topics:** (a) eco-materials compatibility testing with historic substrates and reversible application methods; (b) reversible anchors, low-intrusion strengthening and minimal-intervention retrofit solutions; (c) hygrothermal, structural and durability monitoring (lab and in-situ); (d) life-cycle cost/carbon models supporting investment and permitting decisions; (e) safety, compliance and performance protocols for protected buildings and industrial assets; (f) pilot installations, long-term performance evidence and replication guidelines.

### SRT 5. SMART TOOLS IN HERITAGE INNOVATION

**What:** AI-enabled platforms and smart services that support heritage innovation workflows—such as digital assistants, smart search, decision-support dashboards, and training/showroom resources—integrated with the standalone DTH. These tools may cover the full lifecycle: discovery of infrastructure and datasets, partner identification, proposal preparation, compliance checks, and knowledge packaging for stakeholders.



**Why:** Smart tools reduce fragmentation by enabling open access to knowledge and infrastructure, faster identification of experts and professional support, and more efficient formation of consortia across science and business. They increase the productivity and competitiveness of widening partners under budget constraints, strengthen collaboration across the Alliance, and provide scalable mechanisms to sustain JRA actions beyond individual pilots.

**Exemplary topics:** (a) smart search and knowledge graphs over heritage datasets, infrastructures and methods; (b) AI assistants for proposal drafting, partner discovery, and compliance/IPR pre-checks; (c) capability mapping and partner-matching engines linking academia, SMEs and site owners; (d) automated KPI tracking and reporting dashboards for miniCSA/JRA monitoring; (e) multilingual digital tutors for training, onboarding and micro-credentials (DTH-integrated); (f) workflow automation for governance assets (IP/data templates, approvals, audit trails, secure sharing).

## SRT 6. ARCHITECTURE AND URBANISM RELATED TO CULTURAL, INDUSTRIAL AND MINING HERITAGE

**What:** Research and applied methods supporting heritage-sensitive architectural design and urban regeneration, including adaptive reuse of industrial and mining sites, conservation-led redevelopment, landscape and public-space design, climate-resilient refurbishment, and integrated planning frameworks that balance protection requirements with contemporary functions (education, tourism, SMEs, creative industries, living labs).

**Why:** Many HI-EURECA-PRO demonstrators and stakeholders need ultimately materialise as spatial interventions like re-use strategies, retrofit decisions, and urban or landscape transformations where sustainability, accessibility, and heritage values must be reconciled. Advancing architecture and urbanism research strengthens HEP's SDG12 impact by enabling resource-efficient reuse of existing structures, reducing demolition waste and embodied carbon, and improving the long-term viability of heritage sites through well-justified, evidence-based planning. It also expands the JRA portfolio beyond “digital tools” into tangible implementation pathways that are highly fundable and directly usable by municipalities and site owners.

**Exemplary topics:** (a) adaptive reuse models and feasibility frameworks for industrial/mining assets; (b) circular construction strategies (reuse, reversible interventions, design-for-disassembly); (c) low-intrusion retrofit and climate adaptation for protected buildings and landscapes; (d) multi-criteria decision support for planning (heritage value, carbon, cost, safety, accessibility); (e) public-space, landscape and mobility/visitor-flow planning for mixed-use heritage districts; (f) regulatory pathways, permitting toolkits and stakeholder co-design methods for heritage-led regeneration.

## SRT 7. DATA, ETHICS & IP FOR HERITAGE R&I (GOVERNANCE-BY-DESIGN)

**What:** Rulebooks, IP/data templates and QA/HSSE frameworks enabling secure and efficient cross-institutional collaboration, including red/amber/green data layers, ethical reuse of digital scans, provenance tracking, and attribution models. The scope includes practical governance tools (checklists, model clauses, workflows) that are easy to apply during miniCSA pilots and scalable to Alliance-level use.

**Why:** Heritage innovation depends on trusted data sharing and clear ownership or usage rights, especially



when combining cultural assets, industrial know-how and partner infrastructures. Governance-by-design reduces friction, mitigates legal and reputational risks, accelerates joint research execution, and ensures that outputs can be deposited, reused and scaled through the DTH while protecting sensitive information and respecting heritage rights.

**Exemplary topics:** (a) red/amber/green data classification schemes and secure sharing workflows; (b) consent, rights management, provenance and attribution for digitisation outputs; (c) FAIR-aligned metadata, documentation standards and reusable templates; (d) lightweight IP/TT models for SMEs and municipalities (licensing, joint ownership, access terms); (e) QA/HSSE frameworks, risk registers and audit-ready procedures for cross-site work; (f) traceability and audit trails for DTH assets, showrooms, and joint research outputs.

## SRT 8. IMMERSIVE, INTERACTIVE AND DEMONSTRATOR-BASED HERITAGE INNOVATION (AR/VR/XR + SHOWROOMS/LIVING LABS)

**What:** Development, deployment and evaluation of immersive AR/VR/XR and interactive media together with showroom and living-lab demonstrator formats that make heritage innovation visible, usable and scalable. This topic covers both on-site and remote participation, using 3D scans, digital twins, storytelling layers, participatory interfaces and hybrid events. It also includes demonstrator design protocols, stakeholder panels, evidence capture (before/after metrics), and reusable media packages curated via the DTH.

**Why:** Combining immersive experiences with demonstrator methods creates a single, end-to-end pathway from research to adoption: it enables hands-on validation, supports stakeholder engagement (site owners, municipalities, SMEs, visitors), and generates credible impact evidence for follow-on funding. It also maximises reuse of digital assets produced in other topics (digital twins, monitoring data, retrofit scenarios), strengthens hybrid participation under budget constraints, and produces transferable protocols and content modules that can be replicated across HI-EURECA-PRO demos and the EURECA-PRO Alliance.

**Exemplary topics:** (a) AR-assisted maintenance and conservation guidance (diagnostics overlays, SOP steps, safety cues); (b) VR reconstructions and time-layered storytelling for industrial/mining/cultural processes and social history; (c) living-lab and showroom design patterns (industrial/cultural/mining) with hybrid delivery workflows; (d) interactive scenario dashboards for stakeholders (retrofit options, circularity impacts, visitor flows); (e) XR authoring pipelines linked to DTH assets (3D models, metadata, rights management, licensing); (f) evaluation frameworks for learning, engagement quality, behaviour change, and socioeconomic impact.

## SRT 9. SOCIAL AND SOCIETAL DIMENSIONS OF HERITAGE TRANSFORMATION (COMMUNITIES, GOVERNANCE, IDENTITIES, AND JUST TRANSITION)

**What:** SSH-led and interdisciplinary research on how heritage transformation affects and is shaped by communities, identities, values, governance, and socio-economic development. This topic includes participatory and co-creation methods, social innovation, conflict-sensitive governance, inclusion and accessibility, citizen trust, and the societal impacts of digitalisation and regeneration (including questions of authenticity, ownership, and benefit-sharing).



**Why:** Heritage is not only an asset to preserve or optimise; it is a living social system that creates belonging, contested narratives, and local livelihoods. Making the societal dimension explicit strengthens HEP's relevance to municipalities, civil society and cultural institutions, improves legitimacy and uptake of technical solutions (twins, monitoring, retrofit), and aligns strongly with Cluster 2 priorities (governance, participation, democracy, cultural and creative sectors). It also opens new collaboration routes for widening partners by anchoring technical pilots in robust SSH frameworks, supporting evidence-based policy, responsible innovation, and just transition in post-industrial and mining regions.

**Exemplary topics:** (a) participatory governance models and co-creation toolkits for heritage-led regeneration (citizens, NGOs, SMEs, authorities); (b) social impact assessment frameworks (distribution of benefits/costs, quality of life, local jobs, social cohesion); (c) heritage narratives, identity, memory and contested histories in post-industrial/mining regions (conflict-sensitive approaches); (d) inclusion, accessibility and cultural participation (barrier reduction, minority perspectives, intergenerational engagement); (e) trust, ethics and legitimacy of digital heritage technologies (data rights, representation, authenticity, cultural sensitivities); (f) policy instruments and decision-support for "just transition" pathways linking heritage, innovation, and regional development.

## SRT 10. SKILLS OF THE FUTURE & CITIZEN UPSKILLING (APPLIED TO HERITAGE)

**What:** Micro-credentials, PhD modules, mobility sprints and citizen courses mapped to the toolkits above, with proposal/IPR training embedded in pilots and demonstrations. The scope includes curriculum design linked to real infrastructure use, competence frameworks for digital transformation in heritage contexts, and delivery models that combine hands-on practice with hybrid participation.

**Why:** Skills are the multiplier of the JRA: they ensure that new methods (digital twins, monitoring, circularity, retrofit, XR) are adopted and sustained by researchers, operators and local ecosystems. This action supports modernised research careers, strengthens widening partners' competitiveness through practical experience and proposal readiness, and creates transferable learning assets that can be scaled across HI-EURECA-PRO and the EURECA-PRO Alliance via the DTH.

**Exemplary topics:** (a) micro-credentials and PhD modules aligned to DTH playbooks and real infrastructure use; (b) hands-on labs and research studios using pilots, datasets and demonstrators; (c) mobility sprints with defined learning outcomes and cross-site supervision; (d) citizen upskilling programmes (repair/reuse academies, circularity literacy, heritage tech camps); (e) proposal studios and mentoring tracks targeting WIDERA/Cluster 2/4/EIT pathways; (f) TTO/valorisation and entrepreneurship training (impact plans, exploitation canvases, licensing basics).

