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Survey of Vulnerability Indicators for Flood Risk Assessment in Cultural Heritage

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Abstract: Floods are among the natural hazards that cause the most damage to cultural heritage assets worldwide. Current methods to assess the vulnerability of cultural heritage assets to floods are scarce or have significant limitations. Among the existing conceptual approaches, indicator-based methods appear to be an adequate option, particularly for risk assessments at a large scale, as in principle they can provide a sensible balance between accuracy and simplicity. In light of this, with the aim of developing a new indicator-based flood vulnerability assessment, a comprehensive literature review was conducted by analysing semi-quantitative methods focused on cultural heritage assets. This paper presents a brief discussion of some flood risk assessments analysed and the selection of flood vulnerability indicators, whose final description is underpinned by analysing technical guidelines and reports. Sixteen flood vulnerability indicators resulted from the analysis, which are organised into four groups. Although these indicators may be used to address different types of cultural assets, the present study is focused on historic buildings.

Keywords: literature review; flood vulnerability; index methods; risk assessment; cultural heritage.

1. Introduction

Gerl *et al.* (2016) state that floods, due to natural phenomena or failure of structures such as dams, levees or floodwalls, can significantly damage property, located in flood-prone areas, including cultural heritage assets. Recent cases of historic sites submerged by floodwater include the World Heritage Site of Shibam in Yemen (2008) or the historic city of Ayutthaya in Thailand (2011). These are some examples of flood events that compromise the preservation of cultural heritage assets, highlighting their vulnerabilities through damage to the immovable cultural assets, causing loss of structural stability or loss of contents with high historic significance. Flood risk management for cultural assets requires the development of flood vulnerability assessments to estimate potential damages and support decision-making, for example, in terms of risk prioritization and mitigation of vulnerabilities. In this context, the use of indicator-based methods can be advantageous, as in principle they can be used to reliably estimate the vulnerability of a large number of cultural assets with limited resources. An indicator-based method for flood vulnerability assessment in cultural heritage can be developed based on a comprehensive analysis of available literature. In light of this, building on the work by Miranda and Ferreira (2019), this review involves the selection of flood vulnerability indicators and a brief discussion of scientific publications addressing semi-quantitative methods focused on flood vulnerability assessment for cultural heritage assets. Sixteen flood vulnerability indicators, found feasible for historic buildings evaluations and categorised into four groups, were finally defined with further support from technical guidelines and reports.

2. Review of Methods for Flood Vulnerability Indicators

A comprehensive literature review of semiquantitative flood risk methods was conducted by analysing references that address mostly flood vulnerability in cultural heritage assets. Thus, examining the references led to obtaining sixteen feasible indicators to assess flood vulnerability in historic buildings. Given the

different types of level assessments found through this review, three categories of methods were classified. Category 1 involves large-scale analyses that employ databases and usually assess two to three indicators. Category 2 reflects in-detail assessments that consider three to five indicators to enhance the outcome details. Methods belonging to this category are typically carried out through on-site visits or require specific/refined input data (e.g. coefficient of absorptivity or swelling). Finally, category 3 includes those methods with a defined index structure considering five or more indicators for flood vulnerability that do not require mandatory on-site visits provided that the input data be available. These methods are common to identify vulnerable buildings at a large scale or could support the identification of vulnerable aspects (e.g. soil-structure interaction) that may require refined assessments (e.g. simulations) due to flood events.

In the case of category 1, Figueiredo *et al.* (2020) and Garrote *et al.* (2020) highlight similar approaches by employing a structural/content heritage classification and principles related to their cultural value. From category 2, Figueiredo *et al.* (2021) and Boinas *et al.* (2016) developed methods with a higher level of analysis for historic buildings in a flood. Whereas the first considers specific characteristics to measure the susceptibility of some materials in specific zones of the building and its movable heritage assets, the second integrates analyses with a systematic calculus methodology (i.e. an equation) based on a specific characterisation of the structural materials and their damaging effects due to chemical reactions. Reviewed methods of category 3 were recently published by Miranda and Ferreira (2019), D'Ayala *et al.* (2020), Gandini *et al.* (2020), and Trizio *et al.* (2021). These four approaches consider similar factors related to the geometric and material properties, conservation state, flood preventive features, and considerations regarding their cultural value. Flood vulnerability indicators related to the surroundings of the cultural heritage asset are mentioned by D'Ayala *et al.* (2020) and Trizio *et al.* (2021), which employ hybrid methods combining indicator-based approaches for flood vulnerability assessment for traditional timber house buildings (11 indicators) and monumental/vernacular earthen architecture (9 indicators), respectively. Gandini *et al.* (2020) propose a holistic method considering flooding and extreme precipitation events with fourteen indicators, whereas Miranda and Ferreira (2019) propose a simplified method considering only six indicators devoted to historic districts near rivers/streams. A similar simplified approach of five indicators, considered within category 3, was established by Stephenson and D'Ayala (2014) for historic buildings in England, highlighting the age, listed status, the number of storeys, typology and conservation of the construction. According to this review, it should be noted that the number of indicators for flood vulnerability assessment is lower in large-scale methods (category 1) or methods with a higher level of detail (category 2), whereas the indexing methods of category 3 consider a higher number of indicators.

3. Proposed Indicators for Flood Vulnerability Assessment in Cultural Heritage

Some of the main flooding actions causing damages are mentioned by Drdácký (2010), who describes typical actions on cultural heritage assets during floods, such as horizontal and upward pressures, velocity stream actions, dynamic impacts, the saturation of materials with water, or changes in soil/subsoil conditions. The description of the selected indicators regards these flooding actions and includes information examined in guidelines (HaFMaSCo, 2006) and technical reports (Nedvědová *et al.*, 2014) about expected damages in contact with floodwater and preventive measures for different types of cultural heritage assets. As mentioned, the flood vulnerability indicators were classified into four groups. Group A refers to the geometric properties of the historic building under assessment (e.g. shape, size). Group B is related to the physical properties of the historic building, its structural system and its conservation state, reflecting the expected level of damage due to the presence of floodwater, considering long and short-term chemical or physical reactions. Group C involves emergency preparedness planning that encompasses the actions related to the prevention of damage in case of floods and the level of protection of the assets given their cultural value. Lastly, group D presents characteristics associated with the surroundings of the building that could increase

the damaging effect due to floods. **Table 1** depicts the selected flood vulnerability indicators for historic buildings, indicating their associated group and a brief description.

Table 1 – Selected flood vulnerability indicators for historic buildings.

Group	Indicator	Description
A	1. Presence and height of the basement	It considers the extension of the damage to the cultural heritage assets associated with the existence of a basement and its height to determine reachable zones of the water depth
A	2. Ground floor level	It measures the possible damage effects accounting for the level between the sidewalk/terrain level and the finished ground floor level (e.g. the main entrance)
A	3. Height of the ground floor	This indicator considers the possible extension of the damage to the inter-storey levels associated with the height of the ground floor
A	4. Height of the building	It measures the damage by water contact in proportion to the total height of the building
A	5. Type of windows/openings	It measures the possible entry of the water and potential mechanical damages that can exist on the windows due to the dynamic impacts of the water
A	6. Shape and orientation of building	It measures the capacity of the building due to the lateral or upward pressures with respect to the shape of the building
B	7. Vertical structural supports	It measures the susceptibility of the predominant material of the vertical structure to contact with floodwater, which can result in long- or short-term mechanical failures
B	8. Inter-storey levels	It measures the susceptibility of the predominant material to the presence of floodwater that can be found in the inter-storey levels and can produce the instability of the structure
B	9. Roof (optional)	It assesses the possible damage due to water infiltration from the rooftop by considering its shape, drainage system and conservation status as proposed in Gandini *et al.* (2020)
B	10. Finishings and linings (non-structural)	It considers the susceptibility of the finishing material between floors, walls and ceilings that can be damaged due to floods
B	11. Level of maintenance	It measures the conservation state of the structure that could compromise/assure its structural stability. This indicator could be linked to the age of the construction
B	12. Foundation and soil interaction	It measures the types of the soils and the characteristics of the foundations to assess possible damage due to soil scouring
C	13. Flood preventive measures	It measures the physical preventive measures to reduce potential flood damage, such as flood barriers or dryness measures
C	14. Number of floors	This indicator measures the readiness to store/safeguard movable cultural assets at higher levels of the building in case of a flood
C	15. Cultural value	This indicator account for the cultural significance of the immovable and movable cultural heritage assets based on cultural policies and/or value assessment frameworks
D	16. Surface conditions	This indicator measures characteristics linked to the surrounding surface conditions that can jeopardise the historic building caused by low permeability, concavity, inadequate drainage system, or due to the closeness of unstable slopes

4. Conclusions

A comprehensive literature review is paramount to support the selection of vulnerability indicators for flood risk assessment in historic buildings, considering available flood vulnerability models addressing cultural heritage. This short paper discusses some methods that consider indicator-based approaches applicable to cultural heritage assets. The discussion focuses on different types of assessment levels, their number/type

of indicators, and some considerations related to the inspection process. The selection of sixteen flood vulnerability indicators is part of ongoing research aiming to support the development of a new indicator-based flood vulnerability assessment for cultural heritage. In this sense, the final list only addresses the assessment of historic buildings that may host movable cultural assets. Although this study did not analyse flood vulnerability methods tailored for ordinary buildings, future works could include this analysis to ratify or expand the presented list of flood vulnerability indicators.

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