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Systematic Review

Climate Change Adaptation in Cultural Heritage: A Systematic Mapping Review Using an AR6-Informed Action Typology

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Abstract

Research on climate adaptation for cultural heritage has grown rapidly, but evidence remains fragmented across heritage types, hazards, regions, and forms of action. This PRISMA 2020-guided systematic mapping review analysed 164 peer-reviewed, English language studies indexed in the Web of Science Core Collection through 25 June 2026. Studies were coded by region, heritage type, climate hazard, implementation stage, and a seven-category, AR6-informed adaptation-action typology. The English language publications have substantially expanded since 2015, although they continue to be geographically concentrated in Europe and North America with more limited representation in Africa, Latin America, Asia, and Oceania. The extent to which this reflects the global research landscape and whether it is an artefact of language limitations remains an area for further research. Institutional actions dominate the literature (72.0%), while economic and ecosystem-based responses remain scarce. Built heritage studies revealed a comparatively strong technological and structural/physical profile, which remained when the single earthen-heritage study was included. However, 65.9% of studies only proposed actions, and just two evaluated their outcomes, none in built heritage. Gaps also persist in underrepresented heritage domains and the integration of Indigenous and local knowledge. Future research should evaluate adaptation outcomes, connect climate hazards more directly with building and material performance, and integrate physical interventions with governance, finance, and local knowledge. The findings identified evidence gaps relevant to the cultural heritage indicators adopted under the Global Goal on Adaptation.

Keywords: cultural heritage; built heritage; climate change adaptation; climate action; adaptation governance; systematic mapping review; IPCC AR6; Global Goal on Adaptation

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1. Introduction

Climate change is intensifying risks to natural and human systems, and some impacts can no longer be avoided through mitigation alone. The IPCC defines adaptation in human systems as adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities [1,2]. For cultural heritage, adaptation is urgent because climatic and related hazards can damage material fabric, disrupt traditional practices and livelihoods, and alter the values through which communities understand place. Built and architectural heritage is particularly relevant to this challenge because changing temperature, moisture, precipitation, flooding, and other climatic loads directly affect building materials,

walls, roofs and openings, structural systems, and maintenance requirements. Climate adaptation of built heritage therefore lies at the intersection of heritage conservation and building resilience, requiring responses that reduce climate risk while retaining cultural significance and material authenticity [3].

Cultural heritage includes tangible assets, such as buildings, sites, landscapes and collections, and intangible practices, knowledge, and meanings [4,5]. Both tangible and intangible forms of cultural heritage are exposed to climate risk and constitute a potential resource for adaptation. In the IPCC Sixth Assessment Report (AR6) risk framing, risk arises from the interaction of hazards, exposure, and vulnerability, the latter comprising sensitivity and adaptive capacity. Responses to climate change, including adaptation itself, are recognised as a further determinant of risk, since they may reduce or inadvertently increase it [1]. Heritage resilience therefore concerns not only physical persistence but also the capacity to sustain values, functions, and relationships under changing conditions [6].

Previous reviews demonstrate rapid growth but recurring gaps. Fatorić and Seekamp [7] mapped research to 2015; Orr et al. [8] reviewed 165 publications from 2016 to 2020 and found continued European concentration, limited focus on intangible cultural heritage, and relatively few studies of adaptation implementation. Subsequent reviews have examined World Heritage properties [9], risk assessment and disaster management [10], adaptive solutions for built heritage [3], and the functions of heritage in adaptation [11]. For built heritage specifically, this fragmented evidence makes it difficult to place material, technological, and structural interventions alongside institutional, behavioural, and other forms of adaptation or to determine how the research emphasis differs from that of other heritage types [3,12]. A common action-based framework is therefore needed to compare the forms of adaptation proposed, implemented, or evaluated across heritage types and climatic hazards [10,13,14].

Policy recognition has advanced in parallel. Article 7.5 of the Paris Agreement recognises Indigenous, traditional, and local knowledge in adaptation [15]. The UAE Framework for Global Climate Resilience established a thematic target on protecting cultural heritage from climate-related risks [16]. Under Decision 12/CMA.7, the CMA adopted 59 Belém Adaptation Indicators, which include five indicators under Target 9(g) dedicated to cultural and natural heritage. These indicators address the following: (a) adaptation measures for at-risk heritage guided by traditional, local, and Indigenous knowledge; (b) digitisation for preservation or recovery and protection of movable heritage in climate-resilient facilities; (c) adaptation measures and emergency-preparedness plans; (d) institutional arrangements for regular adaptation training; and (e) sustained engagement with Indigenous peoples and local communities [17,18]. However, Simpson et al. [19] identify unresolved issues concerning definitions, baselines, metadata, disaggregation, and the treatment of diverse knowledge systems.

Recognition has not yet produced comparable evidence on what works. Reviews of built heritage indicate that practical adaptive solutions are rarely evaluated, and analyses of climate plans identify weak monitoring, cross-sectoral integration, and treatment of intangible values [3,20]. Delayed action can increase costs, reduce available options, and permit irreversible loss of material and living heritage [1,21]. Applied to built heritage, systematic comparison can reveal whether the evidence base spans physical, technological, institutional, behavioural, and other adaptation options or remains concentrated in particular forms of action and to what extent adaptation outcomes are evaluated.

This review analyses 164 peer-reviewed studies published from 2008 to June 2026 to examine the following: (1) the distribution of research across time, geography, heritage types, and climatic hazards; (2) the adaptation actions represented; and (3) gaps emerging from relationships among heritage types, hazards, and adaptation actions. A seven-category,

AR6-informed typology is applied to compare adaptation actions across the literature. Frequency represents patterns in the evidence base rather than adaptation implementation or effectiveness. The analysis specifically examines built and architectural heritage within the wider evidence base. The findings are considered in relation to the cultural heritage indicators adopted under the Global Goal on Adaptation.

2. Materials and Methods

2.1. Review Design and Reporting

This study used a systematic mapping-review design to characterise the scope and distribution of research rather than to estimate intervention effects. Reporting was structured with reference to PRISMA 2020 [22], and Figure 1 summarises identification, screening, eligibility, and inclusion. This review was not registered, and no review protocol was prepared or published.

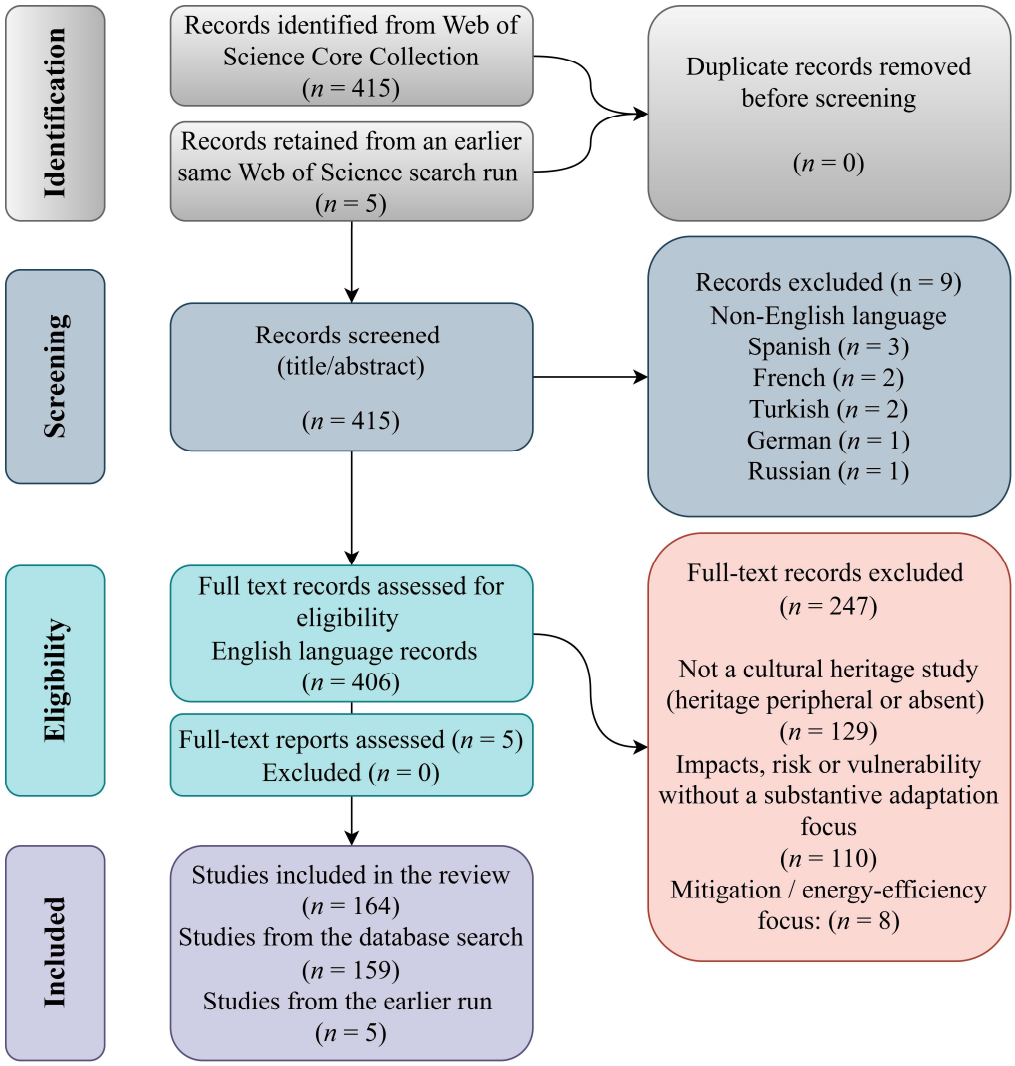


Figure 1. PRISMA 2020 flow diagram of the study selection process. Records were identified through the WoS Core Collection. Source: authors' own work.

2.2. Data Sources and Search Strategy

A comprehensive literature search was performed using the Web of Science (WoS) Core Collection (Clarivate, London, UK). A single database was used to maintain consistent indexing and metadata structure across the corpus. This search was conducted

until 25 June 2026, using a combined semantic and Boolean search strategy, in which a structured Boolean query provided exact keyword matching, and the WoS Core Collection related-records function broadened retrieval to conceptually proximate studies that keyword matching alone would not surface. The final search, run after the verification described below, combined adaptation terms with heritage terms using the following query: ("climate change adaptation" OR "adaptation to climate change" OR "adaptive management" OR "resilience to climate change" OR "adaptation strategy" OR "adaptation planning" OR "adaptive capacity") AND ("cultural heritage" OR "built heritage" OR "archaeological site*" OR "historic building*" OR "heritage site*" OR "monument*" OR "world heritage" OR "museum*" OR "heritage conservation" OR "heritage management")). The initial search, conducted on 25 June 2026, combined the query above with exclusion terms for mitigation and assessment-only studies and returned 415 records. This search defined the review corpus. To test whether the exclusion terms reduced retrieval, the search was repeated on 28 September 2026 under the then-current WoS Core Collection, once with and once without the exclusion terms. Both searches returned 450 records, indicating that the exclusion terms did not affect retrieval under identical September search conditions. The September searches were conducted only as a verification test; records indexed after the 25 June 2026 cut-off were not screened or added to the review corpus. The complete search strings and record counts are provided in Table S1. Studies addressing impacts, risk, or vulnerability without a substantive adaptation focus were excluded during full-text screening based on their content.

2.3. Eligibility and Study Selection

The search yielded 415 records. Nine non-English publications (Spanish, $n = 3$; French, $n = 2$; Turkish, $n = 2$; German, $n = 1$; Russian, $n = 1$) were excluded, leaving 406 records for full-text assessment. Of these, 247 were excluded: 129 were not cultural heritage studies, with heritage peripheral or absent; 110 addressed impacts, risk, or vulnerability without a substantive adaptation focus; and 8 focused on mitigation or energy efficiency. Studies were retained when cultural heritage was an explicit object, setting, or system of the adaptation analysis, including heritage sites considered as visitor destinations and traditional practices explicitly identified by the study authors as cultural heritage. In addition, five records retrieved in an earlier run of the same WoS search on 28 October 2025 were no longer returned in the 25 June 2026 search following database re-indexing. These records were assessed separately by the same eligibility criteria using the full text, and all five were retained. They are therefore shown as a separate identification path in Figure 1 and were not included among the 415 records retrieved in the main search. The final sample comprised 164 studies (159 from the 25 June 2026 search and five retained from the earlier search run) published from 2008 to 25 June 2026.

The resulting corpus is deliberately narrower than that of broader climate-and-heritage reviews. Orr et al. [8] identified 165 publications for 2016–2020 alone using heritage-and-climate keyword pairs without an adaptation requirement or exclusion terms, thereby capturing impact, risk, and vulnerability studies alongside adaptation. Because the present review targets adaptation specifically and excludes assessment-only studies, a smaller corpus over a longer period is expected. Consistent with Orr et al. [8], who found that type-specific search terms returned very few results and were omitted to avoid bias, our low counts for some heritage domains likely reflect how this literature is indexed and termed rather than an artefact of the adaptation filter alone.

2.4. Geography, Heritage Type, and Hazard Coding

One primary heritage type was assigned to each study: built heritage (including historic buildings, monuments, and structures), cultural landscape, intangible, archaeological, coastal-maritime, movable heritage/collections, earthen heritage, or mixed/general. Earthen heritage was coded separately from built heritage, as earthen construction constitutes a distinct conservation and climate-vulnerability domain. Country and continent were recorded from the study's substantive geographic focus. Regions followed a conventional division: North America comprises the United States and Canada; Latin America and the Caribbean comprises Mexico, Central America, the Caribbean, and South America; and studies spanning more than one continent were coded as global/multi-region. Worldwide, multi-regional, and non-place-specific conceptual or methodological studies were coded as global/multi-region. For the country-level analysis, every specific country named in a study was retained (so a study naming several countries contributes to each), whereas studies with only a global, multi-regional, polar, or continent-only focus (that is, naming a continent or supra-national region such as Europe or the Nordic countries but no specific country) have no country-level entry. Hazards were coded non-exclusively according to the climate stressor(s) the adaptation study explicitly addressed, as sea-level rise, flooding, temperature/heat, drought/aridity, precipitation/rain, wind, storms/cyclones, wildfire, humidity/moisture, salinity/seawater intrusion, cryospheric/permafrost, or general/unspecified.

2.5. AR6-Informed Adaptation-Action Typology

AR6 describes adaptation options across structural/physical, social, and institutional domains, with technological, ecological, and services-based measures situated within these broader groupings [1]. To provide greater analytical resolution for this corpus, we operationalised a seven-category, AR6-informed typology: institutional, behavioural, structural/physical, technological, ecosystem-based, economic, and informational (Table 1). This extension also draws on response categories used in global adaptation evidence mapping [13]. Coding was non-exclusive. Studies were coded under every category for which they substantively presented an adaptation action, without requiring a forced choice between overlapping categories. Actions affecting practice, participation, or stewardship were coded as behavioural, while those involving knowledge transfer, training, or awareness were coded as informational; actions serving both functions received both codes. Monitoring, modelling, and decision-support tools were coded as technological and additionally as institutional when integrated into governance, planning, or management. An action was recorded only when it was substantively proposed, implemented, evaluated, or critically examined; passing references were not coded. To check coding consistency, two co-authors checked the adaptation actions of 51 studies (31.1% of the corpus) using the criteria in Table 1. Agreement across the 357 category decisions was 96.6% (Cohen's $\kappa = 0.91$). Disagreements were resolved by discussion, and the final codes are reported in Table S2.

Traditional, local, and Indigenous forms of knowledge were coded as behavioural, reflecting its expression through community practice and stewardship. They were coded as informational only when the adaptation action itself involved the production or transfer of knowledge, such as documentation or capacity-building programmes. This knowledge has an informational dimension in other studies, and coding it primarily as behavioural simplifies its cross-cutting character.

Table 1. Diagnostic framework for the AR6-informed classification of adaptation actions in cultural-heritage studies.

Diagnostic Criterion	Adaptation-Action Category	Typical Indicators
Governance, planning, regulation, or management actions	Institutional	Policy, governance, regulation, planning, management frameworks, and adaptation strategies
Behavioural change, community participation, stewardship, or cultural practices	Behavioural	Community engagement, stewardship, behavioural change, Indigenous/local knowledge, awareness
Physical or engineering interventions	Structural/physical	Retrofit, restoration, engineering measures, protective structures
Digital technologies, monitoring, modelling, or decision-support tools	Technological	Remote sensing, GIS, sensors, AI, modelling, digital tools
Ecosystem processes or nature-based solutions	Ecosystem-based	Nature-based solutions, ecosystem services, green infrastructure, landscape restoration
Financial instruments or economic mechanisms	Economic	Adaptation finance, funding mechanisms, incentives, cost-benefit analysis, economic valuation
Knowledge generation, information systems, training, or capacity building	Informational	Capacity building, education, training, knowledge exchange, information systems

2.6. Implementation-Stage Coding

To distinguish research attention from the progress of adaptation in practice, each study was also coded by implementation stage. Three ordered stages were defined, and each study was assigned to the most advanced stage it reported. Proposed studies put forward, designed, reviewed, modelled, or simulated adaptation actions, or examined perceptions, barriers, or priorities, without reporting that actions had been carried out. Implemented studies reported adaptation actions carried out in practice, without systematic evidence on their effects. These included interventions built or installed, plans or policies adopted by responsible bodies, planning or capacity-building programmes run with site managers or communities, and traditional practices currently used to cope with climate variability or change. Evaluated studies reported empirical evidence on the performance, effectiveness, or outcomes of implemented actions, such as post-implementation monitoring or cost-benefit analysis of an operating system. The modelled effectiveness of an intervention that had not been carried out was coded as proposed. Passing references to actions were not coded, consistent with Section 2.5. Stage was first coded from titles and full abstracts. All studies coded as implemented or evaluated were then checked against the full text to confirm that the reported actions had been carried out or evaluated. The complete decision rules are given in Supplementary Table S3, and the stage assigned to each study is reported in Table S2.

2.7. Descriptive Analysis

Three descriptive cross-tabulations were produced: heritage type × hazard, heritage type × adaptation action, and hazard × adaptation action. Implementation stage was also summarised by adaptation-action category and heritage type. Heritage type was mutually exclusive, whereas hazards and actions were non-exclusive; a study could therefore

contribute to multiple cells. Counts are co-occurrences, row and node totals may exceed the number of unique studies, and no inferential tests were performed. To account for differences in sample size among heritage types, adaptation-action categories were also expressed as proportions of the studies within each heritage type. Proportions were not interpreted for heritage types represented by fewer than five studies. A sensitivity analysis repeated the built-heritage comparison with the earthen-heritage study included in the built-heritage category.

To relate the findings to the Belém Adaptation Indicators, the seven adaptation-action categories were cross-referenced with the five indicators under Target 9(g) [17]. Because the indicators specify more specific forms of adaptation than the broad action categories, the corpus was then screened directly against the substantive requirements of each indicator, irrespective of implementation stage. Studies were screened for the following: (a) adaptation measures for at-risk heritage explicitly drawing on traditional, local, or Indigenous knowledge or practices; (b) digitisation for preservation or recovery, or protection of movable heritage in climate-resilient facilities; (c) adaptation, management or emergency-preparedness plans, or early-warning systems, for heritage; (d) institutionalised or recurring adaptation training or capacity-building arrangements for heritage actors; and (e) adaptation measures led or co-managed by Indigenous Peoples or local communities or involving their ongoing participation. Passing recommendations and generic decision-support tools were not counted. Implementation-stage coding was then used to distinguish proposed, implemented, and evaluated evidence relevant to each indicator.

References were managed using Zotero (version 9.0.6; Corporation for Digital Scholarship, Vienna, VA, USA). Coding and descriptive analyses, including agreement statistics, were conducted in Microsoft Excel (version 2610; Microsoft Corporation, Redmond, WA, USA). Figure 3 was prepared using QGIS version 3.44.7 "Solothurn" (QGIS Development Team), and Figures 7–9 were produced using SankeyMATIC (https://sankeymatic.com; accessed on 13 October 2026).

2.8. Author Positionality and Reflexivity

Because coding relied on criterion-based expert judgement, the review adopts a pragmatic position in which the adaptation-action categories are treated as analytical constructs rather than fixed representations of adaptation practice. The authors' backgrounds are primarily in heritage conservation, environment and earth science, climate-risk assessment, and adaptation planning, which may privilege site-based, conservation-led, and policy-oriented interpretations of adaptation. The AR6-informed framework may also separate institutional, behavioural, technological, and knowledge dimensions that are integrated in Indigenous and local practices. Reliance on English-language and internationally indexed literature creates further blind spots in relation to regional and community-based knowledge. Following Spennemann [23], it is relevant to acknowledge that not all the blind spots could be identified within the research team. The coding rules and study-level dataset are therefore provided to support transparency and external scrutiny.

3. Results

3.1. Overview of the Corpus

The final corpus comprised 164 peer-reviewed studies on climate change adaptation in cultural heritage, published from 2008 to June 2026. Each study was coded by publication year, geographic focus, heritage type, climate hazard, implementation stage, and AR6-informed adaptation-action category. The studies appeared across 101 sources, 77 of which contributed only one study. Only 43 studies (26.2%) were published in sources whose titles explicitly referred to heritage, archaeology, or conservation. The most frequent sources were

Sustainability (16), Heritage (9), Journal of Cultural Heritage Management and Sustainable Development (7), Climate (6), and Historic Environment: Policy & Practice (5). The corpus also spanned 56 WoS Core Collection categories, led by Environmental Studies and Environmental Sciences (44 studies each), Green & Sustainable Science & Technology (30), and Humanities, Multidisciplinary (20), with further representation in meteorology, archaeology, urban studies, and architecture. Table S2 lists each study with its reference number, and the full references, including sources, are given in the reference list.

3.2. Temporal Distribution

Only seven studies were published through 2014. Output increased after 2015 and rose again after 2022. Of 164 studies, 140 (85.4%) were published from 2018 onward and 92 (56.1%) from 2022 through 25 June 2026. Output peaked at 32 studies in 2025. The 15 studies for 2026 represent a partial indexing year and should not be compared directly with complete years (Figure 2). To examine changes over time, studies were grouped into 2008–2015 ($n = 14$), 2016–2020 ($n = 43$), and 2021–2026 ($n = 107$), broadly corresponding to earlier reviews [7,8]. Intangible cultural heritage increased from no studies before 2016 to 18 (16.8%) in 2021–2026, while built heritage remained at about one-quarter of the evidence base. Sea-level rise was the most frequent specific hazard in 2016–2020, whereas flooding, drought/aridity, and temperature/heat became similarly prominent after 2020. Behavioural actions increased from three of 14 studies to 51 of 107, while institutional actions remained the most frequent category (Table S4). Studies reporting implemented or evaluated actions also increased, from nine of 57 before 2021 to 47 of 107 thereafter.

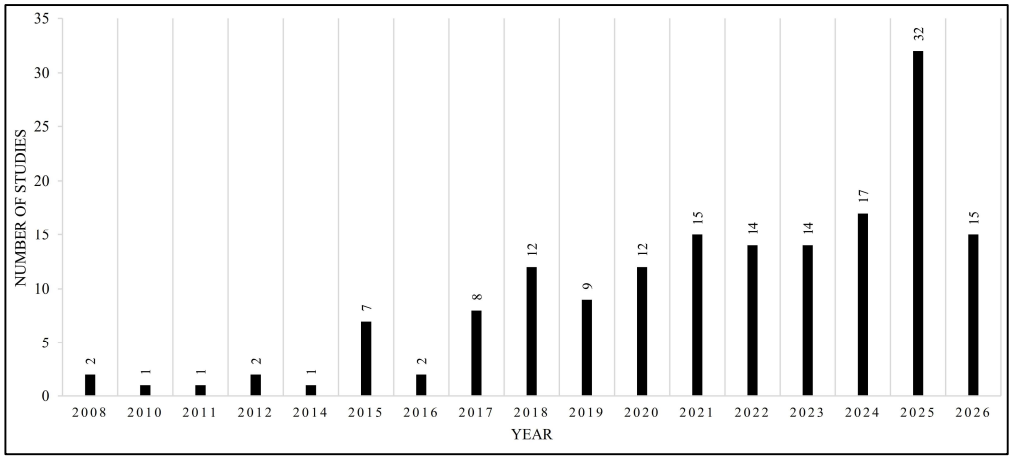


Figure 2. Temporal distribution of publications on cultural heritage adaptation to climate change (2008–2026; $n = 164$). The year 2026 represents a partial year, comprising records indexed up to the search date of 25 June 2026. Source: authors' own work.

3.3. Geographic Distribution

The geographic distribution was uneven. Europe accounted for 62 studies (37.8%), followed by global/multi-regional studies (35; 21.3%), Asia (20; 12.2%), North America (18; 11.0%), Oceania (12; 7.3%), Africa (11; 6.7%), Latin America and the Caribbean (4; 2.4%), and the polar regions (2; 1.2%). At the country level, the United States (19 studies), Italy (14), the United Kingdom (12), Spain (10), and Australia (9) were the most represented; 22 countries appeared in only one study (Figure 3). Studies addressing Arctic or Antarctic contexts without a specific national setting were classified as polar at the regional level and were not included in country-level counts.

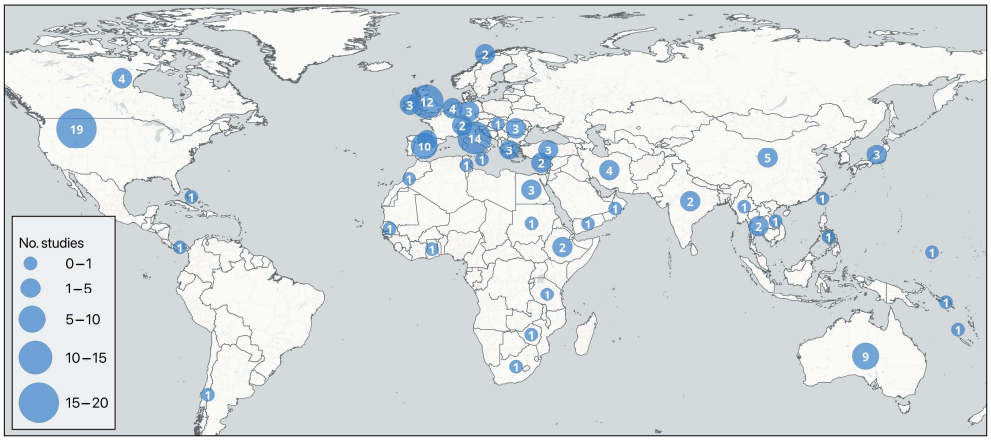


Figure 3. Geographic distribution of studies on cultural heritage adaptation to climate change by country (n = 164). Country-level counts are non-exclusive, as studies addressing multiple countries were counted for each country. The 44 studies without a specific national setting (29 global or multi-regional, 13 continent-only or supra-national, and two polar) have no country-level entry; country mentions therefore total 138 rather than 164. Source: authors' own work.

3.4. Cultural Heritage Types

The corpus was concentrated in mixed/general cultural heritage (42 studies; 25.6%), built heritage (41; 25.0%), and cultural landscapes (34; 20.7%; Figure 4). Intangible cultural heritage accounted for 22 studies (13.4%), archaeological heritage for 13 (7.9%), coastal-maritime heritage for nine (5.5%), movable heritage/collections for two (1.2%), and earthen heritage for one (0.6%).

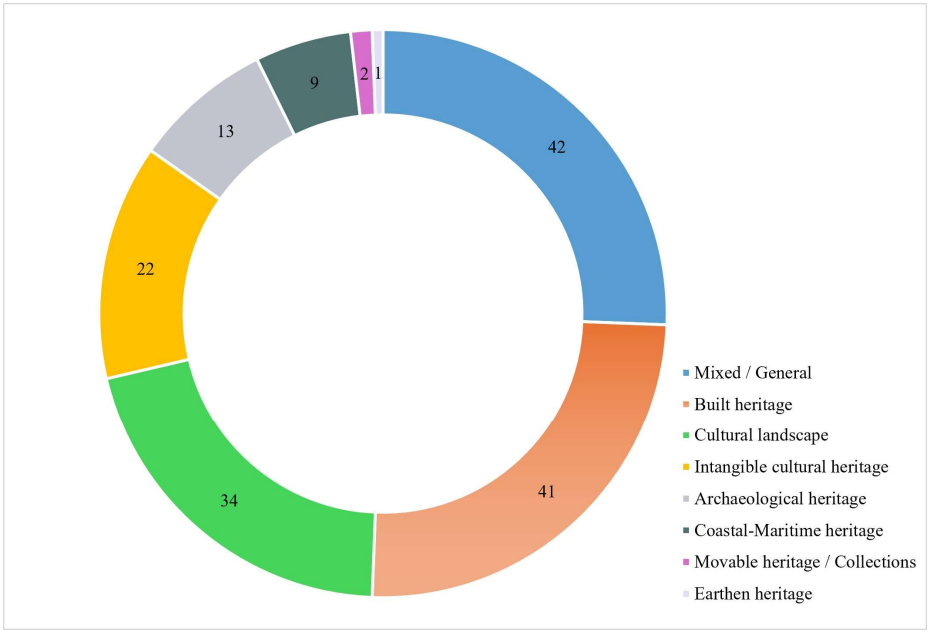


Figure 4. Distribution of studies by cultural heritage type (n = 164). Source: authors.

3.5. Climate Hazards

Hazards were coded non-exclusively according to the climate stressor each adaptation study addressed (Figure 5). Nearly half of the studies (74; 45.1%) addressed climate change without specifying a dominant hazard, framing adaptation in general terms. Among studies that identified a specific stressor, sea-level rise was the most frequent (30; 18.3%), followed by flooding (26; 15.9%), temperature/heat (23; 14.0%), drought/aridity (19; 11.6%), wind

(15; 9.1%), precipitation/rain (13; 7.9%), storms/cyclones (10; 6.1%), humidity/moisture (8; 4.9%), salinity/seawater intrusion (6; 3.7%), cryospheric/permafrost hazards (5; 3.0%), and wildfire (2; 1.2%).

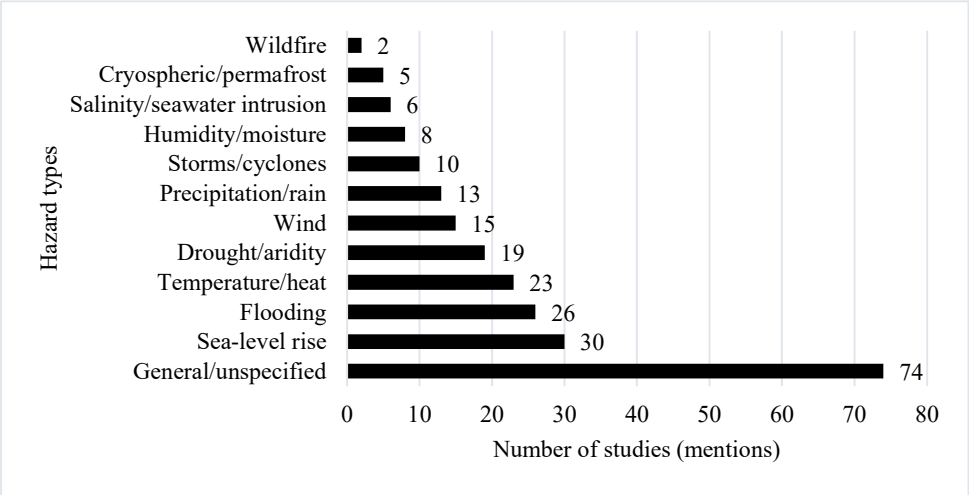


Figure 5. Distribution of studies by climate hazard addressed (n = 164). Coding was non-exclusive; studies addressing climate change without a specified dominant stressor were classified as general/unspecified. Source: authors' own work.

3.6. Adaptation-Action Categories

Action coding was non-exclusive, so percentages sum to more than 100%. Institutional actions appeared in 118 studies (72.0%), behavioural in 69 (42.1%), technological in 47 (28.7%), structural/physical in 22 (13.4%), informational in 21 (12.8%), ecosystem-based in nine (5.5%), and economic in six (3.7%; Figure 6). These values describe representation in the literature, not implementation or effectiveness in practice. Behavioural actions, encompassing community engagement, stewardship, and Indigenous and local knowledge, were the second most frequent category.

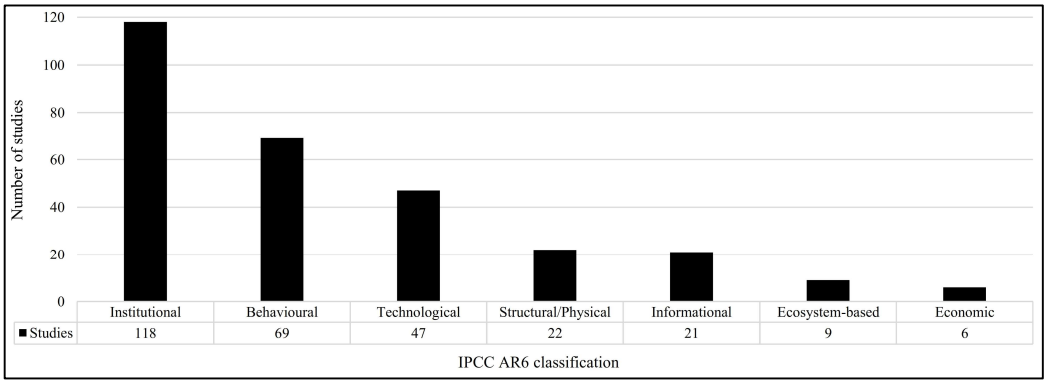


Figure 6. Classification of adaptation actions in cultural heritage studies according to the IPCC AR6-informed adaptation action typology (n = 164). Coding was non-exclusive; a single study could be assigned to multiple action types. Source: authors' own work.

3.7. Cross-Dimensional Patterns

Cross-tabulation of the coded variables identified distinct co-occurrence patterns between heritage types, climate hazards, and adaptation actions. Coastal-maritime heritage was most frequently linked to sea-level rise (seven of nine studies) and cultural landscapes with drought/aridity (eight studies). The two movable heritage/collections studies were

associated only with temperature/heat and humidity/moisture. Built and mixed/general heritage contained the largest numbers of studies addressing climate change without specifying a dominant hazard (21 and 26, respectively; Figure 7). Hazard focus varied by region (Table S5). Sea-level rise was prominent in North American (11 of 18) and Oceanian (six of 12) studies, drought/aridity in African studies (five of 11), temperature/heat and drought/aridity in Asian studies, and flooding and temperature/heat in European studies. Most global or multi-regional studies (26 of 35) did not specify a dominant hazard. These patterns describe the reviewed literature and may reflect regional research concentrations as well as climate exposure.

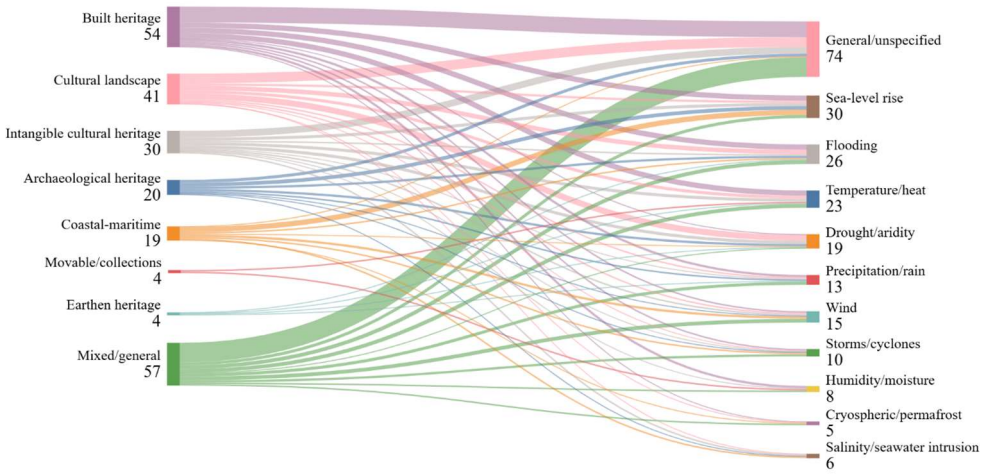


Figure 7. Sankey diagram linking cultural heritage type (left) to climate hazard (right) across the 164 reviewed studies. Each study has one primary heritage type but may address multiple hazards (non-exclusive coding); flows are co-occurrence counts, and their totals exceed 164; zero-value links are omitted. Source: authors' own work.

Adaptation profiles also differed by heritage type (Figure 8). Behavioural actions outnumbered institutional actions for only one heritage type, intangible cultural heritage. Technological actions were addressed by 19 of 41 built-heritage studies (46.3%), compared with 28 of 123 studies in all other heritage types (22.8%). Structural/physical actions were addressed by 10 of 41 built-heritage studies (24.4%), compared with 12 of 123 studies in the remaining heritage types (9.8%). Behavioural actions were less frequent in built heritage (eight of 41; 19.5%) than in the other heritage types combined (61 of 123; 49.6%), while institutional actions occurred at similar proportions (73.2% and 71.5%). Coastal-maritime heritage had the highest structural/physical proportion (three of nine studies; 33.3%), although the small sample limits interpretation. Cultural landscapes had the highest frequencies of ecosystem-based (six studies) and economic (four studies) actions, while the single earthen-heritage study was coded only as institutional. Including this study within built heritage changed the built-heritage proportions only slightly, to 45.2% for technological and 23.8% for structural/physical actions.

Institutional actions were the predominant category for most hazards. Among the specific hazards, sea-level rise was associated with the greatest number of institutional (20), behavioural (16), and technological (12) actions. Temperature/heat was associated with the highest number of informational actions (five studies) among the specific hazards. Behavioural actions outnumbered institutional actions for drought/aridity (14 versus 12 studies), storms/cyclones (six versus five), and salinity and seawater intrusion (four versus three). Ecosystem-based approaches were most frequently associated with flooding (four studies), while economic actions remained infrequent across all hazard categories (Figure 9).

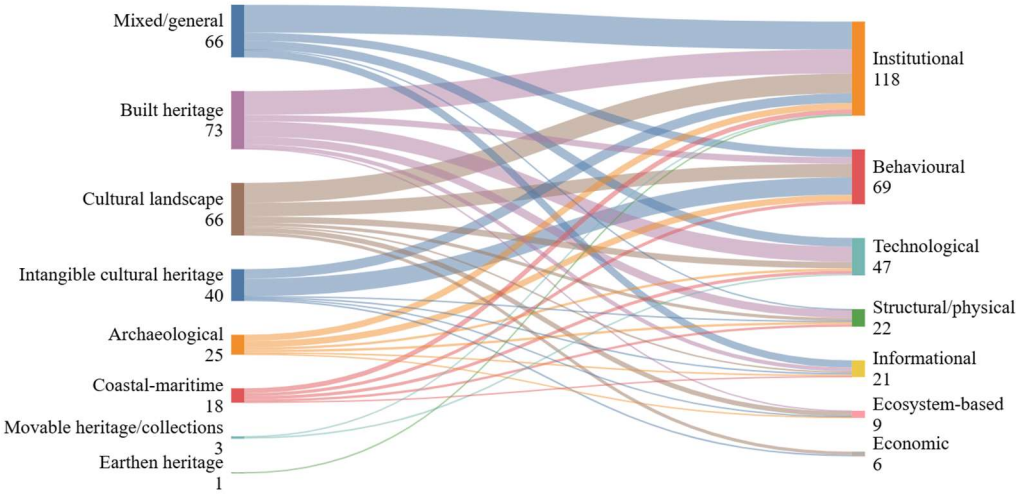


Figure 8. Sankey diagram linking cultural heritage type (left) to AR6-informed adaptation-action category (right). Each study had one primary heritage type but could span multiple actions (non-exclusive coding); flows are co-occurrence counts, and their totals exceed 164. Zero-value links are omitted. Source: authors' own work.

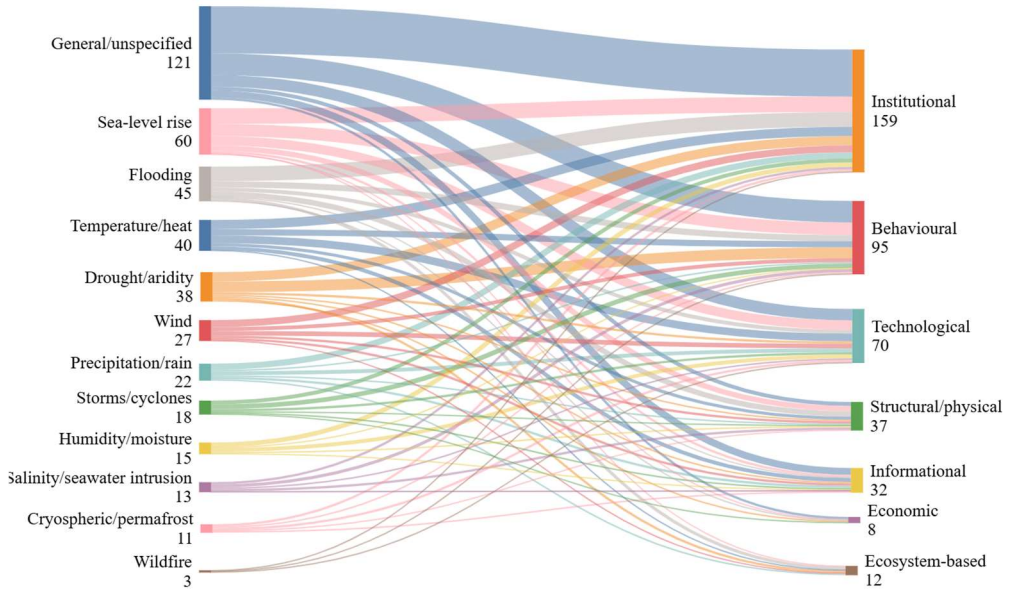


Figure 9. Sankey diagram linking climate hazards (left) to AR6-informed adaptation-action category (right). Both hazard and action coding were non-exclusive; a single study may span multiple hazards and multiple action types. Flows are co-occurrence counts, and their totals exceed 164. Zero-value links are omitted. Source: authors' own work.

3.8. Implementation Stage

Of the 164 studies, 108 (65.9%) proposed adaptation actions, 54 (32.9%) reported actions implemented in practice, and only two (1.2%) evaluated the outcomes of implemented actions. Among action categories represented by at least 20 studies, behavioural (32 of 69) and informational (10 of 21) actions most often reached implementation or evaluation, compared with structural/physical (seven of 22), institutional (38 of 118), and technological (14 of 47) actions. Ecosystem-based (five of nine) and economic (four of six) actions were represented by too few studies for robust comparison. By heritage type, implemented or evaluated studies comprised a larger proportion of the evidence base for cultural landscapes (17 of 34) and intangible cultural heritage (10 of 22) than for built heritage (12 of 41), mixed/general heritage (11 of 42), and archaeological heritage (three of 13). Only

two studies evaluated implemented actions. Aleman et al. [24] assessed long-term morphological change following the maritime restoration of Mont-Saint-Michel Bay using a 22-year LiDAR record, and Vargas et al. [25] assessed the costs and benefits of maintaining and operating the ancestral acequias de careo system in Sierra Nevada, Spain. Both measured environmental or economic outcomes; neither assessed effects on heritage values directly. The implementation stage by category and heritage type is given in Table S6, and the stage of each study is given in Table S2.

4. Discussion

Using an AR6-informed action lens, this review identifies four main features of the evidence base: (i) institutional responses dominate the literature but remain largely at the proposal stage; (ii) built heritage shows a distinct concentration of technological and structural/physical responses; (iii) research remains geographically and thematically concentrated; and (iv) community and Indigenous knowledge is recognised but remains weakly integrated into adaptation governance.

4.1. Institutional Emphasis and Limited Outcome Evaluation

Institutional actions appeared in 72.0% of studies, revealing that governance, planning, and management frameworks are central to the field. This is consistent with the importance of adaptive management [1,26] and with national evidence of both weak preparedness [27,28] and more systematic integration, as in Ireland [29,30]. Implementation-stage coding shows that this emphasis reflects research attention more than practice. Of the 118 studies addressing institutional actions, 80 (67.8%) remained at the proposal stage, and only one reported evidence on outcomes. Across the whole corpus, only two of 164 studies (1.2%) [24,25] evaluated the effects of an implemented action. Governance, planning, and management responses are therefore widely proposed and increasingly adopted, while evidence on whether they reduce climate risk to heritage is almost absent. This finding is consistent with studies and reviews that report limited long-term evaluation, weak monitoring and evaluation, cross-sectoral fragmentation, and few tested practical solutions [3,20,31,32]. This matters because adaptation can be ineffective or maladaptive when underlying vulnerability, values, and distributional consequences are not addressed [1,33]. In this corpus, technological, structural/physical, ecosystem-based, and economic actions were less frequently represented than institutional and behavioural actions. That pattern identifies evidence gaps, not necessarily lower implementation rates. The particularly small economic category (3.7%) is notable because finance, incentives, and appraisal are recurrent enabling conditions and barriers [34–37]. Future studies should distinguish intention, implementation, monitoring, outcomes, and maladaptation, following broader adaptation-evidence approaches [13].

4.2. Adaptation in Built Heritage

Built heritage accounted for one-quarter of the corpus (41 studies). Technological and structural/physical actions were addressed by 46.3% and 24.4% of these studies, about two and two and a half times their respective proportions in other heritage types. This distinguishes built heritage from domains in which institutional or behavioural responses were more prominent and reflects the established role of material, engineering, monitoring, and building-performance approaches in the conservation of historic structures [3,38]. However, technical interventions must be tailored to specific climate hazards, materials, and construction systems. Climate impacts on historic buildings arise through interacting processes involving temperature, moisture, precipitation, flooding, and other environmental

loads [39,40], while the effectiveness of interventions depends on building characteristics, material compatibility, maintenance regimes, and local conditions [3,31,40].

Retrofit is a clear example. Hao et al. [40] showed that interventions aimed at improving energy performance may modify thermal mass, moisture transport, and overheating risk, potentially creating new conservation problems if future climate conditions are not considered. Similarly, hygrothermal modelling demonstrates that projected deterioration risks can vary substantially with climate scenario and building characteristics, supporting the use of building-specific modelling and long-term monitoring [41]. The implementation-stage results make this gap explicit: 29 of the 41 built-heritage studies remained at the proposal stage, and none reported an evaluation of outcomes. Technological and physical interventions also depend on governance and maintenance. Reviews identify limited field evaluation of adaptation measures [3], while studies from the Netherlands, the UK, and Ireland show that finance, specialist skills, institutional coordination, and integration into heritage-management plans strongly influence implementation [12,27,29,30]. Notably, 21 of the 41 built-heritage studies addressed climate change without identifying a dominant hazard. This broad framing limits the ability to connect specific climatic stressors with material response, building performance, intervention selection, and long-term outcomes.

4.3. Geographic and Heritage-Domain Imbalances

The corpus is concentrated in Europe (37.8%) and North America (11.0%), while Africa and Latin America and the Caribbean together account for only 9.1%; 22 countries were represented by a single study. Polar heritage was similarly marginal, with only 1.2% of studies addressing Arctic or Antarctic contexts. This distribution is consistent with earlier reviews that reported a European or Global North concentration and comparatively limited engagement with intangible cultural heritage [7–10], although recent work has begun to develop methods for characterising heritage values within vulnerability assessment [42]. Because this review did not compare publication locations with a formal vulnerability index or research-funding data, it cannot establish why the imbalance occurs. Plausible explanations include uneven research capacity, funding, database coverage, English-language eligibility, and the concentration of internationally designated heritage.

Whatever the cause, sparse evidence from many highly exposed and resource-constrained contexts limits transferability and may obscure locally specific practices, values, and adaptation limits [43,44]. These gaps have implications for climate justice because communities with limited research and adaptation finance may also face high exposure and irreplaceable losses, as shown by community-based vulnerability work in sub-Saharan Africa [45]. Underrepresentation also extends to heritage domains: earthen heritage ($n = 1$), movable heritage/collections ($n = 2$), coastal-maritime heritage ($n = 9$), and intangible cultural heritage ($n = 22$) received far less attention than mixed/general, built, and landscape heritage, despite evidence that earthen heritage in particular faces distinct and escalating climate risks. The contrast between 41 built-heritage studies and only one study classified specifically as earthen heritage is particularly relevant to building conservation because earthen construction presents distinct moisture, erosion, and maintenance challenges under changing climatic conditions [46]. Locally led research, multilingual searching, and equitable partnerships are needed to improve relevance without extracting knowledge from communities.

4.4. Indigenous and Local Knowledge

Behavioural actions were identified in 42.1% of studies and were more frequent than institutional actions only for intangible cultural heritage. This supports the importance of community practice, stewardship, and traditional knowledge in place-based adaptation, as

recognised by Article 7.5 of the Paris Agreement and demonstrated in Australia and the Solomon Islands [15,47,48]. Recognition does not guarantee equitable governance. Indigenous and local knowledge can be treated as supplementary data rather than as knowledge systems with authority over problem framing, values, consent, and decisions [49,50]. The reviewed literature points to top-down governance, limited institutional support, and weak mechanisms for meaningful participation [51–53].

Studies should report on who defines adaptation goals, how consent and benefit-sharing are handled, and whether communities retain control over data and heritage knowledge. Traditional water management, construction and maintenance practices, and other living-heritage systems can contribute to adaptation, but transferring them without attention to context may be ineffective or extractive [54–56]. For historic buildings, such knowledge can complement technological and structural responses by informing material selection, passive environmental control, maintenance, and locally adapted construction practices. The Belém indicators create a policy opening by including tangible and intangible cultural heritage, community participation, and Indigenous, traditional, and local knowledge; their value will depend on precise definitions, disaggregated baselines, and locally meaningful monitoring [17,19].

4.5. Evidence Relevant to the Belém Heritage Indicators

Table S7 relates the corpus to the five indicators adopted under Target 9(g). The review was not designed around these indicators. Its eligibility criteria excluded studies focused on impact, risk, or vulnerability assessment without a substantive adaptation component, although risk assessment is relevant to the Global Goal on Adaptation framework [16]. The indicators are intended to track adaptation progress rather than serve as evaluation criteria [17]. Accordingly, this analysis identifies adaptation-focused research relevant to each indicator and should not be interpreted as a measure of implementation or indicator achievement. Within these limits, coverage was uneven. Research relevant to 9(g)(a) and 9(g)(e) centred on traditional and Indigenous practices maintained by communities, while research relevant to 9(g)(c) mainly concerned adaptation and management plans already in place. Evidence for 9(g)(b) and 9(g)(d) was scarce. Only one study evaluated the outcomes of a measure relevant to any indicator [25]. The literature therefore provides limited evidence on whether actions relevant to these indicators effectively reduce climate risk to heritage.

4.6. Research Agenda

Four priorities emerge from the review. First, adaptation research should move beyond identifying or proposing actions towards testing their implementation and outcomes. This is particularly important for built heritage, for which technological and structural/physical responses are comparatively well represented, but evidence of long-term performance under changing climatic conditions remains limited [3,31]. Studies should connect climate hazards with building-specific deterioration mechanisms and evaluate the effectiveness, durability, compatibility, and maintenance requirements of adaptation interventions. Second, economic mechanisms require greater attention. Economic actions represented only 3.7% of the corpus despite the importance of adaptation finance, incentives, appraisal, and cost-benefit considerations in determining whether interventions can be implemented and maintained [35–37]. Third, the geographic and heritage-domain evidence base should be broadened through locally led research in underrepresented regions and on poorly represented heritage types, particularly earthen and movable heritage. Such research would improve the transferability of adaptation evidence across different climates, building traditions, materials, and institutional contexts [43,44]. Fourth, stronger integration is

needed between physical and technological adaptation, institutional processes, and community knowledge. Differences in concepts and methods across climate science, building science, heritage conservation, archaeology, and policy constrain the development of transferable evidence [31]. For built heritage, combining climate information, building and material performance, conservation requirements, maintenance, economic feasibility, and local knowledge offers a more complete basis for adaptation than any of these dimensions considered independently.

4.7. Limitations

The search was limited to the WoS Core Collection and English-language records, which may have excluded relevant studies indexed only in Scopus or regional databases or published in other languages. Regional differences should consequently be interpreted as patterns within the retrieved evidence base rather than as direct measures of research activity across regions. Coding traditional, local, and Indigenous knowledge primarily as a behavioural action simplifies its cross-cutting character and may understate its informational dimension within the corpus. No formal quality appraisal or risk-of-bias assessment was undertaken, as the review focused on mapping the distribution and characteristics of the evidence rather than evaluating intervention effectiveness. Implementation stage reflects what each study reports and may therefore understate adaptation that has been carried out but not published. Assigning a single primary heritage type also simplifies studies spanning multiple heritage domains. Only one study was classified separately as earthen heritage, and no other included study focused on earthen architectural heritage. Including this study within built heritage did not materially alter the built-heritage adaptation profile. Comparisons between heritage types should therefore be interpreted as patterns in the coded literature rather than as mutually independent characteristics of heritage assets. Finally, 2026 represents a partial publication year, including only records indexed up to the search date.

5. Conclusions

This review synthesised 164 peer-reviewed studies published between 2008 and 2026 using a seven-category, AR6-informed adaptation-action typology. Research on climate change adaptation in cultural heritage has expanded rapidly but remains geographically and thematically uneven. The evidence base is concentrated in Europe and North America, while Africa, Latin America, Asia, and Oceania were less represented in the reviewed literature. This pattern may partly reflect the database and English-language eligibility criteria rather than the overall volume of research conducted in these regions. Heritage domains such as earthen and movable heritage/collections were also poorly represented. Institutional and behavioural actions dominate the literature, whereas structural/physical, ecosystem-based, and particularly economic actions receive comparatively limited attention. Most of this evidence remains at the proposal stage: two-thirds of the studies only proposed actions, and just two of 164 evaluated their outcomes. Built heritage is one of the most represented heritage domains and shows a comparatively strong technological and structural/physical adaptation profile, highlighting the role of building- and material-focused interventions within heritage adaptation. However, stronger evidence is needed for their implementation, long-term performance, and effectiveness under changing climatic conditions. Community participation and Indigenous and local knowledge are increasingly recognised, but their integration into adaptation governance remains limited. Future research should therefore connect climate hazards more directly with building and material performance, evaluate adaptation outcomes, broaden the geographical and heritage-domain evidence base, and integrate physical interventions with governance, finance, and local knowledge. Research

relevant to the Belém cultural heritage indicators concentrates on traditional practices, community-led adaptation, and adaptation planning, while digitisation, movable heritage, and regular adaptation training receive limited attention. A single study assessed the outcomes of an implemented measure that is pertinent to any indicator, underscoring the need of future evaluation of case studies to enhance a more comprehensive indicator reporting system.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/buildings16214401/s1, Table S1: WoS Core Collection search strings and record counts; Table S2: Included studies ($n = 164$) and their coding; Table S3: Implementation-stage decision rules; Table S4: Heritage types, climate hazards, adaptation actions, and implementation stage by publication period; Table S5: Climate hazards by region; Table S6: Implementation stage by adaptation-action category and heritage type; Table S7: Belém Target 9(g) cultural heritage indicators and supporting evidence; Table S8: PRISMA 2020 checklist [22]. Table S2 lists all 164 included studies [3,8,9,12,21,24,25,27,30–32,36–38,44,46–48,51,56–200].

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Data Availability Statement: The study-level dataset (Table S2) and coding rules (Table S3) are provided in the Supplementary Materials. Further data are available from the corresponding author upon reasonable request.

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Abbreviations

The following abbreviations are used in this manuscript:

IPCC	Intergovernmental Panel on Climate Change
AR6	Sixth Assessment Report (of the IPCC)
CMA	Conference of the Parties serving as the meeting of the Parties to the Paris Agreement
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
WoS	Web of Science

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