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TOWARDS SUSTAINABLE HISTORIC CITIES: ADAPTATION TO CLIMATE CHANGE RISKS[1]

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Abstract. During last decades, the international community has become aware of the need to adapt to the effects of climate change, as the sensitivity of natural and human systems gained relevance. Europe is one of the most urbanized regions, accounting for a 73% of people living in urban areas. This share, together with the increase of urban land take, has concentrated the fight against climate change in cities, which are considered as one of the most vulnerable areas.

European cities are characterised by a wide range of cultural heritage, which is commonly located in what is defined as the historic city. In order to protect urban heritage from a changing environment, emphasis should be given to the integration of conservation management and urban planning strategies, within wider goals of local sustainable development.

Historic cities have a great potential in contributing to local economy and enhancing investment climate. Modern conservation strategies need to address a balance between urban growth and quality of life in a sustainable way. They should match the interrelationships of existing building stock, spatial organization, natural characteristics and social, cultural and economic values. Furthermore, the need to address a new generation of strategies, adapted to new climatic scenarios, should be considered as a priority for an effective management of the whole city.

The proposed paper presents research results of the ADVICE project, based on a multiscale approach for the management of climate change impacts on cultural heritage located in the urban context. Vulnerability is addressed for different types of heritage, both at urban or building scale, considering their singularities as well as the context in which they are included. This will permit addressing the overall urban scale, together with data at structure level. Adaptive measures in general can be of a preventive character and improve resilience yet they can also offer preparative support when dealing with the anticipated effects of climate change and extreme events. In order to be effective, they need to be addressed according to the typology of object to be protected and to the scale of the impact or disaster they are facing.

Vulnerability mapping is one of the first steps in clarifying the challenges which climate change pose for a city and its stakeholders. Assessment of climate change impacts and vulnerability vary widely, depending on the subject, time frame, geographic coverage and purpose of the assessment. KPIs are therefore needed to address the overall as well as the specific vulnerability and exposure for risk scoring, in order to propose effective adaptive measures.

[1] *This research was supported by the project ADVICE: Infrastructure and buildings adaptation to climate change, which has received funding from the Basque Government*

Information is supported by a data model for the creation of an evidence-based decision making platform, which will contribute to a more educated and data-driven decision making process. This will permit eliminating one of the barriers to the effective implementation of climate change adaptation strategies by cultural heritage managers and public authorities.

Keywords: climate change, historic cities, cultural heritage, sustainable cities

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1. Introduction

During last decades, vulnerability of cities towards climate change has become evident and the need to adapt to new challenges gained relevance. In order to limit negative effects of climate change, mitigation - focused on the reduction of greenhouse gas emissions - has been addressed worldwide. Nevertheless, mitigation strategies have resulted as insufficient and major efforts are required. According to the IPCC, adaptation is a necessary strategy at all scales to complete climate change mitigation efforts.

Climate change has become an increasing urban problem, as the growth in population and urban land take contribute to cities' vulnerability (. Beyond physical risks, caused by increased incidence and intensity of extreme weather events, cities will have to face challenges related to specific socio-economic and cultural conditions. The impact on historic cities, which are already facing major functional, environmental and socio-economic problems (e.g. ageing, physical and functional obsolescence and lack of economic development), may lead to accelerated degradation or loss of cultural heritage. Cultural heritage, comprising its tangible and intangible components, constitutes a key resource for local communities and accounts for complex interactions which need be addressed in urban planning practices. Historic cities are required to respond to new needs by transforming themselves into resilient systems. Besides, conservation, which is based on the management of change, should consider the impacts of climate change as one of the most significant global challenges today.

In its communication "*An EU strategy on adaptation to climate change*" [1], the Commission recognizes the urgency for implementing adaptation measures to deal with climate impacts on vulnerable sectors, reaffirming the commitment to promote urban adaptation strategies. Cultural heritage, as a sensitive element in the urban context, needs specific tools and methodologies for its inclusion, as a fundamental feature, in the whole city climate adaptation strategy.

Climate change adaptation has broadened its concept, shifting from the management of the direct manifestation of climate change hazards, to risk-based approaches. These incorporate an assessment of vulnerability and capacity to adapt to hazards. Vulnerability assessment is often based on a large scale and buildings are not considered as part of the urban environment. Besides, conservation is often developed on the operational scale of a monument or site. Management of cultural heritage requires an urban approach which considers all the elements and buildings as part of the urban environment. This paper presents the results of a research integrating the operational as well as the urban scale, through the development of an iterative risk assessment method. Multilevel indicators (urban, building, element) have been developed, according to the procedure established by the IPCC, which considers hazard, vulnerability and exposure. The analysis, complemented by stakeholders' involvement, allows mapping the vulnerability to climate change hazards and developing complex adaptation strategies.

2. Climate change risks evaluation and impacts on cultural heritage

Risks on heritage sites are dependent on nature, specific characteristics, inherent vulnerability and geographical location.

In cultural heritage it is possible to differentiate two main typologies of risks: on the one hand, the ones considered as chronic, which produce a cumulative degradation. On the other hand, the ones usually known as catastrophic, which occur accidentally and generating severe damages which may lead to the loss of cultural heritage. As a consequence of climate change, both chronic and catastrophic events are increasing in frequency and intensity, leading to new or accelerated degradation mechanisms and increase in cultural heritage losses respectively.

Damages to cultural heritage have gone from being an extraordinary event to become a continuous threat. For this reason, heritage managers are forced to develop new mechanisms to provide an appropriate response to these challenges. The concept of cultural heritage has broadened considerably since the definition provided by the Venice Charter of 1964 [2]. Nowadays, it includes environmental and social factors and, its preservation, stands away from the past conservation practice as an end. In 1975, the Charter of Amsterdam [3] introduced the concept of "*integrated conservation*", stating that the conservation cannot simply be limited to the built context, but must include protective measures, modification or implementation of uses and activities that take place within the built physical environment. Furthermore, the UNESCO Declaration of Hangzhou of 2013 [4] states that "*culture, in its manifold expressions ranging from cultural heritage to cultural and creative industries and cultural tourism, is both an enabler and a driver of the economic, social and environmental dimensions of sustainable development*". Conservation has traditionally been dealing with deterioration mechanisms related to materials and works of art, but has rarely been applied to the establishment of preventive interventions related to climate change. Nevertheless, the increasing number of extreme events is already affecting cultural heritage.

Integrated urban development has become increasingly important in many Member States, principally as a consequence of the adoption of the Leipzig Charter on Sustainable European Cities in 2007. The charter declares that "*all dimensions of sustainable development should be taken into account at the same time and with the same weight. These include economic prosperity, social balance and a healthy environment. A holistic approach is essential in order to reveal the potential of European cities in terms of cultural and architectural qualities, social integration and economic development*". Given that cultural urban heritage is associated with physical systems and human communities, the priority for an effective management of the whole city is to develop a new generation of strategies that provide mechanisms for balancing conservation and sustainability in the context of a changing environment.

The following table shows how climate change and related hazards may impact on cultural heritage assets, structures and artefacts:

Table 1. Climate change and related hazards impacts on cultural heritage

Climate change effects	Risks	Impact related to cultural heritage	
• Increase in global temperature	• Heat waves and extreme temperatures • Coastal flooding (sea rise level) • Drought • Temperature and	• Social	• Progressive abandonment of urban areas and historic buildings due to temperature increase; evacuation of coastal urban areas due to soil erosion
		• Economic and/or environmental	• Decrease in tourism and related activities; energy demand increase; economic losses for heritage managers and/or insurance companies

Climate change effects	Risks	Impact related to cultural heritage	
	humidity fluctuations and hygrothermal cycles increase	• Physical	• Material and structural decay (cracking, detachment, fungal growth, degradation of material and biogenic patinas…) and possible loss of cultural heritage
• Increase in intense precipitation events	• River or inland flooding • Landslide • Extreme precipitation (rain and snow) and cold waves • Increase in humidity atmospheric level	• Social	• Evacuation; loss of identity and common values; progressive abandonment historic buildings due to poor comfort parameters
		• Economic and/or environmental	• Economic losses for heritage managers and/or insurance companies; energy demand increase
		• Physical	• Material decay (fungal growth, degradation of material, biogenic patinas and deterioration of movable heritage). Partial damage or destruction of cultural heritage structures and artefacts; structural damages due to increase in loads (snow...)
• Increase in the number of extreme storm events	• Intense gust of wind	• Social	• Evacuation. Loss of identity and common values
		• Economic	• Economic losses for heritage managers and/or insurance companies
		• Cultural	• Partial damage or destruction of cultural heritage structures and artefacts

Source: Tecnalia (2014)

In order to build a common analytical framework and link different disciplines, research has applied the adaptation planning concept (Effects-Vulnerability-Adaptation-Implementation (EVAI) model). It started from exploring the expected impacts of climate change on cultural heritage, including chronic degradation mechanisms but also the increased risk of extreme events and hazards. It continued with an assessment of the vulnerability of heritage within the urban context and followed with the consideration of relevant and applicable adaptation solutions and the conditions for their implementation. The use of common frameworks is needed to understand the nature and scope of these challenges, to identify problem drivers and their interconnections.

Many approaches related to the conservation of cultural heritage are still linked to geographically limited sites or to a group of properties. Cultural heritage sites are seen as belonging to the past, disconnected from the present and from each other. Nevertheless, urban heritage is a living and dynamic part of the city, an element of the overall urban setting. Modern conservation strategies need to find a balance between urban growth and quality of life in a sustainable way, matching the interrelationships of building stock, spatial organization, natural characteristics and social, cultural and economic values. In order to support the protection of urban heritage in a constantly changing environment, emphasis should be given to the integration of conservation management within wider goals of overall local sustainable development.

In order to provide integrated urban governance dynamics and identify key values in urban areas, a multidisciplinary approach involving different cross-section stakeholders and decision makers is needed. Furthermore, the uncertainty about the severity and timing of climate change impacts requires an iterative risk management process, involving different skills and knowledge, in a complex decision making scenario.

The assessment of climate change impacts, vulnerability and adaptation has been addressed according the risk management process, which involves exploring, making and acting on decisions under conditions of uncertainty. Decisions in relation to climate change cannot be static, but should be based on an iterative process, learning from and taking advantage of new information, for the inclusion of corrections. The ADVICE project considers, as part of the methodological framework for climate change assessment, the iterative risk management process proposed by the IPCC [5]:

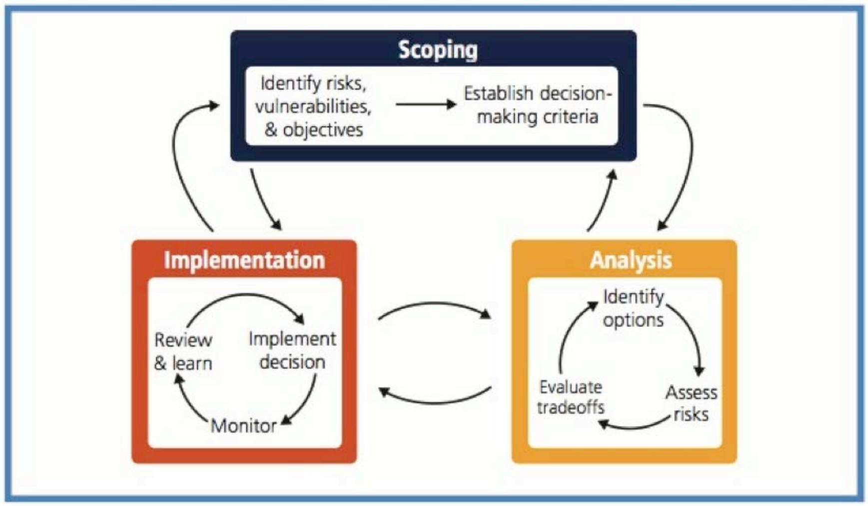

Fig.1. Climate-change adaptation as an iterative risk management process

Source: IPCC (2014) AR5, WG-II

3. Methodology for risk assessment in historic cities

The IPCC highlights several representative key risks for each region, assessed according to three timeframes scenarios. It identifies, in each region, the current existence of adaptation deficits as well as the future potential for adaptation and limits to adaptation. Research activities described in this paper, focus on hazards and impacts identified as critical for Europe:

- Temperature variations: in Europe, there will be a marked increase in extreme temperatures. Projections confirm an increase in the frequency of warm days and night, duration of heat waves and the decrease in the frequency of cold days and night. Daily and seasonal variations of temperature directly affect cultural heritage as freezing-thawing cycles induce thermal stress, accelerate degradation and mechanical damage to materials, reducing their lifetime. This effect will also have consequences on relative humidity variations, which can lead to an increase of several degradation mechanisms, such as efflorescences or biodeterioration. Heat and cold waves will also intensify the use of air-conditioning and heating consumption, increasing the energetic demand.

- Precipitation and sea rise level: changes in extreme precipitation in Europe depend on the region. It is demonstrated that Northern and Continental Europe will register an increase, while in Southern Europe it will depend on regions and seasons. Extreme sea level events will increase, due to the global mean sea level increase, while storm surges will vary along coasts. Climate change is projected to affect the hydrology of river basins. According to these data, extreme precipitation and sea rise level can be directly related to hazards, such as coastal, river and pluvial flooding. Damages related to cultural heritage depend on the intensity of the hazard, as well as on the exposure and vulnerability, varying from moisture and humidity contents variations to flooding.

- Windstorms: Several studies project an overall increase in storm hazards, but variations in frequencies are large. Currently, there is lack of information on these types of events; nevertheless, structural damages in cultural heritage have to be addressed, as they can lead to significant losses.

In order to assess the vulnerability of cultural heritage towards these impacts, a set of indicators has been established. These were designed according to different typologies: quantitative and qualitative indicators, simple or compound indicators and indirect or "proxy" indicators. One of the determinant criteria was to build indicators on existing and available information, using open data at local level. The methodological framework was developed with the main premise of integrating cultural heritage within other existing approaches of adaptation planning, in order to strengthen the overall adaptive capacity of cities.
Indicators have been divided in different categories and respond to a specific hazard:

- **Exposure**: indicators evaluating if a system or element will face an impact or stress factor. They are designed to determine if a certain type of heritage, due to its location, can be threatened by climate change impacts or hazards.

- **Sensitivity or susceptibility to harm:** is the grade in which a system, sector or element is affected by the climatic changeability or extreme event, both in a positive and negative way.

- **Adaptive capacity**: capacity to cope and overtake the effects. Is the ability of systems to assume the potential effects of climate change, taking advantage of the opportunities or overtaking the consequences.

Risk assessment has been developed using the integrated value model for sustainable assessment (MIVES) [6,7], which is based on the establishment of a requirement tree, value functions and analytic hierarchy process (AHP) [8]. The tool can be used to compare variables with different units and taking into account the relative importance of the considered aspects.

With the objective of identifying the most vulnerable buildings to climate change impacts, the following requirement tree was developed:

Table 2. Requirement tree for historic buildings vulnerability

Requirement	Criteria	Sub-criteria	Indicator
• Sensitivity	• Built environment	• Building	• State of conservation
			• Year of construction
			• Basement, type of ground floor, expansion joints
			• Use
			• Cultural value
		• Envelope	• Type of roof
			• Material
			• Colour
			• Orientation

		• Equipment	• Drainage system, shading systems
			• HVAC
		• Structure	• Foundations
			• Material
• Adaptive capacity	• Built environment		• Previous interventions
			• Emergency plans
			• Ordinary maintenance
	• Socioeconomic		• Number of dwellings
			• Older people
			• Economic situation
			• Vacancies
• Exposure	• Built environment		• Urbanisation
			• Risk tendency
			• Waterproof surface
			• Street width
			• Green areas
			• Proximity to river/coastal areas

Source: Tecnalia (2015)

Weights have been assigned starting from indicators [9], through the establishment of value functions based on mathematical elements, in order to identify the most or less vulnerable parameters. The value function has the objective of transforming an attribute to a comparable variable comprised between 0 and 1. Each indicator has its own value function assigned. Weights can be determined through AHP or through a direct scoring, by the use of a pairwise comparison, which establishes how much an element is important compared to another element. Subsequently, based on this assessment, weights are determined through the development of a matrix calculation. Criteria and requirements were also weighted through AHP, relating indicators under the same criteria and criteria under the same requirement. Indicators will be included in an urban data model to facilitate the visualization of most vulnerable areas. The risk assessment methodology is used to prioritise interventions and to define the most suitable adaptive solution for the historic building urban stock. At this moment, the research project is focused on the validation of the risk assessment methodology by means of statistical methods, which will allow verifying the adequate selection of indicators and the robustness of the methodology.

Conclusions

This paper focuses on the research project ADVICE (Infrastructure and buildings adaptation to climate change), funded by the Basque Government. As part of an integrated risk assessment methodology, specific indicators to evaluate the vulnerability of historic buildings have been addressed. The MIVES model has been identified as the most appropriate for this kind of decision-making process, which involves different backgrounds and skills of stakeholders. Fine-tuning of the methodology still need to be addresses by the use of statistical analysis. Data in historic cities are complex and involve a large amount of variables. For this reason, the methodology is accompanied by a 3D data model, based on CityGML, for a proper and friendly data management. Risk assessment should consider also the integration of simulation tools which might enrich the information used, especially in the selection of adaptive solutions. The use of a holistic model, capable of integrating all this information will be addressed in further research, in order to guarantee its success in several historic cities.

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