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An integrated approach for assessing the vulnerability of World Heritage Sites to climate change impacts

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Abstract:
One of the most difficult problem facing those responsible for managing World Heritage Sites (WHS) is climate change, as it poses continuous new challenges to the conservation of cultural heritage. Moreover, as our climate continues to change our cultural heritage will potentially be exposed to diverse pressures and potentially to risks not previously experienced. Thus, management practices will need to be tailored in order to include climate change impacts. For climate change impacts to be incorporated into preservation frameworks and management practices from government policy level down to the practice in the field, data, information and assessment methods need to be available at a scale relevant to decision-makers. This paper presents an integrated vulnerability assessment methodology and applies it to three UNESCO cultural WHS in Europe. Through this process, semi-structured interviews were conducted with academics and experts in the management and conservation of cultural heritage, as well as with the managers and coordinators of WHS. The incorporation of bottom-up knowledge in the assessment process allowed for an understanding of the sensitivity and adaptive capacity of the sites, two components of vulnerability that are not given sufficient attention and ignored, respectively, in typical top-down climate change impact assessments. In particular, the interviews elucidated the determinants that enable or constrain the capacity to adapt, i.e., resources, including technical, economic and human; information and awareness; management capacity; learning capacity; leadership; communication and collaboration; and governance; with the lack of resources most commonly mentioned as the determinant impeding adaptation. 'Information and awareness' and 'management capacity' are determinants that were not previously identified in the field of cultural heritage. The former stresses the need to disseminate the results of scientific research for their incorporation in the management of heritage sites. Vulnerability assessments such as those performed in this paper can be used to target interventions to protect and strengthen the resilience of cultural heritage to climate change impacts.

Keywords: Climate change; cultural heritage; Europe; vulnerability assessment; World Heritage Sites

1. Introduction

Climate change as revealed by variations in, for example, temperature, rainfall and sea level, is undoubtedly having an impact on coastal erosion, the frequency of flooding and periods of heavy rain and prolonged droughts in Europe and further afield. This poses a challenge, amongst many other issues, to the preservation of our cultural heritage. The historic environment is sensitive to climatic changes and particularly to severe weather events (Phillips, 2015). Changes in environmental parameters that control physical effects such as freezing and thawing, thermal shock, or changes in humidity, are critical for the conservation and durability of materials. They can result in exfoliation, powdering, detachment, or worsening crack formation and deformation (Brimblecombe et al., 2011), causing decay with consequently loss of cultural value. Moreover, it is foreseen that in a changing climate cultural heritage will potentially be exposed to unknown multi-risk situations, posing new challenges for its safeguarding (Sabbioni et al., 2008).

Suitable actions at policy level, such as the development of adaptation and mitigation strategies, are therefore required to manage cultural heritage at risk. In spite of the worldwide awareness of the effects of climate change, research investigating and quantifying its impact on cultural heritage (Bonazza et al., 2009a) is still limited, and even more so at a scale relevant to decision-making, thereby making it difficult to incorporate climate change into preservation frameworks and management practices from government policy level down to the practice in the field. Realising the gap in knowledge in this area, the United Nations Educational, Scientific and Cultural Organization (UNESCO), for its part, demands the formation of relationships between organisations to ensure continuation of research in this direction (Colette, 2007, UNESCO 2008).

There is a lack of peer-reviewed publications specifically focusing on approaches and methods required to cope with the challenge of climate change, and this is particularly the case in the field of cultural heritage. Hence, the objectives of this paper are to develop a conceptual framework to assess the vulnerability of cultural heritage to climate change and to critically evaluate this methodological approach through its application in cultural World Heritage Sites (WHS) with different climates and heritage typologies.

2. Addressing climate change impacts on cultural heritage

UNESCO's World Heritage List includes sites that it recommends to be protected and preserved for future generations, notably from climate change impacts (UNESCO et al., 2013). This is because climate change has the potential to damage WHS, requiring remedial costs, and, in the worst case scenarios, to cause their loss (Nik et al., 2015; Sabbioni et al., 2010). The preservation of cultural heritage values and the determination of the risks threatening those values as a result of climate change is a significant challenge facing cultural heritage managers (Sabbioni et al., 2010; UNESCO et al., 2013). In order to address and monitor the risks that climate change poses, site managers require information on the current and projected risks and vulnerabilities and how those could potentially alter the physical condition and values of WHS assets (UNESCO et al., 2013). Sourcing such information requires a collaborative and interdisciplinary approach between academics, public institutions and the managers of the sites, for the identification of the values to be preserved and the potential impacts of climate change, in order to increase managers' preparedness and to strengthen the resilience of sites to climatic stressors (UNISDR, 2015, Bonazza et al., 2018).

To address the challenges of climate change for the management of cultural heritage, a vulnerability assessment is required so that heritage managers are aware of climate change impacts for their incorporation into preservation frameworks and management plans (Sabbioni et al., 2010). For cultural heritage, it is important that a vulnerability assessment methodology incorporates a participatory approach to engage with stakeholders to identify the values to be preserved, and for translating the physical impacts of climate change into risks to heritage assets. Such a framework would also need to be tested in practice in different heritage and geographical contexts, so that different types of impacts and values to be preserved are encountered.

There are different methodological approaches that can be used to assess the impacts of climate change: top-down, bottom-up and integrated approaches. The top-down approach starts with an analysis of scenarios from General Circulation Models (GCMs) to determine potential future climates and has for its objective the identification of adaptation needs. This is accomplished without engaging with the affected community. Therefore, this approach neglects the perceptions of stakeholders with respect to priority consequences and adaptive capacity. The bottom-up approach focuses on the analysis of the vulnerabilities at the local level using, for instance, surveys, interviews, focus groups and workshops to engage with the affected communities. One could simplify this classification by mentioning that the top-down approach aims to address the question: 'What are the projected impacts of climate change on a specific sector or region?', while the type of question that the bottom-up approach addresses is: 'How are the impacts of climate change affecting a community?' (Bruno Soares et al., 2012).

The third approach, referred to as the integrated approach, incorporates components from both the top-down and bottom-up approaches (Bruno Soares et al., 2012; Bruno Soares and Gagnon, 2012). It uses GCM outputs (or downscaled data from a Regional Climate Model

(RCM) or through the use of statistical downscaling) to determine plausible future climates and puts future climate change in the context of current climate risks. It simultaneously considers the social factors underlying vulnerability and how they could impact on future climate risks. In addition, the integrated approach uses local knowledge and experience to inform the vulnerability assessment process (Füssel and Klein, 2006).

The top-down approach has previously been used to assess the impacts of climate change on cultural heritage. For instance, Sabbioni et al. (2010) developed an Atlas depicting the impacts of climate change on cultural heritage in Europe using different climate change scenarios. The Atlas provides an assessment of the potential risks of a range of climatic stressors on cultural heritage, bringing together the outcomes of previous research focusing on individual climate risks (Arino et al., 2010; Bonazza et al., 2009b; Bonazza et al., 2009a; Brimblecombe et al., 2011; Brimblecombe and Grossi, 2009; Gómez-Bolea et al., 2012; Grossi et al., 2007; Sabbioni et al., 2006; Sabbioni et al., 2007; Sabbioni et al., 2008). As an example, the Atlas projects that the decay of buildings and monuments will increase under climate change in some parts of Europe but will decrease in others, depending on the projected changes in climate and the building materials prevailing in the region in question. The top-down approach has also been used to assess the risk of coastal erosion and flooding in the Mediterranean region as a result of sea level rising (Reimann et al., 2018), as well as to determine the consequences of climate change on the interiors of historical buildings in Europe and the collections they hold (Bertolin and Camuffo, 2014; Bylund Melin et al., 2018; Huijbregts et al., 2015; Huijbregts et al., 2013; Huijbregts et al., 2011; Leissner et al., 2015; Leissner and Fuhrmann, 2012; Leissner, 2011; Loli and Bertolin 2018; Tornari et al., 2013; van Schijndel et al., 2011).

A top-down approach was also used to determine the impacts of climate change in specific case studies through the development of local risk maps (HES, 2018; Ciantelli et al., 2018; Mendénez et al., 2018). Historic Environment Scotland (HES) (2018) conducted a risk assessment to identify cultural heritage sites at risk from climate change. Their assessment consisted of a GIS based analysis of the risks of flooding, slope instability and coastal erosion on the properties they manage. Ciantelli et al. (2018) depicted the impacts of different deterioration phenomena under climate change on two cultural WHS in Latin America. Mendénez et al. (2018) estimated the variation of salt weathering under climate change affecting built cultural heritage in specific locations in France. In those three cases, the risk assessment was performed without consulting with local actors.

A top-down approach allows for an examination of potential changes in climate and their impacts on cultural heritage. However, vulnerability is not only a function of the physical impacts of climate change, but is also dependent on the adaptive (or coping) capacity. Consultation with local actors could generate a more refined assessment, particularly regarding the consideration of management practices and interventions. Engaging with stakeholders also allows for an assessment of the capacity for adaptation at the sites, which in turn influences the overall assessment of vulnerability. Adaptive capacity depends on a number of determinants, including access to information and technology, availability of skilled people and economic resources (Smit and Pilifosova, 2001). It is an important component to consider in the overall assessment of vulnerability, as it determines the extent to which a community can alter its sensitivity to climate change risks. The central role of stakeholders in assessing climate change vulnerability and in particular adaptive capacity is highlighted by the Intergovernmental Panel on Climate Change (IPCC) (2007).

Most adaptation will take place at the local level, hence it is important for the analysis of vulnerability to be conducted at the same scale, a heritage site for instance, for the results of the assessment to be relevant to decision-makers. However, there is limited research investigating the vulnerability of cultural heritage to climate change at the local level, making it difficult to incorporate climate change into preservation frameworks and management practices from government policy level down to the practice in the field.

Vulnerability assessment methodologies incorporating a bottom-up component tend to focus on the analysis of vulnerabilities at the local level and are therefore more in tune with the local context. Cassar (2005) and Cassar and Pender (2005) followed an integrated assessment methodology, and hence including a bottom-up component, to assess the vulnerability of the historic environment of the East and North-West of England to climate change. Their approach consisted of examining scenarios of potential future climates together with consulting heritage specialists to identify the consequences of those changes in climate for cultural heritage.

An integrated approach to vulnerability was also used by Forino et al. (2016), Daly (2014) and Woodside (2006). Forino et al. (2016) consulted with professionals and the owners of a heritage site in Australia to determine the potential impacts of different climate change scenarios on the heritage site. Their framework focused on determining the sensitivities of cultural heritage to a given exposure and did not consider ‘adaptive capacity’. Daly (2014) followed a framework that incorporated the three IPCC components of vulnerability: exposure, sensitivity and adaptive capacity. She combined climate change projections with stakeholders’ interviews, site visits and analysis of documents to assess the vulnerability of two archaeological sites in Ireland to climate change. Woodside (2006) developed a framework, building on Schröter et al. (2005), and applied it to the Tower of London. As in Daly (2014) their framework included the three components of vulnerability, but their assessment of adaptive capacity was done through consultations of management and conservation plans as well as surveys and reports rather than conducting interviews with stakeholders.

3. Research aims

Most research to date has focused on the assessment of climate change risks to cultural heritage using a top-down approach with limited examples incorporating a bottom-up component. This paper explores the process of conducting a vulnerability assessment of cultural heritage sites to climate change using an integrated approach with a focus on the immovable, tangible cultural heritage. The objectives of this paper are to develop a conceptual framework to assess the vulnerability of cultural heritage to climate change and to critically evaluate this methodological approach through the assessment of the vulnerability of three UNESCO WHS to climate change: New Lanark (Scotland), Crespi d'Adda (Italy) and Rjukan-Notodden, two municipalities in Norway, which together form a WHS (Figure 1). To date no vulnerability assessment framework has been applied to more than one country or on more than one heritage typology.

4. The development and application of an integrated vulnerability assessment framework

4.1 Development of the framework

The vulnerability assessment framework was developed on the basis of the three IPCC components of vulnerability. Exposure refers to the climatic conditions that can negatively impact on the cultural assets (IPCC, 2014) and it is thus considered to encompass all potential climate change related risks such as gradual changes in temperature and relative humidity, as well as extreme events. Sensitivity, for its part, denotes the degree to which a cultural heritage site is susceptible to that climatic exposure (IPCC, 2007).

Adaptive capacity is a key component of vulnerability assessments (Turner et al., 2003; Schröter et al., 2005; O'Brien and Vogel, 2006; IPCC 2007). The IPPC (2014) defines adaptive capacity as the ability of a system to cope with the potential damage arising from climate change in such a way as to minimise or avoid negative consequences. "*Adaptive capacity is the outcome of a combination of determinants. These determinants represent conditions that constrain or enhance the adaptive capacity* " (IPCC 2001, p. 897). In other words, adaptive capacity is an ensemble of conditions available to cope with the sensitivities associated with a change in climate.

The IPCC (2001) identified economic resources, technology, information and skills, infrastructure, institutions and equity as the six determinants of adaptive capacity (Figure 2). Economic resources are important as accessibility to financial resources allows a community to fund adaptation efforts. Technology includes any adaptive strategy in the management of climate change that involves technology. Information and skills refers to knowledge about potential adaptation options and the capacity to identify and implement the most appropriate option (Fankhauser and Tol, 1997). Infrastructure influences the capacity to respond to changing environmental conditions, for example the presence of a drainage system capable of dealing with increased precipitation (Pelling, 1997). Institutions in developed countries can facilitate the management of climatic risks, but they are often less effective in developing countries (Smith and Lenhart, 1996). Kelly and Adger (1999) and Adger (1999) showed that adaptive capacity is higher in communities where there is an equitable distribution of resources, hence the IPCC considers ‘equity’ as a determinant of adaptive capacity.

Gupta et al. (2010) also identified six determinants of adaptive capacity: resources, variety, learning capacity, room for autonomous change, leadership and fair governance (Figure 2). The determinant ‘resources’, is not limited to financial resources, as in the IPCC (2001), but also includes human resources. Variety represents the diversity of adaptive solutions available. Learning capacity refers to learning based on past experiences dealing with hazardous climatic events. The determinant 'room for autonomous change' includes access to information and the ability to adapt independently. For instance, when a flood is imminent, the public is kept informed so that preparations can be undertaken to minimise its negative impacts. In communities where leadership encourages social responses, as well as fair governance, i.e., taking account of legitimacy, equity, responsiveness and accountability, there is higher adaptive capacity and, for this reason, Gupta et al. (2010) consider ‘leadership’ and ‘fair governance’ as determinants of adaptive capacity.

In the field of cultural heritage, Phillips (2015) identified six determinants of adaptive capacity. Three of the determinants, i.e., resources, learning capacity and leadership, were identified and defined in Gupta et al. (2010), while ‘access to information’ was mentioned under ‘room for autonomous change’ in Gupta et al. (2010) and under ‘information and skills’ by the IPCC (2001). By ‘resources’, Phillips (2015) refers to financial, human and technological resources and thus includes ‘technology’, a determinant previously noted by the IPCC (2001). The remaining two determinants are cognitive factors and authority. Cognitive factors refer to psychological factors influencing adaptation and include perceived risks and adaptive capacity (Lopez-Marrero, 2010), and approach to uncertainty. This is further supported by Burnham and Ma (2017), who found that not only do perceived climate change risks and impacts influence adaptive behaviour, but also the perceptions of the ability to adapt. Authority, for its part, refers to the availability of plans and policy instruments as well as political will (Phillips, 2015).

On the basis of the above studies, a potential list of determinants of adaptive capacity (Figure 2) was assembled as a reference for the identification of the determinants of adaptive capacity in the case study sites on the basis of the interview transcripts (see below).

A five-step vulnerability assessment framework was developed (Figure 3). The first step requires the identification of the Outstanding Universal Values (OUV) of the heritage site. Second, the impacts of climate change on the region where the cultural heritage site is located are identified. This includes an assessment of the exposure of the site to climate change and its sensitivity to the projected changes. Third, the impacts of climate change on cultural heritage are assessed at the scale of the heritage site. In this step, the assessment is not limited to exposure and sensitivity but also includes an assessment of the adaptive capacity. Fourth, the overall vulnerability is assessed qualitatively by putting together the information gathered on exposure, sensitivity and adaptive capacity. The last step consists of repeating periodically the assessment given the variability of its components over time.

The current framework was developed on the basis of the IPCC definition of vulnerability and the frameworks of Woodside (2006) and Daly (2014), which both focus on cultural heritage. The first step, in agreement with those two frameworks, consists of establishing the values of the heritage site (Table 1). The step “define the study area” in the framework of Woodside was excluded as the sites of interest to those who are applying the framework are already known and are described in the first step of the current framework. The second and third steps of the developed framework differs from the ones of Woodside (2006) and Daly (2014), as the idea behind its development was the inclusion of all available literature and tools, and, more importantly, the inclusion of bottom-up knowledge at two different geographical scales, i.e., national/regional and local, to inform the assessment process, and hence reaching experts involved in sites other than the one being examined as well as different levels of government. The last step of the current framework was also not included in previous frameworks, and was added to emphasise the importance of re-assessing vulnerability over time given the dynamic nature of its components.

The current framework aims to be simpler and more adaptable than the previously developed frameworks in the field of cultural heritage. Unlike the framework of Daly (2014), this framework does not require one to be an expert to apply it, but it does require consultations with experts working on the preservation of cultural heritage and local stakeholders to assess the sensitivity of - and the adaptive capacity at - the heritage sites. Such engagement with stakeholders is also not included in the framework of Woodside (2006).

This framework was created to provide guidance in the assessment of the vulnerability of cultural heritage to climate change. The framework also had to be sufficiently general so that it could be applied to any heritage site. This research builds on the stakeholders' engagement activities reported in Sesana et al. (2018, 2019) who found that WHS managers were not aware of any methodology to assess the vulnerability of cultural heritage sites to climate change.

4.1.1 Understanding the values of the site (Step 1)

Assessing the vulnerability of a cultural heritage site to climate change first requires an understanding of the values associated with the site. In the case of a WHS, the values of a heritage site correspond to the OUV, while for other sites, the values can be determined by consulting management plans, listing guidance and with stakeholders involved in the management and preservation of the site. Then, one needs to understand what climatic conditions can negatively impact on those values (UNESCO, 2014a). Hence, as UNESCO recommends, in the current framework, the cultural values of the site are placed in their social and environmental context (Colette, 2007).

4.1.2 Assessing the impacts of climate change on cultural heritage at the national and/or regional level (Step 2)

This step consists of collecting data on the exposure and sensitivity to climate change impacts of the wider region where the heritage site is located. Exposure is assessed through the analysis of climate change projections and the literature investigating climate change impacts on cultural heritage.

The sensitivity of the site to climate change can be assessed by reviewing the literature, for example, Sabbioni et al. (2010) and Bertolin and Camuffo (2014) provide scenarios of variations in chemical, biological and mechanical degradation of cultural heritage materials under climate change in Europe. In addition, Sesana et al. (*in preparation*) summarises the impacts of climate change on cultural heritage and develops diagrams that can be used by practitioners to easily identify the potential risks that various climatic parameters pose to cultural heritage assets.

This step also benefits from consultation with experts working on cultural heritage preservation, as performed by Cassar (2005) and Cassar and Pender (2005), to translate the potential changes in climatic variables on impacts on cultural heritage. In this step, the specific concerns and detailed impacts at the site itself do not necessarily need to be considered nor do the stakeholders consulted need to have specific knowledge of the site. This step can also inform the assessment of adaptive capacity by providing information on national policies, resources available from higher level of government and governance issues.

4.1.3 Assessing the impacts of climate change on cultural heritage at the local scale (Step 3)

The third step consists of identifying vulnerabilities at the local level. In this step, local scenarios of climate change, or regional if the latter are not available, are consulted to determine the exposure of the site to future climate change. Then, as in the previous step, the sensitivities of the heritage site to a given exposure are determined through consultations with experts and local stakeholders involved in the preservation of the heritage site. During the interviews, local issues of concern are identified as well as existing and past impacts of climatic changes. The assessment of adaptive capacity is performed in this step and this is done by categorising the interviewees' answers on the basis of the determinants of adaptive capacity identified using the procedure described above.

4.1.4 Assessing vulnerability (Step 4)

The fourth step brings together information collected from the previous steps to make an overall assessment of vulnerability. The assessment is made qualitatively with vulnerability represented by the following expression:

$$\text{Vulnerability} = f\{\text{exposure, sensitivity, adaptive capacity}\} \quad (1)$$

Vulnerability and adaptive capacity are often considered to be negatively correlated: the higher the adaptive capacity of a system, the lower is its vulnerability to climate change (Smit and Pilifosova, 2003; Fussel and Klein, 2006).

4.1.5 Repeat periodically (Step 5)

Finally, it is recommended that the application of the framework be repeated every few years, i.e., when there is a change in management or in the site condition, or when new climate change scenarios become available. Adaptive capacity at the sites is dynamic, as it is influenced by changes in the management of the site and legislation.

4.2 Application of the framework in the case study sites

The framework was used to assess the vulnerability of three industrial WHS in Europe. The three sites are located in different countries with contrasting climates and heritage typologies. The climate of New Lanark is considered a temperate oceanic climate according to the Köppen climate classification. Average temperatures range from a low of 2.0 °C in January to a high of 13.7 °C in July, hence winters are mild and summers warm, and there is no significant difference in precipitation between seasons. Crespi d'Adda has a humid subtropical climate. As for the Scottish site, precipitation does not vary significantly between seasons and winters are mild, but the Italian site experiences hot summers. Rjukan and Notodden have a humid continental climate with warm summers. Winters are cold with temperatures of only -3.9 °C on average in January, but temperatures are on average 16.2 °C in July. Thus, the selection of more than one site allowed the authors to determine the applicability of the methodology in different climates and heritage contexts. Moreover, the assessment of adaptive capacity in different locations led to a more comprehensive assessment of the factors enabling and those constraining adaptation.

4.2.1 Understanding the values of the site (Step 1)

New Lanark, Scotland

New Lanark is an industrial heritage site set in a natural landscape next to the river Clyde. The village was founded in 1786 based on Robert Owen's utopian idea of an industrial community. It consists of cotton mills and houses for the workers initially built with sandstone and wood. In later construction, the wood was replaced by cast iron columns and beam framing with brick arched ceilings overlaid by fireclay tiles in the industrial buildings. The village is managed by a Trust together with the local council and HES. The site was inscribed in the UNESCO World Heritage List (WHL) in 2001. The recognition of the site as a WHS is not only because of its historical buildings, but also the recognition of Robert Owen's model of an industrial community that influenced industrial sites all over Europe, including the two case study sites in Italy and Norway (Historic Scotland, 2013; UNESCO, 2014b; UNESCO, 2013).

Crespi d'Adda, Italy

Crespi d'Adda is a hamlet of the municipality of Capriate San Gervasio in the province of Bergamo. This industrial village was founded in 1875 and is set in natural settings between two rivers, which merge at the southern side of the village. The site was listed as a UNESCO WHS in 1995 and the municipality is responsible for its management together with the *Consorzio Parco Regionale Adda Nord*. The village is an archetype of a 'company town' with its unspoiled urban and architectural structure, as well as a paradigm of a working village of the 19^{th} and 20^{th} centuries. The industrial buildings of the site were built with brick walls, plasters, terracotta decorations and iron windows, while the residential buildings were built with mixed masonry (bricks, sandstone and conglomerate stone) and wooden windows.

The site has a high level of authenticity in comparison to other industrial sites, likely because of the remoteness of the site (Borgarino et al., 2016a, 2016b; Gasparoli and Ronchi, 2013).

Rjukan-Notodden, Norway

The Rjukan-Notodden WHS is larger than the two other sites and also more recent. The site comprises the towns of Rjukan and Notodden, and is located in a dramatic natural landscape with steep mountains, rivers, waterfalls and lakes. It was founded at the beginning of the 20th century for the purpose of producing fertilizers from atmospheric nitrogen using locally generated hydropower. The site was inscribed in the UNESCO WHL in 2015. The management of the heritage site is under the protection of a World Heritage Council, including members from the Directorate for Cultural Heritage, the county authority, the municipalities, and the Norwegian Industrial Workers Museum (Taugbøl et al., 2014). The site comprises mostly residential wooden houses and concrete structures for the industrial buildings.

4.2.2 Assessing the impacts of climate change on cultural heritage at the national and/or regional level (Step 2)

In the UK, a key source of climate change scenarios are the UK Climate Projections 2009 (UKCP09), which provide probabilistic projections for a range of atmospheric variables at a spatial resolution of 25 km. Hence, these projections were used for the Scottish site. For the other two sites, the climate change scenarios were obtained from the 'Climate Change Knowledge Portal'[1], which are available at a 1°x1° spatial resolution from 35 GCMs used by the IPCC 5th Assessment Report. The magnitude of the projected climatic changes

[1] https://climateknowledgeportal.worldbank.org/

throughout the 21th century depend on the GHG emission scenario selected and, for the purpose of this assessment, the medium GHG scenario was selected.

To determine the sensitivity of each cultural heritage site to climate change, 28 semi-structured interviews were conducted with a first group of interviewees (Group 1 in Table 2). The interviewees were academics and researchers from different universities and research centres in Scotland, Italy and Norway as well as experts involved with EU projects focusing on the theme of climate change and cultural heritage, members of governmental institutions working on the preservation of cultural heritage and managers of heritage sites (other than the ones under investigation). The expertise of the interviewees varied greatly and included anthropologists, archaeologists, architects, conservation scientists, geologists, climatologists, biologists, sustainability officers and urban planners, in addition to the managers and coordinators of heritage sites.

The interviews were transcribed and analysed using the NVivo software (Version 11, QSR International (UK) Limited, Daresbury, Cheshire, UK). Ethical approval was sought and obtained through the University of the West of Scotland procedure. The analysis first aimed at identifying the issues of concern in terms of changing environmental conditions in the region/country where the cultural heritage site is located. As an example, an increase in rainfall and landslides was of concern to the interviewees in Scotland (Table 3). Then, the sensitivity of cultural heritage to those climatic issues, as perceived by the interviewees, were identified. For example, an increase in the decay of sandstone buildings in Scotland due to increased precipitation (Table 4).

4.2.3 Assessing the impacts of climate change on cultural heritage at the local scale (Step 3)

Semi-structured interviews were conducted with the managers and coordinators of the case study sites as well as with other professionals and academics directly involved in the preservation of the heritage sites being studied (Group 2 in Table 2). The interview questions were worded so as to assess the sensitivities of - and the adaptive capacity at - the sites. The analysis highlighted the issues of concern, as identified by the interviewees, in relation to climate change in the three WHS. Table 5 provides a selected number of quotations from the interviewees, highlighting the interviewees' awareness of the exposure and the sensitivities of the sites to climate change. Table 6 presents examples of the interviewees' responses at the three WHS in relation to the analysis of adaptive capacity.

Comparing the determinants of adaptive capacity identified in the literature with the interviewees' responses, a list of determinants was identified: resources; information and awareness; management capacities; learning capacity; leadership; communication and collaboration; and governance (Figure 2). The determinant 'resources' comprises economic, human and technical resources. 'Information and awareness' include knowledge of climate change impacts on cultural heritage. 'Management capacities' is referred to as 'institutions' as in IPCC (2001). 'Learning capacity' and 'leadership' have the same meaning as in Gupta et al. (2010). 'Communication and collaboration', which were considered part of the determinant 'leadership' in Phillips (2015), here refer to international partnerships, the sharing of tools and information, and collaboration between institutions. 'Governance' has a similar meaning to 'authority' in Phillips (2015), but it does not only include the availability of plans and policy instruments and political will, but also the governance process.

4.2.4 Assessing vulnerability (Step 4)

After gathering information on the heritage values of a site, its exposure and sensitivity to climate change, and the capacity to deal with climate change impacts, vulnerability is assessed.

Exposure

For New Lanark, climate change scenarios project the climate to become warmer with an increase and a decrease in winter and summer precipitation, respectively, and a decrease in summer relative humidity. Moreover, an increase in storms, wind intensity and wind-driven rain, time of wetness and landslides is projected (Sabbioni et al., 2010).

For Crespi d'Adda, there are contrarieties amongst GCMs in their climate change projections. The models project the region centred on Crespi d'Adda to become warmer, however, some models project wetter conditions while others project drier conditions under climate change and hence the ensemble median of the projected precipitation change is near zero. In Sabbioni et al. (2010), only one climate model was used to assess the impacts of climate change on cultural heritage in Europe and, using that model, a decrease in the frequency of precipitation and an increase in its intensity are projected together with an increase in the risk of landslides.

Rjukan-Notodden is projected to become warmer while winter and summer precipitation will increase and decrease, respectively, under climate change according to the majority of the GCMs. A risk of landslides is also projected due to extreme precipitation, as well as an increase in wind, wind driven rain and the number of freeze-thaw cycles (Sabbioni et al. 2010).

Sensitivity

As a result of the projected increase in precipitation and storminess, the interviewees consulted as part of step 2 of the framework (i.e., Group 1 in Table 2) identified flash floods and landslides as potential issues of concern for New Lanark. A risk for ground instability and thus landslides was also mentioned in an unpublished risk assessment by HES as well as river flooding, although the part of the WHS that was identified to be at risk was not where the historical buildings are located (HES, *personal communication*, September 2016). Accordingly, river flooding was not perceived as an issue of concern in the interviews conducted locally as part of step 3 of the framework, but issues related to the maintenance of the retaining walls on the hillslopes were highlighted. Past failures of the retaining walls, which had put at risk part of the heritage site, were mentioned by the interviewees, as well as the potential for flash floods, ground instability and landslides. In addition, the interviewees were not concerned with the potential for long-term decay of the building materials comprising the site, as they considered the buildings to be robust. However, Bertolin and Camuffo (2014), Leissner et al. (2015) and Sabbioni et al. (2010) reported projections towards an increase in weathering of the buildings in the region where the site is located because of climate change related impacts (e.g. salt crystallization, corrosion, biomass accumulation). Furthermore, an increase in heavy rain may overwhelm roofs and gutters with a subsequent risk of penetrating damp and the associated degradation of building materials.

In Crespi d'Adda the interviewees were not concerned about climate change impacts on the site. Past floods and landslides were mentioned by the interviewees, but they occurred in areas close to the site and outside the WHS boundaries. One interviewee expressed concern for the natural heritage within the site due to tropicalization of the weather and subsequent biodiversity changes. No interviewees were aware of potential changes in the long-term decay of the historical buildings comprising the site due to changing climatic conditions. In the literature, a projected increase in salt-crystallization, 'thermoclastism' and corrosion is projected for the region where the site is located as well as a possible increase in landslides due to an increase of extreme rainfall (Sabbioni et al., 2010). It was also mentioned that the buildings on the site are perceived as robust if they are properly maintained. Some buildings deteriorated after the cessation of industrial activity because of the associated lack of maintenance, which may make them more susceptible to climate change impacts.

In Rjukan-Notodden the interviewees raised flooding, ground movement and erosion, landslides, avalanches and snow melting as issues of concern with regard to the preservation of the historical site. A gradual degradation of heritage materials under climate change was mentioned by only one interviewee, and it referred to a potential increase in the corrosion of reinforced concrete if not properly maintained. Likewise, the literature indicates potential increases in landslides and corrosion under climate change, but also an increase in biomass accumulation, fungal decay on wooden structures, and salt-crystallization for geomaterials (Sabbioni et al., 2010; Bertolin and Camuffo, 2014). Some of the buildings are built with robust materials, but others, for instance timber houses, require continuous maintenance and repairs.

Adaptive Capacity

In New Lanark the managers were aware of the potential impacts of climate change on the site. They periodically monitor the buildings and, when needed, conduct maintenance. Financially, the site is supported by a governmental institution, however, there would be issues if expensive adaptation measures were to be needed subsequent to an extreme event, for instance. The determinants that were identified as enabling adaptive capacity at this site are resources (economic, human and technical), information and awareness, leadership and governance (Table 7). However, it is suggested that the management capacity at the site could be improved by incorporating climate change in the site management plan and by sharing experiences through international partnerships.

At Crespi d'Adda, there was limited awareness of climate change impacts amongst the interviewees, notably on the influence of climate change on the long-term decay of the heritage assets. An important issue of concern was the lack of maintenance of the buildings comprising the WHS, because of a lack of financial resources and the high number of privately-owned historical buildings, as some owners cannot cope with the expenses related to building maintenance. Therefore, a lack of awareness of climate change impacts and resources were found to be the determinants constraining the capacity to adapt at Crespi d'Adda; this is in addition to the need for better governance and management capacity as described in Table 7. 'Leadership' and 'communication and collaboration', for their part, were found to be enabling adaptive capacity. However, the community engagement was not related to climate change and the managers of the site need to build partnerships, as the lack of the latter is currently a constraint to adaptation.

At Rjukan-Notodden there is good awareness of - and preparedness for - climate change impacts on cultural heritage. The heritage assets are periodically maintained and monitored and the site receives financial help from government (Table 7). However, more information and a higher level of preparedness are needed to deal with the projected increase in the gradual degradation of historical materials under climate change. Most determinants were found to enable the capacity to adapt at this site, but 'human resources' and 'information and awareness' can be improved by hiring experts with traditional skills in conservation and getting more information on the effect of gradual changes in climate on heritage decay.

Vulnerability

In New Lanark, an increase in precipitation and humidity is projected under climate change, which might cause further weathering of building materials. Although the buildings are made of robust materials, they are at risk of ground instability and landslides on hillslopes because of higher precipitation. The draining system, retaining walls and vegetation on the hillslope need continuous monitoring and maintenance. Site managers are aware of some of the potential impacts of climate change. They are periodically monitoring the heritage assets and maintenance does take place when needed. However, climate change is not included in the management plan of the site and if the site were to face a disaster, expensive adaptation might be required with a likely lack of financial resources to deal with it without external support.

The sensitivity of the Crespi d'Adda WHS is overall low with the exception of abandoned buildings, which are more sensitive to degradation caused by environmental change. However, the adaptive capacity of this site is arguably the lowest of the three sites due low awareness by managers on how the site might be impacted by climate change and hence a low degree of preparedness. Therefore, if increased precipitation were to occur as a result of climate change, and there is high uncertainty about this given the contrarieties in the projections amongst GCMs for this region, the ability to cope might be limited.

Rjukan-Notodden is projected to be exposed to an increase in precipitation, flooding and landslides, as well as a greater occurrence of freeze-thaw cycles under climate change, and hence greater weathering of the materials of historical buildings. The site comprises industrial buildings made of concrete, but also timber houses that are more sensitive to environmental stressors. Adaptive capacity at the site is good. In fact, the site is an example of best practice in the assessment of climate change impacts on cultural heritage. There is good awareness of climate change risks, because of experience dealing with past hazardous events, with the latter having led to accomplishment of a risk assessment. There is, however, less awareness of the long-term decay of the site due to potential changes in climate, as projected in literature.

4.2.5 Repeat periodically (step 5)

The outcome of the application of the framework in the three WHS constitute a baseline for future assessments.

5. Discussion and conclusion

Although historical buildings have been resilient to past climatic conditions they may become more vulnerable under climate change as changing conditions alter and accelerate decay processes. Hence, a changing climate leads to the need for risk and vulnerability assessments. Such assessments are performed to evaluate the potential risks arising from climate change for the purpose of improving adaptation decision-making, notably in terms of prioritizing conservation efforts and maintenance. Most research conducted to date used a top-down approach to assess the impacts of climate change on cultural heritage. The research presented in this paper investigates the incorporation of a bottom-up component by engaging stakeholders in the analysis of vulnerability.

This study presents the development and application of such a vulnerability assessment framework using an integrated approach. The conceptual framework was critically evaluated

through the assessment of the vulnerability of three UNESCO WHS to climate change. To the authors' knowledge, no framework has previously been applied to more than one country or on more than one heritage typology. The methodology developed as part of this paper is intended to be applicable to any cultural heritage site. The framework combines climate change projections, academic literature and bottom-up knowledge derived from interviews with academics, members of governmental institutions and managers of heritage sites.
The assessment of vulnerability using the developed framework was informed by stakeholders' perceptions of the sensitivity of - and the adaptive capacity at - the sites to climate change. The integrated approach that the framework followed identified specific vulnerabilities, which could be contextualised against large-scale top-down climate change scenarios.

An integrated approach results in a more relevant and detailed description of adaptation potential through the identification of the factors that enable (or constrain) adaptation, as determined by local stakeholders. The analysis of adaptive capacity highlighted a lack of decision-makers' awareness of climate change impacts on cultural heritage and thus also a lack of dissemination of knowledge on this topic. Specifically, awareness of the impact of extreme events, such as flooding, was higher in comparison to awareness of the consequences of gradual degradation due to long-term climate change. Step 2 of the framework helps to overcome this barrier by encouraging communication between site managers and experts working on preserving cultural heritage. The latter can facilitate adaptation by providing reliable information not only on climate change impacts but also on adaptive responses, including technical assistance, which was found to be a constraint to adaptation in this study and in previous research on cultural heritage (Sesana et al., 2018; Fatorić and Seekamp, 2017; Phillips, 2015, 2014). Moreover, as climate change is rarely incorporated in the management plans of cultural heritage, it is hoped that the application of this framework can facilitate its incorporation (Bonazza et al., 2018). Furthermore, it was found that it is misleading to believe that adaptation is solely a local response as it requires significant resources and hence often support from national government. Governments can also implement regulations to encourage adaptation and the way it is informed and implemented.

The application of the framework also identified some limitations of the available tools projecting climate change impacts. For example, there is a difficulty in interpreting projections when they differ between models. There is also a question as to whether such tools provide sufficient details, for instance on the frequency of some climatic events. In some cases, the resolution of the tools was seen as insufficient to provide data at the specific site scale, for example when sites are located at boundaries between different zones with different climate change projections. Uncertainty in - and difficulty in using - climate change projections because of the lack of availability of a user-friendly interface and the lack of detailed information are commonly referred to in the literature (Sesana et al., 2018; Carmichael et al., 2018; Phillips, 2014). Moreover, studies that used climate change projections to assess the impacts on cultural heritage, such as Sabbioni et al. (2010) and Bertolin and Camuffo (2014), provide key information for informing the assessment of vulnerability, and the next step would be to provide more detailed information at the scale of the heritage site. Ciantelli et al. (2018) and HES (2018) did further research in this direction by developing local scale risk maps, but more work still remains to be done. In addition, it is also recommended that further research should be conducted on the applicability of the methodology applied in this paper to natural WHS and particularly to areas where cultural and natural heritage are mixed. In fact, during the application of this framework, some interviewees highlighted the interconnections between the natural and the cultural heritage in the case study sites.

The framework was designed to be applied without the figure of an 'expert assessor' in a way to be suitable for application in any cultural heritage sites. This may include sites with sparse technical or economic resources, or where there is low awareness of climate change impacts. The framework can be applied in different contexts and to different heritage typologies, it can be modified and implemented further by the stakeholders using it or it can be integrated within existing risk assessments.

The framework was developed to help site managers and decision-makers. This new understanding should help improve knowledge of the impact of climate change on cultural heritage sites and aid site managers and decision-makers to include the outcomes of vulnerability assessment in sites management plans. This information can be used to develop targeted interventions aimed to drive the development of new conservation strategies that incorporate climate change risk assessment into the management of the sites. The step subsequent to a vulnerability assessment is the identification of adaptation measures to cope with the identified vulnerabilities. Further research should then be undertaken to investigate the process of adapting cultural heritage to climate change.

Acknowledgements

We thank all the interviewees who participated in this study as well as HES for the information provided. We are also grateful to the Institute of Atmospheric Sciences and Climate, National Research Council of Italy (ISAC-CNR) and the Norwegian University of Science and Technology (NTNU) who both hosted the first author for a month, and the

Scottish Funding Council via the Scottish Alliance for Geoscience, Environment and Society (SAGES) who funded those two academic visits.

Conflicts of Interest: The authors have no conflict of interest to declare.

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Captions for figures

Figure 1. Location of the case study World Heritage Sites

Figure 2. Determinants of adaptive capacity

Figure 3. Conceptual framework to assess the vulnerability of cultural heritage to climate change

Captions for tables

Table 1. Comparison of the developed framework with previous frameworks assessing the vulnerability of cultural heritage to climate change

Table 2. Number and categories of stakeholders interviewed

Table 3. Climatic issues and natural hazards of concern to cultural heritage assets in the study countries as indicated by the interviewees

Table 4. Issues leading to the decay of cultural heritage as identified by the interviewees in the three study countries

Table 5. Selected interview quotations in relation to the exposure and sensitivity of the case study
sites to extreme events and gradual changes in climate.

Table 6. Selected quotations from the interviewees that were used to determine the determinants of
adaptive capacity

Table 7. Assessment of adaptive capacity at the three World Heritage Sites