CULTURAL HERITAGE AND THE CLIMATE CRISIS: A LITERATURE REVIEW

PATRIMÔNIO CULTURAL E CRISE CLIMÁTICA: REVISÃO DA LITERATURA

PATRIMONIO CULTURAL Y CRISIS CLIMÁTICA: REVISIÓN DE LA LITERATURA

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ABSTRACT
Extreme weather events have been increasing over time. In this way, climate change represents obstacles to society, imposing challenges on cities. Among them is the preservation of their cultural and natural heritage. Urban complexes with a preservation interest face greater vulnerability due to natural, cultural and social factors. In this context, the aim of this article is to present the state of the art on research into the impacts of climatic events on sites of preservation interest. The methodological procedures comprised four stages: defining the topic and research question; searching academic databases; establishing inclusion and exclusion criteria; and analyzing the materials. The research found shows a consensus on the need to pay attention to the impacts of climate change on cultural and natural heritage. As limitations, most of the research with case studies focuses on the Global North. In terms of gaps, the research highlights the need for an integrative approach to the preservation of cultural heritage in the face of the impacts of climate change.

KEYWORDS
climate change; cultural heritage; sustainability.

RESUMO
Os eventos climáticos extremos vêm aumentando com o passar do tempo. Dessa forma, as mudanças climáticas representam obstáculos à sociedade, impondo inúmeros diversos desafios às cidades. Dentre eles, está a preservação de seu patrimônio cultural e natural. Os conjuntos urbanos com interesse de preservação enfrentam maior vulnerabilidade, devido a fatores naturais, culturais e sociais. Nesse contexto, este artigo possui como objetivo apresentar o estado da arte sobre as pesquisas dos impactos dos eventos climáticos nos sítios com interesse de preservação. Os procedimentos metodológicos compreenderam quatro etapas: delimitação do tema e pergunta de pesquisa; busca em bases de dados acadêmicas; estabelecimento de critérios de inclusão e exclusão; e análise dos materiais. As pesquisas encontradas mostram um consenso quanto à necessidade de atenção aos impactos das mudanças climáticas ao patrimônio cultural e natural. Como limitações, a maioria das pesquisas com estudos de caso concentra-se no Norte Global. Sobre as lacunas, as pesquisas evidenciam a necessidade de uma abordagem integrativa na preservação do patrimônio cultural, diante dos impactos das mudanças climáticas.

PALAVRAS-CHAVE
mudanças climáticas; patrimônio cultural; sustentabilidade.

http://dx.doi.org/10.29183/2447-3073.MIX2024.v10.n4.127-142
ISSN: 2447-0899 (IMPRESSA) | 2447-3073 (ONLINE)

RESUMEN

Los eventos climáticos extremos han ido aumentando con el tiempo. De esta manera, el cambio climático representa obstáculos para la sociedad, imponiendo numerosos desafíos a las ciudades. Entre ellos se encuentra la preservación de su patrimonio cultural y natural. Los conjuntos urbanos con interés de preservación enfrentan una mayor vulnerabilidad debido a factores naturales, culturales y sociales. En este contexto, el objetivo de este artículo es presentar el estado del arte sobre las investigaciones de los impactos de los eventos climáticos en los sitios con interés de preservación. Los procedimientos metodológicos comprendieron cuatro etapas: delimitación del tema y la pregunta de investigación; búsqueda en bases de datos académicas; establecimiento de criterios de inclusión y exclusión; y análisis de los materiales. Las investigaciones encontradas muestran un consenso sobre la necesidad de prestar atención a los impactos del cambio climático en el patrimonio cultural y natural. Como limitaciones, la mayoría de las investigaciones con estudios de caso se concentran en el Norte Global. En cuanto a las brechas, las investigaciones evidencian la necesidad de un enfoque integrador en la preservación del patrimonio cultural, ante los impactos del cambio climático.

PALABRAS CLAVE

cambio climático; patrimonio cultural; sostenibilidad.

1. INTRODUCTION

Climate change has become a major challenge for society, imposing obstacles to the preservation of heritage. Among them is the need to guarantee a sustainable environment for future generations, since meeting current needs is already severely compromised. Extreme climatic events have been seriously increasing over time (Roaf; Crichton; Nicol, 2023). These include the rise in global temperatures and the intensification of phenomena such as El Niño and La Niña, with changes in ocean temperatures and a high incidence of cyclones, storms and thunderstorms. This leads to major droughts, floods and torrents that affect cities and cause damage to material and immaterial heritage. Forests go up in flames, causing changes to biomes, while rivers dry up, causing climate inversions.

The IPCC Climate Change Report (2023) indicates that human activities are the main drivers of global warming. In urban areas, this phenomenon causes adverse effects on human health, livelihoods, and food security. Furthermore, these changes impact cities and their inhabitants due to factors such as rising average temperatures, reduced daily temperature ranges, and an increased frequency of extreme events (IPCC, 2023; Alvez, 2019; NU, 2022). Consequently, these effects exacerbate inequalities, putting the most vulnerable populations at risk and leading to social problems (Iwama, 2016; Peiter, Maluf, Rosa, 2011).

According to the UN (2022), IPCC data show that the current period is critical, as pollutant emissions were the highest in history between 2010-2019. This scenario indicates the need to anticipate measures to mitigate the adverse effects of climate events. As pointed out by the IPCC (2020), the development of actions at all scales helps create adaptation strategies to climate effects, seeking development suited to new climate conditions. According to the latest IPCC report (2023), responsive planning actions can ensure full sustainable development for the future of cities.

Within this context, the challenge arises for heritage preservation, composed of assets susceptible to the effects of climate events. Urban areas of preservation interest face greater vulnerability due to the interactions between natural, cultural, and social aspects. The safeguarding of heritage is a growing concern, as extreme climate events and rising average temperatures can accelerate the degradation of protected assets. Urban centers and their surroundings must be protected against the increasingly frequent effects of climate change (ICOMOS, 2011). Furthermore, when addressing this issue, it is essential to consider not only the physical impact but also the social and cultural implications of interventions (Iwama, 2016; Peiter, Maluf, Rosa, 2011; IPCC, 2020).

Focusing on the urban context, it is known that cities are the main consumers of energy and agents in greenhouse gas emissions (UN, 2022). Consequently, urban areas are sources of anthropogenic climate change due to the concentration of inhabitants, buildings, and infrastructure that, if not addressed responsively, can generate environmental and climatic impacts. Therefore, planning focused on climate change in urban areas must consider the interaction between mitigation and adaptation actions (Grafakos et al., 2020).

Based on these aspects, the general objective of this work is to present a literature review on studies of the impacts of climate events on sites of preservation interest. Additionally, it aims to discuss the main research results, understanding the main knowledge gaps related to the impacts of climate change on cultural heritage.

2. THEORETICAL REFERENCE

When addressing the issue of climate change and its impacts on areas of preservation interest, some concepts and theoretical bases are important. Therefore, the following topics will deal with the main references on climate change, cultural heritage and the impacts of climate change on cultural heritage.

2.1 Climate change

Climate change refers to significant and long-lasting alterations in global and regional climate patterns, primarily driven by human activities such as the burning of fossil fuels and deforestation. Concern about climate change began to gain prominence in the 1980s. At that time, research indicated a decrease in ozone concentration, caused by increased greenhouse gas emissions (Brazil, 2024).

Subsequently, numerous reports started to warn about the problems arising from climate change. This includes the IPCC Report (Intergovernmental Panel on Climate Change), first published in the 1990s. Later, important international agreements, such as the United Nations Framework Convention on Climate Change (1992) and the Kyoto Protocol (1997), solidified global

recognition of the need to mitigate the effects of climate change. Despite this, the implementation of effective policies faces significant challenges.

The latest IPCC reports provide a comprehensive and alarming overview of climate change and its impacts. The most recent data, from the AR6 report (IPCC, 2022), highlight the accelerated increase in global average temperatures, the intensification of extreme climate events such as heat waves, storms, and heavy rainfall, and the rise in sea levels. According to the report, "human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020)" (IPCC, 2022, p.42).

Furthermore, the report states that "Cultural losses, related to tangible and intangible heritage, threaten adaptive capacity and may result in irrevocable losses of sense of belonging, valued cultural practices, identity and home (...)" (IPCC, 2022, p. 51). This highlights the need for adaptation and mitigation actions to prevent losses related to cultural and natural heritage.

The 2030 Agenda for Sustainable Development, established by the UN, created global actions aimed at improving living conditions in the present and for future generations. The action plan, composed of the Sustainable Development Goals (SDGs), sets targets in 17 areas (NU, 2015). Regarding climate change, several goals are relevant, with SDG 11 (Sustainable Cities and Communities) standing out, which includes target 11.4: "strengthen efforts to protect and safeguard the world's cultural and natural heritage" (NU, 2015a); as well as SDG 13 (Climate Action), emphasizing the importance of the issue on the contemporary global agenda (NU, 2015b, 2015c, 2015d).

Therefore, the urgent need to mitigate the effects of climate change and adapt to these new conditions is emphasized, as a way to ensure the resilience of communities and the sustainability of natural resources for future generations. There is an urgent call for decisive actions to mitigate the effects of climate change and adapt infrastructures and public policies to face future challenges, generating a coordinated global response to limit global warming and reduce adverse impacts.

2.2 Effects of climate change on urban areas and the built environment

Climate change causes profound changes in urban structures and the built environment. Furthermore, it can cause or exacerbate economic and social problems (IPCC, 2022). Large-scale disasters and humanitarian emergencies resulting from climate change have become increasingly frequent and severe, triggering a series of crises that deeply affect communities around the world (Weissbecker and Czincz, 2011).

Extreme events, in addition to causing damage to cities and buildings, also lead to forced population displacements, food and water shortages, and public health crises. Humanitarian emergencies require a rapid and coordinated response that includes humanitarian assistance, recovery, and effective adaptation strategies to reduce the impact of future disasters and strengthen the resilience of affected populations.

Among the main impacts of climate change on cities are extreme weather events such as floods, heat waves, droughts, and storms. Rising average temperatures and sea levels increase the risk of flooding in coastal areas, while uncontrolled urbanization worsens the heat island effect, affecting the health and well-being of populations (IPCC, 2022; NU, 2022).

In response to the damage caused by climate change, actions are divided between adaptive and mitigation measures. Mitigation measures "aim to directly address the root cause (the cause) of global warming" (Barbieri and Viana, 2013, p.60). Thus, they are difficult to implement because they require large-scale actions, such as the Kyoto Protocol. In the case of adaptive measures, they seek to mitigate the impacts, generating a quicker and more noticeable response (Barbieri and Viana, 2013).

Given the above, the phenomena caused by climate change require an urgent adaptation of urban infrastructures, planning policies, and mitigation strategies to face the challenges of climate change, while directly affecting economic development, the environment, and the quality of life in urban centers.

2.3 Challenges of preserving cultural heritage in the context of the climate crisis

According to IPHAN (2014), "cultural heritage consists of monuments, groups of buildings, and archaeological sites of fundamental importance for the memory, identity, and creativity of peoples and the richness of cultures." It includes monuments, historical buildings, archaeological sites, traditions, knowledge, practices, languages, and artistic expressions that are passed down through generations. The preservation of cultural

heritage is essential to ensure the continuity of identity and collective memory, as well as to promote respect for cultural diversity.

With climate change, sites of cultural interest face increasing threats. The World Heritage Committee (UNESCO, 2006) points out that climate changes can cause physical, social, and cultural damage to heritage. Thus, both isolated buildings and complexes, environmentally significant areas, and cultural practices are at risk. Additionally, social impacts may occur, which must be considered in analyses and proposals.

According to Colette (2007), heritage and climate are interconnected, and the stability of heritage depends on interactions with the environment. Among the consequences of climate change on heritage are physical damages, such as losses due to erosion, humidity, flooding, and salt weathering. Moreover, social and cultural problems can arise from the perspective that heritage is dynamic and encompasses all relationships within a given community. Additionally, climate change may force migrations, dissolving communities, practices, and memories.

According to the Valletta Principles (ICOMOS, 2011), historic areas are subject to continuous changes that impact all elements that constitute these sites, including natural, human, tangible, and intangible aspects. In general, buildings are more vulnerable, subject to physical and structural changes due to weathering. Therefore, climate issues exacerbate the problem, potentially accelerating degradation through phenomena such as porosity, thermal stress, and corrosion (Pereira; Paes; Pasini, 2023; Ziebell et al., 2023).

Given the above, it becomes essential to understand the potential impacts of climate change on cultural and natural heritage. Adaptation and mitigation strategies must be developed to preserve the environment, culture, and memory of these sites.

3. METHODS

The work sought to establish the state of the art, with the following stages:

Stage 01 - Delimiting the topic and research question: the initial search involves the terms Cultural Heritage and Climate Change. Based on this, the research seeks to answer the following question: what are the main studies dealing with the impacts of climate change on areas with cultural value?

Stage 02 - Search in academic databases: search in various databases: Scielo, Scopus, Periódicos Capes; Catalog of Theses and Dissertations and the Brazilian Digital Library of Theses and Dissertations (BDTD). The strings entered into the platforms were: "climatic changes" OR "climate variations" AND "cultural heritage sites" OR "cultural heritage preservation"; e “patrimônio cultural” AND “mudanças climáticas”.

Stage 03 - Establishment of inclusion or exclusion criteria for the materials found: systematic reviews and empirical studies were considered for analysis. The study site was not delimited. The period of publication considered included the last 10 years (2013 to 2023). Scientific articles published in journals and at scientific events were searched for and evaluated on the Scielo, Scopus and Portal de Periódicos da Capes databases.

As the strings used are wide-ranging, it was necessary to filter the articles found. Initially, the titles were considered for a first filtering. Studies dealing with, for example, biological and agricultural sciences were removed, as were studies that did not correspond to the area of cultural heritage studies. After filtering, 71 articles remained. The abstracts were read in depth to select the articles included in the review, resulting in 4 systematic reviews and 4 empirical studies. In addition, searches with the same strings were carried out on Google Scholar, adding 5 articles to the analysis.

Stage 04 - Analysis of the materials: based on the research and scientific papers found, we identified the research that addresses the effects of climate events and the strategies for mitigating the effects in areas with cultural heritage. In addition, the gaps in knowledge in the area were assessed.

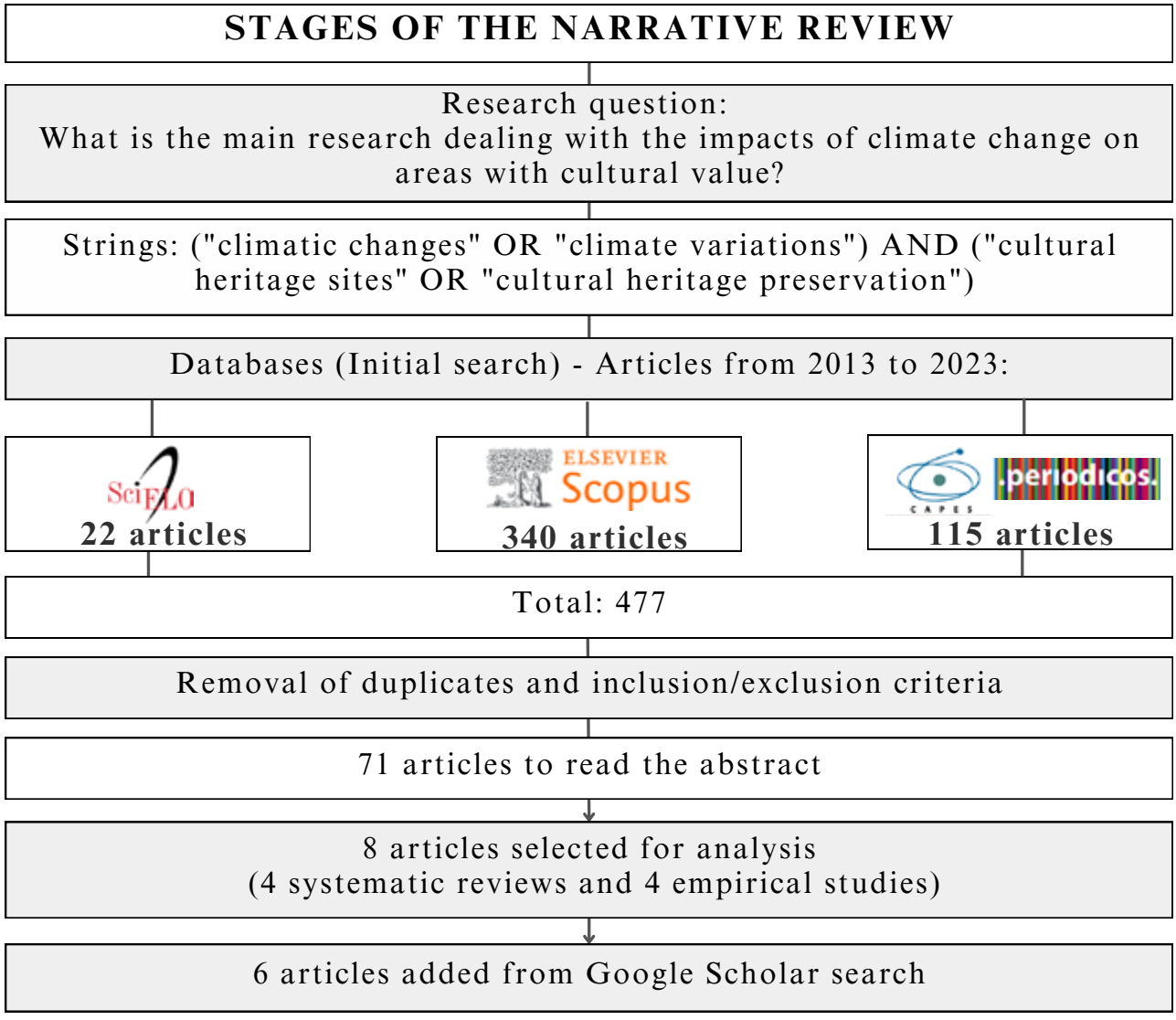

Figure 01 - Summary of the stages of the review.
Source: prepared by the authors.

4. LITERATURE REVIEW

In the current literature, several studies deal with issues of adapting heritage to climate conditions. Among them, four systematic reviews were found, published between 2021 and 2023. The reviews and objectives are shown in the table below.

Title: Climate change impacts on cultural heritage: A literature review	
Authors	**Objectives**
Sesana, et al. (2021)	This review synthesizes the international literature on climate change impacts on tangible cultural heritage by developing hazard-impact diagrams focusing on the impacts of gradual changes in climate on: (1) the cultural heritage exposed to the outside environment, (2) the interiors of historical buildings and their collections, and (3) a third diagram associated with climate change and the impacts due to sudden changes in the natural physical environment. **Keywords:** climate change; impacts; natural hazards; risks; tangible cultural heritage
Title: Climate Change and Cultural Heritage: A Systematic Literature Review (2016–2020)	
Authors	**Objectives**
Orr; Richards; and Fatorić. (2021)	This systematic review reflects on the state of the art by evaluating 165 publications (2016–2020) about cultural heritage and climate change. To capture relevant literature, the authors used five sets of English keywords, using the asterisk wildcard to include permutations of each phrase: i) 'cultural resourc*' AND 'climat* chang*,' ii) 'cultural heritag*' AND 'climat* chang*,' iii) 'historic* heritag*' AND 'climat* chang*,' iv) 'heritag* site*' AND 'climat* chang*,' and v) 'historic* environment*' AND 'climat* chang*.' **Keywords:** cultural resources; historic environment; cultural landscape; heritages sites; climatic change; research meta-characteristics
Title: Do we know how urban heritage is being endangered by climate change? A systematic and critical review	
Authors	**Objectives**
Quesada-Ganuza, et al. (2021)	The main objective of the article is to conduct a systematic review and meta-analysis of risk assessment methodologies for cultural heritage in historic urban areas in the context of climate change, aiming to bring these methodologies closer to urban planners. The research aims to contribute to more efficient climate adaptation policies, highlighting the knowledge gap in methodologies focused on other climate risks beyond flooding, such as heat and cold waves, and proposing a more holistic approach to cultural heritage preservation. Keywords: Historic urban areas; Extreme events; Risk assessment; Vulnerability assessment; Exposure.
Title: Climate Change and UNESCO World Heritage-Listed Cultural Properties: A Systematic Review (2008–2021)	
Authors	**Objectives**
Nguyen and Baker (2023)	The article aims to systematically review 58 peer-reviewed publications from 2008–2021 that examine the relationship between climate change and UNESCO World Heritage-listed cultural properties. It highlights key trends, such as the increase in research since 2008, the regional focus on Europe and North America, and the predominance of studies on natural over cultural sites. The study also identifies critical gaps, including the need for greater representation from the Global South, better interdisciplinary collaboration between STEM and HASS fields, and the importance of considering both tangible and intangible elements in the safeguarding of cultural heritage sites. Keywords: climate change; cultural sites; hazards; UNESCO; World Heritage Properties

Table 01 - Summary of systematic reviews

Source: Authors, 2024.

As for the empirical and theoretical works, four articles were analyzed, published between 2017 and 2023. The papers and objectives are shown in the table below.

Title: Smart Cities and Cultural: Heritage Protecting historicalurban environments from climate change	
Authors	**Objectives**
Marsella and Marzoli (2017)	The paper illustrate the approach of the STORM project that mitigate the impact of climate changes on cultural heritages and the mutual benefits which could derive from an integration of the STORM outcomes with smart cities systems through the use of standard emergency data exchange protocols and an integrated framework aimed at improving existing processes related to the three identified areas: Prevention, Response and Policy. **Keywords:** smart cities, cultural heritage, climate change,safety, interoperability
Title: Climate change challenges to existing cultural heritage policy	
Authors	**Objectives**
Dastgerdi; Sargolini; and Pierantoni (2019)	This study aims to debate the cultural heritage concept as the primary and neglected factor for wise development of climate-resilience policies. It adopted the qualitative meta-synthesis method to analyze the impacts of climate change on world heritage sites, through a systematic review of reports published by the UNESCO. **Keywords:** cultural heritage; climate change; conservation; climate resilience; protection; sustainability; territorial planning
Title: Optimizing preservation for multiple types of historic structures under climate change	
Authors	**Objectives**
Xiao et al. (2021)	The article aims to address the challenge of adapting cultural resources in coastal parks to climate change, focusing on the limitations of current adaptation planning due to insufficient funding. It introduces the Optimal Preservation (OptiPres) Model as a decision support framework to help managers evaluate trade-offs among different types of historic structures—such as wooden buildings and masonry forts—under various budget constraints. The study emphasizes the need to integrate factors like vulnerability, cultural significance, and costs into adaptation decisions and highlights that periodic funding and adaptive use of buildings can optimize preservation efforts across coastal parks. **Keywords:** Climate change; Adaptation planning; Historic preservation; National park; Decision support tool.
Title: Heritage sites, climate change, and urban science	
Authors	**Objectives**
Smith, Ortman and Lobo (2023)	The article proposes a new research perspective on the relationship between climate change and heritage sites, emphasizing that these sites offer valuable empirical records of past urban responses to environmental shocks. By scientifically analyzing archaeological remains, the study seeks to generate hypotheses on factors that influenced resilience and adaptation success. This knowledge can inform contemporary urban climate adaptation strategies. The article highlights that this approach complements existing efforts focused on climate-related damage to heritage and the role of local communities in preserving these sites, adding a new dimension to climate change and heritage research. **Keywords:** Heritage sites; Archaeology; Urban adaptation; Urban sustainability.

Table 02 - Summary of empirical studies

Source: Authors, 2024.

In addition, searches were carried out using the strings in Google Scholar, and 6 articles were added for analysis.

Title: Are cultural heritage and resources threatened by climate change? A systematic literature review	
Authors	**Objectives**
Fatorić and Seekamp (2017)	The article addresses the gap in understanding the impacts of climate change on cultural heritage and resources across different continents and disciplines. Through a systematic literature review, the study identifies and characterizes the current state of knowledge. Based on the analysis of 124 publications, the article highlights the growing academic interest in the topic, though with a limited geographical focus, predominantly on Europe. The study also emphasizes the need for future research to propose sustainable adaptation options and to document whether, and how, the implementation of cultural heritage preservation measures is effectively taking place. The goal is to guide academic research and influence policy formulation for the preservation and adaptation of cultural heritage on a global scale. **Keywords:** Climate change; Geographical Information System; Cultural Heritage; Climate Change Impact; Systematic Literature Review.
Title: An innovative methodology of assessing the climate change impact on cultural heritage	
Authors	**Objectives**
Rajčić, Skender and Damjanović (2017)	The main objective of the article is to present a methodology developed as part of the FP7 project "Climate for Culture," which aims to assess the impact of climate change on cultural heritage collections housed within historic buildings. The key innovation of this study is the combination of high-resolution future climate projections with building simulation tools to predict indoor climate conditions and identify future risks. **Keywords:** accuracy assessment; biological damage; building simulation; climate change; heating; indoor climate; mechanical damage; painted wood; risk assessment;
Title: Review of Potential Risk Factors of Cultural Heritage Sites and Initial Modelling for Adaptation to Climate Change	
Authors	**Objectives**
Carroll and Aarrevaara (2018)	The paper reviews the climatic and meteorological factors that contribute to the degradation of cultural heritage buildings, structures and sites. It focuses on the Nordic countries, where climate change trends such as shorter winters and increased precipitation are accelerating this process. The paper proposes an initial classification of affected materials and structures, together with a numerical scale to assess the urgency of action. The aim is to provide guidance on how best to allocate resources for the preservation of cultural heritage sites in the context of climate change mitigation and adaptation. **Keywords:** cultural heritage; preventative conservation; climate change; mitigation; adaptation; climate modelling.
Title: Economic and Societal Impacts on Cultural Heritage Sites, Resulting from Natural Effects and Climate Change	
Authors	**Objectives**
Alexandrakis, Manasakis and Kampanis (2019)	The research proposes a new approach to cultural heritage, understanding monuments and landscapes as important in creating a sense of history and place. The paper presents a socioeconomic impact model that links the economic benefits of heritage sites, particularly through tourism, to the natural risks caused by climate change. The study highlights the market and non-market benefits that heritage sites provide to society and suggests that this understanding can guide policy interventions aimed at conserving, promoting and protecting cultural heritage from climate-related risks and natural disasters. **Keywords:** Tourism; Cultural heritage; Climate Change; economy; society; natural hazards
Authors	**Objectives**
García (2019)	The paper examines the risks that climate change poses to tangible and intangible cultural heritage around the world. By reviewing examples of heritage threatened by rising sea levels, storms and droughts, the paper aims to explore potential solutions, such as integrating cultural heritage into disaster risk management and leveraging cultural traditions to improve understanding and communication of climate risks. Finally, the paper seeks to highlight the role of cultural heritage in strengthening resilience and promoting recovery within local communities facing climate-related challenges. **Keywords:** Not applicable.

Title: Managing Cultural Heritage In The Face Of Climate Change	
Authors	**Objectives**
Jigyasu (2019)	The article explores how climate change is creating environmental conditions that increase the vulnerability of cultural heritage to damage and risks. Using case examples, the article demonstrates the need for more research, data collection, and modeling to develop future climate scenarios. Additionally, it emphasizes the importance of translating this knowledge into practical and feasible strategies for managing cultural heritage. **Keywords:** Not applicable.

Table 03 -Summary of papers found on Google Scholar
Source: Authors, 2024.

5. CLIMATE CHANGE IN CULTURAL HERITAGE AREAS

Climate change poses significant challenges to the preservation and management of cultural heritage sites worldwide. As environmental conditions change, areas with cultural heritage face increasing risks from phenomena such as rising sea levels, extreme weather events, and temperature fluctuations. These changes not only threaten the physical integrity of historical buildings, landscapes, and artifacts, but also can interfere with the social and cultural practices associated with these sites. This section explores studies on the impacts of climate change on cultural heritage sites, highlighting the need for integrated approaches that reconcile preservation with new environmental realities.

The first study, by Sesana et al. (2021), provides a systematic review of the impacts of climate change on cultural heritage. After systematic searches and specific inclusion and exclusion criteria, 100 articles were analyzed, published in journals, book chapters, and conferences. The study categorized the research into three key themes: exposed cultural heritage (external environment); building interiors and collections; and the impact of extreme events on the physical and natural environment. Regarding impacts on built heritage, three main categories were identified: changes in temperatures, precipitation, and winds. For the interiors of buildings and collections, the main challenges are mechanical, chemical, and biological degradations. Finally, in the category of events affecting the physical environment, the main climate change-related problems are flooding, sea-level rise and coastal impacts, changes in ocean characteristics (temperature, salinity, and acidity), thawing soils, drought, and extreme heat.

Thus, the authors point out that climate change can increase the exposure of cultural heritage to various stressors. Although research predominantly focuses on the European scenario, articles from studies in North America, Australia, and New Zealand were included. As gaps, the authors note that most research does not consider uncertainties when projecting the real impacts of climate change. They recommend using a set of scenarios that can capture uncertainties and identify actual vulnerabilities to adverse climate events. As final considerations, the authors suggest further research in other regions, seeking tools and practices to manage cultural heritage in the current climatic context.

The second study, by Orr, Richards, and Fatorić (2021), conducted a review from 2016 to 2020 on the impact of climate change on cultural heritage. The study, published in 2021, analyzed a total of 165 publications. The authors note the predominance of studies in the European context and few studies focusing on the relationship between climate change and intangible heritage. Additionally, they mention that the field of study is growing and has a diversity of research and methodologies. Nevertheless, studies remain few compared to publications addressing physical impacts on buildings. The authors warn of the need for research that addresses the complexity of the topic, bringing practical strategies for action in mitigating the effects of climate change on cultural heritage sites.

Next, the work of Quesada-Ganuza et al. (2021) on the threats of climate change to urban heritage was analyzed. The study is a systematic and critical literature review from the Web of Science and Scopus databases. After applying search and inclusion and exclusion criteria, 29 articles from journals and conferences published in English between 2015 and 2020 were analyzed. Most of the studies (22 articles) address issues related to flooding and sea-level rise.

The authors point out that the main gap is the lack of an integrated view of the risks to cultural heritage in urban areas, considering, in addition to physical aspects, the impacts on socio-economic, cultural, and governmental systems. They also emphasize the need

to assess other impacts in urban areas beyond flooding. The cited impacts include drastic temperature changes. Moreover, the authors call for more in-depth studies on the impacts of climate change on urban heritage and its cultural values to achieve resilience and sustainability in the environments where they are located. Additionally, they state that cultural heritage is an essential part of the sense of place and belonging, which are crucial to the sustainability of any community with preservation areas. They highlight the need for practical tools for urban planning agents to develop strategies for protecting urban heritage.

The last review found in the search, by Nguyen and Baker (2023), is a systematic literature review from 2008 to 2021 on climate change in UNESCO-listed cultural heritage sites. The study was published in 2023 and analyzed 58 articles available on Scopus and Google Scholar. The study points out an increase in publications on the topic after 2018, mostly corresponding to case studies, followed by conceptual and review studies. Additionally, there is also a predominance of studies on sites of natural preservation interest and few studies focused on areas with cultural heritage. Furthermore, they note the concentration of studies on the topic in northern countries, with a lack of substantial studies in the global south.

Regarding empirical and theoretical studies, four articles were analyzed. The first empirical study analyzed was conducted by Marsella and Marzoli (2017). The study addresses the interface between smart cities and cultural heritage, dealing with the protection of urban historical areas from the effects of climate change. Thus, the study integrates the monitoring of climate sites of cultural interest with the theme of smart cities, in a case study on the STORM project. The project aimed to create information systems for managing damage to cultural heritage. There are three main focus areas: prevention, intervention, and planning policies. Digital and computational technologies, such as IoT, are used to integrate data collected in smart cities to assess and protect urban cultural heritage.

Then, the work of Dastgerdi, Sargolini, and Pierantoni (2019) on the challenges of climate change to current preservation policies was evaluated. The article, published in 2019, discusses the concept of cultural heritage as a neglected factor in developing climate resilience policies. The study analyzed data from UNESCO reports from 2006 to 2019 on the major impacts of climate change. A total of 46 sites considered World Heritage - both cultural and natural - were identified as having threats from climate change.

The study highlights different types of risks and difficulties in preserving these sites, emphasizing the need to rethink current heritage policies. According to the authors, the uncertainties about the effects of climate change require a new perspective on cultural heritage. Thus, a model of heritage appreciation as a dynamic resource is suggested, considering the specificities of each territory. The proposed model would involve different stakeholders, including planners, researchers, and the community.

Subsequently, Xiao et al. (2021) bring a study on optimizing the preservation of various types of historical structures in the face of climate change. The research conducts a case study on coastal parks and recreation areas in the United States, which face challenges from the adverse effects of climate change. The proposed model aims to develop risk management models for preserving historical structures in coastal areas directly affected by climate change. The proposed model seeks to analyze the feasibility of interventions based on funding for periodic maintenance.

Finally, the work of Smith, Ortman, and Lobo (2023) discusses the relationships between sites of preservation interest, climate change, and urban sciences. The research suggests that heritage archaeological analyses can serve as a source of knowledge for urban climate science. The authors propose the need to decolonize research on climate change and heritage and to create a decolonized urban science that seeks climate resilience in traditional knowledge.

Regarding the studies found using the Google Scholar search tool, one systematic review and five empirical works or case studies were identified. The systematic review conducted by Fatorić and Seekamp (2017) aimed to address the gap regarding the impacts of climate change on cultural heritage. A total of 124 publications were included, limited to English-language publications. The authors point to an increase in publications in the field from 2003 to 2015. Most studies are concentrated in Europe (59%). Only 2% of the studies are located in South America (Chile, Colombia, and Peru).

Moreover, of the analyzed publications, 69% correspond to case studies or conceptual articles. Regarding methods, they were varied, with research involving secondary data (36%) and modeling and simulations (25%) standing out. In terms of publication areas, fields such as Architecture & Built Environment (26%), Climate & Natural Hazards (20%), and Archaeology (14%) dominate. The authors note that there are still knowledge gaps in the field that can be explored. Among the gaps are the importance of community engagement in preserving cultural heritage

and resources. Additionally, the authors point out a gap between legislation and preservation plans and their actual implementation to achieve adaptation for preservation (Fatorić and Seekamp, 2017).

The study by Rajčić, Skender, and Damjanović (2017) addresses a methodology for assessing the impact of climate change on cultural heritage. The methodology was developed during the execution of the FP7 Climate for Culture project, from 2009 to 2014. For its execution, it was based on high-resolution models that have building simulation tools to predict future internal climate, identifying possible risks. More than 100 case studies located in Europe and the Mediterranean region were generated.

The representative case study chosen is a wooden chapel in Croatia. The church, built of wood, has numerous internally painted panels that are susceptible to damage from climate changes. The model was validated for accuracy in the context of preventive conservation. The methodology is used to assess possible risks of biological, mechanical, and chemical damage to heritage objects, especially under conditions of intermittent heating. Thus, it provides support for applying this damage assessment method to buildings with active climate control (Rajčić, Skender, and Damjanović, 2017).

For acquiring temperature and humidity data in the building, three sensors were initially attached: two indoors and one outdoors. Later, only one indoor and one outdoor sensor remained since the indoor sensors always presented the same data. Data were collected from October 14, 2011, to June 18, 2014. In the case of high-resolution climate models, simulations were conducted for the recent past (1960 - 1990), near future (2020 - 2050), and distant future (2070 - 2100), using the past as a control period. The model was tested and validated, and statistical assessments of the simulation quality were subsequently performed. The main results indicate that the model was validated and could be useful for computing future data, assessing potential biological, mechanical, and chemical risks to wooden panels. The authors suggest further research in other locations and with other materials susceptible to different types of damage (Rajčić, Skender, and Damjanović, 2017).

The study by Carroll and Aarrevaara (2018) analyzes the potential risks to cultural heritage considering the context of Nordic countries. In these countries, the trends resulting from climate change are shorter winters and increased annual precipitation. The authors classify materials and structures that may be affected, using a numerical scale of intervention urgency. These measures can assist in decision-making regarding heritage management in this region. As a case study, the authors analyze a set of rural residences in Finland. As considerations, the authors highlight the need for more case studies on the impacts of climate change, as the scenarios are uncertain. They also note that natural deterioration is exacerbated by climate change, necessitating further analysis (Carroll and Aarrevaara, 2018).

The research by Alexandrakis, Manasakis, and Kampanis (2019) examines the economic and social impacts on preservation sites from natural effects and climate change. The work is linked to the European HERACLES Project (HEritage Resilience Against CLimate Events on Site). The cities defined as case studies are Gubbio (Italy) and Heraklion (Greece). For the analysis, categories were defined for classification based on economic theories, resulting in data for analysis. Thus, the risks are analyzed along with the economic aspect to support decision-making for cultural heritage management. Another important factor considered by the study is the social and economic impact of tourism on communities.

The results indicate that areas with cultural heritage offer non-market benefits to society, providing an opportunity for conservation and protection interventions against the impacts of climate change and natural disasters. The authors highlight preventive maintenance as essential in all cases, as well as measures to ensure safety during potential natural events and climate change impacts (Alexandrakis, Manasakis, and Kampanis, 2019).

In her article, García (2019) discusses the impact of climate change on cultural heritage and the need for resilient strategies to protect tangible and intangible cultural assets. The author notes that assessing the impact of climate change on cultural assets faces challenges. In the case of historical environments, they naturally suffer greater damage from climatic instability, such as changes in rainfall and temperature patterns.

Another important point raised by the research is the difference between adaptation and mitigation. The term adaptation is used to describe the process of adjusting to the climate (actual or expected) to reduce damage. Mitigation, on the other hand, refers to any human intervention that has the potential to reduce greenhouse gas emissions. Thus, in the field of cultural heritage, most research refers to adaptation. Additionally, the research field is still emerging and faces challenges. The article also

addresses risk management and resilient recovery in the context of climate change (García, 2019).

Among the possible solutions to the problems highlighted in the article, the author points to the need for integrating cultural heritage into the field of disaster risk management; the importance of culture and traditions, including providing solutions; and communication of risks and necessary actions as a way to strengthen the resilience of local communities (García, 2019).

Finally, Jigyasu (2019) addresses the importance of considering climate change in disaster risk analyses in the context of cultural heritage. The study outlines the main types of risks to cultural heritage, whether tangible or intangible. According to the author, climate change exacerbates disasters by increasing the number and intensity of climate-related events that cause damage to heritage. Additionally, factors such as the unpredictability of most climatic phenomena make heritage management challenging.

Strategies to improve management include adopting preventive conservation techniques, enhanced monitoring systems, and adaptation practices. Furthermore, it is essential to revisit traditional knowledge for effective responses to climate change challenges. The author also points to the need for a shift in approach to heritage conservation and management, promoting pre-disaster actions, mitigation, and adaptation. This includes developing risk scenarios based on predictive models and databases on damage to cultural heritage from climatic disasters (Jigyasu, 2019).

Regarding the location of the studies, when case studies are involved, there is a predominance of works in European countries. For the United States, Xiao et al. (2021) presents the issue of climate change in protecting coastal parks considered natural heritage. Systematic review works were not included in the map. Additionally, the work of Dastgerdi, Sargolini, and Pierantoni (2019) identifies UNESCO-protected sites and their main damages, including natural and cultural heritage. There is greater geographical diversity, including natural parks in locations such as Peru, South Africa, Indonesia, India, and Australia. For cultural heritage, countries such as Peru, Russia, Canada, Mali, Lebanon, and other European countries are cited. Since these are informational data, they were not included on the map.

Regarding the most frequent keywords, "climate change" and "cultural heritage" appear in almost all keyword sets. Other frequently related keywords include "conservation," "adaptation," and "risk assessment," showing a focus on adaptive planning. Among the less frequent words are "smart cities," "mechanical damage," "painted wood," and "building simulation," highlighting more specific and technical aspects of the interactions between climate and cultural heritage.

Overall, the articles show a consensus on the need to address the impacts of climate change on cultural and natural heritage. The review highlights methodological gaps and the need to integrate preventive and adaptive policies in the management of cultural heritage in the face of climate change. The main goal should be adaptation, seeking resilience in the conservation of cultural heritage.

4. FINAL CONSIDERATIONS

With climate change, cultural heritage sites face increasing threats. It is essential to understand the potential impacts and develop mitigation strategies for extreme events to preserve both memory and the environment. Regarding adaptation strategies, in-depth studies on local climate patterns are necessary. Consequently, tailored climate simulation models can assist in developing strategies that preserve the environment and enhance its long-term environmental resilience.

Although it is widely acknowledged that climate change affects heritage, there are gaps in understanding the damage to both built and natural cultural heritage. Many areas of heritage interest have yet to receive substantive assessments, lacking detailed studies on their exposure to extreme weather events. Additionally, there is a growing need to develop and implement innovative technologies and tools capable of improving the monitoring, assessment, and preservation of heritage in the face of the current climate crisis.

Based on the analyzed articles, it is clear that this field of study is broad and requires a multidisciplinary approach that accounts for the complexity of the issue. The systematic reviews highlight the need to address various identified gaps, ranging from the predominance of studies in certain geographic regions to the lack of a holistic approach that considers not only physical aspects but also socioeconomic, cultural, and governmental impacts. In this sense, the diversity of studies in recent years reveals a growing field of knowledge. Nonetheless, it is necessary to develop practices and actions that ensure the resilience and preservation of cultural heritage globally.

In both empirical and theoretical studies, there has been progress in understanding and addressing the intersections between climate change and cultural

heritage. These works emphasize the complexity of these relationships and offer perspectives on how to tackle the emerging challenges posed by the current climate situation. From the use of digital technologies to monitor heritage to reflections on preservation policies in the face of climate uncertainties, the studies converge on the urgency for integrative and dynamic research.

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HOW TO CITE THIS ARTICLE:

ENGEL, Ernestina Rita Meira; LIBRELOTTO, Lisiane Ilha. Cultural heritage and the climate crisis: A literature review. **MIX Sustentável**, v. 10, n. 4, p. 127-142, 2024. ISSN 2447-3073. Disponível em: <http://www.nexos.ufsc.br/index.php/mixsustentavel>. Acesso em: _/_/_. doi: <https://doi.org/10.29183/2447-3073.MIX2024.v10.n4.127-142>.

SUBMITTED ON: 12/09/2024
ACCEPTED ON: 13/09/2024
PUBLISHED ON: 30/09/2024
RESPONSIBLE EDITORS: Lisiane Ilha Librelotto e Paulo Cesar Machado Ferroli

Record of authorship contribution:
CRediT Taxonomy (http://credit.niso.org/)

ERME: conceptualization, data curation, formal analysis, investigation, methodology, visualization, writing - original draft and writing - review & editing.

LIL: data curation, formal analysis, investigation, methodology, supervision, validation and writing - review & editing.

Conflict declaration: nothing has been declared.