Peer-reviewed version available at *Geosciences* **2018**, *8*, 322; doi:10.3390/geosciences8090322

Title: Review of potential risks factors to cultural heritage sites and initial modelling for adaptation to climate change

Authors: Paul Carroll[1] & Eeva Aarrevaara[2]

1: Lahti University of Applied Sciences, Niemenkatu 73, 15100 Lahti, Finland
paul.carroll@lamk.fi
2. Lahti University of Applied Sciences, Niemenkatu 73, 15100 Lahti, Finland
eeva.aarrevaara@lamk.fi

Abstract

There is a range of local weather and climate-related factors that contribute to the degradation of cultural heritage buildings, structures and sites over time. Some of these factors are influenced by changes in climate and some of these changes manifest themselves though a speeding up of the rate of degradation. It is the intention of this paper to review this situation with special reference to the Nordic Countries, where typical trends resulting from climate change are shorter winters and increased precipitation all year round. An attempt is made to initially draw up a classification of materials and structures relevant to cultural heritage that are affected, with a proposed numeric scale for the urgency to act. The intention is to provide information on where best to concentrate cultural heritage site preservation resources in the future.

Key words: Cultural heritage, Preventative conservation, Climate change, Mitigation, Adaptation, climate modelling

---

Introduction

There is a range of local weather and climate-related factors that contribute to the degradation of cultural heritage buildings, structures and sites over time. Some of these factors are influenced by changes in climate and some of these changes manifest themselves though a speeding up of the rate of degradation. The authors will be looking at existing literature from relevant geographic areas and especially concentrating on models proposed, which may contain promising methodology for testing to contribute to the body of knowledge to apply to preventative conservation in Finland. The emphasis will be on built heritage and structures constructed from all materials most commonly used in the Nordic Countries.

Researchers in this multi-disciplinary area usually tend to concentrate on particular aspects of either the mechanisms of climate change, or its effects on particular material groups. While it is the intention here to refer to a range of these, the emphasis will be on approaches relevant to Southern Finland, either sub-arctic or warm summer continental climate (according to the Köppen system), here typical trends resulting from climate change are shorter winters and increased precipitation all year round. While several of the studies referenced occurred under different climate zones, the adaptability of the methodology, and thereby the relevance of the results of these to the region of special reference in the present study will be

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 July 2018 doi:10.20944/preprints201807.0068.v1

Peer-reviewed version available at Geosciences 2018, 8, 322; doi:10.3390/geosciences8090322

reflected on in each case. Our interest on cultural heritage sites is also connected with UNESCO global geopark concept in which the valuable geology, cultural heritage and liveability of the area are reviewed together. This perspective requires not only the preservation and sustainable use of the geologically valuable formations but also the need to promote the maintenance and sustainability of the cultural built tradition in the area together with development of geotourism and environmental education. Global Geoparks network (2018). Visitors to geoparks in this network expect to experience both natural geological features in their natural form, as well as cultural heritage existing as a result of human activities, reflecting the special features of the region, how people through time have used the local natural features of their region to make a living and express themselves.

UNESCO (1972) distinguishes between two types of tangible cultural heritage, there are moveable, paintings, sculptures, coins and manuscripts; immovable, monuments and archaeological sites, and then also those of the underwater variety. Ethnography divides cultural tradition into material (buildings, artefacts, etc.) and immaterial (culture, customs, ceremonies, storytelling, music, etc.). This study will deal with the immovable type of cultural heritage above the surface.

Potential risk factors to cultural heritage

The range of elements in local weather that are being and will be potentially altered as a result of global level climate change is not always agreed on, but there is general consensus on those which could be damaging to aspects of cultural heritage. Brimblecombe (2014), referring to the increasingly damp English climate lists the following five: 1. Rainfall 2. Flooding and soil moisture content 3. Extreme weather (winds and rainfall) 4. Temperature and relative humidity 5. Pests and diseases (humidity and temperature affect pests). Humidity prevents wooden and brick buildings from drying during certain periods of the year, leading to structural stress.

Lemieux et al (2017) refer to Last Chance Tourism (LCT), but interpret the increased interest in it as being based on perceptions of climate change and specific aspects such as glaciers melting and icecap ice retreating; the central idea of the concept being that people are motivated to visit places while they still exist in the present form. Forino et al. (2016) give a longer list of nine categories of climate change-related impacts to cultural heritage, referring specifically to Australia. This paper first generally summarises them as fitting into the three categories based on how their effects come about, these are: meteorology, hydrology and climatology. Meteorology refers here to different types of storms, and climatology to extremes of temperature. The longer list itemises 1. Various types of physical damage, 2. Soil instability, 3.Susceptibility to changing soil moisture, 4. Changes in hydrology, 5. Changes in humidity cycles, 6. Changes in vegetation, 7. Migration of damaging pests, 8. Climatic zone movements impacting cultural landscapes and 9. Changing economic and social patterns of settlements.
Philips (2014) interviews a range of professionals involved with UK World Heritage sites in order the assess, firstly, how climate change was taken into account in preservation plans and, secondly, how those working with these sites are informed

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 July 2018 doi:10.20944/preprints201807.0068.v1

Peer-reviewed version available at Geosciences 2018, 8, 322; doi:10.3390/geosciences8090322

or react to the information provided to them on climate change considerations. Since 2006 it has been a requirement for the management of sites in this network in the UK to have not only an appropriate management plan for their protection for future generations, but specifically one for dealing with the possible impact of climate change. The range of reactions obtained from the interviewees fitted into five categories: not knowing what information they receive is relevant or reliable, uncertainty about the whole science of climate changes, a lack of availability of the skills or knowledge needed to act, difficulties with risk perception and getting others motivated about climate change issues and lastly the challenge of devoting additional time or financial resources to cope with climate change challenges. Accordingly, Philips observed that the obstacles identified in her study as a whole have slowed down climate adaptation in the management of UK World Heritage sites, and that mainstreaming of such considerations is required and will be able to happen if climate change impact is dealt not with as a separate issue of its own, but rather within the context of other risk preparedness.

In another publication Philips (2015, 118-121) introduces the concept of adaptive capacity of cultural heritage under the impacts of climate change. Adaptive capacity is an approach to investigating the state of the management of cultural heritage sites in consideration of climatic change. The key determinants of adaptive capacity are defined as 1. Learning capacity, 2. Room for autonomous change, 3. Access to resources and 4. Leadership in an institution. The qualitative research material was gathered from persons engaged with management of different heritage sites in the UK that had suffered from severe weather event impacts in the previous five years. Based on the results obtained the concept of adaptive capacity was divided into six different factors: resources, access to information, authority, cognitive factors, learning capacity and leadership. (Philips 2015, 122.) This concept creates a wider framework in which risk assessment is an important factor and must be combined with other competences to manage successfully cultural heritage under climate change.

According to Kaslegard (2011, 9) increasing strain will effect buildings with cultural value. A warmer and damper climate will cause deterioration of building materials. Coastal buildings face the impacts of sea level rise, flooding and erosion. In general more extreme weather events will cause more acute damage to traditional buildings. Due to climate change impacts the management of cultural heritage will face new challenges. It is suggested that more attention will need to be paid to the identification, documentation and mapping of those heritage sites that are most vulnerable from the point of climate change. More intensive maintenance and coastal defence methods will be needed as future actions.

Arctic regions are predicted to face the greatest increase of warming in winter time. The temperature is expected to rise by 3-4° by 2050. The rainfall in Nordic countries will increase by about 10 % on an annual level. Exceptionally, the west coasts of Norway and Finland might face as much as a 20-30 % increase in rainfall in winter periods. At least extreme rainfall events are expected to appear more frequently in the whole Nordic area in the future. (Kaslegard 2011,11) For example, in Norway two out of three cases of building damage is classified to be caused by humidity affecting

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 July 2018 doi:10.20944/preprints201807.0068.v1

Peer-reviewed version available at Geosciences 2018, 8, 322; doi:10.3390/geosciences8090322

the outer surfaces of buildings, such as roofs, facades and floors in contact with the ground. All kinds of building materials suffer from high humidity while in Nordic countries the building tradition is mostly based on timber constructions. Impacts of rainwater and meltwater are also identified in wooden buildings, causing favourable conditions for example for fungal growth, different pest damage and biological growth, such as mosses and algae, while water penetrates into the building through different surfaces. (Kaslegard 2011, 15-16)

Physical disintegration means the decomposition of materials into smaller fragments; that is typical for example with traditional brick buildings. In practise this can be caused by frost damage or salt crystallisation; which both cause damages to the appearance of the building. The character of the frost damage can be described through the freeze/thaw cycle, meaning the phenomenon when the temperature falls below zero and then climbs to over 0°C again. Considering both freeze-thaw cycles and wet frost, most parts of Finland, the inner and northern part of the Scandinavian Peninsula and the Arctic regions are likely to face greater risks of frost damage, although the risk will remain at a moderate level. The salt crystallisation is likely to grow in all Nordic countries because the increase of humidity brings the salt out from the built structures more easily. (Kaslegard 2011, 17-18.)

Cultural heritage buildings, especially old industrial buildings, but also other types of buildings contain metal building elements like iron beams, iron bolts and wall anchorages in stone or brick walls, as well as roofing and guttering of copper or zinc. Chemical decomposition causes corrosion in these kinds of structures and might also affect the stone and brick structures of the building. Corrosion together with humidity and temperature is a threatening combination. Although, it has been noted that the previous acid rain due to SO_2 pollution is not any more as serious a problem as it used to be in earlier decades. (Kaslegard 2011,18.)

Cultural heritage will face several threat factors caused by climate change, but one can also conclude that the traditional building materials and structures have capabilities to recover more easily from heavy rain events and flooding. Usually the structures are more permeable, which ensures natural ventilation and helps with drying out. (Kaslegard 2011,23.)

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 July 2018 doi:10.20944/preprints201807.0068.v1

Peer-reviewed version available at *Geosciences* **2018**, *8*, 322; doi:10.3390/geosciences8090322

Table 1. Causes, results, models and proposed scale of urgency for acting

Climate change Category	Measure or scale	Result/effect	Materials /structures affected	Proposed Urgency rating*
Warmer climate	° C/ a			
		Freeze –thaw damage	Stone Brick	3
		Rust	Metal	5
		New fauna – pests	Wood	5
Longer growing season	Days/a	New/increased flora, algae, moss, root damage	Wood Brick	
Increased precipitation: rain or snow	mm/a			-
		Humidity	Wood Brick structures	10
	mm/a			-
		Increased loads (snow)	Wood Brick	10
		Soil and material degradation	Foundations, base floor	5
		Flooding (due to any increased precipitation effect	Wood Brick structures	10
Severe rain incidents	mm/h	Erosion	Wood Brick stone	5
Extreme winds	m/s	Damage to structures through falling trees etc.	Wood & brick structures	5

**Key to numeric scale given in table 2 below*

Modelling for mitigation and adaptation to climate change

Forino et al. (2016) present the Cultural Heritage Risk Index (CHRI), which gives a score from 1 –next to no risk to 10 the greatest risk of loss of cultural heritage assets. It is designed to be applied to particular sites and first takes three categories of analysis: hazard analysis, exposure analysis and vulnerability analysis. The findings from these are then combined and subjected to a risk analysis to give the result. Hazard analysis is stressed more in scoring on the ration between the three initial analysis types is 5:3:2.

Rajčić et al. (2018) as part of the EU research project Climate for Culture propose and describe an innovative method for assessing climate change impact, but apply it to a specific aspect of cultural heritage, namely to wooden buildings. Nevertheless, their methodology contains a number of aspects that are relevant and transferable to other materials. Here the regional atmospheric REMO model was used, which was developed at the Max Planck Institute for Meteorology Jacob (2001).

Modelling of different kinds of environmental hazards is also connected with disaster risk reduction (DRR) and disaster risk management (DRM) in order to reduce the impacts of different disasters, like severe climate change impacts. In 2005 the Hyogo Framework for Action (HFA) 2005-2015 was introduced as the first international model for Building the Resilience of Nations and Communities to Disasters (Hyogo Framework). The strategy launches five different priorities of action, like national and local priorities connected with institutions, the use of knowledge, innovation and education to support culture and resilience, reducing the underlying risk factors and strengthening of disaster preparedness in all levels to minimise the impacts. Priority action 2. concentrates on identifying, assessing and monitoring disaster risks and enhancing the early warning of them. These viewpoints can be adapted successfully to modelling and adaptation of climate change.

Romãoa & al. (2016, 697-699) conclude that a framework adaptable to risk assessment in the built environment needs to involve the following viewpoints: (1) reliable and sufficient data to establish suitable hazard models;(2) sufficient and reliable data on the assets under risk;(3) suitable procedures to model the vulnerability;(4) adequate models to predict the multidimensional consequences of the hazardous event and (5) sufficient human, time and economic resources. It is recognised that there is often a lack of adequate models to predict impacts as well as a lack of sufficient resources. They also conclude that it is important to have a simple methodology adaptable to preliminary risk analysis, especially in the case of cultural heritage. A qualitative approach is suggested as a usable method to evaluate multidimensional risks in the cultural environment, due to its complexity. Understanding the behaviour of cultural heritage sites and structures are more important than detailed measurements of the objectives when developing a simplified model for practical use.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 July 2018 doi:10.20944/preprints201807.0068.v1

Peer-reviewed version available at Geosciences 2018, 8, 322; doi:10.3390/geosciences8090322

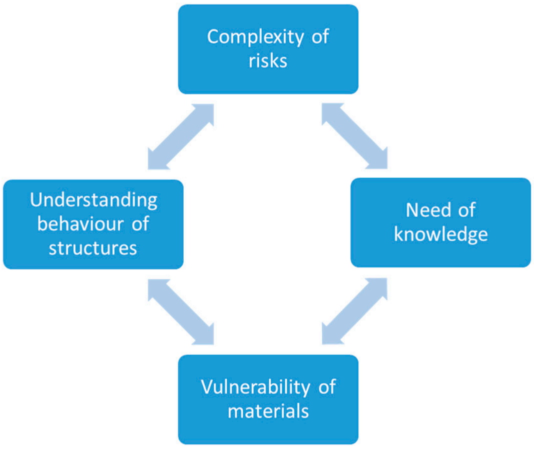

Figure 1. Elements having impact on a practical based model

One of the principal materials of interest in this study is stone. Hambrecht & Rockman (2017) point out that although stone is considered a very strong material and one that is resilient in the face of climate change, that this is not always the case; they refer to several study projects (Goudie 2016 etc.) that reveal worrying vulnerability of stone under the influence of variables such as moisture and vegetation. The type of rock is another relevant factor and softer stones such as limestone and soapstone are eroded much more quickly (Geological Survey of Finland 2006). While the predominant stone type in Fenno-Scandinavia is hard granite, there are also natural occurrences of softer stone types.

The model being proposed here is intended to serve the purpose of prioritising cultural heritage elements and sites for protection against the ravages of climate change and partially identifying adaptation and / or mitigation steps.

Then by combining elements of the modelling methods outlined above, and illustrated in summary in Figure 1, the following is suggested as a means of evaluating the relative risks to different materials. A scoring system from 0-10 which can apply to either individual materials or to an entire structure or site and takes into account both the vulnerability of the item in question and over how long a scale potential damage to it may have effect, then how severe this effect is likely to be.

Table 2. Proposed scale for urgency to act with particular materials /cultural heritage site

0	No effect or close to insignificant effect over a period of 100 years
1	A mild or minor perceivable long term effect (100 years or more)
3	A major perceivable long term effect
5	A mild or minor perceivable short to mid-term effect (1-99 years)
10	A major short to mid-term effect

 doi:10.20944/preprints201807.0068.v1

Peer-reviewed version available at Geosciences 2018, 8, 322; doi:10.3390/geosciences8090322

Discussion and conclusion

In predicting and planning to combat he detrimental effects of climate change on cultural heritage sites we are faced with many unknowns: it is not clear by what scenario climate change will proceed, meaning somewhere from the optimistic slower rate to a pessimistic more rapid and intense one. Projections are currently being generated by different Global Climate Models (GCMs) hosted by different research institutions, each with its own formulation of the atmospheric flow dynamics and physics.

Four Representative Concentration Pathways (RCPs) have been considered in the fifth Assessment Report (AR5) (Taylor et al., 2012) of the Inter-Governmental Panel on Climate Change (IPCC) (IPCC, 2013). These Greenhouse Gas (GHG) concentration (not emission) trajectories, all considered as realistic, are used by modellers as atmospheric system forcing for generating climate response and change projections. The RCPs, namely RCP2.6, RCP4.5, RCP6.0 and RCP8.5, have been defined according to their contribution to atmospheric radiative forcing in the year 2100, relative to pre-industrial values. RCP4.5 is based on active GHG emission reduction interventions that could lead to a ceiling of approximately 560 ppm (a doubling of concentrations since the start of the industrial revolution) by the year 2100, while concentrations could stabilise or even decrease after the year 2100. (IPCC, 2013). The RCP4.5 and RCP8.5 trajectories are associated with CO2 concentrations of approximately 560 ppm and 950 ppm, respectively, by the year 2100 (Riahl et al., 2011).

The local weather changes will also vary in terms of amounts of precipitation and extremes of temperature, storms and so on; then the predictions for how various materials, here in particular all traditional materials that are typical elements of Nordic cultural heritage (wood, brick, stone), will react contain uncertainties. Nevertheless, it is still possible to at least initially classify these risks using indexing methods, then based on what the risks are perceived to potentially be, models can be drawn up for how to deal with them and as a whole serve to reduce the levels of uncertainty involved.

It can be concluded that the natural processes which lead to the deterioration of cultural heritage features will as a whole increase in their effect as a result of climate change; there will also be new potential threats involved. Many unknowns remain as to the relative influence of certain factors on particular materials and although predicting these is difficult, there is a benefit from using models and attaching them to different scenarios for how severe climate change could be. Furthermore, an awareness of the relative urgency to react to threats to different building materials and types of structures can help in planning to protect them on time. Although the numeric scale for this purpose provided above, and the respective classifications into climate change threats and material features all contain approximations, it still may as a whole contribute to the planning process towards mitigation of the effects of climate change on cultural heritage, and to the appropriate adaptation to these changes.

Furthermore, even if risk analysis provides important information about the possible occurrence of damage involving cultural heritage, the vulnerability should also be regarded as one aspect in a larger context of management of cultural sites and buildings. The preconditions to a successful management system are being able to secure the preservation of cultural heritage and to indentify other actions needed to prepare and mitigate for the damage likely caused by changing climate conditions.

References

Brimblecombe, P. 2014. Refining climate change threats to heritage. Journal of the Institute of Conservation Vol. 37, Is. 2 [accessed 4 Jun 2018] Available at: https://doi.org/10.1080/19455224.2014.916226

Daly, C., 2016. The design of a legacy indicator tool for measuring climate change related impacts on built heritage. Heritage Science 2016 Jun 9, Vol.4: [accessed 4 Jun 2018] Available online at: https://heritagesciencejournal.springeropen.com/articles/10.1186/s40494-016-0088-z

Forino, Giuseppe. MacKee, Jamie. Von Meding, Jason 2016 A proposed assessment index for climate change-related risk for cultural heritage protection in Newcastle (Australia) In International Journal of Disaster Risk Reduction 19 2016 pages 235-248 [accessed 4 Jun 2018] Available at: https://doi.org/10.1016/j.ijdrr.2016.09.003

Geological Survey of Finland/ Geologian tutkimuskeskus 2006. Retkeilijan kiviopas (In Finnish) Available at: http://tupa.gtk.fi/julkaisu/erikoisjulkaisu/ej_060.pdf

Goudie, A.S. 2016. Quantification of Rock Control in Geomorphology. Earth Sciences Reviews 59: 374-387

Global Geopark Network [accessed 21 Jun 2018] Available at: http://www.globalgeopark.org/

Hambrecht, G. ; Rockman, M.: 2017. Approaches to Climate Change and Cultural Heritage. American Antiquity International 1 October 2017, Vol.82(4), 627-641

IPCC, 2013. Climate Change 2013 –The Physical Science basis- Chapter 9: Evaluation of climate models. Available at: http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter09_FINAL.pdf

United Nations International Strategy for Disaster Reduction. 2018 Summary of the HYOGO framework for Action 2005-2015 [accessed 26 Jun 2018] Available at: https://www.unisdr.org/files/8720_summaryHFP20052015.pdf

Jacob, D., 2001: A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin. Meteorology and Atmospheric Physics, Vol.77, Issue 1-4, 61-73 [accessed 4 Jun 2018] Available at: https://www.remo-rcm.de/059966/index.php.en

Kaslegard, A. 2011: Climate Change and Cultural Heritage in the Nordic Countries. TemaNord 2010:599. Nordic Council of Ministers. Copenhagen: Rosendahls Bogtrykkeri AS.

Lemieux, Christopher J. ; Groulx, Mark ; Halpenny, Elizabeth ; Stager, Heather ; Dawson, Jackie ; Stewart, Emma J. ; Hvenegaard, Glen T.: 2017."The End of the Ice Age?": Disappearing World Heritage and the Climate Change Communication Imperative In: Environmental Communication 08 December 2017, 1-19 [accessed 4 Jun 2018] Available at: https://doi.org/10.1080/17524032.2017.1400454

Philips, Helen (2014) Adaptation to Climate Change at UK World Heritage Sites: Progress and Challenges. The Historic Environment Vol. 5, (3), 288-299 | Published online: 16 Oct 2014 [accessed 4 Jun 2018] Available at: https://doi.org/10.1179/1756750514Z.00000000062

Philps, Helen. 2015. The capacity to adapt to climate change at heritage sites - The development of a conceptual framework. In Environmental Science and Policy 47 (2015) 118-125. | Published online: 16 Oct 2014 [accessed 4 Jun 2018] Available at: https://doi.org/10.1016/j.envsci.2014.11.003

Rajčić, Vlatka ; Skender, Ana ; Damjanović, Domagoj: 2018. An innovative methodology of assessing the climate change impact on cultural heritage. International Journal of Architectural Heritage 02 January 2018, Vol.12 (1), 21-35 [accessed 4 Jun 2018] Available at: https://doi.org/10.1080/15583058.2017.1354094

Romãoa, X., Paupério, E., Pereiraa, N. 2016. Journal of Cultural Heritage 20; 696–708

UNESCO, 1972. Convention concerning the protection of the world cultural and natural heritage, United Nations Educational, Scientific and Cultural Organisation, Adopted by the General Conference at its Seventeenth Session, Paris,16 November 1972.