European Heritage Hub Policy Papers

Climate Heritage Green Paper for Regional and Local Authorities

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1. Executive Summary

Europe's cultural heritage faces a dual reality. On the one hand, accelerated warming, rising seas and compound weather extremes are eroding monuments, archives, landscapes and the social practices that give them meaning. On the other, those very places, skills and material stocks offer practical leverage for a climate-neutral, climate-resilient Europe. The *Climate Heritage Green Paper for Regional and Local Authorities* translates the best available science, policy and practice into a step-by-step handbook that helps municipalities, site managers and cultural institutions translate high-level EU climate targets into day-to-day decisions. Its argument rests on three pillars: (1) a clear, quantified understanding of the hazard landscape; (2) a practical, five-stage risk-assessment method that bridges science and conservation practice; and (3) an implementation toolkit - governance, finance, skills and monitoring - that turns plans into measurable outcomes.

The document reframes heritage from a passive "victim" to an active "vector". Reusing the existing building stock can avoid up to three-quarters of the embodied carbon emitted by demolition and new construction, while historic blue-green infrastructures already deliver nature-based flood and heat mitigation. Aligning with the European Climate Law and the Green Deal, the Green Paper positions municipalities, provincial governments and site managers as the main agents of change: they control planning permits, public building portfolios and the everyday maintenance budgets where climate ambition lives or dies.

A concise survey of the science anchors the handbook. Drawing on IPCC Sixth-Assessment data, it shows that Europe has already surpassed land-surface warming and that heat-wave days, storm-surge peaks and drought-wildfire cascades are accelerating. Four geographic clusters - Mediterranean coasts, North Sea–Baltic lowlands, Alpine valleys and drought-prone Iberia - concentrate the highest and most immediate risks. Yet hazards are only one side of the equation; exposure and vulnerability hinge on material properties, maintenance regimes and social value. That triad sets the stage for the Green Paper's methodological heart.

The five-stage Integrated Risk-Assessment Framework adapts the IPCC risk formula to heritage practice:

1. **Scoping and stakeholder mapping** clarifies institutional mandates and community values before technical work begins.
2. **Baseline documentation** - digital twins, material audits, micro-climate logs - captures the "as-is" condition that future models must respect.
3. **Climate-hazard screening** overlays down-scaled projections on asset inventories, translating meteorological indices into heritage-specific hazard terms.

4. **Damage functions and loss scenarios** convert those hazards into quantified risk: repair costs, downtime, embodied-carbon leakage or loss of social use.
5. **Adaptation pathways and monitoring** sequence actions over time, guided by a decision tree that weighs Protect, Accommodate, Adaptive Reuse, Move or Document-and-Release options against significance, feasibility and equity.

The framework is more than a checklist; each stage ends with a formal checkpoint, ensuring that low-regret measures (e.g., clearing rain-goods, widening RH bands in stores) can proceed while deeper analysis continues. This prevents "analysis paralysis" and accelerates tangible progress.

Recognising that a timber belfry, a maritime archive and an irrigated rice terrace respond differently to the same climate driver, the handbook dedicates a sector-specific chapter to five asset classes. For each, it couples diagnostics - hygrothermal simulation for walls, piezometers for buried archaeology - with performance thresholds and an intervention ladder that climbs from preventive maintenance to transformational adaptation. The technical guidance is intentionally pragmatic: capillary-active insulation that halves energy demand without trapping moisture; hybrid desiccant systems that cut electricity peaks in archives; lime-stabilised ditch linings that lower pump costs in historic irrigation networks.

Good practice is illustrated rather than celebrated. Short vignettes - from IoT-guided tree care in Sanssouci Park to heritage energy passports in rural Ireland - demonstrate how the framework functions across climates, materials and governance settings. The cases are diverse but converge on four success factors: data-driven baselines, layered intervention, participatory governance and a finance–skills fly-wheel in which measured carbon and risk savings attract the investment that sustains further work.

Implementation pivots on two chapters. "Governance, Finance and Capacity Building" maps EU-to-local policy levers, identifies funding windows (RRF, Horizon Europe, LIFE, Heritage Impact Funds) and outlines a micro-credential pipeline for the crafts and data skills the transition demands. "Roadmap and Monitoring" then converts ambition into calendar time. A front-loaded Sprint 0 (to 2025) establishes hazard baselines, data lakes and regional hubs. Phase 1 (2025–2030) completes risk assessments for the majority of high-value assets; Phase 2 mainstreams heritage indicators in every National Adaptation Report; by Phase 3 (2040–2050), public heritage operations are net-zero and annual heritage-loss rates fall below half a percent. A linked MRV architecture reports five headline indicators - risk coverage, adaptation readiness, carbon savings, skills capacity and finance leverage - into EU Climate-ADAPT and Copernicus platforms, turning data into iterative governance.

The concluding chapter ties the strands together. Heritage can deliver an immediate mitigation dividend, a tangible adaptation buffer and a social narrative that makes the energy transition locally relevant. Success depends on five enablers - legislative integration, dedicated finance, FAIR data, skilled labour and participatory governance - balanced by guardrails against maladaptation, inequity and data fatigue. Some loss is inevitable; ethical “document-and-release” pathways must sit alongside protection. Yet the central message is optimistic: with the right framework, Europe’s past can scaffold its climate-resilient future.

2. Introduction and Scope

2.1. Why a Cultural-Heritage Green Paper on Climate Action?

Europe now faces a dual emergency: rapidly escalating climate hazards and the progressive loss of cultural capital that underpins community identity, creativity, and green growth. The Sixth Assessment Report projects that, without deep mitigation, coastal flood damage in Europe could increase at least ten-fold by 2100, while heat-related mortality may triple at 3 °C of global warming. Heritage assets - ranging from Roman mosaics to post-industrial landscapes - are already registering salt crystallisation, biological decay, and visitor-comfort thresholds being exceeded. These losses erode not only irreplaceable records of the past but also sustainable development pathways grounded in place-based value chains such as crafts, creative tourism, and circular construction.

2.2. Audience and Mandate

This Green Paper is designed for officials and technical staff in **regional (e.g. NUTS-2), provincial, and municipal authorities**, managers of **museums, archives, and historic sites**, as well as professionals in the wider built-heritage supply chain. It answers also the call issued by the draft **European Partnership on Resilient Cultural Heritage**, which urges member states to embed heritage in their National Energy & Climate Plans and Just Transition strategies. By aligning with EU directives - from the *European Green Deal* to the *Renovation Wave* - the document supports compliance duties while unlocking heritage-led climate solutions.

2.3. The Threat Landscape

Multiple meta-analyses document a steep rise in compound hazards - heat-wave-drought sequences, storm-surge-river-flood combinations, and wildfire smoke intrusions - that exceed the design limits of traditional conservation practice. According to UNESCO, one in six World Heritage properties is already at high risk from climate impacts, with the figure rising to one in three for Mediterranean coastal sites . Recent research further stresses that intangible practices - from seasonal transhumance to vernacular building skills - are highly vulnerable yet poorly monitored in existing risk registers.

2.4. Closing the Implementation Gap

A constellation of guidance notes - *Adapting Historic Buildings for Energy and Carbon Efficiency* (Historic England Advice Note 18) , Ireland's *Improving Energy Efficiency in Traditional Buildings*, and the pan-European KERES ontology, among others - demonstrate that technically robust, heritage-sensitive adaptation and mitigation measures already exist. However, uptake remains patchy because local authorities lack:

- Integrated risk-assessment protocols that couple down-scaled climate data with heritage-value metrics;
- Dedicated finance mechanisms to reward circular retrofit and preventive maintenance;
- Scalable training modules for craftsmen, architects, and conservators.

2.5. Scope, Method, and Evidence Base

This Green Paper synthesises **20+ peer-reviewed studies, EU project deliverables, and national guidance documents** spanning climate science, conservation, building physics, and socio-economic valuation. Key knowledge pillars include:

- **Risk and Resilience Science** – AR6 climate impact-driver framework, IPCC Special Reports, and the ICSM CHC White Papers ;
- **Technical Retrofit Guidance** – Historic England HEAN 18 and Irish DHPLG guidance;
- **Policy and Governance** – European Green Paper on Cultural Heritage and Climate Change, Strengthening Cultural Heritage Resilience for Climate Change and Theory of Change documents (internal project deliverables);
- **Data Standards and Ontologies** – KERES hazard taxonomy and the Climate-Hazard Vocabulary for Heritage. The methodology combines a *rapid evidence assessment* with *stakeholder co-design workshops* carried out in 12 EU regions between 2023-2025. This hybrid approach ensures scientific rigour while honouring practitioner insights.

2.6. How to Use This Document

Each chapter pairs **background analysis** with **Action Boxes** that list concrete next steps, responsible actors, and indicative timelines. Quick-reference icons flag mitigation, adaptation, finance, and capacity-building measures, while the Bibliography offers full list for deeper study.

Reading time: The complete text is ~30 min; Action Boxes alone ~7 min.

Key Take-Away – By treating cultural heritage as both an *asset at risk* **and** an *enabler of climate-resilient development*, regional and local authorities can unlock high-impact, low-regret interventions that advance the EU's 2030 and 2050 climate targets.

3. Climate Change: State of the Art for Europe

3.1. Observed trends

- **Temperature** – Europe's land area has warmed by **≈ 2.2 °C** relative to 1850-1900, more than twice the global mean. Five of the ten hottest summers since records began occurred after 2015.
- **Extreme heat** – The frequency of days with maximum air temperature above 35 °C (TX35) has already **tripled** in the Mediterranean since 1950, leading to material decay (salt crystallisation, pigment fading) and visitor health risks.
- **Precipitation and flooding** – Central Europe has seen a statistically significant rise in *short-duration intense rainfall* events, while peak river discharge in the Rhine–Meuse basin has increased by **about 11 %** since 1970, raising scour and damp-ingress threats for riverside monuments.
- **Cryosphere loss** – Alpine glaciers have lost **≈ 60 % of their mass** since 1980, destabilising historic mountain routes and increasing glacial-lake outburst flood (GLOF) risk.
- **Sea-level rise (SLR)** – Mean sea level along Europe's Atlantic coast now rises by ~3.5 mm yr^{-1}; *relative* SLR exceeds 4 mm yr^{-1} in parts of the Baltic due to subsidence.

Take-away Europe is already in a +2 °C world; even moderate emission scenarios lock-in multi-decadal hazards that interact with legacy infrastructure built for a cooler, more stable climate.

3.2. Projected hazards for global warming levels

To translate the observed shifts into forward-looking planning decisions, this section scales the IPCC's impact-driver data to three policy-relevant temperature benchmarks - 1.5 °C, 2 °C and 3 °C above pre-industrial levels - mirroring the Paris Agreement's ambition, the EU's current 2050 neutrality trajectory, and a high-emissions fallback. The matrix that follows distils how the principal climate drivers highlighted in AR6 (heat & cold, wet & dry extremes, drought, coastal processes, cryosphere change) are likely to evolve across Europe and pinpoints the thresholds at which heritage-critical materials, structures, and cultural landscapes may experience irreversible damage well within the lifetime of existing assets. The projections combine the IPCC Europe fact-sheet, the Heritage Climate Hazard Vocabulary, and recent integrative reviews from the KERES and ICOMOS programmes, ensuring that generic climate metrics are translated into heritage-specific risk indicators.

Climate driver (CID)	Indicator	1.5 °C GWL (≈ 2030)	2 °C GWL (≈ 2045)	3 °C GWL (≈ 2080)	Confidence	Key heritage impacts
Heat and Cold	TX35, warm nights	+15 days/yr (S. Europe)	+30 d	+60 d	High	Stone exfoliation; softening of waxes & resins; HVAC load spikes
Wet and Dry	Rx1-day, soil moisture	+7 % Rx1-day (NW EU)	+12 %	+18 %	Medium	Foundation scour; archive water damage
Drought	SPEI<-1.5 event days	+25 d/yr (Med.)	+45 d	+70 d	High	Clay shrink–swell, wildfires, vegetation die-off in historic gardens
Coastal	Relative SLR	+0.18 m (North Sea)	+0.35 m	+0.84 m	High	Loss of coastal archaeology; salt uptake in masonry
Cryosphere	Glacier volume loss	40 %	60 %	80 %	High	Destabilisation of alpine trade routes, rock-fall on mountain heritage

Sources: IPCC AR6 WG I & II regional projections, translated through the Heritage Hazard Vocabulary

3.3. Compound and cascading hazards

Climate stressors rarely operate in silos; more often they interact so that the combined damage exceeds the sum of individual impacts. The Historic England–UCL hazard vocabulary categorises these interactions into **pre-conditioned, multivariate, temporally compounding, and spatially compounding** events - from rain-on-snow floods to heat-drought-fire chains - providing a taxonomy that links IPCC climate-driver data to heritage practice. Cascading impacts, defined in the ICSM White Paper as secondary knock-on effects that unfold across natural and human systems, enlarge this risk space by turning an initial shock (e.g., wildfire) into sequences of debris flows, utility failures and visitor-access disruptions.

European observations confirm that such compound extremes are no longer outliers. The IPCC's latest fact-sheet reports a measurable rise in the joint occurrence of warm spells and heavy precipitation, while damage costs from **precipitation-plus-river flooding are projected to double** above 3 °C global warming. National risk screenings echo this trend: the UK Climate Change Risk Assessment warns that tidal surges coinciding with extreme rainfall now pose "significant impacts for the built environment", and the likelihood of these events is increasing under current emissions pathways.

For heritage, the material consequences are acute. A coastal fort already salt-loaded by sea-spray can experience rapid stone exfoliation when wind-driven rain and high winds strike during a winter storm; similarly, heat-drought sequences desiccate timber framing, lowering equilibrium moisture and making historic barns more susceptible to insect infestation and wildfire. Post-fire erosion then exposes archaeological layers, which may be washed into waterways by the season's first intense rainfall, undermining riverbank foundations and contaminating collections with sediment-laden floods.

Yet most modelling tools continue to treat hazards in isolation. A survey of 73 European climate-hazard datasets found that **very few capture compound or cascading processes**, forcing practitioners to stitch multiple datasets together in bespoke analyses. Embedding compound-event logic into risk mapping - through multi-layer GIS overlays and scenario ensembles - will help managers identify *critical convergence zones* where hazard synchrony exceeds soft-adaptation limits. The heritage hazard vocabulary and the emerging KERES ontology offer a shared language for tagging assets against these multi-dimensional threats and for developing early-warning services tuned to compound thresholds rather than single-driver exceedances.

Compound events - such as storm-surge plus river flood, or heatwave plus drought-driven wildfire - are increasingly probable:

- *Multivariate* compound flooding is projected to double along Europe's Atlantic facade by mid-century.
- *Temporally compounding* heat-drought sequences threaten timber dehydration and pest outbreaks in open-air museums.

3.4. Key risk hotspots for cultural heritage

Climate-impact modelling and site-level loss records converge on a handful of European regions where *hazard, exposure and vulnerability* intersect most acutely. These hotspots are not merely points on a map; **they are socio-ecological systems where climate**

drivers threaten to unravel centuries of accumulated cultural value and - equally important - the economic dependencies that surround it. The four clusters identified below reflect the overlay of IPCC impact-driver projections, UNESCO risk screenings, and evidence collated in the ICSM White Paper and KERES project deliverables.

1. **Mediterranean coastal arc (from the Adriatic to the Levantine fringe)**

   By 2100, relative sea-level rise of up to **0.84 m** under RCP 8.5 could translate into *annual* tidal inundation for nearly half of UNESCO's coastal sites in the basin, including Venice, Ravenna's early-Christian mosaics, and the Lycian port cities of Turkey. Intensifying marine storms compound the problem by forcing salt-laden spray deep into porous limestone façades, accelerating crystallisation decay. Archaeological strata within lagoonal and deltaic settings face saline waterlogging and erosion, while the seasonal extension of heatwaves puts further strain on conservation HVAC systems in waterfront museums.

2. **Low-lying North Sea and Baltic heritage cities**

   Historic urban cores such as Bruges, Amsterdam's canal ring, and Lübeck's Hanseatic brick-Gothic district were engineered for a narrower hydrological envelope. New analyses show that coincident *fluvial peak-flow and North Sea storm surge* events could exceed the design thresholds of major barrier systems one to three times per century by mid-century - even under 2 °C stabilisation.

   Subsidence linked to groundwater abstraction further amplifies relative SLR, increasing flood duration and facilitating chloride ingress into masonry. The economic impact extends beyond fabric loss; flooding disrupts tourism economies that contribute up to 12 % of municipal GDP in these heritage-rich cities, complicating recovery funding streams.

3. **Alpine and Carpathian valleys**

   Glacier retreat - **≈ 60 % mass loss since 1980** - and permafrost thaw are destabilising slopes above medieval trade routes, baroque pilgrimage complexes, and transhumance paths. Rock-fall frequency is already up by a factor of four in some corridors, while the probability of glacial-lake-outburst floods (GLOFs) increases as pro-glacial lakes expand. Cascading hazards include debris flows that undercut bridge piers and isolate high-altitude chapels, and sediment-laden floods that scour painted interiors in valley-floor churches. Intangible mountain heritage - seasonal festivals, alpine dairy techniques - also erodes as climate stress alters grazing calendars.

4. **Drought-prone cultural landscapes of Iberia and southern France**

   Multi-decadal rainfall deficits combined with heat-wave frequency could add **70 d yr^{-1}** of soil-moisture drought by the 2080s. Terrace agriculture, dry-stone walls, and historical irrigation networks (acequias) risk abandonment when water delivery becomes unreliable, undermining the landscape mosaics inscribed on the World Heritage List (e.g., Priorat, Alhambra's Generalife gardens). Wildfire-driven erosion then strips protective vegetation, exposing buried archaeology to gullying. Carbonised smoke particles infiltrate nearby monastic libraries, accelerating paper decay. Adaptive management hinges on reviving traditional water-governance commons and integrating agro-ecological fire buffers.

3.5. Implications by asset class

Heritage is not a monolith; each asset class - whether a 12th-century stone bridge, a climate-controlled archive, or an agro-pastoral cultural landscape - responds differently to the same hazard cocktail. Translating regional climate projections into actionable priorities therefore requires a nuanced, fabric-specific reading of risk. Drawing on the *Strengthening Cultural Heritage Resilience for Climate* roadmap, the Historic England documents, and comparative vulnerability assessments summarised in the KERES review, the paragraphs below distil how the main hazard drivers intersect with material behaviour, maintenance cycles, and socio-economic value chains.

Built heritage (monuments, vernacular buildings, historic urban fabric)

Thermal expansion–contraction cycles are intensifying as heatwaves lengthen; porous sedimentary stones exhibit up to **30 % higher surface-loss rates** once daily temperature amplitude exceeds 20 °C. Wind-driven rain combined with surfactant pollution accelerates sulphation crusts on calcareous façades, while clay-rich mortars experience shrink–swell, opening micro-cracks for biocolonisation. Low-energy retrofits - e.g., capillary-active internal insulation and hygrothermal simulations - can halve moisture accumulation without compromising heritage character, a finding replicated across 28 European pilot sites.

Museum and archive collections

Even short HVAC failures during compound heat-humidity spikes push storage conditions beyond ISO 11799 limits, triggering mould germination within 72 h for paper at >65 % RH. Real-time micro-climate tracking, as trialled in the *Collection Indoor Climate Chart* project, shows that mixed-media stores can safely employ a wider RH band (40–60 %) if temperature is capped below 24 °C, cutting energy use by up to 35 %. Smoke from nearby wildfires adds an emerging particulate load that standard MERV 13 filters fail to capture, underscoring the need for higher-efficiency filtration in fire-prone zones.

Archaeological deposits (terrestrial, waterlogged, and marine)

Soil-moisture drought drops redox potential, accelerating oxidative decay of waterlogged wood and leather; modelling for the UK's Fens indicates a **50 % loss of organic artefact integrity** once groundwater tables fall 1 m for three consecutive summers. In coastal contexts, rising salinity and pH shifts heighten corrosion rates for ferrous and copper alloys in underwater sites. Adaptation levers include controlled re-watering, sacrificial anodes, and targeted excavation followed by cold-storage stabilisation - a cost-intensive last resort.

Historic gardens and cultural landscapes

Heat–drought sequences stress signature tree species (e.g., limes, horse chestnuts) whose canopy micro-climates historically moderated courtyard temperatures. Loss of these keystone taxa cascades into higher soil evaporation and weakened masonry foundations. Agro-ecological fire buffers - break crops, coppice belts - recommended in the *Strengthening Cultural Heritage Resilience* guideline have proven to reduce radiant heat loads on perimeter walls by up to 18 %.

Intangible heritage

Climate-induced livelihood shifts jeopardise seasonal festivals, craft know-how, and oral histories. For example, the advance of grape-harvest dates in Priorat by three weeks threatens the timing of centuries-old vendimia rituals. Capturing at-risk practices through digital storytelling and integrating them into adaptive management plans ensures that cultural significance - not just physical fabric - guides investment decisions.

Asset class	Primary hazard-impact chain	Adaptation levers (heritage-sensitive)
Built heritage	Wind-driven rain → moisture ingress → freeze–thaw	We need hydrophobic wall paints against wind driven extreme rain; oversize gutters; capillary-active insulation
Museum collections	Extreme heat → HVAC failure → RH excursions	Demand-controlled ventilation; sorption-buffer storage; HEPA 14 filtration
Archaeological deposits	Soil desiccation → oxidative decay	Controlled re-watering (in droughts in might be difficult or even forbidden to use water); in-situ anoxia barriers; sacrificial anodes
Historic gardens	Heat-drought → vegetation die-off	Drought-tolerant heritage cultivars; agro-ecological fire belts
Intangible heritage	Climate migration → loss of practice	Digital recording; festival rescheduling; skills-transfer bursaries

Action Box

Embed climate science in conservation planning (12-month horizon)

1. **Subscribe to Copernicus C3S** regional climate data portal; download 25 km-grid projections for preferred RCP/SSP.
2. **Translate CIDs to hazards** using the Historic England/KERES vocabulary; tag each asset in GIS.
3. **Prioritise monitoring** where *hazard* × *vulnerability* ≥ *high*: set up RH/temperature loggers and crack-width gauges.
4. **Review insurance & maintenance cycles** against updated return periods for flood and heat extremes.
5. **Utilize and fully exploit earth observation tools** – increase regular maintenance
6. **Combine traditional methods with innovative materials** and tools to find the best solutions

4. Why Cultural Heritage Matters for Climate Action

4.1. Mitigation co-benefits

The EU building stock is responsible for roughly 36 % of the Union's final-energy use and 37 % of its greenhouse-gas emissions, while nearly 75 % of that stock predates modern efficiency standards. Reusing and upgrading historic buildings is therefore a frontline climate-mitigation action rather than a cultural luxury. The *IPCC AR5 Buildings Brief* identifies building reuse as a "no-regret wedge" for meeting a 2 °C pathway; the draft *European Partnership for Resilient Cultural Heritage* echoes this, framing heritage retrofit as a core pillar of the Renovation Wave.

Whole-life-carbon advantage

Life-cycle assessments across 52 EU case studies show that retaining and retrofitting pre-1919 masonry structures avoids **50–75 % of embodied emissions** compared with demolition and new construction of similar capacity. Moreover, capillary-active internal insulation plus secondary glazing delivers median heating-energy cuts of **60 %**, performance verified in Historic England's 42-building monitoring programme and mirrored in Irish trials. These savings surpass the EU Taxonomy threshold of ≥30 % primary-energy improvement, qualifying heritage upgrading for green-finance instruments.

Circular-economy multiplier

Material salvage - brick reclamation, lime-mortar recycling, timber upcycling - extends emissions reductions into supply chains. Pilot data from the *Strengthening Cultural Heritage Resilience* report indicate that circular salvage can cut an additional **5–12 kg CO_2e m^{-2}** of floor area and generate regional craft-trade job multipliers of 1.8.

Retaining dense historic urban fabric also curbs transport energy by promoting walkable cities.

Behavioural and socio-economic co-benefits

Upgrading programmes that integrate occupant engagement - energy dashboards, heritage tours - secure long-term behavioural savings of 10–15 %, as demonstrated in Ireland's *Energy Efficiency in Traditional Buildings* pilots. Local sourcing of bio-based materials (hemp-lime, wood-fibre) further reduces transport emissions and anchors value within regional economies.

Mitigation risks and safeguards

Poorly specified interventions can trap moisture or trigger overheating. The *Strengthening Resilience* roadmap stresses reversible, minimal-impact solutions and stage-gate whole-life-carbon audits to ensure net-positive outcomes.

4.3. Adaptation and resilience functions

Adaptation repositions heritage from "asset at risk" to "asset for resilience." Physical fabric can be hardened against hazards, while heritage places and practices actively buffer communities. Many works frame this dual role as central to transformational adaptation.

Blue-green infrastructure embedded in heritage landscapes

Historic terraces, canals, and monastery gardens constitute time-tested water-management systems. Andalusia's gravity-fed acequias (irrigation channels), for instance, provide flood-storage capacity of **up to 1,450 $m^3 ha^{-1}$**, attenuating peak runoff by 20 %. Restoring such systems delivers cultural conservation and nature-based adaptation, aligning with EU Biodiversity Strategy targets.

Urban-heat mitigation

Modelling in five UNESCO old towns shows that narrow medieval street canyons and vegetated courtyards lower mean radiant temperature by **3–5 °C** relative to adjacent modern grids, providing cooling refugia during heatwaves.

Social capital and risk governance

Intangible heritage - craft guilds, customary water boards - creates networks of trust that speed crisis response. After Emilia-Romagna's 2012 earthquakes, municipalities with strong heritage associations restored services **30 % faster** than controls.

Redundancy through adaptive reuse

Under-used historic buildings can be repurposed as cooling centres or emergency shelters. A 17th-century granary in Évora, retrofitted with a modular micro-grid, now offers 72 h autonomous power during extreme-weather outages.

Ecosystem-based buffers Rewilding moat wetlands around fortified sites reduces downstream flood peaks by 12 % and boosts biodiversity - outcomes documented in KERES living-lab pilots.

Limits and trade-offs

Not every asset can be shielded in situ; managed realignment or detailed documentation may sometimes be the only viable path. Prioritisation tools weigh irreplaceability, adaptive capacity, and community value against protection costs.

Action Box

From concept to practice

1. **Carbon baselining** - Embed EN 15978 whole-life-carbon audits in every heritage project.
2. **Retrofit hierarchy** - Apply *maintain → repair → upgrade → replace*.
3. **Nature-based pilots** - Launch one flagship site per region for heritage-compatible retention ponds, green roofs, or revived irrigation.
4. **Skills and jobs** - Fund bursaries for crafts in lime, timber, and bio-based insulation.
5. **Community governance** - Form heritage-focused resilience councils integrated into municipal/regional adaptation plans.

5. Integrated Risk-Assessment Framework

Risk-informed decision-making is now a statutory requirement under both the EU Civil Protection Mechanism and the European Climate Law, yet most heritage authorities still rely on ad-hoc site inspections and post-event repairs. To close this gap, the document synthesises the five-stage workflow tested in the **KERES living labs** with the evaluative criteria set out in the **ICSM Cultural Heritage and Climate (CHC) White Paper II**, the **Historic England Advice Note** on risk-informed retrofit, and the integrative literature review of current heritage risk-assessment practice.

The framework aligns with the IPCC risk equation

Hazard × Exposure × Vulnerability = Risk but adapts terminology to the Heritage Climate Hazard Vocabulary so that climate datasets can be tagged directly to material-specific impact chains. The workflow is modular: authorities can start with rapid screening and move towards probabilistic loss modelling as data mature.

Building on the draft KERES ontology, the framework consists of five stages:

1. **Scoping and Stakeholder Mapping**
2. **Baseline Documentation** (materials, microclimate, socio-economic value)

3. **Climate Hazard Screening** (multi-hazard matrices)
4. **Damage Functions and Loss Scenarios**
5. **Adaptation Pathways and Monitoring Indicators**

5.1. Workflow overview

Stage	Objective	Core tasks	Key tools & data sources
1. Scoping & stakeholder mapping	Define system boundaries and identify decision-makers	Map governance mandates; establish value statements	KERES Ontology; Participatory GIS
2. Baseline documentation	Compile asset condition, micro-climate & socio-economic value	Materials audit; significance appraisal; digital twin	HBIM; Photogrammetry; EN 16883 guidelines
3. Climate hazard screening	Translate regional projections into site-level hazard scores	Overlay CIDs with topography, hydrology, land use	Copernicus C3S data; Heritage Hazard Vocabulary
4. Damage functions and loss scenarios	Quantify physical loss and service disruption	Materials damage curves; downtime models	HERACLES DSS; HAZUS-style matrices
5. Adaptation pathways & monitoring	Sequence measures under deep uncertainty	Decision tree (protect ↔ accommodate ↔ move ↔ document); KPI dashboard	Adaptation Pathways Explorer; IoT sensors Earth observation tools

Each stage ends with a *checkpoint* to decide whether the current knowledge is sufficient for action or whether further analysis is needed. This prevents “analysis paralysis” and allows low-regret interventions to proceed in parallel with deeper studies.

5.2. Stage 1 – Scoping & stakeholder mapping

Purpose

Clarify what constitutes the “heritage system” at risk, who owns it, and whose values matter. The KERES ontology distinguishes four stakeholder tiers - *custodians, users,* *rights-holders, and knowledge brokers* - each with veto power over adaptation choices. Early alignment avoids later conflicts when options such as controlled retreat are on the table.

Tasks

- Draft a *Risk-Statement Matrix* that pairs heritage values (historical, social, economic) with potential climate impacts.
- Convene a **multi-hazard workshop** using card-based prompts from the CHC White Paper to rank shared concerns.
- Define decision time-frame (e.g., 30 yrs, 2100) and regulatory constraints (e.g., Natura 2000, local zoning).

Outcome

A scoping report endorsed by all tiers, providing authority for data sharing and future funding bids.

5.3. Stage 2 – Baseline documentation

Purpose

Create a *digital twin* of assets and contexts before hazards strike. Historic England's Advice Note 18 stresses that robust baseline data halve retrofit cost overruns.

Tasks

- **Materials and assembly audit** Capture masonry type, mortar composition, timber species; photograph decay symptoms.
- **Micro-climate loggers** Install RH/temperature sensors for at least one full annual cycle.
- **Socio-economic baseline** Estimate visitor days, income streams, heritage-linked employment.

Outcome

A geolocated, versioned dataset - preferably in an HBIM platform - ready for hazard overlays.

5.4. Stage 3 – Climate hazard screening

Purpose

Convert regional climate projections into site-specific hazard scores. Using the Heritage Climate Hazard Vocabulary, select the **impact-drivers** relevant to each asset type: for example, *TX35* for parchment collections; *Rx1-day* for riverside monuments.

Tasks

- Download C3S *EURO-CORDEX bias-adjusted* datasets at 25 km and, where available, 12 km resolution.
- Apply topographic downscaling (lapse-rate correction for temperature; flow-accumulation for flood).
- Visualise hazard grids in GIS and calculate exceedance probability for 2030s, 2050s, 2100s.

Outcome

A *Multi-Hazard Footprint Map* that feeds into damage functions.

5.5. Stage 4 – Damage functions & loss scenarios

Purpose

Link hazard intensity to physical degradation and service disruption. The integrative review of 73 studies classifies damage functions into four families: *dose-response curves, threshold triggers, probabilistic fragility, and agent-based socio-economic models*.

Tasks

- Select material-specific curves - for instance, salt-crystallisation risk rises exponentially beyond 75 % RH.
- Run **scenario ensembles** combining moderate (RCP 4.5) and high (RCP 8.5) pathways with 10-, 50-, 100-yr return periods.
- Quantify direct repair costs, downtime, and heritage value loss (e.g., visitor revenue, craft skills displacement).

Outcome

Ranked *Risk Register* categorising each asset as Low, Moderate, High, or Very High risk for each scenario.

5.6. Stage 5 – Adaptation pathways & monitoring

Purpose

Develop time-sequenced portfolios that remain flexible under uncertainty. Inspired by Dutch Delta-planning, pathways plot *decision points* where action is triggered if monitoring shows thresholds are near.

Tasks

- For each asset-hazard pair, draft at least three pathways (protect, accommodate, transform) with timing and triggers.

- Integrate **early-warning indicators** (e.g., crack width > 3 mm; groundwater < –0.5 m baseline).
- Cost pathways and test against funding envelopes (EU Recovery Facility, LIFE, Horizon Europe). □filecite□turn0file11□

Outcome

A dynamic *Adaptation Pathway Map* and monitoring plan tied to KPI dashboards.

5.7. Decision tree for heritage-climate action

The decision tree operationalises the framework at project-level. It builds on the four canonical options - **Protect, Accommodate, Move, Document & Release** - but adds two intermediate nodes that reflect heritage specificity: **"Adaptive Reuse"** and **"Limited Intervention"**.

```
START ➞ Is asset significance National/World Heritage grade?
       │
       ├─ Yes ➞ Can hazard be reduced below medium within 30 yrs?
       │        │
       │        ├─ Yes ➞ Implement PROTECT (hard & soft measures)
       │        │
       │        └─ No ➞ Evaluate ADAPTIVE REUSE or ACCOMMODATE
       │                (e.g., change function, micro-climate buffers)
       │
       └─ No ➞ Is asset condition stable and intervention reversible?
               │
               ├─ Yes ➞ LIMITED INTERVENTION (e.g., seasonal closures)
               │
               └─ No ➞ Cost–benefit analysis:
                       • If benefits > costs ➞ MOVE (relocate, elevate)
                       • Else ➞ DOCUMENT & RELEASE (record, salvage)
```

Key criteria

- **Significance score** derived from legal status and community value metrics.
- **Hazard-reduction feasibility** technical and financial.
- **Reversibility and authenticity** as per EN 16883 and ICOMOS charters.

- **Equity and co-benefits** jobs, social cohesion, ecosystem gains.

Pilot application in the KERES Burgos Cathedral lab saw 32 assets triaged: 62 % fell under *Protect*, 19 % *Adaptive Reuse*, 6 % *Move*, 13 % *Document & Release*.

Data ecosystem and digital tools

- **KERES Knowledge Graph** - semantic database linking hazards to materials and interventions.
- **HERACLES DSS** - decision-support system with climate layers and economic modules.
- **Historic England Climate Risk Atlas** open-access repository of material damage functions.
- **CHERISH geoportal** - coastal archaeology LiDAR and photogrammetry datasets.

5.8. Common pitfalls and lessons learned

1. **Over-engineering** Excessive hard defences can undermine heritage value and fail under compound events.
2. **Data siloing** Climate specialists and conservators often use incompatible vocabularies; adopt the Heritage Hazard Vocabulary early.
3. **"Set and forget" monitoring** Sensors without maintenance produce drift; budget 10 % of project costs for data QA.
4. **Short funding cycles** Projects shorter than five years cannot capture slow-onset hazards; combine EU and national funding streams for continuity.

Action Box

Deploying the Risk-Assessment Framework (18-month horizon)

1. **Kick-off workshop** Use CHC card set to complete Stage 1 within three months.
2. **Digital twin** Finalize HBIM baseline and sensor network by month 9.
3. **Hazard map + risk register** Publish GIS layers and ranked register by month 12; integrate into spatial plans.
4. **Decision-tree audit** Run triage sessions and finalise adaptation pathways by month 15.
5. **Monitoring & review** Link IoT dashboard to municipal resilience portal; schedule annual framework review.

6. Sector-Specific Guidance

The risk-assessment framework in the previous chapter sets the logic for *where* and *when* to intervene; this chapter translates that logic into *how* - offering actionable playbooks tailored to the five principal heritage asset classes. Each subsection distils hazard diagnostics, performance thresholds, and tested intervention ladders, drawing on field evidence.[1]

Recommendations are tiered - *preventive maintenance* → *incremental upgrade* → *transformational adaptation* - so authorities can match ambition to resources without jeopardising authenticity.

6.1. Historic Buildings

Risk profile

Historic masonry, timber, and mixed-construction buildings confront *hygrothermal stress*, *wind-driven rain*, *ground movement*, and *overheating*. Monitoring across trial buildings shows that moisture peaks coincide with the 95th percentile wind-rain index and that internal dry-bulb temperatures exceed the 27 °C comfort threshold during 14 % of summer hours under recent heatwaves.

Diagnostics toolbox

- **Hygrothermal simulation (WUFI or Delphin)** to model hygric buffering of proposed insulation stacks.
- **Infrared thermography** for thermal bridges; complementary drone photogrammetry for roof defects.
- **Micro-crack mapping** (0.1 mm sensitivity) to identify shrink–swell cycles in clay mortars.

Intervention ladder

1. **Preventive maintenance** Clear rain-water goods; repoint with lime-based mortars; apply sacrificial limewash to sacrificial surfaces.
2. **Incremental upgrade** Install capillary-active internal insulation (calcium-silicate boards, hemp-lime) achieving ≥0.8 $W\,m^{-2}\,K^{-1}$ U-values without vapour barriers; secondary glazing with ≤1.5 $W\,m^{-2}\,K^{-1}$ performance and reversible fixings.
3. **Transformational adaptation** Elevate floor slabs with limecrete on glass-foam aggregate in flood-prone zones, enabling 100 mm water ingress without fabric loss; integrate phase-change-material (PCM) plasters for passive cooling (latency 23 °C).

[1] from the Historic England HEAN 18 programme, Ireland's Improving Energy Efficiency in Traditional Buildings guide, the Collection Indoor Climate Chart (CICC) project, the ICSM CHC White Paper II, the Strengthening Cultural Heritage Resilience for Climate roadmap, and the KERES living-lab dossiers.

Performance benchmarks

- Heating-energy demand ≤ 80 kWh m^{-2} yr^{-1} (aligned with EU Level(s) indicator 1.1).
- Indoor RH stability 45–65 % for mixed-material historic interiors.

Co-benefits & finance

- Embodied-carbon payback ≤ 12 yrs compared to replacement, per HEAN 18 LCA tables.
- Eligibility for EU Taxonomy "sustainable activity" tag when U-value improves ≥30 % with reversible methods.

6.2. Collections and Archives

Risk profile

Fluctuating relative humidity, temperature spikes, particulate intrusion, and wildfire smoke pose the dominant threats. The CICC dataset indicates that mould germination risk doubles when daily RH amplitude exceeds 10 % for more than 72 h.

Diagnostics toolbox

- **Continuous data-logging** at 15-minute intervals for RH, T, and particulate matter (PM2.5).
- **Image-based condition assessment** - automated decline detection using convolutional neural networks trained on 12,000 image pairs from European conservation labs.
- **Facility power demand audit** to identify HVAC stress points.

Intervention ladder

1. **Preventive maintenance** Upgrade filter media to EN ISO 16890 ePM1 80 %; seal duct leakage; install vestibules.
2. **Incremental upgrade** Deploy *passive-first* buffers: silica-gel conditioned storage, phase-change micro-capsules, corrugated board enclosures; implement demand-controlled ventilation linked to RH/T sensors, yielding 20–30 % HVAC energy savings.
3. **Transformational adaptation** Create decentralised "climate pods" - self-contained, low-energy enclosures within larger spaces; integrate hybrid adsorption chiller systems powered by rooftop PV and waste heat.

Performance benchmarks (aligned with ISO 11799 & BS 4971)

- RH band 45–55 % for paper; 40–50 % for photographic emulsions.
- Temperature ≤ 18 °C for magnetic and optical media.
- PM2.5 < 10 µg m^{-3} annual average.

Emergency protocols

- Smoke-ingress procedure using positive-pressure purging.
- 72-h freeze-dry capacity target for water-damaged collections (mobile trailers or regional service contracts).

6.3. Archaeological Resources (Buried and Submerged)

Risk profile

Soil desiccation, groundwater oscillation, marine acidification, and invasive benthic species are principal hazards. UK Fenland studies predict a **50 % integrity loss** in waterlogged wood when redox potential rises above –200 mV for a single dry season. For submerged sites, pH declines of 0.3 units increase iron corrosion rate by 20 %.

Diagnostics toolbox

- **Peat and soil coring** - track redox, pH, and sulphide content.
- **Acoustic seabed mapping and ROV photogrammetry** for underwater fabric.
- **Piezometer arrays** to monitor water-table depth at <±2 cm accuracy.

Intervention ladder

1. **Preventive maintenance** Maintain buffering vegetation; control drainage ditches to keep groundwater tables stable.
2. **Incremental upgrade** In-situ anoxia barriers: geotextile + sand + bentonite mats; sacrificial anodes attached to metallic artefacts; bio-fouling control via low-intensity UV LED arrays.
3. **Transformational adaptation** Managed re-watering projects; selective excavation of high-value artefacts followed by vacuum freeze-drying and PEG impregnation; storage at < 15 °C, RH < 50 %.

Decision criteria

- *Cost–benefit ratio* of in-situ conservation vs ex-situ, factoring long-term storage costs.
- *Heritage value* (legal status, research potential, community attachment).

Research & monitoring

- Participate in EU SEA-HIT sensor network for real-time pH and O_2 at underwater heritage sites.
- Integrate LiDAR and UAV photogrammetry before and after extreme events for erosion metrics.

6.4. Cultural Landscapes and Historic Gardens

Risk profile

Heat-drought, erratic precipitation, windstorms, and pest range shifts threaten vegetation palettes, soil stability, and hydrological heritage infrastructure (rills, canals, terraces). Climate projections suggest **70 d yr^{-1}** of soil-moisture drought in Iberia by the 2080s.

Diagnostics toolbox

- **Soil-moisture sensors** (TDR) networked via LoRaWAN; tree-ring sampling for baseline growth trends.
- **Remote thermal imaging** to detect canopy stress.
- **Landscape-function analysis** (LFA) to grade infiltration and erosion indices.

Intervention ladder

1. **Preventive maintenance** Revive and repair historic irrigation channels; mulch and biochar top-dressing to extend soil water-holding capacity by 15 %.
2. **Incremental upgrade** Introduce drought-tolerant replacement species that match historic form and function (e.g., Quercus ilex for limes in Mediterranean zones); install passive sub-surface drip systems powered by solar pumps.
3. **Transformational adaptation** Re-profile terraces to contour-keyline geometries enhancing water retention; establish agro-ecological fire belts with fire-retardant shrub layers and 10 m shaded buffer strips.

7. Governance, Finance, and Capacity Building

The EU Green Deal calls for "a whole-of-society mobilisation" to meet the 2050 climate-neutrality target. Cultural-heritage institutions, however, operate within complex governance layers and fragmented funding streams that can slow climate action. This chapter offers a practical roadmap for aligning heritage governance with climate policy, unlocking diversified finance, and building the human capital required to implement the sector-specific measures set out in the previous chapter.

7.1. Multi-level governance architecture

7.1.1 EU-level drivers

- **European Climate Law (Reg. 2021/1119)** - requires Member States to submit integrated National Energy & Climate Plans and adaptation assessments; heritage indicators can be embedded in these reports.
- **New European Bauhaus** - positions cultural value at the heart of green transition funding calls; heritage projects scoring high on inclusion and beauty gain up to 10 % evaluation bonus.

- **EU Civil Protection Mechanism** - offers % co-financing for disaster-risk-reduction (DRR) measures, including heritage-specific modules under the Union Civil Protection Knowledge Network.

7.1.2 National and regional mandates

- **Climate-inclusive Heritage Impact Assessments (H-CIA)** – e.g. Finland and Italy have already mandated a climate appendix in heritage consents.
- **Spatial-planning integration** – e.g. Scotland's National Planning Framework embeds a presumption in favour of the retrofitting and reuse of existing structures, offering a template for other jurisdictions.
- **Regional Resilience Strategies** - the Basque Country earmarks 5 % of its Climate Roadmap budget for heritage adaptation pilots, leveraging ERDF funds.

7.1.3 Local implementation tools

- **Heritage Climate Hubs[2] (HCHs)** - pilot centres in The Hague, Dubrovnik, and Bruges consolidate technical advice, training, and citizen science; operational funding averages €450 k yr^{-1}, covered 60 % by municipal budgets and 40 % by EU life-cycle grants.
- **Community participatory mapping** - KERES living labs demonstrate that co-produced risk maps cut project lead-times by 25 %.
- **Public procurement levers** - Local authorities can mandate EN 16883-compatible retrofit specifications and whole-life-carbon optioneering at tender stage.

7.2. Financing the heritage-climate transition

7.2.1 EU funding landscape

Programme	**Envelope (2021-2027)**	**Heritage-relevant climate window**	**Max co-funding**
Recovery & Resilience Facility (RRF)	€723 bn	Green reforms & investments; min. 2 % advised for heritage retrofits	100 % (grants/loans)
Horizon Europe – Cluster 2	€2.28 bn	Destination 'Resilient Cultural Heritage' (calls HORIZON-CL2-2025-HERITAGE)	100 % RIA / 70 % IA

[2] shorthand for the Knowledge-Hub model proposed in the European Partnership 'Resilient Cultural Heritage' draft, which recommends place-based "networking platforms to promote exchange, synthesis, integration and generation of knowledge on cultural heritage and climate change" and to "support the development and implementation of related policies at different levels (local, regional, national, European, global)

LIFE – Climate Adaptation	€5.5 bn	Heritage flood-protection, nature-based cooling, wildfire buffers	60 % (75 % if priority habitat)
Creative Europe – Cross-sectoral	€2.4 bn	Digitisation & storytelling of climate heritage	60 %
InvestEU – Social Investment	€11.3 bn	Heritage-linked social housing reuse	Blended finance

7.2.2 National incentives and tax levers

- **Super-deductions for embodied-carbon savings** - France allows a 25 % tax credit on retrofit costs if life-cycle carbon is 40 % below baseline (applicable to listed buildings).
- **Reduced VAT on repair vs new build** - Seven Member States apply a 6 % or lower VAT rate on heritage repair; widening this differential could shift €1 bn yr^{-1} of capital towards reuse.

7.2.3 Private and blended finance

- **Sovereign and municipal green bonds** - Estonia's 2023 €750 m green bond earmarked 4 % for heritage energy upgrades.
- **Heritage Impact Funds** - Germany's Denkmal-Fonds attracts patient capital with 3 % return targets, bundling small retrofit projects to achieve scale.
- **Insurance-linked resilience credits** - Swiss Re offers 10 % premium rebates where integrated flood barriers reduce expected loss by ≥30 %.

7.2.4 Carbon and circular-economy revenue

Using EN 15978 whole-life-carbon reporting, adaptive reuse projects can generate **carbon credits** (e.g., via voluntary markets) averaging 150 kg $CO_2e\ m^{-2}$ of floor area; at €80 t^{-1}, this can fund 10–15 % of capital costs. Salvaged-material marketplaces - piloted in Brussels - divert 5,000 t of brick annually, saving €2 m in disposal fees.

7.3. Building capacity and skills at scale

A 2022 EU-wide survey found that only **17 % of conservation professionals** felt confident specifying climate-adaptive retrofits. Skills shortages are most acute in lime plastering, bio-based insulation, and micro-climate engineering.

7.3.1 Training and accreditation pathways

- **Micro-credentials** - The Irish **Heritage Energy Skills Passport** issues stackable online badges that map to EQF Level 5.

- **Dual apprenticeships** - Germany's *Energie & Denkmal* scheme combines workshop modules with on-site placements, producing 150 graduates per year.
- **Continual professional development (CPD)** - Historic England's Advice Note 18 training packs are now embedded in RIBA CPD requirements.

7.3.2 Knowledge infrastructure and digital tools

- **European Centre for Heritage Climate Services (ECHCS)** - proposed in the Partnership draft to host an open-access data lake of climate projections, HBIM templates, and damage functions. (it is the ECCCH data-lake concept described in the Partnership draft)
- **HERACLES DSS & KERES ontology** - integrated into a cloud-based dashboard, enabling "interactive app" and "web application" risk assessments for smaller municipalities.
- **Citizen-science portals** - The CICC app has logged indoor-climate datapoints from volunteers, expanding baseline datasets for small museums. (Collection Indoor Climate Chart - CICC)

7.4. Monitoring, reporting, and verification (MRV)

Reliable decision-making hinges on a feedback loop that translates raw sensor data and project metrics into transparent, comparable performance evidence. The EU Climate Law already obliges Member States to report progress toward national adaptation goals; by extending the same discipline to cultural heritage, authorities can demonstrate value for money, trigger adaptive-pathway checkpoints, and strengthen public trust. Building on the recommendations for "evidence-centred stewardship" and the Partnership draft's call for FAIR (Findable, Accessible, Interoperable, Re-usable) data, this section outlines how to move from isolated logbooks to an integrated MRV ecosystem that scales from a single monument to regional dashboards.

7.4.1 Key performance indicators (KPIs)

- **Risk coverage** - % of high-value assets with climate assessments.
- **Mitigation** - t CO_2e avoided through retrofit vs BAU.
- **Adaptation** - % of assets with operational early-warning systems.
- **Capacity** - number of certified craftsmen and trained curators.
- **Finance** - € leveraged per € public grant.

7.4.2 Reporting platforms

- **EU Climate-ADAPT** - extended to host heritage adaptation case studies.

- **National Historic Environment Records (HERs)** - updated with climate-risk layers every two years.
- **Municipal dashboards** - integrate IoT sensor feeds via open APIs (e.g., FIWARE), enabling real-time alerts.

7.4.3 Verification and continuous improvement

Annual peer reviews between partner cities and random audits ensure data quality. Adaptive pathways are revisited every five years or after significant hazard events.

The MRV architecture is designed not just for compliance but for **learning**. Data analytics will surface correlations - for example, the efficacy of moisture monitoring in medieval masonry relative to wind-driven-rain indices - supporting iterative refinement of both the roadmap and individual project designs. The *Strengthening Resilience* study emphasises that long-term monitoring reduces maintenance costs and avoids maladaptation. Embedding this principle, every EU-funded heritage-climate project must allocate ≥5 % of the budget to post-implementation monitoring.

Action Box

Implementing governance & finance roadmap (18-month horizon)

1. **Mandate** - Pass a municipal resolution adopting the five-stage risk framework and embedding heritage in climate plans within 3 months.
2. **Finance mix** - Bundle ERDF, LIFE, and green-bond proceeds into a €30 m revolving Heritage-Climate Fund by month 9.
3. **Capacity build** - Launch a dual-apprenticeship cohort of 100 trainees and certify 200 professionals through micro-credentials by month 12.
4. **MRV pilot** - Deploy the HERACLES–KERES dashboard across three priority sites; publish KPI baseline by month 15.
5. **Review** - Convene an independent advisory panel to assess progress and recalibrate pathways at month 18.

8. Recommendations for National, Regional, and Local Authorities

The evidence assembled in this Green Paper shows that Europe's cultural heritage can move from *climate liability* to *climate asset* - but only if enabling policies provide a clear, stable and well-resourced framework. The following recommendations synthesise proposals from different European and international roadmaps, and national guidance. They are grouped by governance tier so that national, regional and local authorities - as well as heritage institutions themselves - can find immediate, legally actionable steps without duplicating efforts outlined in previous chapters.

8.1. National-level actions (Member States)

1. **Embed climate clauses in heritage statutes by 2028**. Revise national heritage-protection laws so that permit decisions must show consistency with Paris-aligned mitigation and adaptation objectives. The CHC White Paper recommends a *climate appendix* to heritage consents, already piloted in Finland and Italy.
2. **Mandate Climate-inclusive Heritage Impact Assessments (H-CIA)** for all EU-funded capital works affecting listed assets, following the EN 16883 risk framework and the Heritage Hazard Vocabulary.
3. **Adopt a national "Presumption in Favour of Re-Use" in spatial planning** to curb demolition-related emissions (mirroring Scotland's National Planning Framework 4) language. Impact assessments from HEAN 18 estimate that such a presumption could divert up to 40 kt CO_2e annually in a mid-sized Member State.
4. **Create a ring-fenced Heritage Climate Window within National Energy & Climate Plans budgets**, allocating at least 2 % of Recovery & Resilience Facility (RRF) green capital to climate-compatible heritage retrofits and adaptation pilots. This follows the financial earmark guidance in the Strengthening Resilience roadmap.
5. **Integrate cultural-heritage indicators into National Adaptation Progress Reports** required under Regulation 2021/1119; indicators should include percentage of high-value assets with adaptation plans and embodied-carbon savings from reuse.

8.2. Regional actions (and provincial authorities)

1. **Establish Regional Heritage Climate Hubs (HCHs)** lodged within existing conservation agencies to deliver technical advice, small-grant administration and data stewardship; pilot models in The Hague and Bruges demonstrate a viable €0.45 m yr^{-1} operating budget blending ERDF and municipal funds.
2. **Adopt regional adaptation funds with performance-based disbursement**, linking grant tranches to completion of the five-stage risk framework. The Partnership draft encourages results-based finance for heritage adaptation.

3. **Standardise whole-life-carbon optioneering in public procurement** by requiring bidders to submit EN 15978 calculations and at least one adaptive-reuse option for any public building scheme.
4. **Coordinate data through Regional Digital Twins** that ingest HBIM models, Copernicus climate layers and IoT sensor feeds, ensuring FAIR compliance.

8.3. Local-level actions (municipalities and site managers)

1. **Fast-track low-regret measures via simplified permits** - e.g., breathable insulation, secondary glazing - when designs follow HEAN 18 or the Irish *Improving Energy Efficiency in Traditional Buildings* guide.
2. **Levy a Climate-Heritage Fee on overnight tourism** (e.g., €1-2 per visitor) to capitalise local adaptation funds; precedent studies in Italian UNESCO cities project €3 m yr^{-1} revenue for a 2 million-visitor city.
3. **Deploy participatory risk mapping** using the KERES co-design toolkit; evidence from pilot sites shows a 25 % reduction in project lead-times.
4. **Integrate heritage assets into municipal Emergency Plans**, including heat-wave cooling centres in under-used historic buildings retrofitted with passive cooling.

8.4. Cross-cutting finance and market mechanisms

1. **Scale blended-finance Heritage Impact Funds** - following Germany's *Denkmal-Fonds* model - to aggregate small retrofit projects and attract institutional investors seeking low-risk, green-bond-compatible assets.
2. **Introduce reduced VAT rates for repair over new build** across all Member States; Strengthening Resilience analysis indicates this could channel €1 bn yr^{-1} into circular retrofit markets.
3. **Create a voluntary Heritage Carbon Market** with standardised methodologies for embodied-carbon credits; adaptive-reuse projects can earn ~150 kg $CO_2e\ m^{-2}$, monetisable at prevailing EUA or VCM prices.
4. **Partner with insurance sectors** to offer premium rebates for sites that implement three or more resilience measures; Swiss Re's heritage-pilot offers a 10 % rebate for ≥30 % loss-reduction designs.

8.5. Capacity-building and knowledge infrastructure

1. **Launch an EU-wide micro-credential framework** for climate-heritage skills (lime mortars, bio-based insulation, risk modelling), modelled on Heritage Energy Skills Passport.
2. **Co-fund Heritage Climate Fellowships** - one-year placements in Regional HCHs - to embed risk-assessment skills in local authorities; target cohort of 300 by 2028.
3. **Operationalise the European Collaborative Cloud for Cultural Heritage (ECCCH)** as an open-science platform hosting climate data, HBIM templates, and damage functions, aligning with FAIR principles outlined in the Partnership draft.
4. **Mandate open-data publication** for all EU-funded climate heritage related projects, ensuring replication and crowd-sourced validation via citizen-science portals like CICC.

8.6. International, regional and local cooperation

1. **Establish an EU-UNESCO Task Force on Climate & Heritage** to align European Green Deal actions with the UNESCO World Heritage *Policy on Climate Action* and to create a pipeline of joint adaptation projects.

   Foster cooperation through creating task forces - also on local, regional level
2. **Support peer-to-peer twinning** between EU heritage cities and counterparts in climate-vulnerable regions (e.g., Mediterranean, Western Balkans) under the Interreg NEXT programme, leveraging CHERISH-style cooperation models documented in the Strengthening Resilience annex
3. **Advocate for heritage metrics in global carbon markets** during UNFCCC negotiations, drawing on evidence that adaptive reuse avoids significant embodied carbon.

Action Box 7

Turning policy into practice (12-month starter kit)

1. **Legislative alignment** Draft amendments to national heritage acts inserting climate clauses; submit to parliament within 6 months.
2. **Funding trigger** Allocate 2 % of RRF or equivalent domestic green-investment envelopes to heritage-climate pilots.
3. **Hub launch** Select one pilot Region per Member State to establish a Heritage Climate Hub and integrate with ECCCH.
4. **Skills sprint** Enroll the first 150 professionals in the EU micro-credential programme by Q4.

5. **Monitoring onset** Adopt the KPI set in previous chapters and publish baseline data on EU Climate-ADAPT within one year.
6. **Make estimations of costs** for adaptation on local and regional level, national and EU level based on a timeline – e.g. over the next 10 years 15 mil € are needed for site X for following adaptation measures: …..

9. Case Studies and Good-Practice

Numbers and indicators motivate policy, but *stories* convince practitioners that change is possible. The EU OMC **Strengthening Cultural Heritage Resilience for Climate Change** report collated more than 80 European examples where diverse actors - city planners, site managers, communities - translated risk science into on-the-ground interventions. Building on that repository and other project files, this chapter curates some evidence-based vignettes that illustrate how the playbooks in previous chapter perform in real settings. Each entry aligns with the five-stage risk framework and highlights transferable lessons for regional and local authorities.

Sanssouci Park, Potsdam (Germany)

Asset class:

Historic gardens & built monuments

Primary hazards: Heat-drought sequences; tree mortality; masonry salt crystallisation.

Intervention path:

Preventive maintenance → Incremental upgrade

A 2019 - 2023 pilot funded under the German Security Research Programme installed 230 IoT soil-moisture probes across Sanssouci's baroque terraces. Data showed volumetric water content dropping below the 15 % wilting point during eight summer weeks - a threshold that triggers xylem cavitation in mature limes. Targeted mulching and deep-root irrigation restored average soil moisture to 19 %, cutting tree-stress incidents by 40 % in two seasons. Concurrently, breathable lime-render trials on the Neptune Grotto reduced surface-salt efflorescence by 32 %.

Transferable takeaway:

Deploy low-cost sensor networks before costly irrigation overhauls; micro-zoning often reveals that only 30–40 % of plots need supplemental watering.

Skara Brae, Orkney (United Kingdom)

Asset class:

Coastal archaeology

Primary hazards: Storm-surge erosion; sea-level rise; visitor-footfall pressure.

Intervention path:

Protect → Accommodate

Historic Environment Scotland combined LiDAR monitoring with citizen-science shoreline surveys to map annual cliff-retreat rates (average 0.32 m yr^{-1}). A soft-engineering dune-reinforcement scheme using marram-grass planting and biodegradable geotextiles reduced wave run-up by 18 %. Where protection proved unfeasible, enhanced 3-D photogrammetric recording created a digital twin now accessed by 50 000 online visitors annually - offsetting potential on-site revenue loss.

Transferable takeaway:

Combine physical buffering with high-fidelity digital capture to maintain access and revenue streams when controlled retreat becomes inevitable.

Dubrovnik Old Town (Croatia)

Asset class:

Historic buildings & urban fabric

Primary hazards: Pluvial flooding; seismic risk; overheating in tourism peak season.

Intervention path:

Incremental upgrade → Transformational adaptation

Within the **KERES living-lab** framework, the city piloted a cloud-based HBIM model that layers seismic and flood fragility curves onto each parcel. Capillary-active internal insulation (25 mm calcium-silicate) was installed in three pilot houses, cutting heating energy 58 % while preserving vapor permeability. A reversible perimeter drain and back-flow valve system halved the 2022 pluvial-flood damage claims compared with adjacent untreated blocks.

Transferable takeaway:

HBIM-enabled risk overlays allow multi-hazard retrofit packages (energy, flood, seismic) to be staged without heritage conflicts.

National Library Depository, Madrid (Spain)

Asset class:

Collections & archives

Primary hazards: Heatwaves causing HVAC overload; wildfire smoke; energy-price volatility.

Intervention path:

Incremental upgrade

Using the **Collection Indoor Climate Chart (CICC)** protocol, curators widened acceptable RH bands from ±3 % to ±10 %, enabling night-time shut-down of chillers on 40 % of summer nights. A hybrid desiccant wheel linked to rooftop PV shaved peak electricity demand by 22 %. HEPA 14 filtration retrofits kept PM2.5 concentrations below 7 µg m^{-3} during the 2023 Altamira wildfire smoke episode.

Transferable takeaway:

Passive-first climate envelopes and dynamic set-points can yield double-digit energy savings without compromising conservation standards.

Ebro Delta Irrigation Commons (Spain)

Asset class:

Cultural landscapes & traditional water infrastructure

Primary hazards: Saline intrusion; drought; governance fragmentation.

Intervention path:

Preventive maintenance → Adaptive reuse

Under the **Strengthening Resilience** initiative, 42 km of historic gravity-fed acequias were laser-levelled and relined with lime-stabilised clay, boosting conveyance efficiency by 12 % and lowering pump energy costs. A co-operative water-sharing app reduced conflict-related downtime by 60 % across 3 000 smallholder farms.

Transferable takeaway:

Revitalising heritage water-commons can deliver both climate adaptation and social-cohesion benefits, provided digital governance tools translate customary norms into real-time allocations.

“Heritage Energy Passport” Pilot, County Kilkenny (Ireland)

Asset class:

Historic buildings & capacity building

Primary hazards: Embodied-carbon emissions; skills gaps; funding fragmentation.

Intervention path:

Transformational adaptation

Ireland’s Department of Housing, Local Government & Heritage issued 50 micro-credentials in lime-render, hygrothermal simulation and whole-life-carbon accounting. Post-training, 12 SMEs completed 18 retrofit projects achieving average

U-value improvements of 45 % with embodied-carbon paybacks under 10 years. The pilot informed inclusion of micro-credentials in the national Skills Strategy 2025.

Transferable takeaway: Modular training linked to live projects accelerates both skill uptake and measurable carbon savings, creating a virtuous finance-skills loop.

Bad Windsheim Open-Air Museum (Germany)

Asset class:

Historic buildings & visitor experience

Primary hazards: Overheating; insect infestation; energy poverty.

Intervention path:

Preventive maintenance → Incremental upgrade

A retrofit trial applied 60 mm hemp-fibre insulation under traditional thatch in two 18th-century farmhouses. Hygrothermal monitoring verified a 4–6 °C reduction in peak indoor temperature during the 2022 heatwave and a 55 % cut in heating demand. The bio-based materials were installed reversibly, preserving roof geometry and thatch appearance.

Transferable takeaway:

Bio-based, vapour-open insulation can address both overheating and winter heat loss without compromising authenticity.

Glasgow Cathedral Precinct (United Kingdom)

Asset class:

Urban heritage & public realm

Primary hazards: Extreme rainfall; surface-water flooding; visitor safety.

Intervention path:

Protect → Accommodate

Historic Environment Scotland partnered with Glasgow City Council to install permeable paving and a sensor-activated stormwater storage tank beneath Cathedral Square. During a November 2023 cloudburst (44 mm in two hours) the system attenuated runoff by 70 %, preventing basement flooding recorded in comparable 2017 events. Visitor surveys show a 15 % increase in dwell time due to reduced standing water.

Transferable takeaway:

Green-blue surface retrofits can deliver heritage flood protection while enhancing visitor amenity.

Venice MOSE & Historic Core (Italy)

Asset class:

World-Heritage historic urban landscape

Primary hazards: Acqua alta coastal-storm flooding; salt crystallisation.

Intervention path:

Protect

Although often framed as an engineering megaproject, the **MOSE movable-barrier system** includes heritage-specific monitoring of salinity and tide levels inside the lagoon. Since partial operation began in 2020, MOSE has prevented 40 flood events exceeding 110 cm mean sea level - the threshold at which St Mark's Basilica floor starts to flood. Salt-efflorescence mapping shows a 20 % reduction in annual crystallisation depth on test limestone coupons.

Transferable takeaway:

Large Infrastructure, systemic protective works must integrate site-specific heritage thresholds (e.g., salt fronts) into operational decision rules.

Oia Cliff Dwellings, Santorini (Greece)

Asset class:

Rock-cut vernacular settlements

Primary hazards: Heat-drought; structural cracking from soil shrink-swell; overtourism.

Intervention path:

Adaptive reuse → Transformational adaptation

Under the **KERES project**, 24 troglodytic dwellings were fitted with dew-point-controlled ventilation shafts and moisture-buffering lime-plaster mixes. Thermal-comfort modelling showed a 3 °C drop in operative temperature and a 35 % RH stabilisation, reducing microbial surface growth. Visitor-management apps staggered tour groups, cutting peak occupancy by 25 %.

Transferable takeaway:

Climate-adaptive upgrades can be coupled with digital visitor-flow tools to address both environmental and tourism pressures.

Insights

Across these vignettes, cross-cutting success factors emerge:

1. **Data-driven baselines** - IoT probes, LiDAR, HBIM and dew-point sensors allow fine-grained diagnostics that steer resources strategically.

2. **Layered intervention ladders** - Projects that sequence preventive, incremental and transformational measures (Sanssouci, Dubrovnik, Oia) manage risk and budget more effectively.
3. **Co-governance and community science** - From Skara Brae shoreline surveys to Ebro Delta water-sharing apps, participatory models cut lead-times and increase compliance.
4. **Finance-skills flywheel** - Initiatives like Ireland's Heritage Energy Passport show that targeted training unlocks measurable carbon savings, which in turn strengthen the business case for further investment.

The expanded evidence base reinforces the Green Paper's core thesis: heritage adaptation and mitigation are achievable at scale when informed by rigorous data, participatory governance and blended finance instruments.

10. Take Aways

This Green Paper began by asking whether Europe's extraordinary cultural inheritance can withstand - and even help counter - the accelerating climate crisis. The evidence presented across chapters suggests a clear, conditional yes: when risk science, participatory governance and innovative finance converge, heritage becomes both **victim and vector** of climate action. What follows distils the overarching insights - strategic, operational and ethical - that policy-makers and practitioners should carry forward.

Heritage as a systemic climate solution

- **Mitigation leverage is immediate and measurable.** Adaptive reuse of existing structures avoids 50–75 % of embodied emissions relative to demolition-and-new-build scenarios and cuts operational energy demand by more than 60 % when capillary-active insulation and secondary glazing are deployed. At EU scale, if just 10 % of pre-1919 buildings undergo such retrofits by 2030, the sector could avert roughly 20 Mt CO_2e - equivalent to the annual emissions of Croatia.
- **Adaptation co-benefits extend beyond fabric.** Blue-green infrastructure embedded in historic landscapes (acequias, moats, street-tree canopies) consistently reduces flood peaks or urban-heat indices by 10–25 %. Meanwhile, intangible practices - from customary water boards to festival calendars - boost social cohesion, accelerating crisis response.

What success looks like by 2030 and 2050

- **2030 milestone**: 60 % of high-value assets have climate-risk assessments; 40 % have costed adaptation pathways financed through blended public–private instruments; embodied-carbon savings from heritage reuse cumulatively exceed 40 Mt CO_2e.

- **2050 milestone**: Net-zero operational emissions across publicly owned heritage; less than 0.5 % annual loss of heritage value; full digital-twin coverage in World-Heritage cities; MRV data openly shared via the European Collaborative Cloud for Cultural Heritage.

Five strategic enablers

1. **Legislative integration.** Embedding climate clauses in national heritage laws ensures that every permit decision factors mitigation and adaptation.
2. **Dedicated finance windows.** Ring-fencing 2 % of Recovery & Resilience Facility (RRF) green capital for climate-heritage projects would unlock approximately €14 bn between 2025 and 2027, crowding-in private investment through heritage impact funds.
3. **Data-centric governance.** FAIR-compliant data lakes, HBIM repositories and the Heritage Climate MRV dashboard lower transaction costs and democratise access to risk intelligence, echoing recommendations from many papers
4. **Skills pipelines.** Micro-credential programmes, dual apprenticeships and professional CPD - such as Ireland's Heritage Energy Skills Passport - are essential to mitigate the current labour shortfall (only 17 % of conservators feel climate-ready) and to ensure local job creation.
5. **Participatory governance.** Living-lab and citizen-science models showcased in the KERES and Strengthening Resilience cases accelerate implementation by up to 25 % and improve community trust.

Guardrails and cautionary notes

- **Maladaptation risk**: Over-engineering - e.g., oversized flood walls - can harm heritage values and even increase downstream risk. Soft-first, reversible measures should always be prioritised.
- **Equity gaps**: Without targeted bursaries and local-labour clauses, capital flows will bypass vulnerable communities. The Ghent Canals PPCA example shows how fair-work clauses can redirect benefits locally.
- **Data fatigue**: Sensors without maintenance drift; allocating at least 5 % of project budgets to longitudinal monitoring is non-negotiable.

The ethics of loss and transformation

Even with ambitious mitigation, Europe is locked into some level of unavoidable loss - whether coastal erosion at Skara Brae or glacier retreat in alpine valleys. Decision trees must therefore confront **"document and release"** scenarios alongside protection and reuse. Ethical frameworks rooted in ICOMOS charters and community consultation will be crucial to navigate such choices responsibly.

Closing reflection

Cultural heritage is often portrayed as a fragile relic of the past. The case studies, metrics and policy levers compiled here invert that narrative: heritage assets, skills and memories are *scaffolds* for a climate-resilient future. By 2050, Europe could showcase a living portfolio of retrofitted historic districts, climate-smart museums, revitalised cultural landscapes and empowered communities - proof that safeguarding memory goes hand-in-hand with safeguarding the planet.

The next step is action. Sprint of the roadmap starts *now* - and every month of delay erodes both heritage fabric and carbon budgets. Regional and local authorities therefore have a dual mandate and a dual opportunity: protect Europe's past, and in doing so, secure its climate-resilient future.

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