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RESEARCH ARTICLE

Preserving the Past, Protecting the Future: A Framework for Sustainable Climate Adaptation of Heritage Structures

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ABSTRACT
Climate change poses an unprecedented challenge to cultural heritage worldwide, requiring urgent adaptation strategies that reconcile preservation with resilience. This paper proposes a structured framework for assessing climate adaptation interventions in heritage structures, addressing the dual imperative of safeguarding authenticity while ensuring long-term sustainability and safety. Drawing on expertise from the International Scientific Committee on the Analysis and Restoration of Architectural Heritage Structures (Iscarsah), the study examines the multifaceted impacts of climate change on heritage sites and evaluates a spectrum of intervention strategies, ranging from minimal interference to more transformative measures. The proposed framework integrates key criteria, including conservation principles, resilience to climate hazards, environmental sustainability, technical feasibility, and sociocultural implications, thus enabling a comprehensive assessment of potential actions. The applicability of this framework is illustrated through case studies on flood and fire management, which demonstrate its capacity to guide decision-making in diverse heritage contexts. By systematically weighing the trade-offs between preservation, adaptation, and ecological impact, the framework provides a practical tool to structure dialogue between experts and stakeholders. In doing so, it fosters more holistic, interdisciplinary solutions for protecting cultural heritage in an era of climate uncertainty.

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1. Introduction

Established to improve the standard of conservation practice for heritage structures worldwide, the International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH) of ICOMOS brings together experts from various disciplines to address the complex challenges of preserving architectural heritage. In response to the growing threat of climate change in heritage structures, ISCARSAH created a climate adaptation working group to discuss how to balance conservation principles with the need for climate adaptation.

The present work highlights a critical challenge in the field: interventions for the climate adaptation of heritage structures must simultaneously uphold conservation principles and ensure protection against future climate hazards. At the same time, it is essential to take into account the environmental consequences of such interventions and to integrate these considerations into the decision-making process. By systematically weighing these factors, both practitioners and scholars can develop guidelines that support conservators in identifying solutions that not only preserve heritage values but also minimize environmental impact. Moreover, resilience and sustainability are not the only competing priorities — additional trade-offs, such as feasibility, authenticity, and socio-cultural significance, further complicate remedial choices. This emphasizes the need to adopt a structured and transparent decision-making approach to guide climate adaptation strategies for

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cultural heritage (Curtis and Snow 2017; Lefèvre 2020).

1.1. *Impacts of climate-induced hazards on the built heritage*

Climate-induced hazards are increasingly impacting cultural heritage worldwide (Hao et al. 2020). Recognized as the most significant economic, social, and environmental challenge facing humanity, climate emergency has nearly doubled the occurrence of climate-related disasters compared to the previous two decades (Rahat et al. 2024). The frequency and severity of these hazards are projected to continue to rise, posing serious threats to historic buildings and sites (Chen et al. 2024; Sesana et al. 2021). Among the most visible risks are extreme weather events (Figure 1). Hurricanes and typhoons, with wind speeds exceeding 250 km/h, bring destructive combinations of rain, wind, and storm surges that endanger coastal heritage sites. Tornadoes, although smaller in scale, can reach up to 320 km/h and destroy structures with airborne debris (Bush and Prociv 2024). Landslides are also becoming more frequent and severe due to climate-driven precipitation changes, threatening buildings on slopes with rockfalls, mudslides, and debris flows (Bonini et al. 2023a; ICOMOS Climate Change and Cultural Heritage Working Group 2019; Sesana et al. 2021; Volpe et al. 2023).

Flooding has become another major hazard. Each 1°C rise in global temperature can intensify extreme daily precipitation events by about 7 % (IPCC 2023). Several countries across the globe have recently suffered devastating floods that damaged heritage sites and structures. A recent study, analysing 1,121 UNESCO World Heritage sites as of March 2021, found that 35 % of natural and 21 % of cultural and mixed tangible UNESCO World Heritage sites are located in flood-prone areas (Davis et al. 2023). These risks stem from both inland and coastal flooding, the latter worsened by sea-level rise (Grünthal et al. 2006; Kirezci et al. 2020). Coastal heritage sites also face increased erosion and saline intrusion. In contrast, droughts are intensifying in many regions, with low humidity and high temperatures accelerating material degradation in heritage structures. Fires are expected to become more frequent and severe, particularly in drier European regions. In 2018 alone, wildfires consumed nearly 178,000 hectares across the EU (European Commission 2019). High-profile losses, such as the 900-year-old Wan'an Bridge in China (2022), the town of Lahaina in Hawaii (2023) and

Figure 1. Impact on historic buildings of 2021 usa tornado (top left), 2022 Italy sea-level rise (top right), 2022 uk wildfire (bottom left) (Blythwood 2023), Italian slow-moving landslide (bottom right) (Ferrero et al. 2021).

wildfire damage in Los Angeles (2025), highlight the growing threat of fire to heritage sites.

Compounding these challenges are multi-hazard scenarios, in which heritage sites are exposed to simultaneous or cascading risks. A site may face both increased flooding and wildfire, or the combined pressures of sea-level rise and intensified storms. Such overlapping hazards complicate conservation planning, as measures designed to mitigate one risk can inadvertently increase vulnerability to another. For instance, flood-proofing interventions may prove ineffective against extreme wind loads, while fire-resistant treatments might compromise a structure's capacity to manage moisture.

Together, these escalating climate risks call for integrated and forward-looking strategies to safeguard cultural heritage. As the impacts of climate change become increasingly complex, adaptation measures must strike a balance between effectiveness and environmental sensitivity. Preservation efforts should not only protect heritage assets against future hazards but also remain consistent with principles of conservation and long-term sustainability. Equally important, the environmental repercussions of any intervention must be systematically assessed and incorporated into the decision-making process.

1.2. The need for intervention strategies to mitigate risks

The escalating threats posed by climate change to cultural heritage demand intervention strategies grounded in the principles of minimal intervention and authenticity. These strategies begin with comprehensive risk assessments that factor in current conditions and projected climate scenarios to inform decisions that ensure long-term preservation.

Technological advances increasingly support heritage risk management across multiple scales. At the territorial scale, unmanned aerial vehicles (UAVs), Light Detection and Ranging (LiDAR) (Foroughnia et al. 2024), and optical or radar satellite imagery (Agapiou 2021), when integrated with Geographic Information Systems (GIS), facilitate comprehensive mapping, risk assessment, and long-term monitoring. At the site level, in situ geotechnical analyses (Bilotta et al. 2013) and landslide displacement tracking (Bonini et al. 2023b) provide detailed insights into localized vulnerabilities. For individual buildings, 3D laser scanning enables high-precision documentation of structural integrity and weaknesses (Figure 2)(Kaushal, Gutierrez Soto, and Napolitano 2023, 2024). While these technologies have significantly improved data acquisition, documentation, and the early identification of risks, they cannot fully capture the multifaceted challenges of safeguarding cultural heritage. Major gaps remain in modeling systemic vulnerabilities, incorporating multi-hazard scenarios, and designing adaptive strategies that are both technically sound and culturally appropriate (Romao and Bertolin 2022).

Once risks are understood, appropriate interventions can be selected. These vary in scope and intensity — from choosing not to act, to relocating structures, to modifying either the surrounding environment or the building itself. Categorizing these interventions helps guide decisions that balance conservation goals with climate adaptation requirements(Harris 2001; Pecchioli 2023). The following typology outlines these different forms of intervention: *Abstention*, *Relocation*, *Circumvention*, and *Direct interventions*, which include *Mitigation*, *Reconstitution*, and *Substitution*.

1.2.1. Abstention

Abstention involves a deliberate decision not to act physically on the site or structure. It is important to distinguish between two modes of this strategy: Passive and Active. Passive Abstention is the most literal form, where the choice is made to simply "accept the condition and rate of continuing [decline]" (Harris 2001). This may be chosen when a risk is deemed acceptable or when resource limitations make intervention unfeasible. Active Abstention, by contrast, is a tolerable risk strategy where the impact is acknowledged but managed through ongoing observation. This proactive approach includes measures like monitoring, modelling, and digital documentation (e.g., generating 3D point clouds) to support future readiness and informed decision-making without physically altering the site.

1.2.2. Relocation

Relocation involves physically moving a heritage structure or object to a safer location (Figure 3). While hazard-independent, it is highly context- and object-dependent, requiring detailed consideration of the cultural, technical, and structural feasibility of disassembly and reassembly. Though effective in preserving the physical fabric, relocation risks compromising the structure's historical and cultural context.

1.2.3. Circumvention

Circumvention refers to interventions — temporary or permanent — that modify the surrounding environment in order to reduce a structure's exposure to hazards. Such measures are rarely designed to protect a single building; rather, they often safeguard wider zones that encompass heritage assets. As a result, their implementation usually involves considerations that

Figure 2. High-precision digital documentation using a terrestrial laser scanner at a heritage site after a tornado. The top left panel is a close up of the 3D model; the top right panel is a top down view of the 3D model; the bottom panel is a picture of student researchers capturing the point cloud after the tornado.

Figure 3. Large historical building relocation, 2009, Salem, Massachusetts.

extend beyond heritage conservation alone. Circumvention strategies are highly context- and hazard-specific. In flood-prone areas, for instance, they may include barriers (Figure 4), elevation of the terrain, or innovative design features such as amphibious foundations (English et al. 2021). For landslide-prone contexts, slope stabilization, drainage systems, and sand-stopping dams have been applied to mitigate risks(Cencetti et al. 2005; Margottini and Spizzichino 2021; Margottini et al. 2016; Sugio 2015). Similarly, vegetation management can reduce wildfire exposure (Kaslegard 2010). Community-based approaches, such as Community Wildfire Protection Planning (CWPP) in the United States, exemplify circumvention measures that integrate local knowledge, foster shared responsibility, and extend risk reduction efforts to the landscape level (Ager, Kline, and Paige Fischer 2015).

Figure 4. Flood circumvention in Bernberg during the 2013 Germany floods.

1.2.4. Direct interventions

These are the most intrusive types of adaptation and act directly on the building. They are both hazard- and building-specific and include mitigation, reconstitution, and substitution.

Mitigation encompasses a range of proactive and preventive measures implemented on an intact heritage structure to reduce its vulnerability to future hazards. The core principle is to enhance resilience by adding to or reinforcing the existing historic fabric, rather than replacing it. The selection of these measures is often guided by a minimal-intervention philosophy and performance-based codes, such as NFPA 914 for fire safety, which offer adaptable solutions that meet safety objectives while protecting the building's authentic character (Garcia-Castillo, Paya-Zaforteza, and Hospitaler 2023; National Fire Protection Association 2023). Specific mitigation strategies are tailored to the hazard and include implementing dry-proofing measures such as applying breathable waterproof coatings to foundations, or wet-proofing strategies like installing engineered flood vents to equalize hydrostatic pressure for flood hazards. Another example could be for fire hazards where you integrate heritage-appropriate active suppression systems that minimize water damage, such as high-pressure water mist systems or pre-action sprinklers, complemented by minimally intrusive detection like aspirating smoke detectors.

Reconstitution is a reactive, post-event strategy focused on the repair of damaged components or the re-assembly of entire systems to restore a structure to a known earlier state. The primary goal is to save and reuse the maximum amount of original historic fabric. This process is fundamentally reparative, even if it requires the limited introduction of new, compatible materials (like mortar, splices, or plaster) to make the original whole again. The new material is subordinate to the goal of saving the larger, authentic component or assembly. For instance, this can involve the large-scale re-assembly of a collapsed historic masonry wall using the original stones, with new lime mortar acting as the binding agent. It also includes more focused repairs, such as splicing a new piece of seasoned timber into a fire-damaged beam to save the largely intact original component. Furthermore, it applies to restoring a damaged system, like re-plastering a flood-damaged wall, which renews the finish without replacing the underlying historic structure.

Distinct from the reparative nature of reconstitution, *Substitution* involves the full replacement of a discrete component that is missing or has been deemed unsalvageable. This strategy is employed when an original component is too deteriorated for repair or is gone entirely. The choice of the new element involves a critical decision between a "like-for-like" substitute to preserve visual and material authenticity, or a modern alternative to enhance performance. This can mean removing an entire severely rotted timber beam and replacing it with one made of laminated timber or steel. In other cases, it involves replacing a historic brick that has crumbled with a newly fabricated unit custom-made to match the original. It also applies to complex assemblies, such as installing a complete replica window sash to replace an original that is decayed beyond repair.

The increasing prevalence of multi-hazard scenarios requires flexible, adaptive strategies that evolve with emerging climate data, materials, and technologies. Holistic risk assessment must account for hazard interactions and potential trade-offs. For example, flood adaptation in coastal areas should be integrated with wind resistance to counter storm surges and high winds International Code Council (2025a,b), while wildfire prevention in drought-prone zones must also prepare for flash flooding. Advanced multi-hazard simulation tools are becoming indispensable for developing these comprehensive, site-specific strategies.

1.3. Challenges of balancing conservation and climate adaptation

The ISCARSAH guidelines highlight several key challenges in balancing conservation principles with the need for climate adaptation in heritage structures. At the core of this challenges is the principle of minimal intervention, which states: "any intervention should respect, as far as possible, the concept, techniques and historical value of the original or earlier states of the structure and traces of its evolution" (ICOMOS/ISCARSAH 2024). This principle aims to preserve the authenticity and integrity of heritage structures. However, adapting to climate change often requires more substantial transformations, creating a tension between the demand of preservation and the need for adaptation(Curtis and Snow 2017; Lefèvre 2020).

The choice between traditional and innovative techniques presents another challenge. The guidelines note that this choice "should be determined on a case-by-case basis with preference given to those least invasive and most compatible with heritage values, consistent with the need for safety and durability" (ICOMOS/ISCARSAH 2024). This highlights the difficulty in selecting appropriate intervention methods that respect heritage values while effectively addressing climate-related risks. These challenges align with the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 on Sustainable Cities and Communities and SDG 13 on Climate Action. SDG 11 aims to "make cities and human settlements inclusive, safe, resilient and sustainable," which includes protecting cultural heritage, while SDG 13 calls for "urgent action to combat climate change and its impacts" (United Nations 2015). The need to balance these goals in the context of heritage conservation exemplifies the complex nature of sustainable development. Furthermore, the Sendai Framework for Disaster Risk Reduction 2015–2030 emphasizes the importance of protecting cultural heritage from disasters and climate-related risks. It calls for "substantially reducing disaster damage to critical infrastructure and disruption of basic services, among them … cultural heritage sites, through developing their resilience by 2030" (United Nations Office for Disaster Risk Reduction 2015). This framework highlights the global recognition of the need to integrate disaster risk reduction and climate adaptation strategies with heritage conservation efforts.

Long-term sustainability adds another layer of complexity, as the ISCARSAH guidelines stress considering the "whole life cycle" of the structure and any interventions, including their environmental impact (ICOMOS/ ISCARSAH 2024). In recent years, the carbon footprint of conservation work has become a more significant consideration. This includes the embodied carbon in new materials introduced during interventions and the operational carbon of the structure moving forward. Minimizing these factors helps mitigate climate change, fostering a positive feedback loop in the conservation effort. The optimization problem extends even further, encompassing factors such as minimizing groundwater contamination from demolition debris in landfills, preserving local ecosystems, and maintaining the social and cultural value of the heritage site to its community (Sannino et al. 2022).

Moreover, although not explicitly stated in the ISCARSAH guidelines, the unpredictability of future climate effects adds complexity to decision-making for interventions. This unpredictability can appear in various forms, such as the difference between the projected rise in sea level and the actual results, the frequency and severity of events, and the interaction of multiple hazards. These uncertainties create significant challenges for conservation efforts, making it extremely complex to accurately gauge long-term risks when future climate scenarios remain ambiguous (Richards and Brimblecombe 2024). This situation raises the possibility of either taking excessive actions that inadvertently undermine heritage values or failing to act sufficiently, leaving structures exposed to risks.

Ultimately, balancing conservation and climate adaptation requires a nuanced, case-by-case approach that carefully evaluates any risks, benefits, and long-term implications of any intervention. It necessitates a shift from a pure preservationist mindset to one that embraces responsible stewardship in the face of a changing climate, all while striving to maintain the authenticity and significance of cultural heritage. As our understanding of climate change and its impacts evolves, so must our approaches to heritage conservation, always striving to balance preservation needs with long-term sustainability. Interaction between resilience and sustainability takes the form of impacts of natural hazards on human health and the environment, further to the damage to buildings and infrastructure.

To address these complex decision-making challenges, this paper presents a framework for evaluating climate adaptation interventions for built heritage. While its principles are broadly applicable, the framework is specifically designed for tangible, immovable heritage and its immediate site context. The primary contribution of this work is not to catalogue potential interventions, but rather to offer a structured, transparent process to guide stakeholders in choosing the most appropriate path forward. Drawing on the principles of MCDA, the framework provides a tool to navigate the difficult trade-offs between conservation, resilience, sustainability, and socio-cultural values, thereby filling a gap between high-level policy and on-the-ground project implementation. The remainder of this paper is organized as follows. First, we present the methodological framework for evaluating climate adaptation interventions. Next, we demonstrate the framework's application through two distinct scenarios: flood risk and fire risk management, highlighting the trade-offs between different strategies. Finally, we conclude by summarizing our findings and outlining priorities for future work.

2. Methodological framework: understanding the tradeoffs in the decision-making process

This section presents the methodology developed to address the trade-offs inherent in adapting cultural heritage to climate change. It introduces a decision-support framework grounded in the principles of MCDA (Belton and Stewart 2002) and designed for use within broader strategies for decision-making under deep uncertainty, such as Robust Decision Making (RDM) (Lempert et al. 2006) and Adaptive Pathways(Opasanon and Miller-Hooks 2006; Werners et al. 2021). The challenge of preserving cultural heritage in the face of climate change has led to the development of various intervention strategies, each with its own set of trade-offs between conservation, resilience, sustainability, feasibility, and socio-cultural impact. As we progress through the decision-making process, it is important to evaluate these interventions within a framework that considers their long-term implications on heritage preservation and climate adaptation.

The challenge of adapting heritage structures to a changing climate is a problem of decision-making under deep uncertainty. The unpredictability of future climate effects, including the frequency and severity of hazards and the potential for cascading impacts, makes it exceptionally difficult to select optimal long-term strategies. Traditional "predict-then-act" planning, which relies on optimizing for a single best-estimate future, is poorly suited to this context and can lead to strategies that are either inflexible or brittle in the face of unforeseen changes.

2.1. Theoretical context and purpose

"Deep uncertainty," in decision science, refers to situations where analysts lack consensus — or even knowledge — about system models, the probability distributions of key variables, or how to assign value to potential outcomes. In the context of cultural heritage, this challenge is amplified: not only are future climate impacts highly unpredictable, but heritage assets also embody complex and often competing values, making agreement on appropriate responses especially difficult.

Decision-science has developed high-level strategic approaches. Robust Decision Making (RDM) (Lempert et al. 2006) seeks to identify strategies that perform satisfactorily across a wide range of plausible futures rather than being optimized for a single, predicted outcome. A complementary approach, Adaptive Pathways (Opasanon and Miller-Hooks 2006; Werners et al. 2021), provides a framework for sequencing adaptation options over time, using pre-defined "trigger points" to signal when a new strategy is needed, thereby maintaining flexibility and avoiding long-term maladaptation (Ranger, Reeder, and Lowe 2013). However, these conceptual frameworks require domain-specific analytical tools to be operationalized at the project level.

This is where Multi-Criteria Decision Analysis (MCDA), a sub-discipline of operations research, offers a practical solution. MCDA is designed to evaluate multiple, often conflicting, criteria to support complex decisions. It is particularly well-suited for the challenges of heritage conservation, which inherently involve a mix of quantitative and qualitative criteria (e.g., structural integrity vs. aesthetic value) and require balancing multiple stakeholder perspectives. MCDA provides a structured process for making the necessary compromises between competing objectives, such as preserving authenticity versus ensuring resilience, in a manner that is explicit, transparent, and auditable.

The framework proposed here builds upon existing literature that catalogues potential adaptation measures. To make an informed decision, heritage managers can draw from two complementary types of resources that identify the universe of possible interventions. First, there are technical inventories, such as the detailed review by Blavier et al. (2023), which catalogue a wide range of possible physical interventions and their inherent pros and cons. Complementing this technical inventory are conceptual models like the ADAPT framework (Acclimate, Dislocate, Abandon, Protect, and Tell the Story) (Wright and Hylton 2024), which offers a typology to help heritage managers brainstorm and categorize the full spectrum of strategic responses.

While such resources are important for identifying what interventions are possible, they do not prescribe a method for selecting the most suitable option in a specific, real-world context. This is the gap the framework developed in this research addresses: it moves beyond cataloguing options to provide a structured process for choosing among them. To do this, the proposed framework facilitates discourse around the question: "Given the available adaptations options, which is most appropriate for this specific heritage asset, in this specific context, considering the values of all involved stakeholders?" Therefore, this work is not a literature review or case study, but rather it operationalizes MCDA to structure stakeholder dialogue, formalize the evaluation of options, and create a transparent and defensible record of the decision-making process.

2.2. Framework structure and criteria

The proposed framework, shown in Table 1, is organized into five primary categories, each containing several subcategories that represent the dimensions of any adaptation intervention for cultural heritage. These categories are designed to cover the core tenets of conservation alongside the practicalities of implementation and long-term performance.

2.2.1. Conservation

The Conservation category evaluates the impact on the authenticity, values, and integrity of heritage structures (Gociman, Moscu, and Georgescu 2015). Authenticity is important for maintaining the historical and cultural significance of a site, yet climate adaptation measures may necessitate changes that conflict with this goal. Values consider whether the intervention maintains the aesthetic, cultural, and historical significance of the site, while integrity assesses the preservation of historical evidence and the cultural context. These considerations can vary among stakeholders, who may prioritize different aspects of conservation based on their roles and perspectives. To enable a nuanced evaluation, the framework makes a deliberate distinction between the intrinsic heritage values of an asset and the sociocultural outcomes it generates. Following established value-based management principles, the 'Values' subcategory within the 'Conservation' domain is defined as the assessment of an intervention's impact on the asset's cultural significance. This includes its aesthetic, historic, social, symbolic, spiritual, and economic qualities(Bond and Worthing 2016; Vecvagars 2006).

2.2.2. Resilience

Resilience focuses on the ability of the intervention to mitigate hazard impacts, its durability, and its adaptability to future climate scenarios. Effective hazard impact mitigation is essential for protecting heritage structures, but it often requires interventions that may not align with traditional conservation principles. Durability ensures long-term resilience, while adaptability addresses the need for flexible solutions that can evolve as climate conditions change. Stakeholders may have differing views on the importance of these factors, particularly as climate predictions and technological capabilities evolve.

2.2.3. Sustainability

The Sustainability category evaluates resource use, carbon footprint, and long-term environmental impact. Sustainable resource use is essential to minimize the environmental burden of interventions, though identifying materials that are both environmentally responsible and compatible with heritage structures often proves difficult. The carbon footprint reflects emissions generated throughout the intervention, linking heritage conservation with broader climate mitigation objectives. Long-term environmental impact considers how the intervention affects ecosystems and resources over time. These sustainability factors are not static: they must be balanced as stakeholders weigh urgent conservation needs against long-term environmental goals. Life-cycle analysis (LCA) can help identify strategies that reduce embodied and operational carbon; however, the data required for such analyses are not always readily available (Mahmad, Suratkon, and Ismail 2024).

2.2.4. Feasibility

Feasibility addresses the cost, technical complexity, and regulatory compliance of interventions. Cost is a significant factor, as budget constraints can limit potential interventions. However, investing in resilient solutions can offer long-term savings. Technical complexity evaluates whether the necessary expertise and technology are available, while regulatory compliance ensures that interventions meet legal requirements. Stakeholders may prioritize these factors differently based on available resources and regulatory environments.

2.2.5. Socio-cultural Impact

Finally, the Socio-cultural Impact category considers community acceptance, educational opportunity, and economic impact. Community acceptance is key for the success of any intervention, ensuring local support and engagement. Educational opportunity can enhance community awareness and support for climate adaptation efforts, while economic impact assesses how interventions affect local economies and tourism. These categories and subcategories are synthesized in the assessment matrix presented in Table 1.

Table 1. Assessment framework for climate change adaptation interventions in heritage sites.

Category	Subcategory	Explanation	Reference
Conservation	Authenticity	How does this intervention affect the original fabric and design?	English (2008); Falser (2010); Stovel (2008); Walter (2024)
	Values	Does it preserve the values of the site, including the aesthetic, cultural, economic, and historic values?	Albert et al., (2012); English (2008); ESPON (2020); Koens, Postma, and Papp (2018); Mason (2022)
	Integrity	Does it preserve or compromise historical evidence? Does it maintain or alter the site's cultural context?	English (2008); Petzet (2004)
Resilience	Hazard Impact Mitigation	How effectively does it address the specific climate threat(s)?	International Charter Space and Major Disasters (2025); UNESCO World Heritage Centre et al. (2010)
	Durability	What is the expected lifespan of the intervention?	Strongly depends on individual material and environment.
	Adaptability	Can it be adjusted for future climate scenarios?	ICOMOS Climate Change andCultural Heritage Working Group (2019)
Sustainability	Resource Use	What materials and energy are required for implementation?	(2017), Scotland, (2014)
	Carbon Footprint	What are the emissions associated with the intervention?	Commission Directorate-General for Education, and Culture (2022); Historic England (2024)
	Long-term Environmental Impact	How will it affect the local and global environment over time?	Enríquez-de Salamanca et al. (2017)
Feasibility	Cost	What are the financial implications?	Girard (2019); ICOMOS (2023)
	Technical Complexity	Is the required expertise and technology available?	Sustainable Traditional BuildingsAlliance (2015)
	Regulatory Compliance	Does it meet heritage conservation and building regulations?	Green (2011); IEBC (2021); Kaplan (2024); Weeks and Grimmer (1995)
Socio-cultural Impact	Community Acceptance	How will it be perceived by local stakeholders?	Brown and Hay-Edie (2014)

2.3. Assessment matrix

Each proposed intervention for addressing climate change impacts on cultural heritage should be systematically evaluated using an assessment matrix, such as the example presented in Table 1. The matrix provides a structured framework for comparing alternative strategies on a set of predefined criteria, ensuring that decisions are transparent, consistent, and reproducible. The tool is intended for use in the early stages of planning, before undertaking detailed — and often costly — analyses. At this stage, the matrix can be populated through expert elicitation, literature review, or stakeholder consultation when empirical data are limited or unavailable. This allows for a preliminary yet structured appraisal of options, highlighting trade-offs and identifying where further data collection or more in-depth modeling may be required. Beyond its function as a decision-support tool, the matrix also serves as a communication instrument, making the reasoning behind choices explicit and fostering dialogue among conservators, engineers, climate scientists, policymakers, and community representatives. By capturing a range of perspectives and uncertainties, the assessment matrix helps to establish a shared basis for prioritizing interventions that balance conservation principles, resilience, sustainability, and feasibility.

2.4. Scoring process

To apply the framework, the impact of each proposed intervention is rated against each subcategory using a bipolar, 11-point Likert-type scale ranging from −5 to 5. This numeric scale is not intended for quantitative analysis; rather, it serves to structure and guide a qualitative assessment, making trade-offs more transparent. The framework allows decision-makers to explicitly consider and communicate these trade-offs. The scale provides a common language for experts to express both the magnitude and direction of an intervention's anticipated impact. To ensure consistency and reduce subjectivity, the meaning of each point on the scale is explicitly defined in the rubric provided in Table 2.

2.5. Implementation through structured dialog

The assessment framework is not a static checklist but a tool for facilitating dynamic, structured dialogue among a diverse group of stakeholders. It is designed to guide the evaluation of climate adaptation interventions for heritage structures. Rather than being confined to a single stage, the framework is flexible and can be applied throughout the entire assessment process (Figure 5). At the outset, it can function as a rapid, preliminary "œdesk" assessment to identify potential interventions and their broad impacts. As the project progresses, the framework can be iteratively refined to incorporate more accurate and detailed data, supporting informed and adaptive decision-making.

While full Life Cycle Assessment (LCA), Life Cycle Cost Analysis (LCCA), structural analyses, or non-destructive testing (NDT) may be too resource-intensive for the initial conceptual stage targeted by this framework, results from these analyses can be incorporated as they become available. For example, the categories for Resource Use and Carbon Footprint are designed to align with LCA principles and can be refined later if LCA data for a given intervention are

Table 2. Scoring rubric for assessment criteria.

Score	Descriptor	Guiding definition
+5	Major Positive Impact	The intervention provides a transformative, exemplary enhancement to the criterion, creating significant, long-term, and synergistic benefits that extend beyond the initial objectives.
+4	Significant Positive Impact	The intervention provides a substantial and clear positive impact that significantly improves performance against the criterion in a durable manner.
+3	Moderate Positive Impact	The intervention provides a clear and effective positive impact, resulting in a noticeable and desirable improvement for the criterion.
+2	Minor Positive Impact	The intervention results in a slight but discernible positive impact on the criterion.
+1	Negligible Positive Impact	The intervention has a very small, barely perceptible positive impact on the criterion.
0	Neutral/No Discernible Impact	The intervention has no discernible impact, or the positive and negative impacts are fully balanced and negligible. This is the baseline.
−1	Negligible Adverse Impact	The intervention has a very small, barely perceptible adverse impact on the criterion.
−2	Minor Adverse Impact	The intervention results in a slight but discernible adverse impact on the criterion, which is easily reversible or mitigated.
−3	Moderate Adverse Impact	The intervention causes a noticeable and undesirable adverse impact on the criterion, which may be difficult or costly to mitigate.
−4	Significant Adverse Impact	The intervention causes a substantial and highly undesirable adverse impact, which may be irreversible or require significant resources to address.
−5	Major Adverse Impact	The intervention causes severe, widespread, or irreversible damage to the criterion, fundamentally compromising its value or function.

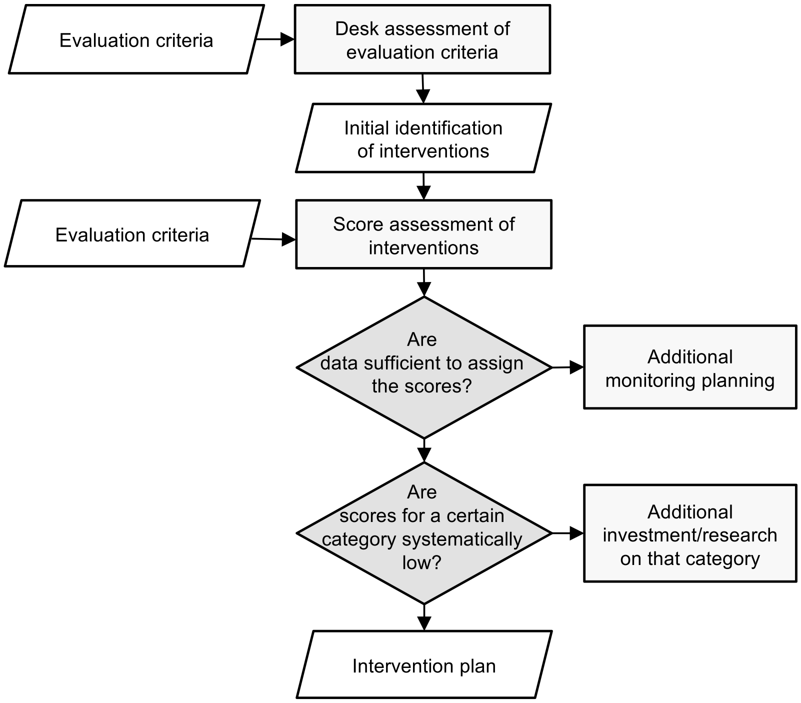

Figure 5. A flowchart illustrating the iterative application of the decision-making framework. The process begins with an initial conceptual assessment involving stakeholders and progresses to a more detailed evaluation, which is refined over time as additional data become available, ultimately guiding the selection and implementation of an adaptation strategy.

obtained. This iterative approach enables continuous refinement and adjustment of intervention strategies, accommodating evolving priorities and newly acquired insights.

To minimize subjectivity in the scoring process, a formal expert elicitation approach is essential. The framework is intended to be populated by an interdisciplinary team, which may include conservation architects, structural engineers, climate scientists, archaeologists, materials scientists, and representatives from the local community, following a structured procedure. The Delphi method is recommended as a suitable approach. This method involves several rounds of anonymous, iterative consultation facilitated by a neutral party. In the first round, each expert independently and anonymously provides scores and justifications for a given intervention using the matrix (Table 1) and the rubric (Table 2). The facilitator then aggregates the scores (e.g., median and interquartile range for each criterion) and compiles the anonymized justifications. This summary is circulated to the panel for a second round, allowing experts to revise their initial assessments based on the reasoning of their peers. The process is repeated for two or three rounds until either a stable consensus emerges or the reasons for persistent disagreement are clearly articulated.

Ultimately, the framework's primary value lies in its role as a flexible tool to stimulate critical thinking and structure dialogue. It is important to emphasize that this decision-making framework is not exhaustive or prescriptive, but builds upon existing methodologies for evaluating adaptation measures, such as the impact tables developed by (Blavier et al. 2023). By systematically considering these diverse factors, the framework can identify areas requiring further investment, research, or data collection. For example, consistently low scores in the “œSustainability” category across multiple interventions may indicate the need for more sustainable technologies or materials in heritage conservation. Similarly, low “œAdaptability” scores could point to a need for more flexible, modular designs that can be adjusted as climate conditions change. The framework can also inform monitoring initiatives. Future monitoring programs may focus on elements that frequently lack sufficient data for accurate scoring. For instance, if assessing “œLong-term Environmental Impact” proves challenging, it could justify the establishment of long-term monitoring protocols for heritage sites.

This iterative and transparent approach encourages practitioners to consider a broader range of impacts and trade-offs, fostering more holistic, defensible, and sustainable adaptation strategies for cultural heritage in a changing climate. Ultimately, the framework serves as a starting point for an interdisciplinary approach to heritage conservation, guiding practitioners to evaluate diverse factors and make informed decisions. The two examples discussed in the next section illustrate the complexity and nuance inherent in these decision-making processes.

3. Demonstration of the framework: flood and fire scenarios

This section presents two applications of the decision-making framework introduced in the previous section. The first examines flood risk management for heritage sites, comparing circumvention strategies with relocation. The second focuses on fire risk management, evaluating direct mitigation measures against circumvention-based approaches. These examples were selected for their documented significance, diversity of intervention types, and relevance to heritage conservation challenges under climate risk. Each case study includes an evaluation based on structured qualitative judgment, using score ranges to assess key decision factors: conservation, resilience, sustainability, feasibility, and socio-cultural impact. They are not tied to a single site, though; rather, they are designed to illustrate how the framework can be applied across different types of interventions. Furthermore, as detailed in Section 2, the scores adopted here are informed by published literature, technical reports, and professional practice. While empirical data is referenced where available, the scoring primarily reflects a comparative reasoning approach suited to complex, context-specific heritage settings. This method offers transparency and supports reproducibility of the framework's logic, even where quantitative data is limited or not directly transferable.

3.1. Flood management technology

As mentioned, this first case study applies the framework to flood risk management for heritage structures, assessing the trade-offs between circumvention and relocation strategies.

3.1.1. Circumvention

Circumvention strategies for flood management involve interventions designed to reduce or redirect floodwater impacts around or away from heritage structures. Examples of engineered solutions include the construction of levees, berms, or floodwalls, the installation of water pumps and drainage systems, and the use of deployable barriers. For instance, the mobile barriers currently being deployed at the three inlets of the Venice Lagon to protect the city from high tides represent a targeted circumvention measure for safeguarding an invaluable heritage site (Venezia Nuova 2025). In addition to these engineered solutions, nature-based solutions (NbS) offer a complementary approach. Wetland restoration, reforestation, and riparian buffer zones can mitigate flood impacts by enhancing the landscape's natural capacity to absorb and manage water. For instance (Su et al. 2024), proposed integrating technical and societal strategies into NbS for urban flood mitigation in the heritage city of Guangzhou, China. Similarly, Copenhagen has implemented various NbS, including green roads and floodable parks such as Enghaveparken, to manage flooding within the city (Negrello 2022). NbS are particularly advantageous in their ability to integrate cultural and ecological priorities.

Engineering solutions, while effective in mitigating immediate flood impacts, often alter the surrounding nature or cultural landscapes. For example, floodwalls can disrupt the visual integrity of a historic site, and drainage systems may require invasive construction methods that affect the site's authenticity. In contrast, NbS preserve the aesthetic and functional aspects of the site while delivering co-benefits such as biodiversity conservation, improved water quality, and carbon sequestration.

The assessment presented in Table 3 evaluates a composite hybrid strategy that incorporates both engineered and nature-based elements, reflecting common practice. The score ranges are designed to capture the inherent trade-offs described above: the lower end typically represents the negative impacts of an intrusive engineered solution (e.g., visual disruption from a floodwall), while the higher end reflects the co-benefits of a well-integrated nature-based solution (NbS).

3.1.2. Relocation

Relocation exemplifies a drastic but sometimes necessary intervention for heritage sites facing repeated, severe flooding. Although more commonly adopted as a last resort, it may be the only viable option to prevent a structure's complete loss, particularly for coastal heritage threatened by sea level rise. This strategy raises critical questions about authenticity in heritage conservation. While relocation ensures the physical survival of a structure, it may alter the relationship to the landscape and community for which it was originally designed. In some cases, however, relocation may be the only viable option to prevent a structure's complete loss.

The materials and construction systems of a heritage building strongly impact the technical and economic feasibility of deconstruction, if this is needed to enable relocation. Lightweight, modular elements like timber

Table 3. Assessment of a circumvention strategy for flood management. Score ranges reflect the high degree of variability in this approach.

Category	Subcategory	Score range	Explanation
Conservation	Authenticity	−4 to −2	The range reflects the solution mix. A low score (−4) represents a heavy reliance on intrusive engineered elements like floodwalls, while a high score (−2) reflects a solution dominated by well-integrated Nature-Based Solutions (NbS).
	Values	0 to +2	A neutral score (0) is for an effective but purely functional engineered solution. A high score (+2) reflects the added community and cultural synergies of a well-designed NbS.
	Integrity	−1 to +1	A low score (−1) is for engineered interventions that compromise the historic landscape. A high score (+1) is for NbS that restores or maintains the landscape's original character.
Resilience	Hazard Mitigation	+3 to +5	A baseline NbS provides good mitigation (+3), while a robust, well-maintained engineered system offers a higher degree of protection (+5).
	Durability	+3 to +5	Both well-designed engineered systems and mature, self-sustaining NbS can provide very long-term protection.
	Adaptability	+2 to +4	Engineered solutions can be adaptable (+2), but NbS are often more inherently flexible and responsive to changing climate scenarios (+4).
Sustainability	Resource Use	−2 to +2	A low score (−2) reflects resource-intensive engineered solutions. A high score (+2) reflects the lower lifecycle resource needs of most NbS.
	Carbon Footprint	−2 to +1	Engineered solutions have a negative footprint from manufacturing (−2), while NbS can offer modest carbon sequestration benefits (+1).
	Long-term Environmental Impact	+2 to +4	The range reflects the substantial long-term benefits of NbS, including enhanced biodiversity and ecosystem services.
Feasibility	Cost	−1 to −3	The range reflects that while NbS can be cost-effective (−1), large-scale engineered solutions are typically more expensive (−3).
	Technical Complexity	+1 to +3	While both require expertise, many solutions use established practices and are considered technically feasible in most locations.
	Regulatory Compliance	+2 to +4	Both approaches generally comply with flood management regulations, but heritage guideline conflicts can lower the score.
Socio-cultural Impact	Community Acceptance	+2 to +4	Engineered solutions may draw criticism for visual impacts (+2), while NbS are generally better accepted for their co-benefits (+4).
	Educational Opportunity	+1 to +3	Both approaches demonstrate innovative flood management techniques that can serve as educational models.
	Economic Impact	+2 to +4	Both strategies prevent costly flood damage and can positively impact local economies through tourism and resilience.

and steel are easier to disassemble, transport and reassemble, making relocation more practical and environmentally sustainable due to relatively lower carbon emissions. Conversely, deconstruction of masonry structures into their original units is impractical, and alternative, more complex techniques, such as sectional deconstruction, may be partially destructive and are more prone to altering the original structural behavior after reconstruction (Yazgan and Ihsan Unay 2020).

Examples of successful relocations, such as the Frank Lloyd Wright-designed Bachman-Wilson House (Conservancy 2014) and Zhang Fei's Temple in China (Zhu and Li 2022), illustrate a decision-making logic that is applicable to climate-induced hazards. The relocation of Zhang Fei's Temple, for instance, highlights the complex trade-offs involving intangible values. Planners had to evaluate sites that would best match the original landscape against those that would maintain the cultural and socio-economic ties with the original community, which was also being relocated. These cases demonstrate that relocation affects not just a physical structure, but its entire web of cultural significance and community connections.

The following assessment in Table 4 quantifies these impacts. The scores reflect the most probable outcomes of this last-resort strategy, highlighting its fundamental trade-off: while relocation guarantees the physical preservation of the structure (yielding high scores in Resilience), it comes at a significant and often irreversible cost to the historic context and authenticity (resulting in low scores in Conservation).

3.1.3. Comparison

The comparison between a hybrid Circumvention strategy and Relocation reveals two fundamentally different approaches to flood management for heritage. These strategies are not co-equal alternatives but represent distinct philosophies of risk management. Circumvention, assessed as a hybrid of engineered and nature-based elements, presents a flexible but highly variable strategy. As shown in Table 3, its wide score ranges across categories like Authenticity (−2 to −4) and Cost (−1 to −3) highlight that its ultimate impact is entirely dependent on the specific design mix. A strategy emphasizing Nature-Based Solutions will achieve the high end of the scores for cultural and environmental co-benefits but may offer less protection against extreme events. Conversely, a strategy dominated by engineered elements provides stronger hazard mitigation at a significant cost to authenticity. This

Table 4. Assessment of a relocation strategy for flood management. Scores are presented as single values, representing the most probable outcomes of this drastic, last-resort intervention. The assessment highlights the fundamental trade-off between the guaranteed physical preservation of the structure (high scores in resilience) and the significant, irreversible loss of its historic context and authenticity (low scores in conservation).

Category	Subcategory	Score	Explanation
Conservation	Authenticity	−4	The loss of original context and setting results in a significant and unavoidable negative impact on authenticity.
	Values	−2	While social value can be preserved if the community also relocates, the loss of connection to the original landscape significantly impacts overall value.
	Integrity	−2	The historical connection to the original location is permanently severed, compromising the site's integrity.
Resilience	Hazard Mitigation	+5	Relocation is the most effective strategy, as it completely removes the structure from the immediate flooding threat.
	Durability	+4	The intervention ensures the long-term physical survival of the structure in its new, safer location.
	Adaptability	+3	The new location can be chosen with future climate scenarios in mind, providing a high degree of adaptability.
Sustainability	Resource Use	−3	The process is highly resource-intensive, though this varies with the structure's size, materials, and travel distance.
	Carbon Footprint	−3	The process involves significant emissions from transportation, new foundation work, and reconstruction activities.
	Long-term Environmental Impact	+2	Preventing repeated flood damage and reconstruction at the original site may offset initial environmental costs over time.
Feasibility	Cost	−4	Relocation is typically an extremely expensive undertaking, requiring significant financial and logistical resources.
	Technical Complexity	−3	The process requires highly specialized expertise in preservation, structural engineering, transportation, and reconstruction.
	Regulatory Compliance	−2	Relocation often faces significant and complex regulatory challenges in both the original and new locations.
Socio-cultural Impact	Community Acceptance	+1	The impact is mixed; the original community loses a landmark, while the new location gains one. Acceptance is highly variable.
	Educational Opportunity	+3	The relocation process itself can provide powerful educational opportunities about climate change, engineering, and preservation.
	Economic Impact	+2	While the original location may see a negative impact, the new location could benefit from increased tourism and attention.

variability makes Circumvention a context-dependent approach that requires careful balancing of stakeholder priorities.

Relocation, in stark contrast, offers predictable and extreme outcomes. The single scores in Table 4 show its unambiguous nature. It is the only strategy that guarantees a perfect result in Hazard Mitigation (+5), ensuring the physical survival of the asset. However, this certainty comes at a catastrophic and equally certain cost to the Conservation category, with Authenticity (−4) and Integrity (−2) being permanently compromised. Its feasibility is also predictably challenging, with high costs (−4) and technical complexity (−3).

Ultimately, the framework distills the decision into a clear choice. Circumvention is a strategy of managing risk within the original context, requiring a nuanced design process to find an acceptable balance between protection and preservation. Relocation is a strategy of eliminating risk by sacrificing context, a last-resort option for when the physical asset's survival is deemed more critical than its connection to its original landscape and history.

3.2. Fire management technology

To better demonstrate the proposed decision-making framework, we will explore two distinct methods for protecting heritage structures from fire. One approach emphasizes direct intervention strategies, while the other evaluates the abstention approach. These examples illustrate the intricate balance required in climate adaptation efforts for cultural heritage sites.

3.2.1. Direct interventions

Direct interventions for protecting heritage buildings from wildfire can range from moderately invasive to highly invasive (Garcia-Castillo, Paya-Zaforteza, and Hospitaler 2023). Active control systems can include the installation of fire suppression systems, such as exterior sprinklers mounted to the building, while passive fire protection utilizes fire-resistant building materials to prevent fire spread and can include the replacement of combustible exterior materials, such as roofs and siding, with non-combustible materials or the encapsulation of combustible elements with non-combustible materials.

While fire suppression systems, including exterior sprinkler systems, can be a practical tool in the protection of historic structures from wildfire, the impacts of the installation depend largely on the existing construction, including whether sprinkler pipes can be concealed or must be exposed, and how much historic fabric is lost or altered in the installation. The system can have an impact on the aesthetic value of a building. Extreme weather and high winds can also degrade the effectiveness of such systems. Additionally, activated sprinklers can result in water damage to significant historic materials, finishes, and artifacts. Passive strategies may include the replacement or encapsulation of combustible materials, such as wood, with fire resistant construction materials, such as gypsum board, or the application of chemical flame retardants. These result in a significant impact on historic fabric, while studies have indicated limited effectiveness in protecting historic sites from fire using these approaches (Garcia-Castillo, Paya-Zaforteza, and Hospitaler 2023).

Table 5 provides an assessment of the impacts of direct intervention strategies on heritage sites, highlighting both the benefits and the potential challenges in various aspects of conservation, resilience, sustainability, feasibility, and socio-cultural impact.

3.2.2. Abstention

As established in the framework's typology, Abstention is not a singular approach but can range from passive acceptance of decline to a proactive, informed strategy. This section details the components that constitute Active Abstention in the context of wildfire risk,

Table 5. Assessment of direct interventions as a wildfire management strategy for heritage sites. Scores are presented as single values where the outcome is predictable and as ranges where there is a high degree of uncertainty (e.g., the conflict between meeting modern safety regulations and preserving historic character, or the varying levels of community acceptance).

Category	Subcategory	Score (range)	Explanation
Conservation	Authenticity	−3 to −1	The impact on authenticity is always negative but varies. A low score (−3) reflects a highly visible, irreversible intervention, while a high score (−1) represents a well-concealed and potentially reversible measure.
	Values	−3 to +3	The range reflects a trade-off: a low score (−3) is for interventions that significantly compromise the site's aesthetic values. A high score (+3) is achieved when the effective protection of the site's overall cultural and historic value is deemed to outweigh any negative aesthetic impact.
	Integrity	−1 to +2	The low score (−1) reflects an intervention that compromises or obscures critical historical evidence within the fabric. The high score (+2) is for a well-designed strategy that successfully protects the site while preserving its overall cultural context.
Resilience	Hazard Impact Mitigation	+2 to +4	The effectiveness of any direct intervention varies. A low score (+2) represents a basic intervention with known limitations, while a high score (+4) reflects a well-designed system that significantly mitigates the hazard.
	Durability	+1 to +3	Interventions add durable elements, but their lifespan varies. The low score (+1) is for systems with shorter service lives or higher maintenance needs, while the high score (+3) reflects a highly durable, long-lasting installation.
	Adaptability	−1 to +3	The adaptability depends on the strategy. A low score (−1) reflects an irreversible action like replacing original materials. A high score (+3) is for a modular or technological system (like fire suppression) that can be updated in the future.
Sustainability	Resource Use	−4 to −1	All direct interventions are resource-intensive. The range reflects the scale of the project, from a highly targeted system with lower material needs (−1) to a large-scale intervention requiring extensive new materials (−4).
	Carbon Footprint	−3 to −1	The carbon footprint is always negative due to manufacturing and installation. The low score (−3) reflects the use of high-carbon materials like concrete or steel, while the high score (−1) is for more sustainable, locally sourced materials.
	Long-term Environmental Impact	+2 to +4	The primary impact is positive by preventing catastrophic waste from fire damage. The low score (+2) accounts for potential collateral impacts (e.g., water damage), while the high score (+4) represents a clean, effective protection of the site.
Feasibility	Cost	−3 to −1	All direct interventions involve significant initial costs. The range reflects the strategy's scale and complexity, from a more affordable system (−1) to a highly complex and expensive installation (−3).
	Technical Complexity	−1 to +2	The complexity varies by strategy. A high score (+2) represents a straightforward installation (e.g., exterior sprinklers). A low score (−1) reflects a more specialized or technically complex intervention requiring expert knowledge.
	Regulatory Compliance	−2 to +4	This range reflects the potential conflict between regulations. The high score (+4) is achieved by meeting modern building and fire safety codes. The low score (−2) is the result of violating heritage conservation regulations.
Socio-cultural Impact	Community Acceptance	−3 to +2	The outcome depends on public perception. A high score (+2) reflects community support for protecting the site. A low score (−3) reflects controversy and opposition due to significant negative visual impacts on the historic structure.
	Educational Opportunity	+4	There is a potential to utilize the intervention to raise awareness about climate resilience in historic structures.
	Economic Impact	+4	There is a potential for reduced insurance costs and the prevention of economic losses from fire damage.

demonstrating how a decision to avoid direct physical intervention can be coupled with a suite of complementary measures.

The foundation of this approach is monitoring and risk assessment, which combines modern technology (such as satellite imagery, drones, and GIS) with the cooperation and knowledge of local communities. Tools like the Fire Weather Index (FWI), a worldwide index used to estimate fire danger from meteorological conditions, are important for risk mapping, which in turn informs strategic planning for firefighting activities (Barroso, Winkler, and Daria Vaverková 2024).

This ongoing assessment informs direct management and preparedness strategies. These include landscape-level decisions, such as the strategic use of fire-resistant plant species to create buffer zones around the heritage site (Gültekin and Gültekin 2024), as well as on-site fire safety management, which includes ensuring clear access routes and a sufficient water supply for firefighting operations. The strategy also encompasses emergency planning, resource allocation decisions, safety training, and educational initiatives for site managers and local stakeholders. Finally, an Active Abstention strategy includes thorough documentation to prepare for a worst-case scenario. By generating detailed records like 3D point clouds, a digital blueprint of the site is preserved. This would be important to aiding in any future restorative or reconstitution efforts should extensive fire damage occur, even if no action is taken to the building in the present. To illustrate the difference in outcomes, Table 6 provides a comparative assessment. It evaluates both the multi-faceted Active Abstention strategy detailed above and a baseline Passive Abstention, where no complementary measures are undertaken.

3.2.3. Comparison

By summing the high and low ends of the score ranges for each strategy, the overall risk profiles become clear. A well-executed Direct Intervention offers the highest

Table 6. Assessment of abstention as a wildfire management strategy for heritage sites. Scores are presented as single values where the outcome is predictable and as ranges where there is a high degree of uncertainty (e.g., the potential for both low initial cost and catastrophic future loss).

Category	Subcategory	Score	Explanation
Conservation	Authenticity	+5	*Passive*: No impact on original fabric; authenticity is preserved.
		+5	*Active*: No physical intervention; authenticity is preserved.
	Values	+5	*Passive*: Aesthetic, cultural, and historic values are preserved.
		+5	*Active*: Values are preserved; monitoring may enhance understanding.
	Integrity	+5	*Passive*: The site's cultural context and evidence are preserved.
		+5	*Active*: The site's integrity is preserved.
Resilience	Hazard Impact Mitigation	−5	*Passive*: Does not address or mitigate the physical hazard impact.
		−5	*Active*: Does not physically mitigate the hazard, but informs management plans.
	2=Durability	0	*Passive*: Not applicable, as there is no intervention.
		0	*Active*: Not applicable, as there is no physical intervention.
	Adaptability	−3 to −1	*Passive*: Unmonitored decline hinders and limits future adaptation options.
		+3 to +5	*Active*: Monitoring and planning are foundational for future adaptation.
Sustainability	Resource Use	−4 to +3	*Passive*: Range reflects the gamble: from no initial use (+3) to a resource-intensive reconstruction after loss (−4).
		0 to +2	*Active*: Low and predictable initial resource use for monitoring/planning.
	Carbon Footprint	0	*Passive*: Not applicable, as there is no intervention.
		0	*Active*: Not applicable, as there is no intervention.
	Long-term Environmental Impact	−5 to +2	*Passive*: Range reflects risk: from no impact (+2) to major waste and debris from total loss (−5).
		0 to +2	*Active*: Minimal initial impact; managed risk reduces the worst-case scenario.
Feasibility	Cost	−5 to +3	*Passive*: Range reflects extreme uncertainty: from no initial cost (+3) to catastrophic financial loss (−5).
		−2 to 0	*Active*: A predictable, upfront investment with a narrow cost range.
	Technical Complexity	+3	*Passive*: No technical complexity.
		−3 to 0	*Active*: Complexity ranges from simple (0) to advanced (−3) depending on the monitoring technology.
	Regulatory Compliance	−4 to −2	*Passive*: Very unlikely to satisfy safety regulations.
		−2 to 0	*Active*: A formal plan is viewed more favorably and may meet some requirements.
Socio-cultural Impact	Community Acceptance	−4 to −2	*Passive*: Likely to be perceived negatively, ranging from disappointment (−2) to outrage (−4).
		−2 to +1	*Active*: Outcome depends on communication; could be seen as inaction (−2) or responsible stewardship (+1).
	Educational Opportunity	0	*Passive*: No planned initiatives, so no educational opportunity.
		+1 to +4	*Active*: Monitoring and planning create educational opportunities, from minor (+1) to major (+4).
	Economic Impact	−5 to 0	*Passive*: Range reflects risk: from no change (0) if no fire occurs, to total loss of the asset (−5).
		−5 to 0	*Active*: The ultimate risk of total loss remains (−5), but is actively managed.

potential outcome (+28), while a poorly chosen one carries significant risk (−11). Conversely, Passive Abstention represents an extreme gamble, with the lowest potential floor of any strategy (−17) offset by a positive best-case scenario (+16) that is entirely dependent on a hazard not occurring. The core difference between the two abstention approaches is one of risk management. Passive Abstention is a strategy of inaction, which is reflected in its volatile feasibility scores (Cost: −5 to +3) and its catastrophic potential for economic loss (−5). Active Abstention, with a total score range of 0 to +24, presents a much more stable and defensible management position. While it requires a predictable upfront investment (Cost: −2 to 0), this investment yields significant returns in critical areas like Adaptability (+3 to +5), creating a resilient strategy built on information and preparedness rather than chance.

When comparing a Direct Intervention to Active Abstention, the fundamental trade-off for decision-makers becomes explicit. The choice is a direct exchange between preserving authenticity and guaranteeing physical protection. Active Abstention achieves perfect scores (+5) in the Conservation category but fails completely to mitigate the physical hazard (−5). Direct Intervention presents the inverse scenario: it successfully mitigates the hazard (+2 to +4) but does so at the cost of the site's authenticity and integrity (−3 to 0). Furthermore, a successful Direct Intervention is the only strategy with a guaranteed positive Economic Impact (+4), as it secures the heritage asset for future use. In stark contrast, both Abstention strategies carry a significant risk of catastrophic economic loss (−5). The framework thus distills the decision into a clear, albeit difficult, question: is it preferable to compromise material authenticity to secure the asset's physical survival and positive economic contribution (Direct Intervention), or to preserve the fabric perfectly while accepting a significant, actively managed risk of physical and economic loss (Active Abstention)?

4. Conclusions and looking forward

The preservation of cultural heritage in the face of climate change presents a complex challenge that requires a delicate balance between conservation principles, climate adaptation, and sustainability. This paper has presented a framework for evaluating interventions, highlighting the multifaceted nature of decision-making in this field. As demonstrated through the flood and fire management scenarios, the framework excels at clarifying the distinct risk profiles and fundamental trade-offs of different strategies, such as choosing between the certainty of a direct intervention and the managed risk of an active abstention approach.

The framework presented holds specific, actionable implications for the various stakeholders involved in this work. For policymakers and funding bodies, this research highlights the need to integrate heritage preservation into broader climate adaptation strategies, moving beyond siloed approaches. Policies must become more flexible to support innovative, context-specific solutions rather than enforcing rigid conservation doctrines. Furthermore, funding mechanisms should be adapted to support long-term monitoring and adaptive management, recognizing that climate adaptation is an ongoing process, not a one-time fix. For heritage planners and practitioners, the primary implication is the adoption of a structured, transparent, and defensible decision-making process, grounded in the principles of MCDA. The framework provides a practical tool to facilitate difficult conversations about trade-offs, document the rationale behind choices, and engage a wider range of experts. It encourages a shift from reactive repairs to proactive, long-term risk management that considers a full spectrum of interventions, from minimal to transformative. For local communities, this work highlights their essential role as active partners. The framework's emphasis on socio-cultural impact empowers community members to articulate the values they attach to heritage sites and to participate in shaping their future. When co-designed with local stakeholders, adaptation projects can become powerful opportunities for education, skill-building, and reinforcing cultural identity in the face of environmental change.

Building on these implications, future efforts must continue to address the complexities of multi-hazard scenarios and the deep uncertainties of climate change. Priorities for future research include the development of more flexible and adaptive intervention strategies, the advancement of multi-hazard risk models tailored to heritage contexts, and continued exploration of innovative, sustainable materials compatible with historic fabric. Fostering deeper interdisciplinary collaboration and establishing long-term monitoring programs will be important for validating the effectiveness of interventions and informing the next generation of policy.

Ultimately, the preservation of cultural heritage is not just about protecting physical structures; it is about maintaining the cultural, historical, and social fabric of our societies. As we confront this challenge, we must strive for solutions that are not only effective in preserving our heritage but also contribute to a more resilient and sustainable future. By adopting a holistic, interdisciplinary, and collaborative approach, we can work to protect our shared legacy in the face of a changing climate.

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Conceptualization (RN, MR, AC, TMF, LP, CF, SV, XC, QD, GG, MBD); **Methodology** (RN, MR, AC, TMF, LP, CF, SV, XC, QD, GG, MBD); **Writing — Original** Draft (RN, MR, AC, TMF, LP, CF, SV, XC, QD); **Writing — Review & Editing** (RN, MR, AC, TMF, LP, CF, SV, XC, QD, GG, MBD).

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