Natural Hazards
https://doi.org/10.1007/s11069-024-06970-x

ORIGINAL PAPER

Integrated understanding of climate change and disaster risk for building resilience of cultural heritage sites

Gül Aktürk[1] · **Stephan J. Hauser**[2]

Received: 5 December 2023 / Accepted: 11 October 2024

Abstract
Heritage assets are vulnerable to climate change and disaster risks. However, existing literature has long been separating climate change from disaster risks, which were mainly considered as natural disasters. Recently, the framework of integrated understanding of climate change and disaster risk reduction in international policies started to be discussed in sustainable development discussion, while mentioning opportunities to build resilience of cultural heritage sites (United Nations Office for Disaster Risk Reduction 2020). But this framework is yet to be implemented and detailed in the context of heritage sites. Therefore, the aim of this paper is to analyze how the integrated understanding of climate change and disaster risk reduction policies can contribute to building climate resilience of cultural heritage sites by reviewing the key themes emerging from the literature. The question this paper answers are how can the integrated understanding of climate change and disaster risks reduction tackle barriers to the resilience of heritage sites? And what can be done to fill the gaps identified in the literature? To understand it, four elements from the literature are analyzed, including methodological contributions, temporalities, challenges and gaps, and opportunities. The findings of this review help in understanding the gap and interplay between science and policy in decision-making processes. We conclude by discussing the ways forward for the applicability of the framework in building resilience of cultural heritage sites.

Keywords Disaster risk reduction · Climate change adaptation · Cultural heritage · Climate resilience · Policy

✉ Stephan J. Hauser
stephan.hauser@helsinki.fi

[1] Faculty of Archaeology, Leiden University, Leiden 2333 CC, The Netherlands

[2] Faculty of Social Sciences & Helsus, University of Helsinki, Helsinki FI-00014, Finland

Published online: 22 October 2024

1 Introduction

The United Nations Disaster Risk Reduction (UNDRR) defined a disaster as "a serious disruption of the functioning of a community or a society due to hazardous events interacting with conditions of vulnerability and exposure, leading to widespread human, material, economic and environmental losses and impacts" (UNDRR). Disaster risk as defined by the same UNDRR is "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability, and capacity" (UNDRR). Because scholars rarely consider climate change caused by human activities as the major driver of disasters (Ihinegbu 2021), "natural hazards", as mentioned in past studies, dominated the disaster risk literature. However, by altering the intensity and frequency of hazards, climate change is increasing the scale and consequences of disasters, thus also increasing risks on people and buildings (Prevention Web). Disaster risks, which were for a long time conceptualized as natural hazards and required immediate actions, have not included the slowly emerging and evolving impacts of climate change in a holistic way so far. These two themes of climate change adaptation and disaster risks reduction grew apart, with studies focusing majorly on, as mentioned in the literature, "natural disasters" without considering much climate change. Despite the strong interlinkage between climate and disaster risks, these concepts are disentangled, thus still viewed and assessed separately (Delica-Willison 2015).

This division creates backdoors for governments to neglect their responsibilities in addressing the challenges from the broader view of disaster risks (Delica-Willison 2015; Raju et al. 2022). The separation between these two frameworks also results in incomprehensive policies and the fragmentation of both organizations and management within institutions (Nemakonde et al. 2021). On the one hand, disaster risk reduction (hereafter DRR) as a policy objective for disaster risk management (hereafter DRM) (Prevention Web) aims at prevention, to reduce disaster risks. On the other hand, climate change adaptation (hereafter CCA) by taking actions to reduce vulnerabilities to the adverse and diverse effects of climate change aims to build resilience (Sesana et al. 2019). The definition of adaptation developed by the IPCC AR6 2022 report captures the essence of the notion through a division between human and natural systems: "In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects" (IPCC, 2022). Rethinking climate and disaster risk helps us address the existing and emerging issues derived from climate change, environmental degradation, poorly managed urban development, and insecure livelihoods (Davis and Vulturius 2014). For instance, the building of a dam can change the course of water flow and discharge, thus reducing disaster risks, but can, if not considered along with urban development planning and climate change consequences, create new risks (Davis and Vulturius 2014). One regular criticism of DRR is that its policies focus on extreme climate-related events and other hazards but do not take the developmental context into consideration (Gaillard 2010). This results in strategies aimed at reducing short-term risks without anticipating the future, nor addressing the root cause of the problem (Gaillard 2010).

Consideration for the origins of contemporary issues is of paramount importance when knowing that cultural heritage is exposed to multiple and multifaceted risks (e.g. earthquakes, floods, volcanic activities, wars, mismanagement, developments etc.). In the existing literature, studies on cultural heritage management and conservation have for a long time focused on impact assessments of natural hazards and human-induced threats. A number of guidelines from the UNESCO and other partner institutions such as ICOM, ICOMOS, IUCN, and ICCROM assessed natural and anthropic disaster risks on the World Heritage, cultural and natural heritage properties and provide a methodology to identify, assess and mitigate disaster risks (Valagussa et al. 2021). In the UNESCO report "Managing disaster risks for World Heritage," it was stated that the proper integration of DRR into DRM in a number of world heritage sites is relatively low (UNESCO 2010). It marks the importance of mainstreaming heritage sites' contribution to DRR but also a relative absence of implementation in protection policies linked to heritage sites. Furthermore, climate change was viewed as a risk multiplier. By modifying climatic and non-climatic factors, climate change greatly influences the DRM of cultural heritage sites which needs to constantly evolve to anticipate risks on cultural heritage.

In spite of the great influences of climate change on the DRM of cultural heritage, it has been long separated from disaster risks (Giliberto 2021) both in the literature and in policies for building the resilience of cultural heritage. Climate change adaptation of cultural heritage, an ever-growing literature, has yet to focus on DRM or DRR for building resilience. Similarly, DRR and DRM have not yet considered CCA of cultural heritage sites. Yet, both DRR and CCA agendas aim to decrease vulnerabilities and build resilience (Begum et al. 2014). The link between DRR and CCA has been the topic of policies at various levels, including regional, national, and international levels. At a national level, Joint National Action Plans on Disaster Risk Management and Climate Change (JNAPs) is adopted by three Pacific island countries, including the Cook Islands, Solomon Islands and Tonga for addressing disaster risk reduction (DRR) and climate change adaptation (United Nations Department of Economic and Social Affairs 2021). The assessment of the four cases of Bahamas, Guyana, Barbados and Trinidad and Tobago in the Caribbean context proved that disaster risk management and climate change adaptation can be integrated into national public investment systems by using a Comprehensive Disaster Management regional strategic framework (United Nations Department of Economic and Social Affairs 2021). In countries such as in sub-Saharan Africa, namely Benin, Niger, Malawi, and Uganda, the integration of such policies and practices allowed the development of a platform for knowledge sharing among experts and stakeholders from their respective fields to coordinate and plan actions and monitor (UNDRR 2022). It is found to be particularly effective in terms of disaster risk governance by fostering institutional coordination and collaborations for establishing initiatives and activities (Leitner, 2020). Although the adoption of this framework has yet to be improved at the local scale, it has been used in dealing with disaster risks in cultural heritage sites. So far, only policies, conventions, and guidelines such as "The Centre for the Preservation and Protection of Cultural Heritage" (CPCH) (LAU- Louis Cardahi Foundation (LCF) and WATCH 2019) have been mentioning the development of DRR-CCA in cultural heritage. This integration has yet to be widely implemented in the practice of heritage management to increase its adaptability and transferability.

Therefore, this paper, by adopting the conceptual framework of DRR and CCA in the context of cultural heritage aims to review the emerging themes within the literature. We

first give a background on the integrated understanding of climate change and disaster risks. Then, we present an overview of the literature by categorizing it based on the dominating factors, including (1) impacts of climate change and disaster risks on cultural heritage sites, (2) methodological contributions, (3) temporalities, (4) challenges and gaps, and (5) the opportunities. Eventually, we conclude with policy implications and the expected or required focus of future studies.

2 The integrated understanding of climate change and disaster risks

The importance behind the mix between DRR and CCA needs to be understood in a relational way. DRR is centered around risks and their detrimental consequences on humans or the environment. They can be climate-related or not, and they tend to highlight vulnerabilities. In CCA, climate change needs to be understood as a risk driver that is altering the consequences and occurrences of the risks, thus also vulnerabilities (UNDRR 2022a). Thus, DRR and CCA complement each other by looking at different spatial and temporal scales. But the conceptual framework of the linkages between DRR and CCA in a cultural heritage context is not new. In this sense, existing literature on the intersection of CCA and DRR along with considerations for sustainable development, heritage conservation, and management was emphasized when discussing heritage preservation (Jigyasu 2015). However, the existing literature lacks a systematic understanding of the use of this framework and its efficiency in building resilience in cultural heritage sites. It may be due to the divergences between the two approaches. CCA is viewed as long-term, politically-driven, originating from science, encompassing changes to average conditions, focusing only on climate-related hazards, and with sizeable and growing funding streams (Trobe 2008; Gero et al. 2011). Conversely, DRR includes geophysical hazards, builds on past experiences and knowledge, focuses on extreme events only, has origins in humanitarian assistance, has relatively low to moderate political interest, and funding streams are ad-hoc and usually insufficient (Trobe 2008; Gero et al. 2011). DRR has a long record of local-level successful works in reducing vulnerabilities of communities and supporting development, which could only be achieved based on past knowledge whilst considering future threats (Mercer 2010). In this regard, the CCA discourse in the local context was found to be problematic as scholars studying DRR including climate hazards already stated this gap decades ago (Gaillard 2021).

By recognizing the differences between the two, the adoption of the framework combining DRR and CCA can ensure a holistic view of the integrated understanding of disaster risks in cultural heritage sites, challenges encountered, and opportunities presented by its adoption in terms of building resilience. However, most of existing international policies and articles developing this integrated framework are not focusing nor mentioning cultural heritage sites, and how their management would benefit from this holistic perspective (Begum et al. 2014). The tools and concepts developed through this integrated approach, such as stakeholder and cross-sectoral engagement or targeted funding allocations among many others, are particularly relevant to improve the resilience of cultural heritage sites. Yet, only a few studies exist on the integrated view of disaster risks and climate change in the heritage context.

DRR in supporting CCA has been for a while playing an important role in building resilience of communities and cities in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 (United Nations 2015), the Sustainable Development Goals (United Nations 2021), and the Paris Agreement (United Nations 2016) for the cohesion of international policies. Aligning the inter-and cross-knitted agendas of DRR and CCA can create a systematic and integrated understanding of climate change and disaster risks which can enhance the ability of policies to provide concrete solutions to reduce existing multi-hazard risks and strengthen resilience. From this perspective, disaster risks, including social, environmental, and economic, could be conceived as an integral part of development and planning strategies. While this framework was recently adopted in policies at national and regional scales, only few scholars have used this framework in their publications on the resilience of cultural heritage sites. And beyond studies, the implementation of this unique framework is still lacking, as highlighted by the UNDRR in its 2022 report "Technical Guidance on Comprehensive Risk Assessment and Planning in the Context of Climate Change."

It is important to mention the role of insurance in addressing the damage and loss that might derive from the disasters and climate change effects. A survey on the use of insurance as a risk management tool on cathedrals in Italy among Dioceses gave great importance to insurance to cover the damages on their cultural heritage (De Masi and Porrini 2021). The insurance sector could play a key role in the protection of World Heritage Sites to cover for damages from disasters and climate change effects by working together with the key stakeholders (United Nations Environment Programme; Principles for Sustainable Insurance; World Wildlife Fund; United Nations Educational Scientific and Cultural Organisation, 2018). Thus, the adoption of insurance for protection of material and immaterial damages could act as an efficient risk assessment tool.

CCA and DRR are converging, however, gaps remain, mainly in practical applications. The role of insurance is one good example, but a consistent risk approach, which fully considers the context of climate change and other underlying risk drivers for the current situation or potential future states and an integration of the CCA approach into the existing practice of disaster risk management (DRM) and vice versa, is still not a common standard (UNDRR 2022a).

3 Methodology

Climate change adaptation of cultural heritage is ever growing with research and practice but is yet to be understood and implemented. This domain grew immensely in the last decade with 2,451 publications using the key terms "climat* chang*" AND "herit*" in Scopus in May 2022, out of which only 145 mention disaster risks. This itself reveals the scarcity of studies of disaster risks in the intersection of climate change and cultural heritage sites despite the broad spectrum of risks, including those derived from earthquakes, wildfires, landslides, wars, and more. Similarly, CCA of cultural heritage has rarely brought light to disaster risks other than climate change such as urban development or management failures. Although climate change is sometimes closely linked to anthropic events, CCA of cultural heritage papers have rarely highlighted disaster risk reduction for building resilience. Centralizing heritage within this framework, this review investigates how such a framework is

used in the management of heritage sites and what challenges and opportunities it presents within the heritage context.

For the sake of clarity, two elements deserve an explanation for a better understanding of the following developments. First, the term cultural heritage refers to the understanding and definition given by the UNESCO: Cultural heritage includes artefacts, monuments, a group of buildings and sites, museums that have a diversity of values including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific and social significance. It includes tangible heritage (movable, immobile and underwater), intangible cultural heritage (ICH) embedded into cultural, and natural heritage artefacts, sites or monuments (UNESCO Institute for Statistics 2009).

This broad definition illustrates why the term "herit*" was used when investigating Scopus' database. The aim was to include as many types of heritage as possible, beyond the simple built or intangible heritage listed or protected by national or international frameworks. Similarly, the second point is also linked to a definition given by the UNESCO and refers to the notion of disaster risk. Thus, we follow the understanding of this notion as explained by the UNESCO as: Disaster risk is a product of hazard and vulnerability. While a hazard is a phenomenon (such as an earthquake or a cyclone) which has the potential to cause disruption or damage to cultural property, vulnerability is the susceptibility or exposure of cultural property to the hazard. Whereas a hazard is the external source of a disaster, vulnerability is the inherent weakness of the heritage property (due to its location or its specific characteristics). It is important to bear in mind that hazards such as earthquakes can trigger disasters although they are not disasters in themselves (UNESCO et al., 2010).

The objective behind limiting the search to "disast* risk*", as mentioned in the next section, rather than purely "risk*", is to consider not only hazards, or only vulnerability, but their intersection. In parallel, it also relates to the need to remain within the scope of the DRR framework by strictly sticking to "disaster risks".

To address the research question, a systematic literature review is conducted both qualitatively and quantitatively. The method of systematic literature review has been widely used in studies around climate change adaptation (Owen 2020; Robinson 2020), disaster risk management (Djalante 2018), and cultural heritage (Orr et al. 2021; Aktürk 2022). Gaps, barriers, challenges, limitations, and constraints to climate change adaptation have been systematically analyzed in this review along with drivers, enablers, and opportunities (Simoes et al. 2017; Mu et al. 2020), especially in the context of cultural heritage (Aktürk and Dastgerdi 2021). Specifically, the alignment of CCA and DRR has been systematically reviewed both in literature and policies through the inclusion of sustainable development with a focus on the impacts and challenges (Wen et al. 2023; International Federation of Red Cross and Red Crescent Societies, 2019, Djalante 2018). However, we touch here upon a limitation of the paper as the implementation of a framework combining both DRR and CAA often happens in experiments and projects which do not necessarily produce scientific articles discussing their outputs. As such, the views developed in this paper, although useful to the improvement of a framework combining DRR and CCA, are biased because relying on the sole analysis of articles. And if the sources of information could be expanded, they would require work and collaborations beyond the scope and timeline of this paper.

Through a systematic literature review, temporalities, gaps, challenges, barriers, and opportunities detailed in the literature can be analyzed to strengthen the policy and science

Table 1 The inclusion and exclusion criteria

Inclusion	Exclusion
Year: Published between 2009 and 2022	Published beyond 2022
Language: English	Other than in English. The search did not yield non-English publications.
Database: Indexed only in Scopus and Web of Science	Not indexed in Scopus and Web of Science
Document type: Peer-reviewed journal articles, book chapters, and conference papers and proceedings	Others: Reviews, books, editorials, letters, viewpoint, non-peer-reviewed documents, grey literature etc.
Terms: Key terms mentioning "disast* risk*" AND "climat* chang*") AND "herit*"	Terms not specifically mentioned in the inclusion criteria
Focus: The mentioning of both disaster risk and climate change and cultural heritage	Only disaster risks, only climate change effects/impacts/adaptation or only one of these concepts with cultural heritage or only cultural heritage

Table 2 The review questionnaire

General Characteristics
What is the publication type per year?
What is the name of publication source?
What is the geographical location is the subject of the publication?
What is the main methodological contribution?
What is the research method used?
Focus and Content
What are the assessed risks (climate change and disaster risks)
What temporalities are mentioned?
Are there any challenges, barriers, limitations, constraints to DRR and CCA in cultural heritage
Are there any opportunities?

interface. The steps taken in the systematic searching strategy consists of identification, screening (inclusion and exclusion criteria) and eligibility (Tables 1 and 2).

3.1 Data selection

The search was conducted in July 2022 by using the internationally recognized database of Scopus and Web of science, and was updated in July 2023 due to the review process of journals. The key terms searched for this research are ((“disast* risk*” AND “climat* chang*”) AND “herit*”) which yielded 83 publications in total, including 40 in Scopus and 43 in Web of science between 2009 and 2021. After the removal of duplicates which included 19 publications, 64 publications remained. 10 publications were removed due to the exclusion criteria in terms of publication year which retained 54 publications. The search did not yield any non-English publications from the two databases. Additionally, 5 review documents, 1 conference review, and 2 books were excluded which yielded 46 publications. 10 publications were excluded due to the inclusion/exclusion criteria in terms of focus which retained

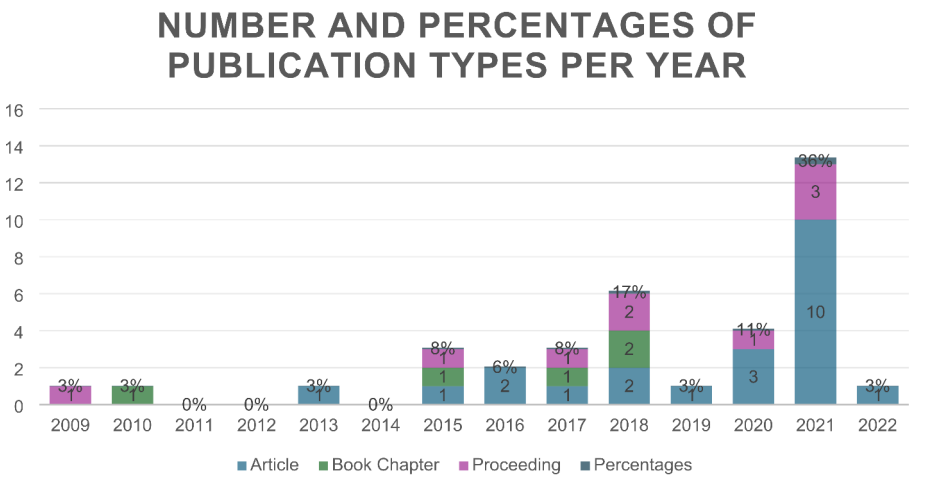

Fig. 1 The number of publication types per year

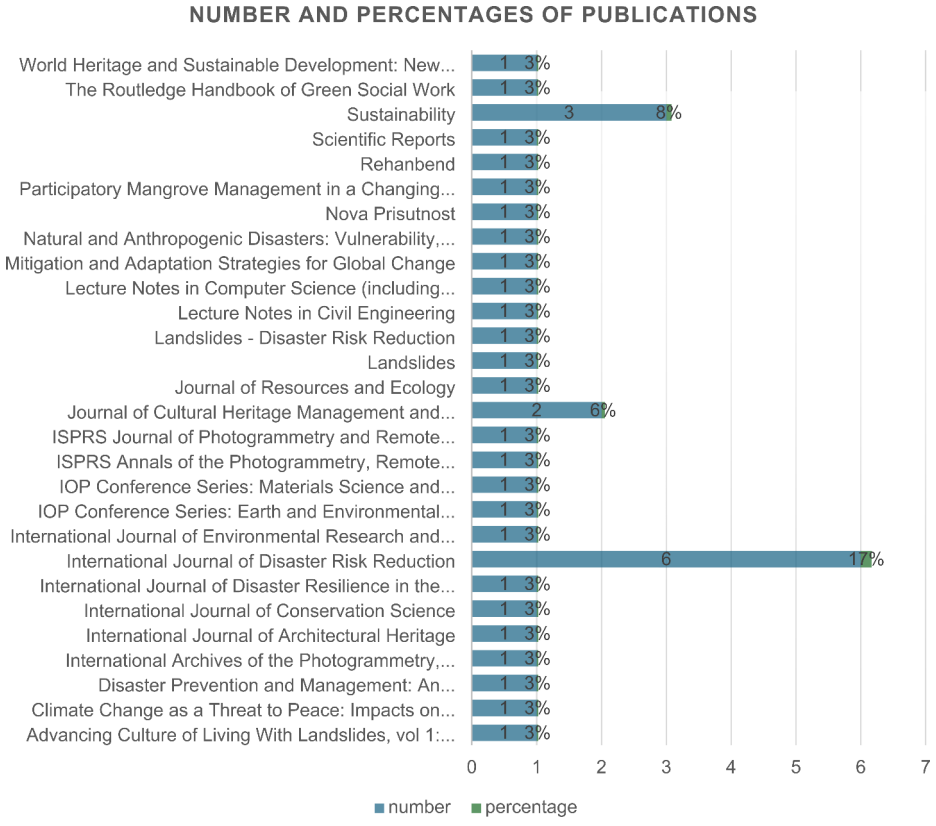

Fig. 2 The number and the percentages of publication sources

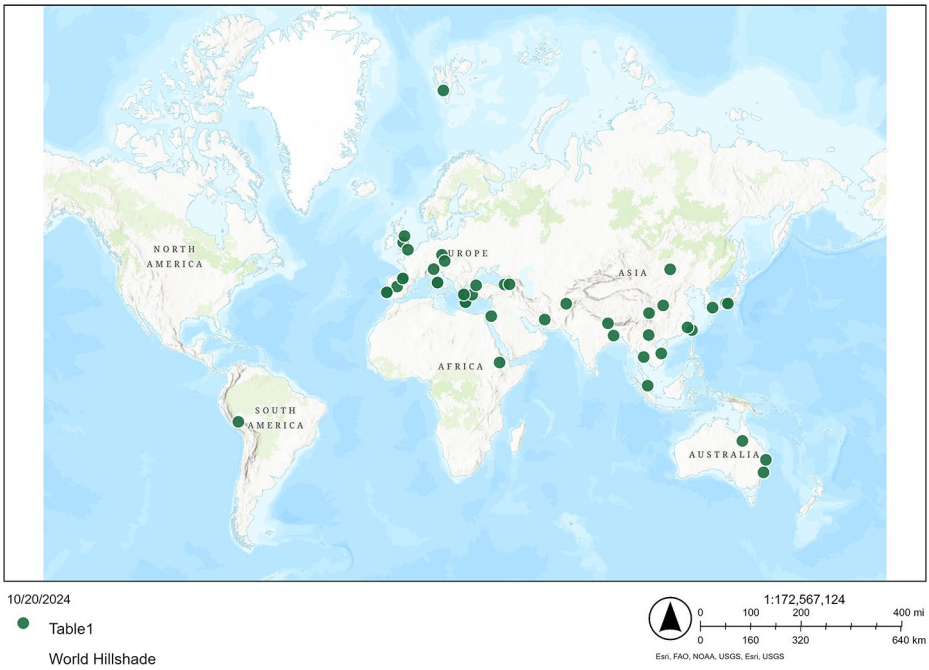

Fig. 3 Geographical focus of the reviewed literature. Note that the locations of the multiple cases mentioned in the studies were also shown in the map

36 publications. The mentioning of both disaster risk and climate change and cultural heritage was an important criterion for conducting this analysis. Although this paper is focusing on the integrated view of CCA and DRR in cultural heritage, some of the studies included in this literature review treat them separately.

3.2 Data analysis

Following document screening, 36 publications were retained for full review. A questionnaire for the review is developed quantifying the general characteristics of the literature, including document type per year, publication sources, geographic interest, methodological contribution (conceptual, case studies, multiple cases), methods (quantitative, qualitative, mixed), type of cultural heritage in numbers and percentages (n, %) (Table 2).

Content analysis was undertaken following the three steps, including preparation, organizing and reporting (Elo and Kyngäs 2008). Inductive content analysis yielded the results in the emerging themes which were qualitatively analyzed.

We then focused on the main barriers by asking the question of what the barriers and knowledge gaps of integrated understanding of CCA and DRR in cultural heritage are. As mentioned earlier, the integration and implementation of both CCA and DRR together are still only emerging in the cultural heritage context. Thus, the reviewed publications did not specifically analyze the barriers relating to this integrated framework.

In the identification of the barriers, the quotes were extracted mainly from the results and discussions sections. The keywords of “barriers,” “challenges,” “concern,” “constraints,”

"limits," "lack," "need," "must," and "should" were searched for the initial analysis (Fatorić and Seekamp 2017). Barriers were divided into six categories, namely Climate change underestimated; Lack of data; Lack of engagement; Conflicting interests; Unclear objectives; and Lack of means. They emerged from the analysis of the literature.

3.2.1 General characteristics of the literature

The publication period for the search included the last 13 years as there was no publication found prior to 2009. The integrated view of climate change and disaster risks in cultural heritage in the literature reached its peak in 2021 ($n=13$, 36%) with the highest number in articles, which signals it as an emerging research field. Until 2015 there were none to only 1 publication, with a relative increase in the publications since 2015 ($n=3$, 8%), with the same amount of publications in 2017 ($n=3$), and an increase in 2018 ($n=6$, 17%) (Fig. 1). However, half of the analyzed publications ($n=18$) are concentrated over the last 3 years (2020, 2021, and 2022) with an overwhelming number of articles ($n=14$).

The distribution of publication sources revealed that most of the publications were published in the *International Journal of Disaster Risk Reduction* ($n=6$, 17%) which was followed by *Sustainability* ($n=3$, 8%) and *Journal of Cultural Heritage Management and Sustainable Development* ($n=2$, 6%). This result has not only revealed that these three top publication sources are journals but also showed that environmental journals were the most preferred publication sources rather than cultural heritage journals. Even the number of publication sources in the list illustrates the few numbers of publication sources from cultural heritage (Fig. 2). The analysis displays the lack of inter- or transdisciplinarity when discussing as well as in merging disaster risks and climate change in the context of cultural heritage.

The distribution of the geographical interests of the studies revealed that most of the studies equally focus on European Union countries ($n=14$), mainly Italy, Spain, Greece, Austria, and Czech Republic, and on Asian countries ($n=14$), mostly China, India, Thailand, Vietnam, Mongolia, and Japan. Other cases are Australia ($n=5$), Turkey ($n=4$), the UK ($n=2$), Jordan, Iran, Ethiopia, Norway (Fig. 3). The geographical analysis of the case studies demonstrates a greater focus on the European and Asian continents, with only one case in Africa and South America, and none in North America. If these results reveal a greater diversity than those highlighted by De Masi et al. in 2021, the geographical focus still ignores cultural heritage sites at risk in America, Africa, and central Asia (De Masi et al. 2021).

The publications were then categorized depending on methodological contributions: case studies, conceptual articles, and multiple case studies. The largest methodological contribution of the publications deals with case studies ($n=20$, 56%), while the next common type of contribution was conceptual ($n=11$, 31%). Only very few publications used multiple cases ($n=5$, 14%).

In terms of research methods, slightly more than half of the publications ($n=18$, 55%) comprised of quantitative studies (i.e. model/ simulations, GIS, statistical analysis, questionnaire, and workshops) while the rest was shared between the use of qualitative (i.e. interviews and literature) ($n=14$, 45%) and mixed methods ($n=4$, 13%) (Fig. 4).

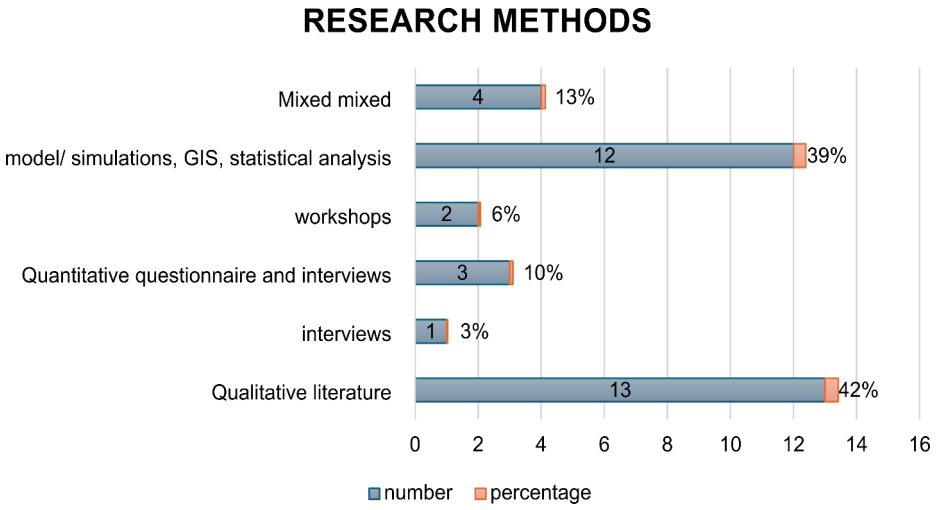

Fig. 4 The number and percentages of the main research methods used in the reviewed literature

4 Results

4.1 Examples assessing, recovering from, and adapting to climate change and disaster risks

In the literature analyzed, methodological approaches to risk assessments include spatio-temporal analyses across scales and perspectives. The recent development of innovative tools and techniques, to identify threats or countermeasures to risks for cultural heritage sites, regularly highlights the increasing effects of climate change and the disaster risks faced across the globe. As climate change and disasters risks are intertwined and have both various origins and consequences, they must be considered across disciplines and techniques to be included in an integrated framework.

Techniques linked to geoinformatics technology, with 2D and 3D spatial information are, among others, used for the documentation of structural damages induced by natural disasters such as flooding and earthquakes. It was used, for instance, in the restoration of the World Heritage sites in Spain, Vietnam, and Nepal (Xiao et al. 2018). Similarly, the 3D model and the GIS analysis of the UNESCO rupestrian world heritage list (Bamiyan in Afghanistan; Lalibela in Ethiopia; Petra in Jordan and Vardzia in Georgia) is used for the development of restoration techniques in the case of rock degradation (Margottini et al. 2017). 3D printing and modelling of objects and artworks at risk due to climate-, biological-, human-, geological-related degradation has become an innovative tool for the recording of the risks as well as for post-disaster reconstruction of heritage. By knowing which parts of cultural heritage are damaged during disasters, and by developing techniques to restore them, these techniques participate to the adaptation to climate change and disasters. However, these technological tools can be complex to implement, thus their scalability and wide use can prove difficult.

GIS and/or remote sensing can also be a powerful method in detecting and illustrating threatened cultural heritage sites under climate change and disaster risks. This method was

Table 3 Categories of barriers identified during the analysis, and their explanations

Category of the barrier	Explanation	Quotations
Climate change underestimated	The role of climate change as a risk multiplier which requires better integration of DRR and CCA is either ignored or underestimated.	"All the sites analysed included more than one hazard/threat as an observed/experienced problem, this indicates the folly of adopting approaches to risk management that focus on a specific type of hazard/ threat rather than considering a multi-hazards/ threats approach to DRM." (Bosher et al. 2020)
Lack of data	An absence of data or data sharing on the effects of climate change on cultural heritage sites.	"Baseline data development is a matter of necessity toward disaster risk reduction and climate change adaptation for mangroves." (Kandasamy 2017)
Lack of engagement	The inclusion of stakeholders or experts from different backgrounds and the mix of disciplines is missing, leading to a lack of data management or interdisciplinarity.	"The need to consider climate change and disaster scenarios as part of the city planning, will contribute to the generation of further critical information, which should be considered as part of the sustainable development." (Gandini et al. 2018)
Conflicting interests	Different actors, groups, or institutions have competing or conflicting interests around cultural heritage sites and are delaying actions to improve cultural heritage sites' resilience.	"There is a real need to manage the conflicting viewpoints between the actors involved in developing CCA strategies for cultural heritage." (O'Brien et al., 2015)
Unclear objectives	Definitions and objectives set in policies or regulations are unclear, leading to technocratic processes or inadequate practices.	"This, in conjunction with the indirect applicability of the regulations, significantly reduces the policy implementing potentialities. The guidelines, regulations and actions identified are mainly operational/administrative while those referring to studies or projects are met less frequently." (Asprogerakas et al., 2021)
Lack of means	Actors or institutions in charge of the protection of cultural heritage sites lack training, management experts, or equipment for their missions.	"Risk-preparedness policies and practices, at national, regional and local levels, mainstreaming cultural heritage through a collaborative approach, should be developed and promoted, together with the setup of effective risk governance for cultural heritage on a national level, promoting agreements between different actors, improving resources availability and increasing training opportunities." (Bizarro and Alexandre 2020)

used to demonstrate that archaeological remains in Svalbard are under the threat of climate change-triggered hazard of thaw slump scars (Nicu et al. 2021). Moreover, the overlapping of historical aerial images in ArcGIS can help to detect non-listed or lesser known vernacular heritage sites located in disaster-prone areas, like in Rize, Turkey (Aktürk and Hauser 2021). The spatial analysis of the Jinjiang River Basin, including land cover information, vegetation cover information, topography information, and soil erosion information contributed to the monitoring of the destroyed Shunji Bridge in Fujian Province of China (Liu et al. 2021). Most often, flood risk models comprise the use of GIS in combination with risk indexes and could increase the resilience of heritage sites by reducing disaster risks and improving climate change adaptation practices. Although technical, these GIS tools are widely available and can, in conjunction with other disciplines, bring new perspectives

and understandings on past and contemporary developments to improve planning practices around risk-prone areas.

These tools, along with necessary interdisciplinary analyses, and their combination led to the creation of multiple models to assess the vulnerability of cultural heritage sites to disasters. The MIVES methodology is one example, with the modelling of historic urban areas of San Sebastian in Spain to create vulnerability maps for flooding (Gandini et al. 2018). MIVES methodology, which stands for the Spanish Integrated Value Model for Sustainability Assessment, is commonly used in architecture, construction, and urban planning sector (Pons et al. 2016) for giving homogeneity to sustainability indexes (Gandini et al. 2018). Similarly, a multi-hazard risk assessment of hazards (sudden- and slow-onset) with consideration given to the future effects of climate change is provided for the Historic Centre of Rethymno in the island of Crete in Greece by analyzing GIS modelling, hazard mapping, and climate projections (Ravankhah et al. 2019). While the quantification of the disaster risks is often done for multi-hazard assessment, it is sometimes for the investigation of one hazard type such as flood risk in multiple cases. For instance, hazards maps and vulnerability assessments of climate-induced hydro meteorological hazards were created for monuments in Prague and Troja in Czech Republic and Krems and Stein in Austria (Bonazza et al. 2021). In risk analysis, hazard mapping can and should be conducted in consultation with experts and communities to better identify potential threats that could otherwise be ignored or underestimated.

This interdisciplinary approach using a combination of innovative tools requires further engagement, not only between academic experts, but also with relevant local or national stakeholders. Based on a questionnaire of households and in-depth interviews with local governors and companies, a new conceptual model of adaptation of terrace landscapes in Yuanyang, China, gives insight of drought disaster risk reduction (Sun et al. 2013). As the study conceptualizes risks as compound, land-use changes are incorporated into the analysis of climate-related disasters (Sun et al. 2013). Another questionnaire developed via snowball sampling in the old quarter of Malacca in Malaysia assessed disaster risks on cultural heritage (Mansir et al. 2018). The combination of this engagement with tools previously described led, through the analysis of a household survey and GIS mapping, to the creation of a flood risk assessment for Ayutthaya UNESCO World Heritage Site in Thailand (Daungthima and Kazunorib 2013). The results not only evaluate the link between past flood disasters and current disaster readiness of local communities in the heritage site but also reveal strategies to improve flood resilience (Daungthima and Kazunorib 2013). Expert interviews, site observation, and analysis of the documents as a mixed method can also be useful for proposing Cultural Heritage Index for the analysis of the risk indicators such as hazards, exposure, and vulnerability resulting from earthquakes in the case of the city of Bam in Iran (Ravankhah et al. 2021).

Eventually, Cost-Effectiveness analysis as a tool to compare policies within H2020 project STORM (Safeguarding Cultural Heritage through Technical and Organisational Resources Management) is proposed for disaster risk management and conservation of the Roman wells of Tróia, in Portugal (Revez et al. 2021). Notably, this project criticizes the inexistence of risk management policies for cultural heritage and recommends a number of suggestions for the adoption of disaster risk reduction policies, including raising political and public awareness, facilitating collaboration and communication both within the institutions and beyond with other stakeholders, assessing and mapping risks in heritage sites, and

securing funding (Bizarro and Alexandre 2020). Participatory approaches such as workshop agreements on the EU-Horizon 2020 project ARCH with the participation of researchers and project partners identified 18 challenges, while a follow-up workshop, The European Committee for Standardization (CEN), worked on the development of standardization of the DRM framework (Lindner et al. 2021).

While heritage assets may be used as a focus in many studies, these assets are still missing in national policies of most developing countries. However, EU-funded projects such as SHELTER (Sustainable Historic Environments holistic reconstruction through Technological Enhancement & community-based Resilience) and OPERANDUM (Open-Air Laboratories for Nature based solutions to Manage hydro-meteo risks) support the resilience of historic and natural areas in the face of climate change through data-driven and community-based techniques. With the partnership of UNESCO, these projects provide good examples that take a user informative approach (Mysiak 2021). These good practices, as well as research results in this field, now need to be better advertised and transfer to improve the creation of anticipative measures within DRR and CCA policies.

All these tools and projects highlight the importance of holistic approaches for the successful implementation of a CCA and DRR integrated framework. The development of new tools using interdisciplinary methods and analysis in combination with a more varied engagement with local stakeholders proved its efficiency in assessing, restoring, and adapting to risks, although often on a limited scale. Such tools have the capacity to support new studies and the application of an integrated approach increasingly emphasized in projects, the literature, and in this article. By adopting a more holistic and trans-institutional framework, governments and institutions can come up with a more coherent policy agenda and foster more coordinated and structured approach to respond to climate and disaster risks.

4.2 Temporalities

The necessity of providing holistic and inclusive perspectives has been emphasized for both short- and long-term effects of climate and disaster risks across disciplines and in sectors beyond the heritage world (Forino et al. 2016; O'Brien et al., 2015; Bonazza et al. 2021). It is important for decision-makers in public institutions to adopt the both short-and long-term strategies as the latter, as demonstrated in the case of Ravenna (Rosa et al. 2021), is often overlooked in urban planning policies on the improvement of the adaptive capacity of archaeological sites. Similarly to urban planning developments and studies, the emphasis on the short and long term effects of natural disasters on cultural heritage calls for the cooperation and collaboration of various stakeholders, mainly of emergency management and cultural heritage professionals (Bizarro and Alexandre 2020). Although DRR and CCA serve different temporalities, it is acknowledged that in the reduction of vulnerabilities to natural disasters and increase of human, environmental and social capacities, DRR has been increasingly viewed as not only a short- but also long-term strategy (Espada et al. 2017). Such an integrated model has already been developed, like in the study of climate-related events in Brisbane in Australia in response to short-term effects of flood on January 2011 and their long-term impacts, which contributed to the development of efficient policies (Espada et al. 2017). The development of policies considering both short-and long-term disaster risks is itself not enough for practice. It still requires the engagement of local actors to plan and act for short-and long-term consequences of disasters, but also of financial institutions

to provide coverage and risk-sharing mechanisms that can reduce harm and improve the resilience of building and communities (Porrini and De Masi 2021). This financial obstacle has been a long lasting one, with local or regional authorities gaining, through the years, increasing responsibilities to assess risks and adapt to climate, but without increasing financial support from the States.

Rather than short-term, the focus in the literature has mainly been on the need for long-term risk evaluation. This is especially demonstrated in addressing the challenges of earthquakes, with for instance the 1995 earthquake of Kobe, in Japan, or the 2008 earthquake in Sichuan, China, where planning for a hazard that may happen every thousand years was not deemed necessary by authorities (Sassa et al. 2009). In the same case study area, green social workers facilitate long-term sustainable development of the community by engaging social, cultural, and environmental issues in the post-Lushan earthquake reconstruction and recovery (Wu 2018). These efforts include coordinating with professionals in the understanding of local heritage, training local residents on new skills in preserving their heritage, and creating new income resources while addressing gender pay gaps (Wu 2018). In the preservation of Rupestrian World heritage site, the rock fall and erosion of rocks, exacerbated by climate change, is a major threat which also requires a long-term maintenance, inclusiveness, and financial support. Local traditional knowledge can in this case be a leverage for ensuring better local management and improving conservation policies (Margottini et al. 2017). The preservation of grassland as agricultural heritage in the Mongolia Autonomous Region is a perfect example but challenged by the impacts of climate change, including droughts and rainstorms. Despite measures aimed at reducing vulnerabilities in the short-run, the efforts in the long run are key in enhancing resilience of heritage sites and their environments and communities when applied in combination with local knowledge (Guoping et al. 2021). However, the long term impact of damaged cultural heritage sites is, in addition to urban and economic developments, the loss, for their communities, of traditional knowledge that could help maintain and restore cultural heritage sites.

4.3 Gaps, challenges, and constraints

A majority of the studies in the literature refer to gaps, challenges, and constraints, sometimes mentioning them in a broader way, as it could be outside of their scope. Those which mention sites or method specific gaps and limitations are grouped under a broader theme.

The integration of heritage in DRR and CCA policies is emphasized in the literature for building resilience through heritage (Longworth 2014). The need for an inclusive framework dealing with disaster risks and climate change in building resilience of urban community and infrastructure has been emphasized in the literature, like in the case of Brisbane, Australia (Espada et al. 2017). Yet, the lack of inclusion of cultural heritage in policies and practices in line with the agendas for DRR and CCA is discussed as a great gap (Bizarro and Alexandre 2020). This gap could be bridged via cross-sectoral, -scalar, and -collaborative works with various actors. As such, there is a need for multi-hazard approaches including the many stakeholders in addressing challenges of climate change and disaster scenarios in urban planning strategies (Gandini et al. 2018). This can also include other aspects of hazard assessments such as historical data of meteorological records, future projections of climate change, and stakeholders' views (Longworth 2014). Especially, there is a lack of studies and data on multi-hazards and their impacts on cultural heritage sites (Bosher et al. 2020).

The initiatives on hazard mitigation and/or retrofitting into cultural heritage in pre-disaster period are missing, further highlighting the shortcomings of the literature around cultural heritage in combination with risks (Bosher et al. 2020).

To address the multiple gaps identified, there is a need to deepen the engagement with local actors when trying to improve the resilience of cultural heritage sites. Participatory approaches in cultural heritage conservation should emphasize the role of community members in activating the restoration of heritage assets after disasters (Kittipongvises et al. 2020). In this regard, actors, most importantly local communities, play a significant role in heritage preservation in pre-, during-, and post-disasters periods. Improving public and private cooperation should be ensured for stakeholders to take an action in DRR and CCA of cultural heritage (Longworth 2014). The Civil Protection authorities and other emergency officials should not only be involved in the post disaster recovery process but also in the disaster planning and preparedness stages. To solve the fragmentation issue in the decision-making identified in existing studies, national and local agencies should work closely in the preparation of emergency plans by exchanging risk data information and defining their roles, tasks, and processes for emergency management (Bizarro and Alexandre 2020). This would prevent a lack of means and anticipation around the consequences of and the actions to take after disasters.

This shortage of engagement is not limited to the inclusion of actors as it also highlights a lack of interdisciplinarity in research. Despite the emphasis, in the literature, on the collective approach to climate change adaptation (Caballero 2016) and disaster risk management of cultural heritage sites, the disciplinary boundaries of institutions and actors tend to be a challenge for stakeholders forced to act collaboratively and work on interdisciplinary approaches, as demonstrated in Bam, in Iran, where heritage sites linked to religion or water require various sets of skills when the need to restore them arise (Ravankhah et al. 2021). Their conflicting priorities in developing CCA strategies for cultural heritage (O'Brien et al., 2015) can often delay decision-making processes. These conflicts are often represented in documents dealing with both the preservation of cultural heritage and the adaptation to climate change. For instance, climate scientists and decision-makers should include the main exposures of heritage assets to hazards and their vulnerabilities, whereas cultural heritage practitioners, managers, and communities should consider climate change as a risk accelerator in anticipation plans and understand how heritage assets respond to these hazards (Forino et al. 2016). Open communication that serves the different needs and interests of various stakeholders can better define the objectives and the goals in developing feasible and efficient plans (Karzen and Demonja 2020). Establishing networks and/or increasing existing partnerships are key to enable coordinated and multi-scales actions (Longworth 2014; Yen et al. 2015), and should aim to develop a sense of urgency and awareness among all stakeholders (Asprogerakas et al., 2021). However, the urgency of the situation and the need to act quickly must not trigger short-term actions dealing with symptoms, but rather be constantly included in a long-term thinking as explained in previous analyses.

The prioritization of the heritage sites (Aktürk and Hauser 2021) is significant in future planning for mitigation (Nicu et al. 2021) as well as the prioritization of the risks in assessing the vulnerabilities of cultural heritage sites (Bonazza et al. 2021) and managing them (Ravankhah et al. 2019). For instance, because of their relative lack of documentation and visibility, vernacular heritage sites' value needs to be reassessed in the contemporary context of changing climate (Aktürk and Hauser 2021). This is linked to climate change increasing the

rate of damage to heritage sites, creating losses to heritage values that should not be disregarded. However, for all types of heritage, missing data and database is often problematic in the risk assessments. For example, the disaster risk reduction policies in Thailand are often impeded by the lack of up-to-date data on flood hazard zoning (Kittipongvises et al. 2020). In the conservation and management of mangroves, more baseline information of flora, fauna, and hydrological features are required for the monitoring as well as for comprehensive site investigations (Kandasamy 2017). The damage from melting permafrost is another example, and the proximity of cultural heritage sites to new risks linked to it should be carefully monitored both on-site and remotely (Nicu et al. 2021). Such regular monitoring and maintenance activities are needed, in addition to complete documentation of cultural heritage sites (Xiao et al. 2018). In the case of vernacular heritage sites in Fındıklı, Rize, the lack of data on the location, attributions, images, and historical background of the sites often lead to improper documentation and conservation practices (Aktürk and Hauser 2021). The use of GIS and/or remote sensing technology then become of paramount importance in hazard mapping and monitoring, for cultural heritage sites in general, and vernacular heritage sites in particular as they are often under investigated heritages (Aktürk and Hauser 2021). For monitoring cultural heritage, the use of Lidar technologies also provides useful data to detect changes in the buildings and vegetation, as explained in the case of The Shunji Bridge, in the Jinjiang River Basin, in China (Liu et al. 2021). Long term monitoring is possible with better means, such as with better resolutions of the satellite images (Liu et al. 2021). By doing so, early detection of hazards risks is possible and can help developing preventive strategies and emergency responses, which in return reduce risks (Liu et al. 2021) and improve resilience. However, provision for monitoring (Asprogerakas et al., 2021) and evaluation criteria for conservation intervention were found to be constraining factors in the efforts to better document threatened heritage sites (Revez et al. 2021).

The lack of resources and capacity in taking preventive measures for cultural heritage is one of the main obstacles in the way of efficient management policies for DRR and CCA. Similarly to the sharing of powers, insufficient funds and/or dispersed funds among distinct ministries signal the need for closer collaboration (Bizarro and Alexandre 2020). Funds that are allocated only for recovery and restoration do not ensure the proper safeguarding of the cultural heritage assets as they are often aiming for specific purposes, away from risk management practices (Bizarro and Alexandre 2020).

The mismanagement of heritage sites and improper interventions in practice can contribute to their vulnerability to climate and disaster risks. The downscaling of global and regional climate projections to local-building scale is a necessary step to improve management practices and better adapt interventions to future threats (Bonazza et al. 2021). In dealing with forest fires in monument preservation, the lack of equipment for firefighting and monitoring alarms in combination with excessive electrical facilities add additional tensions on communications and rescues linked to disaster risks (Yen et al. 2015). It illustrates how different interests linked to urban development, economic considerations, and heritage protection can hamper the creation of holistic and efficient disaster management strategies. While the necessary firefighting equipment is adopted in publicly owned monuments, in the case of small or private monuments, such as those in northern Taiwan, there is a lack of funding, staff, equipment, and training programs for site managers (Yen et al. 2015). Increasing awareness and capacity-building programs are significant for heritage-driven resilience (Longworth 2014). DRM and CCA training programs are necessary for

raising awareness among public and private stakeholders, including heritage professionals, site managers, climate scientists, disaster risk managers, and local residents (Bizarro and Alexandre 2020). Raising and sharing knowledge among the various stakeholders on such topics is a way to circumvent slow political considerations and one step toward the integration of cultural heritage into risk management policies (Bizarro and Alexandre 2020).

The deficiencies in regulations, guidelines, institutional frameworks, and policies can also cause issues in their implementations, thus efficiency. Local traditional knowledge systems embedded in conservation and management practices proved their efficiency and should be better included in policies (Kandasamy 2017). The protection of agricultural heritage by inheriting and transferring local knowledge contributes to the adaptation capabilities of local communities (Guoping et al. 2021). The applicability of knowledge transfer of local history is particularly relevant in the case of floods and forest fires through their interconnections with climate change (Asprogerakas et al., 2021). The inclusion of this local knowledge in the decision-making process requires, however, an open and inclusive process in which locals are invited to contribute. Yet, the unclear and overlapping roles and responsibilities of staff of governmental and local institutions hinder the application of policies and actions, as well as the inclusiveness of the process (Asprogerakas et al., 2021). A study on the analysis of climate change adaptation policy directions in Greece of archaeological sites against four climate disaster risks, namely floods, forest fires, sea level rise and soil erosion, identified that "risk management is lagging behind prevention and adaptation" (Asprogerakas et al., 2021). National legal systems do not include national risk management plans nor climate change adaptation policies for cultural heritage. This has caused shortcomings in understanding cultural heritage as a cross-sectoral field, thus also in its integration in DRR and CCA agendas (Bizarro and Alexandre 2020) at all levels (Longworth 2014). For instance, the implementation of tools on the adaptive capacity of the historic city of Ravenna is missing, even though it is necessary for the integration of disaster risk management of cultural heritage into urban planning and for building the resilience of cultural heritage sites in the city (Rosa et al. 2021).

4.4 Opportunities

Taken together, the intersection of DRR and CCA framework provided many opportunities in developing methodologies, tools, and strategies. While some of the publications contribute to the discussions conceptually, others present strategies for policy development and change. Their contribution to the adoption of a new framework is mainly on policy tools, guidelines, and strategies for public authorities. If some of these strategies can be generic at times, the site-specific analysis can present results that are necessary for bridging the gap between DRR and CCA and building resilience of cultural heritage assets.

When it comes to supporting policy- and decision-making, the development of tools can be quite effective (Bonazza et al. 2021). The ResCUDE (Resilient Cultural Urban context to Disaster Exposure) project is one example as it serves as a knowledge tool to support spatial planning systems as well as multi-disaster prevention policies in the decision-making for emergencies (Esposito et al. 2021). While this tool could be used by decision-makers to design safer infrastructures, it could also help residents to cope with disaster risks (Esposito et al. 2021). Similarly, the quantitative assessments of urban planning tools, as is revealed in the case of the city of Ravenna at the municipal level, demonstrates how cultural heritage

can be integrated in DRM (Rosa et al. 2021). The use of storytelling is often important in this perspective, by promoting and branding heritage places for their representation as desired tourism destinations (Karzen and Demonja 2020). The development of DRM or action plan for resilient tourism can guide heritage managers and prepare them for potential crises and risks (Karzen and Demonja 2020). This bridge between different management strategies for different purposes (communication, risk management, tourism, policy-making) is of prior importance to create innovative tools, inclusive and holistic approaches, as well as raise the awareness of all stakeholders. Bringing DRM and CCA together in heritage context, the EU Horizon 2020 ARCH project, and its DRM framework, develops a standard for mutual learning with the participation of relevant stakeholders to constantly improve the framework through their contributions and validations of the tools (Lindner et al. 2021).

The application of the cost-effective analysis behind STORM policies (mentioned in 4.1) reveals the needed information to implement the cheapest options with the least intrusive interventions. This analysis could be useful in sharing and transferring information on best practices, especially after the collection of sufficient data, and it could be extended to DRM of immaterial heritage (Revez et al. 2021). A self-checklist on the risk assessment based on a five levels scoring system (from very serious with minus 2 to very good with 2) is provided for site managers to assess the disaster risk of cultural heritage sites they are managing (Yen et al. 2015). This practice would easily provide this basic background data needed on the local scale to assess the urgency of preservation plans and actions.

New technological methods and tools also support the gathering and analysis of data. The 3D modelling and 4D analysis of cultural heritage reveal the relevance of geoinformatics technologies for the data acquisition, storage, and processes (Xiao et al. 2018). In addition to data collection via laser scanning and geotechnical monitoring, complementary information coming from local expertise and traditional knowledge can assist with the creation of mitigation strategies and solutions (Margottini et al. 2017). The use of remote sensing and GIS techniques, especially in the monitoring and preservation of cultural heritage has been advantageous in the preparation of regional natural disaster risk assessment as well as in preparing emergency responses (Liu et al. 2021). With this understanding, some proposed multi-hazard assessments include GIS spatial modeling, hazard mappings, and climate model projections to provide strategies for risk mitigation (Ravankhah et al. 2019). The illustrative aspect of the maps produced through GIS techniques contributes to the accessibility of the data for the different stakeholders, thus their awareness on the risks.

Risk mapping is mostly missing when dealing with cultural heritage, yet project demonstrated its usefulness in emergency actions (Bizarro and Alexandre 2020). For example, another framework has brought together the integration of flood risk assessment at local, national, and global levels, together with the integration of social, human, and environmental capacity for changing climate, and adaptation strategies, while interlinking natural disaster risks and climate change risks (Espada et al. 2017). Such holistic perspectives led to the creation of important tools, like the Flood Risk-Adaptation Capacity Index-Adaptation Strategies (FRACIAS) Linkage/Integrated Model which is the grounding of the quantitative data on flood risks and CCA capacity, and presents input variables to examine areas with high flood risk and low capacity (Espada et al. 2017). These frameworks are important tools to consider for DRR and CCA strategies as they attempt to bring results from research into local practices to increase the resilience of historic buildings. However, they are often

implemented in projects and experiments, on specific types of hazards and on a limited scale.

There is no one-fits-all type of solution when dealing with risk reduction, climate change adaptation, and cultural heritage protection. Strategies may vary depending on the heritage site, type of disaster risks, and vulnerabilities, which is why site-specific risk management strategies are proposed for World Heritage sites (Ravankhah et al. 2021). Even though disaster types may differ in temporalities with short-or long-term effects, the use of a disaster risk index such as the Cultural Heritage Risk Index (CHRI) can be useful for the assessments of vulnerabilities of heritage assets (Forino et al. 2016). They tend to simplify the complexity of risk and heritage management systems in one rather holistic tool, easier to use for the different stakeholders. As such, it can also be useful in prioritizing interventions needed while considering the exposure, vulnerabilities, and heritage value (Forino et al. 2016).

Growing collaborations between the various stakeholders as well as between relevant institutions is key to enable efficient and adaptable risk plans. In the case of large-scale disasters, the central government plays an important role in setting objectives and guides, but it is local governments that have to respond to all types of disasters. Studies focusing on drought risk on agricultural heritage emphasize the necessary cooperation between public and private actors in tackling the issue, which refers, among others, to tourism companies and local householders (Sun et al. 2013). Local governments are particularly important in adapting to climate-related disasters as they can foster central government actions when these disasters exceed the capacity of their role (Sun et al. 2013). This latter issue is of tremendous importance in the current trend where more powers and responsibilities are given to local authorities through decentralization, but without the necessary budget to address the full extent of these new powers. Funds are usually not exclusive to risk prevention and management in cultural heritage sites but their accumulation with other funds can help support preservation actions (Bizarro and Alexandre 2020).

The answers to the challenges linked to DRR and CCA policies often relate to the political will of public authorities rather than to new legal tools and documents. STORM recommendations strongly suggest political commitments, which do not require additional legislative instruments, in reducing the risks on cultural heritage by solving funding limitations and promoting preventive measures in cultural heritage management (Bizarro and Alexandre 2020). Furthermore, building a permanent intersectoral forum can be a bridge between central government and local administrations and actors in the promotion of good practices, methodologies, and in the dissemination of knowledge (Bizarro and Alexandre 2020). The information on the vulnerability, exposure, and risks on cultural heritage should also be included in decision-making processes around the designation and listing of valuable heritage sites with citizens' participation (Bizarro and Alexandre 2020). Setting up local framework plans that include preventive measures for the cultural heritage should take territorial planning into account.

5 Discussion and conclusions

Scholars regularly emphasized the need to integrate DRR and CCA into one framework for building resilience of cultural heritage. This holistic framework is necessary to understand the interlinkages and interdependencies of the different gaps, obstacles and opportunities

identified throughout the literature. This paper analyzes literature to investigate how the use of this framework enhances resilience in the context of cultural heritage sites by considering four aspects, which are (1) the assessment of climate and disaster risks, (2) temporalities, (3) gaps, challenges, and constraints, and (4) the opportunities.

If the rise of the topic is fairly new (Fig. 1), the fact that environmental journals are preferred to discuss DRR and CCA framework (Fig. 2) proves the growing interdisciplinarity of scientific contributions. The use of new technologies linked to GIS and 3D modelling in the protection of cultural heritage sites supports this inclusiveness through collaborations and improve the precision of risk assessments. Risk assessment and monitoring emerge as the root for the management of cultural heritage within the use of the DRR and CCA framework. Although risk assessments include quantitative methods such as statistics and GIS mapping at a site level, the use of qualitative methods are also significant in complementing risk assessments by consulting communities and experts via interviews and workshops.

Community- and people-centered approaches were also found to be efficient in harnessing traditional local knowledge and skills, although hardly considered in decision-making processes. The analysis of bottom-level decisions and practices, which are often ignored in big data, can be captured by creating opportunities for the participation of local people and communities in decision-making. Narratives of local expertise in the nature-based solutions can be used not only in heritage preservation but also in the forest, biodiversity, and infrastructure management. Although collaboration and cooperation among stakeholders are emphasized by scholars, participatory approaches are rarely used as a methodology. Participatory approaches such as focus groups can be useful in measuring social vulnerabilities and prioritizing cultural heritage. Experts' judgements and local knowledge can justify the prioritization of certain cultural heritage assets and their inclusion into DRR strategies and DRM plans. The integrated management of climate and disaster risks in cultural heritage sites is meant to unlock cross-sectoral and inter-sectoral barriers to inclusive and efficient management practices.

The lack of cross-sectoral, -scalar, and collaborative work highlighted in the literature analyzed previously is the cause of a chain of reactions directly impacting cultural heritage sites. The fragmentation of decision-making is leading to a lack of communication between institutions and actors, which in turn affects the inclusiveness of decision-making processes, leading to a lack of engagement, of means, thus also of data. Eventually, guidelines and policies emerging from such processes become incomplete, inapplicable, or unsuited to on-site situations and developments. This situation partly explains the temporality problem developed in this paper, where short-term and reactive strategies are prioritized over long-term strategies aimed at anticipating risks. A few funded projects showed promising results when applying new methodologies, integrated frameworks, and scholars recommended holistic perspectives. However, they also demonstrate the complexity behind the implementation of DRR and CCA in the cultural heritage sector by requiring a great pool of experts and partners into a carefully organized consortium. These now need to go beyond the simple or small-scale experiment and be more widely adopted to understand how to better implement DRR and CCA, and increase the resilience of cultural heritage sites.

The calls for an attention to tools and development of policies, in this regard, is the key unlocking solution. Fragmented governance structures dealing with climate-induced events and other disasters and developments lead to poorly coordinated actions. Drawn from the segmentation of climatic hazards and other disasters from development policies,

national governments no longer bear the responsibilities of the destructions. Most of the time national policies and organizational structures within governments impede the integrated understanding of climate and disaster risks. This leads to miscommunication and mismanagement between heritage and disaster and climate change stakeholders. The lack of convergence of the institutions such as meteorology, hydraulic works, disaster and emergency, forestry and agriculture, urban planning, national parks, and heritage and tourism cause issues in responding to disaster risks and emergencies. Contemporary governance systems are based on shared powers to include the specific fields of each institution. Yet, often, the overall aim of policies fails to take into account all the conclusions and needs highlighted by the constellation of stakeholders precisely because these different institutions neglect communication and the advertisement of their results. The conflicting interests of the different actors are, in the end, hampering the efficiency of policies linked to DRR and CCA, especially around cultural heritage sites.

As exemplified by this systematic literature review, multiple ways forward are emerging to develop the resilience of cultural heritage sites. The gaps discussed in the literature, but also the case studies, tools, and incentives identified proved that opportunities to improve the development and implementation of an integrated framework exist. These opportunities mostly consist in:

- The inclusion, like in many other sectors such as urban planning, of anticipation in short-, medium-, and long-term temporalities in policies and strategies to better deal with disaster risks and climate adaptation;
- Giving more voices to local actors for the importance of local knowledge on the environment, in maintaining heritage sites and identifying disaster prone areas.
- Shifting away from single hazard and building-level considerations toward multi-hazards approaches on the landscape or regional scale;
- More collaborations and engagement across actors, sectors, disciplines and technologies to consider the full impact of risks and disasters on cultural heritage sites and how they evolve with climate change;
- A better inclusion of cultural heritage sites, in all their forms, in spatial planning strategies and policies;
- More diverse and comparative analysis based on multiple case studies to learn from good practices but also mismanagements and damages happening to cultural heritage sites across the globe rather than focusing on specific areas/continents;
- More research on the implementation of DRR and CCA in the heritage field to fill the lack of data and illustrate new methodologies and practices.
- Sharing the integrative practices of DRR and CCA in heritage sites can present the applicability of this framework in practice.

This set of opportunities highlights two important aspects. First, heritage studies dealing with risks, climate change, and resilience can learn and implement many tools from other sectors facing similar issues. Such a point relates to the lack of engagement discussed earlier in this paper where cross-sectoral and interdisciplinary collaborations are of paramount importance to deal with current crises and risks, but also to successfully implement a unique framework including DRR and CCA. The second major lesson that can be learnt from these opportunities, and linked the previous point, is that none of these ideas are groundbreaking.

They have been discussed for many years now in the literature. The fact that these keep on reappearing in the most recent studies demonstrate a cruel lack of implementation, thus also of lessons learnt on the limits and improvements necessary for their wide use and scalability. Therefore, beyond discussing these points, more experiments and implementation projects are needed to develop a coherent and efficient framework combining both DRR and CCA.

Funding Open Access funding provided by University of Helsinki (including Helsinki University Central Hospital). The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

References

Aktürk G (2022) A systematic overview of the barriers to building climate adaptation of cultural and natural heritage sites in polar regions. Environ Sci Policy 136:19–32

Aktürk G, Dastgerdi AS (2021) Cultural landscapes under the threat of Climate Change: a systematic study of barriers to Resilience. Sustainability 13:9974

Aktürk G, Hauser SJ (2021) Detection of Disaster-Prone Vernacular Heritage Sites at District Scale: the case of Fındıklı in Rize, Turkey. Int J Disaster Risk Reduct, 58

Aspogerakas E, Gourgiotis A, Pantazis P, Samarina A, Konsoula P, Stavridou K (2021) Corrigendum: the gap of cultural heritage protection with climate change adaptation in the context of spatial planning. The case of Greece. IOP Conf Series: Earth Environ Sci 899:012022

Begum RA, Sarkar MSK, Jaafar AH, Pereira JJ (2014) Toward conceptual frameworks for linking disaster risk reduction and climate change adaptation. Int J Disaster Risk Reduct 10:362–373

Bizarro AF, Alexandre LV (2020) STORM Policies and Recommendations – a new vision for authorities, first responders and civil protection towards an effective protection of cultural heritage. *IOP Conference Series: Materials Science and Engineering*, 949, 012108

Bonazza A, Sardella A, Kaiser A, Cacciotti R, De Nuntiis P, Hanus C, Maxwell I, Drdácký T, Drdácký M (2021) Safeguarding cultural heritage from climate change related hydrometeorological hazards in Central Europe. Int J Disaster Risk Reduct 63:102455

Bosher L, Kim D, Okubo T, Chmutina K, Jigyasu R (2020) Dealing with multiple hazards and threats on cultural heritage sites: an assessment of 80 case studies. Disaster Prev Management: Int J 29:109–128

Caballero GVA (2016) The role of natural resources in the historic urban landscape approach. J Cult Herit Manage Sustainable Dev 6:2–13

Daungthima W, Kazunorib H (2013) Assessing the Flood impacts and the Cultural properties vulnerabilities in Ayutthaya, Thailand. Procedia Environ Sci 17:739–748

Davis M, Vulturius G (2014) Disasters, climate change and development: reducing risk by tackling the drivers of vulnerability. Stockholm Environment Institute

De Masi F, Porrini D (2021) Cultural Heritage and natural disasters: the insurance choice of the Italian cathedrals. J Cult Econ 45:409–433
De Masi F, Larosa F, Porrini D, Mysiak J (2021) Cultural heritage and disasters risk: a machine-human coupled analysis. Int J Disaster Risk Reduct 59:102251
Delica-Willison Z (2015) *Disaster and climate risks aren't separate* [Online]. Council for International Development. Available: https://reliefweb.int/report/world/disaster-and-climate-risks-arent-separate [Accessed 3 June 2022]
Djalante R (2018) Review article: a systematic literature review of research trends and authorships on natural hazards, disasters, risk reduction and climate change in Indonesia. Nat Hazards Earth Syst Sci 18:1785–1810
Elo S, Kyngäs H (2008) The qualitative content analysis process. J Adv Nurs 62:107–115
Espada R, Apan A, McDougall K (2017) Vulnerability assessment of urban community and critical infrastructures for integrated flood risk management and climate adaptation strategies. Int J Disaster Resil Built Environ 8:375–411
Esposito D, Cantatore E, Sonnessa AA (2021) Multi risk analysis for the Planning, Management and Retrofit of Cultural Heritage in historic urban districts. In: La Rosa D, Privitera R (eds) Innovation in Urban and Regional Planning, Cham. Springer International Publishing, pp 571–580. *In*:
Fatorić S, Seekamp E (2017) Are cultural heritage and resources threatened by climate change? A systematic literature review. Clim Change 142:227–254
Forino G, MacKee J, von Meding J (2016) A proposed assessment index for climate change-related risk for cultural heritage protection in Newcastle (Australia). Int J Disaster Risk Reduct 19:235–248
Gaillard JC (2010) Vulnerability, capacity and resilience: perspectives for climate and development policy. J Int Dev 22:218–232
Gaillard JC (2021) The invention of disaster: power and knowledge in discourses on Hazard and Vulnerability. Routledge
Gandini A, Prieto I, Garmendia L, San-José JT, Egusquiza A (2018) In: Tanzi T, Sunar F, Altan O, Chandra M (eds) Adaptation to flooding events through vulnerability mapping in historic urban areas. International Society for Photogrammetry and Remote Sensing, pp 221–226. *In*:
Gero A, Méheux K, Dominey-Howes D (2011) Integrating disaster risk reduction and climate change adaptation in the Pacific. Climate Dev 3:310–327
Giliberto F (2021) Heritage, Disaster Response and Resilience. *In*: MacLagan H, Esther Dusabe-Richards (eds.) *Heritage and Our Sustainable Future.*
Guoping W, Lun Y, Moucheng L, Zhidong L, Siyuan H, Qingwen M (2021) The role of local knowledge in the Risk Management of Extreme climates in Local communities: a Case Study in a nomadic NIAHS site. J Resour Ecol 12:532–542
Ihinegbu C (2021) Conceptualization and management of disasters and climate change events in Africa: a review. SN Appl Sci 3:848
Iinternational Federation of Red Cross and Red Crescent Societies (2019) *Literature review on aligning climate change adaptation (CCA) and disaster risk reduction (DRR)*, Geneva, 2019
IPCC (ed.) (2022) Climate Change 2022: impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. pp.: Cambridge University Press, Cambridge, UK and New York, NY, USA, p 3056
Jigyasu R (2015) Challenges and opportunities for Disaster Risk Management of Cultural Heritage against floods. ICOMOS - Booklets German Natl Comm 60:22–29
Kandasamy K (2017) Mangroves in India and Climate Change: an overview. In: Dasgupta R, Shaw R (eds) Participatory Mangrove Management in a changing climate: perspectives from the Asia-Pacific. Springer Japan, Tokyo, *In*:
Karzen M, Demonja D (2020) Importance of storytelling: how to create more resilient Cultural Heritage? *Nova prisutnost*. XVIII:653–667
Kittipongvises S, Phetrak A, Rattanapun P, Brundiers K, Buizer JL, Melnick R (2020) AHP-GIS analysis for flood hazard assessment of the communities nearby the world heritage site on Ayutthaya Island, Thailand. Int J Disaster Risk Reduct 48:101612
Lau- Louis Cardahi Foundation (LCF) and Watch (2019) *The Centre for the Preservation and Protection of Cultural Heritage (CPCH)* [Online]. Available: https://lcf.lau.edu.lb/images/center-for-the-preservation-and-protection-of-cultural-heritage-cpch.pdf [Accessed 28 June 2022]
Leitner M, Buschmann D, Capela Lourenço T, Coninx I, Schmidt A (2020) Bonding CCA and DRR: recommendations for strengthening institutional collaboration and capacities. PLACARD project, FC.ID. PLACARD, Lisbon
Lindner R, Lückerath D, Milde K, Ullrich O, Maresch S, Peinhardt K, Latinos V, Hernantes J, Jaca C (2021) The standardization process as a chance for conceptual refinement of a disaster Risk Management Framework: the ARCH Project. Sustainability 13:12276

Liu Y, Tang Y, Jing L, Chen F, Wang P (2021) Remote sensing-based dynamic monitoring of Immovable Cultural relics, from environmental factors to the protected Cultural Site: a case study of the Shunji Bridge. Sustainability 13:6042

Longworth E (2014) The culture of Prevention: Heritage and Resilience. In: Von Schorlemer S, Maus S (eds) Climate Change as a threat to peace. Peter Lang AG, *In*:

Mansir D, Kasim N, Mat Radzuan IS (2018) An exploration of disaster risk to cultural heritage assets: towards effective conservation. Int J Conserv Sci 9:523–536

Margottini C, Bobrowsky P, Gigli G, Ruther H, Spizzichino D, Vlcko J (2017) *Rupestrian World Heritage Sites: Instability Investigation and Sustainable Mitigation*

Mercer J (2010) Disaster risk reduction or climate change adaptation: are we reinventing the wheel? J Int Dev 22:247–264

Mu L, Fang L, Liu Y, Wang C (2020) Identifying barriers and enablers for Climate Change Adaptation of farmers in Semi-arid North-Western China. Sustainability 12:7494

Mysiak J (2021) Integrating disaster risk reduction and climate change adaptation fir risk-informed and climate-smart development [Online]. United Nations Economic Commission for Europe

Nemakonde LD, van Niekerk D, Becker P, Khoza S (2021) Perceived adverse effects of separating Government Institutions for Disaster Risk Reduction and Climate Change Adaptation within the southern African Development Community Member States. Int J Disaster Risk Sci 12:1–12

Nicu IC, Lombardo L, Rubensdotter L (2021) Preliminary assessment of thaw slump hazard to Arctic cultural heritage in Nordenskiöld Land, Svalbard. Landslides 18:2935–2947

O'brien G, O'keepe P, Jayawickrama J, Jigyasu R (2015) Developing a model for building resilience to climate risks for cultural heritage. J Cult Herit Manage Sustainable Dev 5:99–114

Orr SA, Richards J, Fatorić S (2021) Climate Change and Cultural Heritage: a systematic literature review (2016–2020). Historic Environment: Policy Pract 12:434–477

Owen G (2020) What makes climate change adaptation effective? A systematic review of the literature. Glob Environ Change 62:102071

Pons O, De La Fuente A, Aguado A (2016) The Use of MIVES as a sustainability Assessment MCDM Method for Architecture and Civil Engineering Applications. Sustainability 8:460

Porrini D, De Masi F (2021) Managing climate change risk: the case of the Italian churches. Nat Hazards 105:2619–2637. https://doi.org/10.1007/s11069-020-04415-9

Prevention Web *Understanding Disaster Risk* [Online]. Available: https://www.preventionweb.net/understanding-disaster-risk/risk-drivers/climate-change [Accessed 19 May 2022]

Raju E, Boyd E, Otto F (2022) Stop blaming the climate for disasters. Commun Earth Environ 3:1

Ravankhah M, De Wit R, Argyriou AV, Chliaoutakis A, Revez MJ, Birkmann J, Žuvela-Aloise M, Sarris A, Tzigounaki A, Giapitsoglou K (2019) Integrated Assessment of Natural Hazards, including Climate Change's influences, for Cultural Heritage sites: the case of the historic centre of Rethymno in Greece. Int J Disaster Risk Sci 10:343–361

Ravankhah M, Schmidt M, Will T (2021) An indicator-based risk assessment framework for World Heritage sites in seismic zones: the case of bam and its Cultural Landscape in Iran. Int J Disaster Risk Reduct 63:102405

Revez MJ, Coghi P, Rodrigues JD, Vaz Pinto I (2021) Analysing the cost-effectiveness of Heritage Conservation Interventions: a methodological proposal within Project STORM. Int J Architectural Herit 15:985–999

Robinson S-A (2020) Climate change adaptation in SIDS: a systematic review of the literature pre and post the IPCC Fifth Assessment Report. WIREs Clim Change 11:e653

Rosa A, Santangelo A, Tondelli S (2021) Investigating the Integration of Cultural Heritage Disaster Risk Management into Urban Planning Tools. The Ravenna Case Study. Sustainability 13:872

Sassa K, Fukuoka H, Carreno R (2009) Landslide investigation and capacity building in the Machu Picchu - Aguas Calientes area (IPL C101-1). Springer Science and Business Media, LLC, pp 229–248

Sesana E, Gagnon AS, Bonazza A, Hughes JJ (2019) An integrated approach for assessing the vulnerability of World Heritage sites to climate change impacts. J Cult Herit

Simoes E, Sousa Junior W, De Freitas D, Mills M, Iwama AY, Gonçalves I, Olivato D, Fidelman P (2017) Barriers and opportunities for adapting to climate change on the North Coast of São Paulo, Brazil. Reg Envriron Chang, 17

Sun Y, Zhou H, Zhang L, Min Q, Yin W (2013) Adapting to droughts in Yuanyang Terrace of SW China: insight from disaster risk reduction. Mitig Adapt Strat Glob Change 18:759–771

Trobe PVASL (2008) Linking climate change adaptation and disaster risk reduction. Tearfund, London, United Kingdom

UNDRR (2022a) Technical Guidance on Comprehensive Risk Assessment and Planning in the Context of Climate Change. United Nations Office for Disaster Risk Reduction

UNDRR *Disaster* (2017) [Online]. Available: https://www.undrr.org/terminology/disaster [Accessed 3 June 2022]
UNDRR *Disaster risk* (2017) [Online]. Available: https://www.undrr.org/terminology/disaster-risk [Accessed 3 June 2022]
UNDRR (2022) Policy coherence between disaster risk reduction and climate change adaptation, A case study from Niger
UNESCO I (2010) ICOMOS, IUCN Managing Disaster Risks for World Heritage
UNESCO Institute for Statistics (2009) UNESCO Framework for Cultural Statistics
UNESCO, ICCROM, ICOMOS and IUCN (2010) Managing disaster risks for world heritage. *Paris, France*
United Nations Office for Disaster Risk Reduction (2020) Integrating Disaster Risk Reduction and Climate Change Adaptation in the UN Sustainable Development Cooperation Framework. 1 ed. Geneva, Switzerland
United Nations Environment Programme, Principles for Sustainable Insurance, World Wildlife Fund, United Nations Educational Scientific and Cultural Organisation (2018) Protecting Our World Heritage: The Insurance Industry's Commitment to Protect World Heritage Sites
United Nations (2021) *Website on Sustainable Development Goals* [Online]. Available: https://www.un.org/sustainabledevelopment/sustainable-development-goals/ [Accessed 24 May 2022]
United Nations (2016) *Paris Agreement on Framework Convention on Climate Change* [Online]. Available: http://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf [Accessed 24 May 2022]
United Nations (2015) *Sendai Framework for Disaster Risk Reduction 2015–2030* [Online]. Available: https://www.preventionweb.net/files/resolutions/N1516716.pdf [Accessed 24 May 2022]
United Nations Office for Disaster Risk Reduction Available: https://www.preventionweb.net/publication/integrating-disaster-risk-reduction-and-climate-change-adaptation-risk-informed-and [Accessed 6 June 2022]
United Nations Department of Economic and Social Affairs (2021) Integrated approaches to Climate Action and Disaster Risk reduction. Strengthening the Quality and Impact of Development Cooperation
Valagussa A, Frattini P, Crosta G, Spizzichino D, Leoni G, Margottini C (2021) Multi-risk analysis on European cultural and natural UNESCO heritage sites. Nat Hazards 105:2659–2676
Wen J, Wan C, Ye Q, Yan J, Li W (2023) Disaster risk reduction, Climate Change Adaptation and their linkages with Sustainable Development over the past 30 years: a review. Int J Disaster Risk Sci 14:1–13
Wu H (2018) Promoting public interest design: Green social work interventions during the Post-ya'an earthquake reconstruction and recovery in Sichuan, China. The Routledge Handbook of Green Social Work. Taylor and Francis
Xiao W, Mills J, Guidi G, Rodriguez-Gonzalvez P, Barsanti SG, Gonzalez-Aguilera D (2018) Geoinformatics for the conservation and promotion of cultural heritage in support of the UN Sustainable Development Goals. Isprs J Photogrammetry Remote Sens 142:389–406
Yen YN, Cheng CF, Cheng HM (2015) In: Yen AYN, Weng KH, Cheng HM (eds) Disaster risk management and measurement indicators for cultural heritage in Taiwan. Copernicus GmbH, pp 383–388. *In*: