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CULTURAL HERITAGE FACING CLIMATE CHANGE: EXPERIENCES AND IDEAS FOR RESILIENCE AND ADAPTATION

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TABLE OF CONTENTS

Towards Sustainable Climate Control in Museums. Global Climate Change, Risk and Energy Consumption

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Abstract: This paper discusses existing gaps in knowledge allowing adequate estimation of the risk of mechanical damage in works of art caused by climate variations, also those generated by global climate change. The lack of risk models results in a very precautionary approach to climate control in memory institutions. As a result, significant resources are invested in climate control to minimize risks, which usually are secondary in terms of risk priorities. Beside not-optimal preservation of heritage collections such approaches significantly increase environmental costs of the preservation of museum collections.

Résumé: Cet article discute des manques dans les connaissances permettant une estimation adéquate du risque de dommage mécanique aux œuvres d'art causé par les variations climatiques et aussi celui généré par le changement climatique global. Ce manque de modèles de risque résulte d'une approche très précautionneuse du contrôle climatique dans les institutions mémorielles. Il en résulte que des ressources significatives sont investies dans le contrôle climatique pour minimiser les risques, qui d'habitude sont secondaires en termes de priorité. A côté d'une préservation non-optimale des collections patrimoniales, de telles approches accroissent significativement les coûts environnementaux de la préservation des collections muséales.

Key words: climate change, museums, risks, energy consumption.

Mots clés: changement climatique, musées, risques, consommation d'énergie.

1. State of the art

The notion that the deterioration of objects is related to the environment, and more precisely to indoor climate, has existed long before the first museums were created. Historically, the concept of 'right' environment was reflected in good practice and housekeeping rules, which over the last century evolved into the climate specifications for museums we know today. Until the beginning of 90's of the last century, this evolution was driven by the development of mechanical systems to control indoor climate and set points and ranges they required. As a result, climate control specifications have become very stringent both in temperature (typically **21** or **22 ±1°C**) and Relative Humidity RH (typically **50 ±5%**). However, such specifications occurred to be too tight and therefore impossible to be effectively implemented in most institutions, especially those located in historic buildings, and impose significant financial, organizational and environmental costs. In the early 90's, the trend for more precise climate control was reversed, in large extent, when Marion Mecklenburg and his group at the Smithsonian Institution undertook research that laid a foundation for our understanding of the structural response of museum objects to changes in ambient temperature and RH (Mecklenburg and Tumosa, 1991). Mecklenburg systematically examined the dimensional response to climatic changes and the critical levels of strain/stress at which materials begin to deform plastically or fail physically for wide classes of materials found in museum collections.

The approach developed by Mecklenburg, based on identification of the most vulnerable to humidity variation virtual object – gesso layer on wooden panel in the most responsive to humidity changes tangential direction (Mecklenburg, 1991) – occurred to be extremely useful for the field where the determination of material mechanical properties is especially difficult. The proposed approach provided the field the first maps of allowable RH variations. These maps as well as maps obtained by other researchers take into account the amplitude, duration and starting RH levels (Mecklenburg 1998, Jakieła *et al.*, 2008). They were fundamental in designing environmental specifications for collections of historic objects (Erhard, 1994, ASHRAE, 2007). Scientific research into the damaging impact of RH variations on some materials was further refined by taking into account their vulnerability to fatigue fracture (Michalski, 1991; Rachwał *et al.*, 2012; Bratasz *et al.*, 2015).

The most general conclusion from a critical review of existing data and recent publications is that:

- the risk generated by temperature variations is practically negligible with the exception of extreme temperature changes typically larger than ±20º**C**,
- moderate variations within the approximate RH range **40-60%** are safe for almost all objects.

These results informed recent common consensus on environmental guidelines as IIC and ICOM-CC Declaration (Environmental Guidelines, 2014) as well as practice of climate control in many museums. The new more relaxed environmental specifications are undisputable progress compared to previous unrealistic museum recommendations and also because experiences of numerous institutions have shown that even the slight relaxation of climate control can reduce energy consumption and the use of fossil fuels significantly.

Above safe ranges were derived using the extremes of conservative criteria of the materials' yield or crack initiation in undamaged, usually new, material. In fact, historic objects, and especially panel paintings, with their long environmental history, exhibit complex crack patterns called craquelure. Moreover, objects have survived remarkably well in uncontrolled environments, which are far from the ideal museum conditions (Camuffo 2013). However, heritage science didn't develop adequate models allowing for understanding how objects acclimatize to unstable conditions and how it affects their vulnerability to climate variations.

This lack of knowledge is one of the barrier preventing museums and other memory institutions from resigning from strict climate control and adopting more sustainable strategies of collection care.

2. Research on global climate change on environmentally induced mechanical damage to museum collections

Only two international projects have been funded by European Commission within 5th and 7th Framework programs "Noah's Ark" and "Climate for culture", respectively. Both projects aimed at assessing the impact of global climate change on heritage objects and proposing mitigation and adaptation strategies. The "Noah's Ark" project focused on identifying the main risks for heritage objects outdoors and understanding main risk drivers, whereas "Climate for culture" focused on heritage objects stored in buildings, predominantly historic ones.

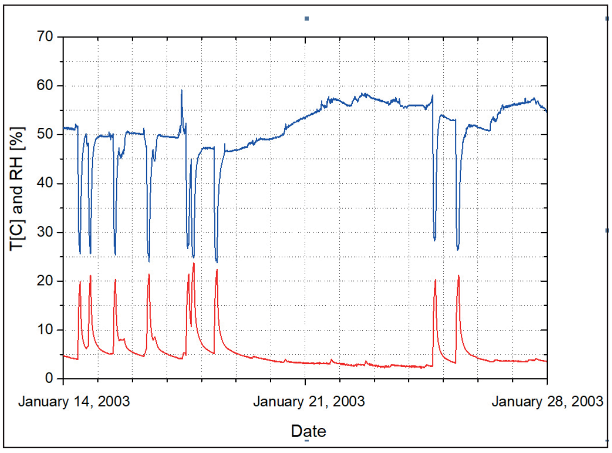
It should be openly stated that both projects delivered extremely valuable data, which pushed our knowledge beyond limits existing at the time. The "Noah's Ark" project:

- identified relevant climate parameters
- identified set of vulnerable materials and structures in outdoor exposure
- developed database of relevant damage functions for historic materials
- developed first climate change maps relevant for the heritage field
- produced the first risk maps for outdoor heritage

The "Climate for Culture" project:

- significantly improved precision of existing climate change models
- developed regional climate change maps with high special resolution
- developed unique building simulation tools allowing for transfer of climate outdoor data to indoor data
- assessed the impact of climate change on energy consumption in museums and historic buildings

However, it seems that risk assessment (at least risk generated by climate variations) performed for collections stored indoors exhibited several flaws which undermined its practical application in heritage institutions and its usefulness for policy development. The main issue with the most recent predictions is that they assume, albeit rather in an



1. - Temperature and relative humidity in the church of Santa Maria Maddalena in Rocca Pietore, Italy. Observed spikes are caused by heating indoor space during service.
Température et humidité relative dans l'église de Santa Maria Maddamela à Rocca Pietore, Italie. Les pics observés sont occasionnés par le chauffage durant les offices.

implicit way, the cumulative nature of mechanical damage. In fact, mechanical damage exhibits a threshold base nature, with a small cumulative component, related to fatigue (Strojecki *et al.* 2014). Consequently, damage develops suddenly when indoor climate events are extreme. Usually, such extreme events are related to malfunction of HVAC systems, electricity outages, human error or other human activity. A typical example of extreme climate variations is heating in historic religious buildings. The graph below illustrates temperature and RH perturbation by heating system installed for thermal comfort of visitors (fig. 1).

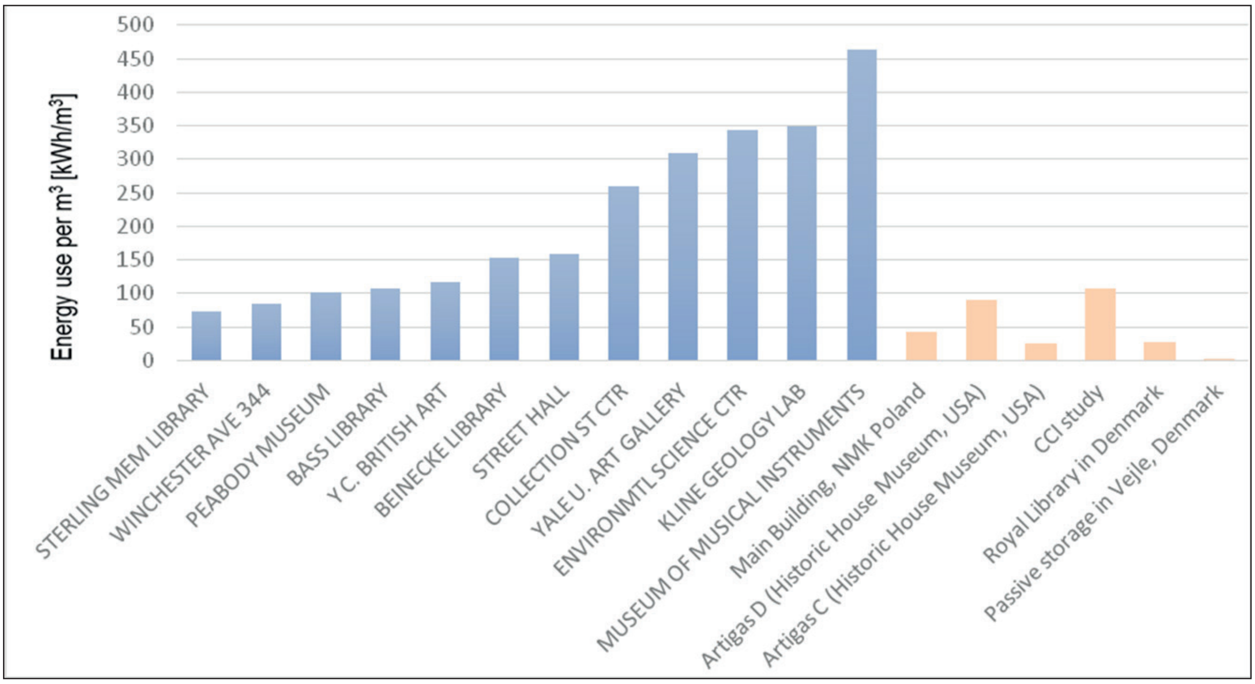
It is obvious that natural climate variability, even including global climate change, is completely overshadowed by human activity in the building, and creates negligible risks of mechanical damage.

Secondly, damage functions used to predict change in risk due to climate variation are not realistic, as they were developed using extremes of conservative criteria i.e. damage initiation in undamaged, usually new material. As consequence the existing damage functions indicate only temperature and RH ranges which are safe for most objects with huge safety margin. However, those damage functions cannot be used to estimate risk when climate parameters go beyond safe ranges. This leads to significant overestimation of risk of mechanical damage caused by climate variations in general, and by global climate change, in particular.

3. Risk aversion as main driver in current management of museum climates

Lack of reliable risk models is caused by limited potential of the young heritage science discipline, which compared to other disciplines is a small research field both in terms of the number of active scientists as well as extremely limited funding. Whatever the reason, the lack of rigorous scientific understanding of the process of mechanical damage development in old objects and reliable tools used to assess the risk impedes the movement towards "green museum", "green archive" or "green library" – the institutions which manage their indoor climate in responsible and efficient manners, especially in terms of energy consumption and CO_2 emission but at the same time maintaining high standards of collection care. When existing gaps in knowledge are combined with aversion to the risk of all participants of design process, when building a new museum or renovating existing one, the final result is usually far from the optimum, both in terms of high energy consumption and poor climate stability as well as the adverse impact on historic building envelope. The short and limited list of main actors of the design process and their motivations include:

- architects and HVAC engineers, who are bound by legal contracts, which explicitly include climate specification defined by the memory institution. To limit the risks of law suits, the HVAC systems are oversized to be able to cope with highest possible loads originating from extreme outdoor climate conditions or an unusually high number of visitors. Moreover, both architects and engineers rarely decide to challenge existing codes, which were developed for standard buildings or standard use, but are not adapted to specific needs of memory institution. Although, the process of adopting non-standard solutions is permitted by many codes and it is easier and less risky for designers to use standard solutions.
- conservators and collection managers are traditionally focused on preserving museum,



2. - Average yearly energy consumption in Yale University buildings housing heritage collections are compared with data from other national or international memory institutions.
Consommation annuelle moyenne d'énergie dans les bâtiments de l'Université de Yale abritant des collections du patrimoine culturel comparée aux données d'autres institutions mémorielles nationales et internationales.

library or archival collections, therefore they usually don't see the benefits in optimizing energy consumption and limiting CO2 emission. For this group, relaxation of climate control is always related to increase of risk of mechanical damage, even if such risk is practically negligible.

- environmental health and safety specialists often classify conservation studios as wet chemical labs recognizing that conservators use volatile chemical solvents when cleaning or treating objects. As a result, conservation studios have extremely high ventilation rates, which in turn significantly increase energy consumption. However, in practice, the amount of volatile compounds released during object treatment is very small (probably effective concentrations are smaller than we have in bathroom when cleaning mirror with a glass cleaning agent).

Surprisingly, the development of far from optimal climate control strategies in memory institutions is more frequent than we think. It happens not only in institutions with limited resources and potential to create innovative solutions but also in institutions which have such potential. Figure 2 shows the average yearly energy consumption in ten buildings at Yale University, USA, housing heritage collections. This data is compared with other national and international institutions.

As can be seen, an average memory institution at Yale uses ca. 5-6 times more energy than typical memory institutions and around 100 times more than the passive storage in Vejle, Denmark.

The existing barriers and natural aversion to the risk can be overcome if interdisciplinary teams of experts are focused on institutional objectives but not on benefits of individual professional groups. Moreover, characteristic of the process requires openness to search for non-standard solutions, which are outside the comfort zone of each professional group and it requires readiness to make decisions in circumstances where uncertainty of our estimations is large rather than small. Only if those conditions are fulfilled the design process can be effective and successful solutions can be developed.

4. Attempts to develop policies supporting sustainable conservation

Although, idea of "green museum", "green library" or "green archive" is widely known and accepted, relatively few countries managed to significantly reduce energy consumption in heritage institutions. To the contrary, an increase in energy consumption by these institutions is observed. The National Museum in Krakow is an example of an institution which managed to renovate 9 out of 10 historic buildings, installing in most of the buildings advanced HVAC systems. All renovations were implemented using external sources, predominantly European Structural Funds and European Economic Area grants. As a consequence, energy consumption increased several times as well as energy bills in buildings where HVAC systems were implemented. Therefore, it seems reasonable that funding agencies require financial analysis not only related to costs of renovation but also for analysis of the maintenance and running costs in multiyear time perspective.

Yale University also recognized issues related to high energy consumptions in university buildings. In August 2014, Yale President Peter Salovey created a task force to determine whether carbon charge should be introduced at Yale. In April 2015, the task force prepared a report in which it recommended the implementation of carbon charge arguing that it has *'... following advantageous features…: it will provide appropriate incentives for decision makers to reduce emissions from carbon-intensive activities; it will focus policies on carbon pricing as a superior tool for providing decentralized incentives and thereby engage students, faculty, and staff; and the program will serve the broader purpose of expanding Yale's role as a pioneer in research, teaching, and policy design to cope with climate change.'*

In December 2015, Yale became first university in the world to approve a university carbon charge pilot program that was implemented in 20 buildings and tested four approaches to reducing carbon. The pilot test showed a charge is feasible, and resulted in a statistically significant emissions reduction in participating buildings.

In 2017, Yale University selected one of the four approaches — a revenue-neutral scheme — for the new carbon charge. It works this way: If a building reduces its carbon emissions more than Yale as a whole does, compared to its historical emissions level, then the building receives funds from the carbon charge pool. If the building performs worse than Yale as a whole, then it pays into the carbon charge pool. More details can be found on http://carbon.yale.edu/.

The carbon charge is implemented on all 250 university buildings. It creates additional economic pressure on all Yale museums and libraries, but especially on those which are currently in less comfortable economic situations. Museums and libraries are predominantly located in historic buildings, which - combined with the aim of providing strict climate control for the preservation of collections - results in high energy demand. As a consequence, museums and libraries belong to the least energy-efficient institutions at Yale. Therefore, we can expect significant energy reduction in all Yale memory institutions in coming years.

5. Conclusions

The young discipline of heritage science requires well-structured funding to grow in sustainable ways and deliver knowledge needed to develop effective policies, including the adaptation and mitigation policies for the cultural heritage field effected by global climate change. It is evident that resources which were invested to tackle problems caused by global climate change in agriculture, water sources, forestry, energy are several orders of magnitude larger than those in cultural heritage. As a result, there are significant gaps in knowledge related to vulnerability of heritage objects to climate, which impedes successful implementations of respective policies.

However, there are examples of policies such as carbon charge designed at Yale University that could be easily adapted for the heritage sector, creating additional incentives for memory institutions to look and reduce their energy consumption.

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