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Paper 124

THE RESILIENCE TO FLOODING OF HISTORICAL ARCHIVES

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Abstract
When the historical archives are concerned, usually closed and controlled environment are considered, protected from the threats from ambient conditions, fires and different kind of pest. What is becoming evident by the historical events is that archives are vulnerable to the acute events, as flooding, that could have short term (document destruction) and long term (e.g. moulds) effects. A fuzzy based methodology is here proposed as a first attempt to support the decision making in terms of resilience to flooding and climate change based on multiple parameters: value at risk, recovery capabilities and probability of occurrence. The case study shows the effectiveness in defining the control measures.

Keywords: *historical archives, resilience, flooding, planning and management, modelling*

1 Introduction

When the historical archives are concerned, usually closed and controlled environment are considered, protected from the threats from ambient conditions, fires and different kind of pest. What instead is becoming evident by the historical events is that archives are vulnerable to the acute events, as flooding. The flooding, that is becoming an increasing threat to the archives can be of external origin, given the climate change and the occurrence of heavy rains that the buildings are not designed to manage (Mazurczyk et al., 2018), or internal, usually due to the failure of water pipes because of the lack of maintenance, or because of stresses deriving from building activities inside or outside the structure hosting the archive (Muir & Shenton, 2002). Two endogenous factors have also been highlighted especially for archives at academic institutions: deferred maintenance of aging facilities and the repurposing of spaces not designed originally for archives and libraries (Fleisher & Calzonetti, 2016).
As highlighted above, climate change is increasingly recognized as a threat to cultural heritage (Fatorić and Seekamp, 2017). Cultural heritage includes both tangible forms such as paintings, buildings, monuments, documents and other material objects, and intangible forms, such as folklore, customs, and traditional knowledge. The well-accepted water-related climate change threats and climate-triggered phenomena that can impact cultural heritage resources include among others: surface flooding; precipitation; temperature change; and humidity.
Much of the recent work on assessing climate risks to cultural heritage has largely focused on immovable heritage. Archives have received less attention in the climate risk literature. Archives preserve historical records in multiple formats that are critical for legal matters, administrative accountability, and documentary cultural heritage. When these records and documents are lost following extreme weather events, for example, their absence severely handicaps socio-cultural and economic reconstruction efforts.

To date, climate change risk studies of movable cultural heritage have emphasized the effects of relative humidity on the condition of objects, and other factors that lead to gradual degradation, using simulation and sampling methodologies. This focus is perhaps warranted as many archives dedicate a large number of resources to maintaining indoor environmental conditions, and these costs are expected to increase in many geographies under climate change. In the paper the specific stressors for the resilience of the archives to the flooding related damages are discussed and included in a risk resilience assessment model considering vulnerabilities and coping capacities, able to support the resilience-based decision making, devising site-specific responses and solutions for the enhancement of archive resilience.

2 Material and method

2.1 Risk assessment

Several options for directing a preservation strategy are available and can be considered in case of flooding, as summarised in Bülow (2010).
Among them, the preservation risk assessment developed by Waller (1994) allows a semiquantitative risk assessment to be carried on, allowing the identification of relevant hazards and the numerical estimation of the related risk, allowing the risk-based decision making to be adopted in defining the strategies for the prevention and the protection of historical archives.
The preservation risk assessment is defined by Waller as:

$$\text{Risk} = \text{Probability} \times \text{Severity}$$

where

$$\text{Severity} = \text{Vulnerable fraction} \times \text{Loss in value}$$

The risk assessment in defined for each potential hazard for the archives, called "agent of deterioration", as: water, fire, pest, pollutants and so on. Depending on the risk index obtained, control actions are defined for each hazard.
In this work, the risk function of Waller has been modified in order to make a step forward towards the archive resilience to the hazard of flooding. In order to reason in terms of resilience the risk function has been enriched and it is based now on 5 parameters:

- Value of the documents in the archive section under analysis - VA;
- Rareness of the documents conserved - RA;
- Probability of the disruptive event – PR;
- Vulnerable fraction – VR;
- Recovery time – RT;

The resilience to the risk is thus a function also of vulnerability (RA, VR) and recovery (RT) and can be evaluated as:

$$R=f\,(VA, RA, PR, VR, RT) \tag{1}$$

The Fuzzy Logic is proposed as a solver, in order to be able to keep into account variables of different units that could not be easily included in a traditional mathematical model.

2.2 Fuzzy Logic methodology

Several applications of the fuzzy logic in risk analysis has been developed as recently summarised in Papazoglou et al. (2017) also by the authors themselves, e.g. in occupational risk assessment (Murè et al., 2009) and in the analysis of accident precursors (Baldissone et al., 2018). A similar approach is here proposed for the archive resilience to flooding. In fact, the advantages of fuzzy logic reside in the capacity of considering very different types of parameters (as the frequency of events, the rareness of the documents, the recovery time, etc.) within the assessment, analysing multiple causes with different degrees of relevance, allowing to link them with the relevant measures available to increase the resilience. The Fuzzy Logic Approach can be described through the following steps:

- Step 1, Selection of the input and output parameters;
- Step 2, Development of the fuzzy rules.
- Step 3, Results

The last step will be discussed in the section 3, about the results of the study

2.2.1 Step 1, Selection of the input and output parameters

The first step in the Fuzzy Logic Approach is the definition of the input and output parameters, according to the aim of the evaluation, that, in this case, is the definition of the optimal preventive and protective measures for increasing the archive resilience to flooding.
The input parameters are those described in section 2.1: VA, RA, PR, VR, RT. The output is the risk flooding resilience, R. The input values are assigned according to the observable or measurable parameters. Since the distribution of the data is unknown, as work hypothesis each variable has been divided in 3 membership functions equally distributed with a triangular shape, as shown in Figure . The membership functions represent the degree of relevance of the variables in the sample and they are defined as: Low, Medium and High, according to the following criteria, chosen as a first attempt:

- Value of the documents in the archive section under analysis – VA: [0, 10M€];
- Rareness of the documents conserved – RA: [0, 10000 copies];
- Probability of the disruptive event – PR: [0, 1];
- Vulnerable fraction – VR [0, 1];
- Recovery time – RT [0, 365 days];

In case of absence of one variable in the sample, its influence on the results is neglected. Also for the output variable, 3 triangular membership functions are used, not overlapping in order to get a response about the flooding risk resilience level of the archive, clearly pertaining to specific boundary. Despite this could result in a reduction of the potentiality of the methodology, a univoque result has been preferred.

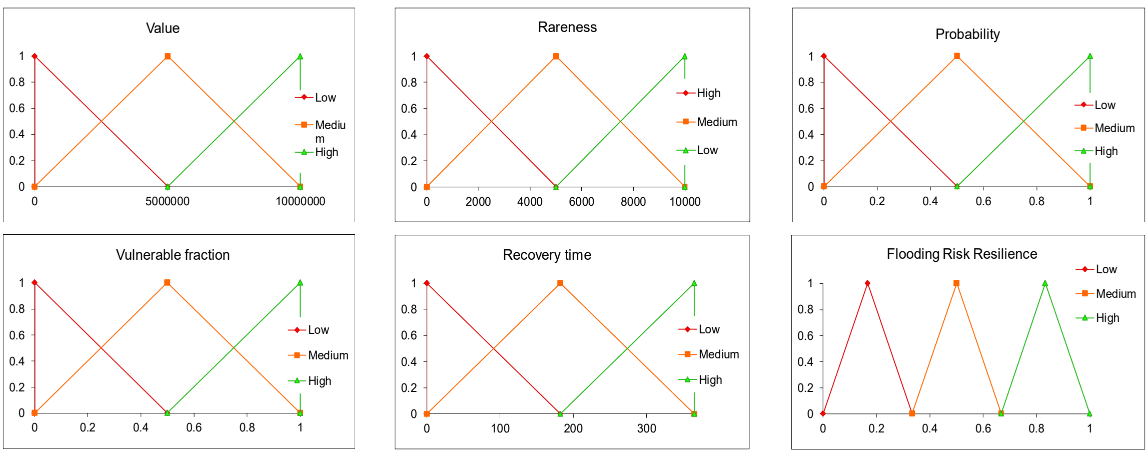


Figure 1. Membership functions for the input and output variables

2.2.2 Step 2, Development of the fuzzy rules

The rules are used to describe how the input variables can influence the output variable result. The rules are of the type "If … Then …" and cover all the 243 possible membership function permutations. Each rule is defined according to Eq. (2):

$$\sum_i w_i \cdot W_{ij} = W_O \qquad (2)$$

Where w_i is the weight of the variable i, W_{ij} is the weight of the membership function j in the variable i and W_O is the value used to evaluate the output membership function. The values of W_{ij} are shown in Table 1, the same value of Wij is used for all the input variables.

Table 1: Value of Wij

	Low	Medium	High
W_{ij}	1	2	3

For the case study presented in Paragraph 2.3., the experts assigned the same degree of relevance to each input variables. Therefore, the value $w_i = 1$ for all the input variables.
W_0 is used to define the output membership function. W_0 ranges between 5 and 15 and its boundaries have been chosen as for Table 2.

Table 2: Value of W_O

	Low	Medium	High
W_O	≤9	9-11	>11

The min-max interference technique was used for the rules' aggregation, so that the degree of relevance of each rule on the output could be considered (Klir and Yuan, 1995). The defuzzification of the results was based on the centroid method, in order to consider also the degree of relevance of each membership function of the output value (Pedrycz, 1993).

2.3 Decision making phase

Once the level of risk has been assessed it could be used to support the decision-making phase, drawing recommendations about the management of the archives to maximise their resilience. Table 3 shows management plan recommendations for archive managers based on level of risk resilience, able to support the decision making, to guide the enhancing measures to be implemented and to demonstrate the resilience enhancement after the measures have been considered in order to reduce vulnerability, increased coping capacity, minimization of impact in case of disrupting events.

Table 3. Management plan recommendations for archive managers based on level of risk exposure.

Recommendations	Level of Risk		
	Low	Medium	High
Implement Environmental Monitoring Tools climate-control standards as EN 15757:2010 (Leissner et al., 2015)		✓	✓
Indoor climate simulation and damage prediction based decision making (Huijbregts et al., 2012) (Bertolin et al. 2015)			✓
Consider Building Upgrades to Enhance Adaptation to Extreme Weather or procedures to reduce the recovery times.		✓	✓
Consider Shifting Selected Collections to Different Storage Environments Locally		✓	✓

Recommendations	Level of Risk		
	Low	Medium	High
Undertake Landscape and Engineering Assessments to Determine Future Environmental Risks to Building			✓
Disaster management plans at local level, minimising recovery times	✓	✓	
Develop regional response network for other archives that can assist in emergencies			✓

3. Case study and results

The case study refers to one of the department libraries at Politecnico di Torino, where the effect of heavy rains in autumn is bringing to an increase in the moisture exposure of the collections. The library has not a control system for the environmental conditions and some damages to the stored collection is starting. In Figure 2 a snapshot of the storage system – open metal shelves – and a detail of the mould growth is shown.

Figure 2. Department library

It is recognised that changing climate conditions will affect biological activity in buildings and on cultural heritage materials. Fungal growth is a widespread problem with implications for or human health and the integrity of heritage material. The effects on heritage items can vary from a light powdery dusting to severe staining, weakening and disintegration of substrate material. Many deterioration processes are accompanied by biochemical transformations that occur only at certain temperatures and humidity values, in the growing phase of the organism.

The most important factors are thus temperature, humidity and the nature of the substrate. It is assumed that mould spores are ubiquitous. At temperatures above 0°C and humidity levels above 70% RH mould spores can germinate. The time to germination decreases as temperature and humidity rise. Most fungi grow in a temperature range from 0 to 50°C, whereby the tolerance to low temperatures is better than to high temperatures in this range. This should suggest the installation of an environmental control system.

Despite the environmental conditions have changed allowing the mould growth, it is important to decide on the basis of the collection at risk and to the coping capability of the system.
Thus, the fuzzy method devised has been applied, with the inputs and outputs in Figure 3. In the left column the variables related to the initial conditions are represented as input membership functions, while on the right side the membership of the variables of the post intervention conditions are shown, together with the risk assessment in both the cases.

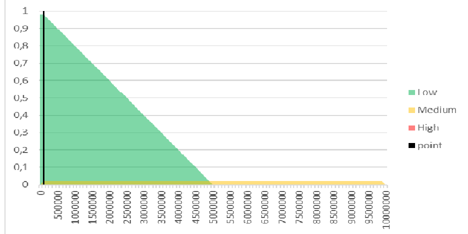
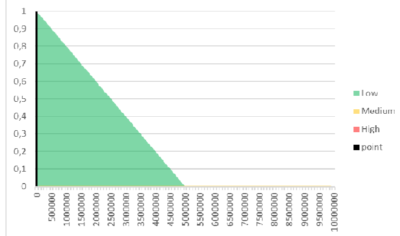
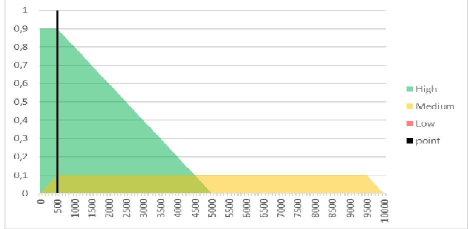
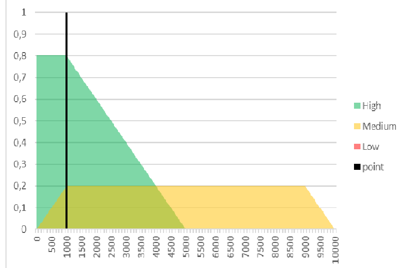
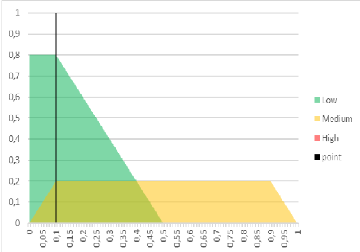
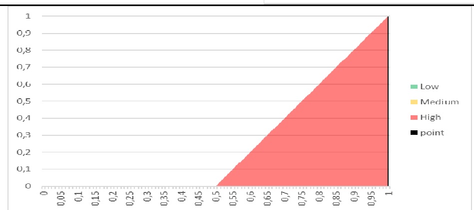
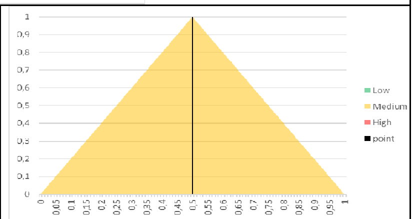
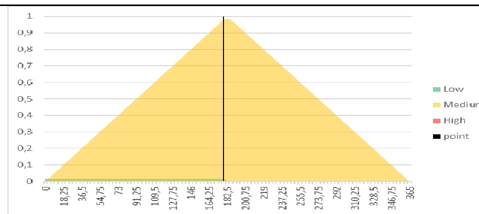
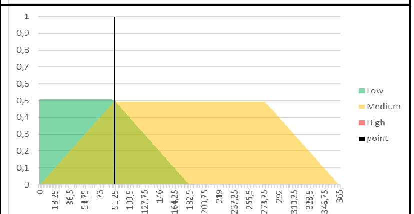
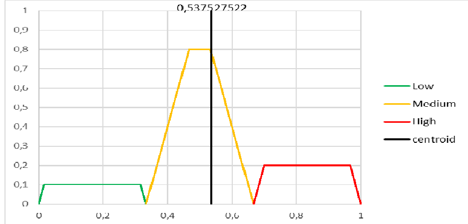
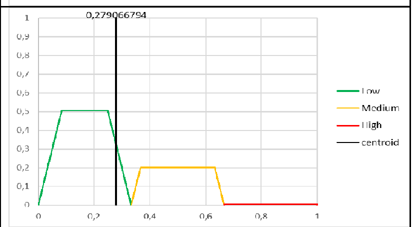
	Initial conditions	Post intervention condition
Value at risk		
Rareness		
Probability		
Vulnerable fraction		
Recovery times		
Risk		

Figure 3. Results of the fuzzy logic methodology to support decision making

Let's consider as an example, the case a collection at risk is of 100000 € of which around 500 copies exist worldwide, the probability of having an intense rain affecting the humidity and temperature enough to bring to the formation of moulds is 0.1, it can affect the entire collection and a recovery time of 6 months is expected. This case brings to a medium risk.
If according to the measures in Table3 the more expensive documents in the collection should have been moved to a more protected location, in order to bring the situation in a tolerable level, should maintain inside the library the documents whose total value sum up to 25000 €, with a mean rareness of 1000 existing copies, moving half of the collection in a mould protected shelves and reducing the recovering time to 90 days. In this case the risk will be low, confirming how the adopted measures are effective
The same approach can be applied to the other cases of interest.

4. Conclusions

This study acknowledges that even the best-resourced archival institutions are unlikely to start receiving significant increases in resources to retrofit or move existing infrastructure, and some collections may remain exposed despite known risks. In addition, a major challenge for archives is that many exist within larger parent institutions such as universities, governments, or corporations in which top-level decision makers may not take risk to archival records as seriously as archivists themselves.
Understanding the impacts of water-related accident and climate-triggered phenomena to archival repositories is imperative for the present and future security of cultural resources. There is an increasingly pressing need to establish strategic disaster planning initiatives that are appropriate for each archival repository and suite of local risk exposure factors.
This require a risk based decision making to be carried on, with a glance to the resilience of the archives. The fuzzy based methodology here proposed is a first attempt to support the decision making in terms of resilience to flooding and climate change. Further development, following several case studies applications will allow refining the methodology, e.g. assigning the weights to the variable on a wider expert judgment collection, better representing the variable through the adoption not of linear scales, but logarithmic ones e.g for the rareness of the documents and including in the model further relevant parameters, as the composition of the collection.

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