DELIVERABLE D.T2.1.3

Decision support tool

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CONTENTS

1. INTRODUCTION

1.1. Objective and scope

Under the activity A.T2.1, WP T2 C*ultural heritage vulnerability in emergency situations* involves the identification of the critical elements which can be subject of improvement in the resilience and risk management of cultural heritage exposed to extreme events. Deliverable D.T2.1.3 aims at the definition of a decision support tool for the harmonization of data related to cultural heritage vulnerability and for a conscious definition of procedures, agreements and cooperation in an overall transnational approach. It endorses the determination of critical elements for cultural heritage vulnerability in the resilience and risk management process which can be a subject of improvement solutions or which represent research gaps or barriers creating challenge for innovative solutions. Critical elements are related to physical, economic, social and managerial aspects that are closely connected to resilience capacity.
This document meets the following objectives:

- Definition of resilience as applied to cultural heritage environments
- Identification of critical elements which can be optimised and outline of their main categories related to CH risk management and resilience building
- Introduction of a decision support tool, to be used as a simplified reference for the PPs and other stakeholders, which relates the controllable critical elements to the possible impact on CH assets exposed to specific hazard situations as well as to possible measures which can be adopted. This should be used as an orientation assessment tool while specific solutions will be provided in deliverables D.T2.2.2

The next section describes the structure of the report.

1.2. Structure of the report

Deliverable D.T2.1.3 *Decision support tool* is composed of the following sections: section 2 presents the concept of resilience as applied to cultural heritage (CH) environments reviewing the basic approaches which can be adopted for its improvement; section 3 outlines the critical elements in CH resilience and risk management and it briefly describes the decision support tool proposed; section 4 discusses the significance of synergies among hazards and critical elements co-existing in a CH environment. Finally, the annex presents the decision support tool for the determination of critical elements for cultural heritage vulnerability in the resilience and risk management process which can be a subject of improvement solutions.

2. RESILIENCE IN CH ENVIRONMENTS

The concept of resilience indicates the capacity of a system to withstand shocks. Cloete defines resilience as “the ability of a system to absorb changes without a transition to a different state”, in

other words “the capacity of a system or object to absorb disturbances and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks” [Cloete 2012].

Historic cities and villages are complex adaptive systems with context-specific characteristics. The resilience of built heritage environments must take into account therefore the resilience of individual cultural heritage objects together with their interactive, dynamic, emergent and adaptive roles.

In the context of the response of cultural heritage areas to disasters, three aspects of resilience must be considered [Vale et al. 2005]:

- **Physical resilience**, which refers to the ability of a city or community to safeguard and restore its physical structure.

- **Emotional resilience**, which refers to the ability of individuals, families and communities to cope and heal from trauma.

- **Cultural resilience**, which signifies the perseverance of cultural practices and norms through events of great cultural trauma (i.e. the ability of customs, traditions, languages or religions to survive and evolve).

The resilience of complex cultural heritage systems to the impact of natural and man-made disasters can be improved by means of four basic approaches: **i) preventive protection**, **ii) adaptation**, **iii) evacuation** and **iv) resilience preparedness**.

- **Preventive protection** is cost demanding, not always feasible and it can sometimes lead only to partial benefits, such as for example in the case of threat of landslides. As far as the scale is concerned, preventive protection can be designed and implemented at territorial, building and material levels. Territorial protection, like barriers against flooding for example, could beneficially influence the resilience capacity of a CH system; however, at the same time, it should be considered that such large scale protection approach might induce a rather significant impact on values of the area with heritage assets, in case stable structural measures are applied. Preventive protection of buildings and complexes of buildings also present greater advantages when implemented using temporary measures, which are removable after the event. Material protection is almost always irreversible, however for individual immovable artefacts or buildings could be very effective.
- **Adaptation** is also cost demanding and can influence negatively the cultural heritage context and values. This approach is usually adopted in relation to climate induced risks or similar largely distributed threats and it needs wider campaigns and appropriate largely adopted financing.
- **Evacuation** is the best protective measure suitable and applicable for moveable heritage. However, it needs planning, fast action and a safe space for temporary storage.
- **Resilience preparedness** combines all the above mentioned approaches, involving to a larger extent the public and proving to be effective in complex situations such as in the protection of CH systems. Such resilience-based approach is a core strategy for the ProteCHt2save project, presenting a clear potential to be cost effective at ensuring high benefits.

Understanding the critical elements of a CH system is a fundamental task which ensures the development of a resilience and risk management approach tailor-made for the CH system considered.

The next section provides a definition of such critical elements, outlining the most relevant categories which should be considered for improvement of resilience of CH.

3. DEFINITION OF CRITICAL ELEMENTS IN CH RESILIENCE AND RISK MANAGEMENT

In order to determine an effective resilience and risk management plan, it is fundamental to individuate the critical elements which affect cultural heritage objects.

> **A critical element** can be defined as a **factor** or **aspect** of a CH system, intended as the ensemble of its physical and managerial characteristics, which proves to be **crucial** for the determination of its **resilience** against natural disasters and climate change actions.

Critical elements therefore set the priorities which resilience and risk management policies should address. For the sake of establishing a proper framework for the decision support tool which can be easy to use and accessible also to non-technical stakeholders, a simplified categorisation of critical elements is here proposed. This considers two main groups of critical elements which characterise a CH system, namely **1) managerial** and **2) physical critical elements**. These categories are further discussed in the following paragraphs.

3.1. Managerial critical elements

Managerial critical elements relate to those aspects of a CH system which are not connected to the physicality of the asset but rather to its operation, administration and care. Managerial critical elements therefore include how CH environments are used and protected involving social and economic as well as policy and regulation issues.

From the main findings of deliverable D.T2.1.1, examples of managerial critical elements include the lack of knowledge or information, negligence (lack of maintenance), inadequate decision making, poorly designed emergency or post-disaster plans, missing funds etc. All these represent fundamental controllable features of a CH system which can be modified and adjusted by adopting appropriate management actions and measures. Each managerial critical element is strongly context-specific and requires an accurate assessment and thoughtful prioritisation in order to reduce the risks related to natural hazards and climate change and improve the resilience of the overall CH system.

The decision support tool presented in the annex of this document provides a detailed list of the managerial critical elements which may affect CH with suggestions of possible measures which could be undertaken to improve its protection.

3.2. Physical critical elements

Physical critical elements relate to the aspects of a CH system involving its actual material composition and structural conditions. The sensitivity of historic structures and structural elements to weather and disasters is influenced by material and structural capability to resist exceptional loads and environments during disastrous situation. As mentioned for the previous category, also physical

critical elements are significantly context-specific and require a thorough investigation of material characteristics and the general environmental situation (e.g. hydrogeological conditions) before being adequately evaluated. In some cases, in fact, it is not the historic structure itself that is sensitive to climatic conditions, but the surroundings and the supporting structure can also be affected. It should be emphasised that it exists a wide range of historic structures and materials, and also a wide range of types of damage. This makes it difficult to design widely applicable measures and unified methods. In the decision tool presented in the annex physical critical elements are analysed considering a ranking of historic structures, elements and situations according to their sensitivity to the effects of weather and natural disasters.

3.3. Decision support tool

The **decision support tool** proposed provides a **harmonization of data** related to cultural heritage vulnerability for a **conscious** definition of procedures, agreements and cooperation in an overall **transnational approach**. The tool is intended to support the PPs and other stakeholders involved in the field of CH protection in the definition of critical elements in the resilience and risk management of cultural heritage. It is developed in English and in the seven national languages represented in the project.

The decision support tool is presented in a simplified form in the annex of this deliverable. For each critical element, tables are used to relate the controllable critical elements to the possible impact on CH assets exposed to specific hazard situations and possible measures which can be adopted [Drdácký et Al. 2006, Drdácký et Al. 2007, Drdácký 2010, Drdácký et Al. 2010].

As mentioned in the previous sections, two main groups of critical elements are considered, namely managerial and physical ones. For practical reasons, physical critical elements are categorised in relation to the disaster type and actions employing a system of ranking of structures, elements and situations into categories, according to the sensitivity of CH objects to the effects of disasters or long term harsh weather actions. The sensitivity categories represent a general description of criticalities which may be subject of some control reducing damage and facilitating resilience. The tool therefore is intended to be used as a reference for a preliminary assessment of risks only and for a fast prioritisation of issues to be addressed by specific measures. Examples of measures, good and bad, are given in D.T2.2.1 and detailed strategies and measures in D.T2.2.2.

Due to the large number of combinations of hazards, CH object typologies and critical elements **the tool should be intended for reference only** while specific analyses and assessments are still strongly suggested in the perspective of the elaboration of an accurate and effective resilience and risk management plan which applies to a specific CH system. Furthermore **the decision support tool proposed**, in order to preserve its clarity and accessibility, **does not consider the effect of synergies among multiple actions** involving CH objects as well as synergies among multiple critical elements co-existing in the CH system **which may necessitate different sets or levels of measures to be implemented.** Such synergies are briefly discussed in the next section.

4. DANGEROUS SYNERGIES

Safety and reliability of historic structures or buildings are typically assessed under “ideal” load or environmental service conditions. However, the natural and man-made actions or interventions during the life of historical constructions may generate synergic effects which decrease their safety and even cause heavy defects or failures [Drdácký et Al. 2017].

In fact, in real-life situations, the combined effects of multiple actions on a structure can be greater than the sum of the effects of each individual action.

This clearly highlights the possibility of underestimating the threat to cultural heritage assets if the occurring synergies are not considered. Examples of synergic effects include: the simultaneous action of temperature and water in repeated freezing/thawing cycles which is a typical threat for wet porous brittle and quasi-brittle materials; the interacting influences of temperature and moisture which cause repeated and uneven volumetric changes, resulting in material deterioration and propagation of defects; in combination with abrasive particles, wind can cause remarkable surface erosion (e.g. of monuments in sandy deserts). There are also numerous other examples of the effect of combined weather factors, e.g. moisture + deposition mechanisms, and wind + water + pollutants penetrating into materials as weak acids.

As a consequence of expected dangerous synergies, it is hence fundamental when assessing the resilience of CH assets to consider the interaction of multiple critical elements which may co-exist in the system.

Elements which may not adversely influence alone the vulnerability of an object can in synergy with other elements provoke very dangerous situation. In this context, the possible combined effects should be closely assessed and a tailored solution should be implemented.

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6. ANNEX (Decision support tool)

MANAGERIAL CRITICAL ELEMENTS

1. Information on CH assets

Understanding and knowing the characteristics of cultural heritage assets and its components represents a fundamental prerequisite for an appropriate disaster planning, response and recovery analysis. This information enables to establish priorities for the protection of a property and for example to guide fire brigades and civil defence officials to handle sensitive areas with care in responding to emergencies. The assessment of cultural heritage values can also help clarify property losses and priority needs for stabilizing and securing the property and its constituent elements during post-disaster processes.

- Critical elements

  1.1 No information about cultural heritage assets
  - 1.1.1 Location unknown
  - 1.1.2 Conditions unknown
  - 1.1.3 Contents unknown (e.g. collections, artefacts).

  1.2 Only partial, not up-to-date or incomplete information existing.

  1.3 Partial or complete data existing but not available to stakeholders.

- Possible and recommended solutions

- Identifying and marking stock at risk through mapping, condition assessment and evaluation
- Regular inspection
- Records of moveable heritage stored in buildings with data on their location and description for evacuation purposes (handling, transportation and storage requirements)
- Digitalization of CH related data
- Integration of existing databases

Rank	Type	Vulnerability	Examples	Preventive measures and priorities
Inf0	**Complete description of CH asset exists and is available to all stakeholders involved**	No major vulnerability issues. Comprehensive risk management plans can be developed and appropriately shared	Data concerning CH assets are complete (maps, condition assessment of objects and records of contents), accessible to all relevant stakeholders and up-to-date	Regular inspection of assets is required on periodic basis to keep risk management plan up-to-date; Regular maintenance is also necessary to ensure conditions of the asset
Inf1	**Partial or complete data existing but not available to**	Loss might be expected particularly during rescue activities when handling, transportation and	Examples include information concerning moveable heritage such as collections and	Records of moveable heritage stored in buildings with data on their location and description for

	stakeholders	storage requirements are not accessible	artefacts in a museum are not available to rescue units	evacuation purposes; Digitalization of CH related data; Integration of existing databases
Inf2	**Only partial, not up-to-date or incomplete information exist**	Damage is expected to the CH object and its contents. Failure of structural components and loss of moveable objects can occur due to incorrect, missing or not valid information	Maps and databases related to CH assets present in a specific area exist however significant information is missing or invalid due to changes in time of asset vulnerability or hazard level	Regular inspection Identifying and marking stock at risk through mapping; Condition assessment and evaluation; Records of moveable heritage stored in buildings
Inf3	**No information about cultural heritage assets (all or one of the following: location, conditions, contents)**	Different levels of damage from minor to collapse can occur even in the case of actions of minor intensity. Lack of information can seriously affect the proper determination of safety against natural disaster or weather effects (e.g. in case of weather induced degradation of mechanical properties of material load bearing capacity might be overestimated)	No mapping of CH assets present in a risk-prone area is available. Unknown structural and material conditions of assets. No data concerning valuable contents of buildings are known.	Regular inspection and repair of found deficiencies; Identifying and marking stock at risk through mapping; Condition assessment and evaluation; Records of moveable heritage stored in buildings; Digitalization of CH related data; Integration of existing databases

2. Funding

Investing in preventive, mitigation and preparedness measures is fundamental for improved CH resilience. Both structural and non-structural approaches allow space for innovative solutions, techniques and for breakthrough concepts and these should be pursued. The specific features of certain natural hazards require preventive measures to be developed and adopted in a harmonized way by several European countries. On the non-structural level, bilateral or multi-lateral agreements are needed, managed by a coordination process.

- Critical elements
  2.1 No funds available for preventive, mitigation and preparedness measures.
  2.2 Funds available but insufficient.
  2.3 Funds available but not accessible.

- Possible and recommended solutions

- Networking for reaching critical mass
- Regional, national and transnational cooperation for cost effectiveness and resource sharing
- Awareness raising for private owners for accessing funds
- Improve participation processes at different levels of governance for impact on budgeting.

Rank	Type	Vulnerability	Examples	Preventive measures and priorities

Fun0	**Funds available and accessible**	No major vulnerability issues. Proper measures are financed.	Necessary funds are allocated for the risk management of CH assets including repair and emergency measures	Regular inspection and maintenance for up-dating priorities and optimising allocation of resources
Fun1	**Funds available but insufficient**	Minor damage might be experienced to assets with low risk of loss of heritage value	Funds are available for high priority measures (e.g. roof repair) and ordinary maintenance of the asset but not for performance improvement actions (e.g. anti-seismic retrofitting)	Networking for reaching critical mass; Transnational cooperation for cost effectiveness and resource sharing
Fun2	**Funds available but not accessible**	Damage is expected to the CH object and its contents due the impossibility to allocate the necessary funds of resilience building and risk mitigation	Lack of awareness of CH assets owners and managers might prevent accessibility of financial resources allocated at regional, national or European level	Networking for reaching critical mass; Transnational cooperation for cost effectiveness and resource sharing; Awareness raising for private owners for accessing funds
Fun3	**No funds available**	Damage is expected to the CH object and its contents due the impossibility to allocate the necessary funds of resilience building and risk mitigation	No funds are allocated for the risk management of CH assets	Networking for reaching critical mass; Transnational cooperation for cost effectiveness and resource sharing; Improve participation processes at different levels of governance for impact on budgeting

3. Knowledge and awareness

Gathering, evaluating and disseminating best practice examples as well as bad ones is also fundamental in order to exploit the full potential of experiences in the perspective of defining an appropriate CH protection strategy. Awareness, public education, systems and facilities that provide advice are proved methods for reducing cultural heritage losses.

- Critical elements

  3.1 Lack of awareness concerning CH at risk and its resilience.

  3.2 Lack of technical knowledge related to CH protection, resilience and risk management measures.

  3.3 No knowledge sharing among different stakeholders and within same group of stakeholders (e.g. among professionals or among different level of governance).

- Possible and recommended solutions

- Dissemination activities
- Research funding
- Training for practitioners

- Introduction of technical standards
- Early-warning systems for natural disasters
- Knowledge sharing platforms based on digital technologies
- Regional, national and transnational programmes for knowledge sharing among neighbouring areas

Rank	Type	Vulnerability	Examples	Preventive measures and priorities
KA0	**Knowledge and awareness are ensured**	No major vulnerability issues. Appropriate knowledge and awareness endorses optimal resilience of CH assets	Technical knowledge concerning CH protection is ensured and shared among professionals; all stakeholders including managers, owners and general public are aware of CH assets at risk and trained	Research funding for innovative resilience-based solutions; Training and dissemination activities to ensure up-to-date knowledge and awareness of technical solutions and risks
KA1	**Lack of awareness**	Minor damage might be experienced due to misinterpretation among stakeholders, underestimation or no knowledge of risks	Managers, owners and general public are not aware of the climate change related risk of CH assets and their resilience	Dissemination activities; Research funding; Training for practitioners; Early-warning systems for natural disasters; Knowledge sharing platforms based on digital technologies
KA2	**No knowledge sharing among different stakeholders**	Damage is expected to the CH object and its contents due to faulty risk management plan, lack of knowledge, poor communication in preparation and during emergency and evacuation phases	Erroneous implementation of technical solutions, Improper handling, transportation and storage of moveable CH objects	Training for practitioners; Knowledge sharing platforms based on digital technologies; Transnational programmes for knowledge sharing among neighbouring areas
KA3	**Lack of technical knowledge**	Heavy damage due to natural disasters and weather effects amplified by human errors such as design and implementation errors, unreliable risk assessment	No technical knowledge is available for the definition of an adequate risk mitigation plan and the implementation of proper non-structural and structural measures	Introduction of technical standards; Training for practitioners; Knowledge sharing platforms based on digital technologies; Transnational programmes for knowledge sharing among neighbouring areas

4. CH protection planning

- Critical elements

  4.1 No resilience and risk management plan.

4.2 Lack of specific emergency procedures related to evacuation or rescue.
4.3 No maintenance schemes for CH at risk.

- Possible and recommended solutions
- Town planning which includes risk management
- Regular inspection and maintenance
- Risk assessment including vulnerability and hazard maps
- Design and implementation of structural measures for CH assets at risk
- Emergency plans
- Early warning systems
- Awareness and knowledge raising and sharing

Rank	Type	Vulnerability	Examples	Preventive measures and priorities
PP0	**Resilience and risk management plan is enforced and up-to-date**	No major vulnerability issues. Adequate protection and resilience of CH assets is provided	Risk management plan exists together with resilience building measures, maintenance schemes and emergency procedures	Regular inspection and maintenance
PP1	**No maintenance schemes for CH at risk**	Minor damage might be experienced due to long-term effects of malfunctioning building control systems (drainage, electrical, ventilation) and protection systems (alarms, early-warning)	Proper maintenance is missing inducing in some cases bad functioning of protection systems, drainage systems, fittings etc.	Regular inspection and maintenance; Awareness and knowledge raising and sharing ; Early warning systems
PP2	**Lack of specific emergency measures**	Damage expected in particular to moveable heritage either immediately after the disaster or due to lack of knowledge, mishandling and improper storage during rescue	No evacuation plan. No rescue plan for valuable objects inside buildings (e.g. galleries, museums). No emergency plan for coordination of efforts after the disaster	Emergency plans; Early warning systems; Awareness and knowledge raising and sharing
PP3	**No resilience and risk management plan**	Heavy damage is expected. Loss of moveable heritage. Complex, at times impossible recovery.	No resilience and risk management plan is enforced	Town planning which includes risk management, Risk assessment including vulnerability and hazard maps, Design and implementation of structural measures for CH assets at risk, Emergency plans, Early warning systems

5. Policy and regulations

- Critical elements

5.1 Property status issues: properties owned jointly by the municipality and the state, for example, imposes additional financial burdens to the local authorities which are asked by the state for advanced funding schemes.
5.2 Lack of building codes with specific approach to cultural heritage
5.3 Problems with responsibilities.

- Possible and recommended solutions

- Strengthening the administrative power of responsible authorities to enforce measures to reduce risks
- Concept of performance requirement introduced in building codes
- Coordination among levels of authorities
- Participation of heritage experts in policy making
- Horizontal governance at local level
- Synergies between policies

Rank	Type	Vulnerability	Examples	Preventive measures and priorities
Reg0	**Resilience-based approach to policies and regulations concerning CH protection**	No major vulnerability issues. The legal framework adequately addresses the needs of CH protection and risk management against climate change and natural disasters	Policies and regulations enforced are tailor-made for risk management of CH assets. Responsibilities among stakeholders are clear and no legal constraints or gaps are present	Regular inspection and maintenance for monitoring and evaluating the effectiveness of legal framework enforced
Reg1	**Property status issues**	Minor damage might be experienced due to legal and financial shortcomings	Properties owned jointly by the municipality and the state. Incomplete or pending restitution processes of built heritage objects	Coordination among levels of authorities; Participation of heritage experts in policy making
Reg2	**Problems with responsibilities**	Damage expected. Often, disaster risk prevention and management instruments are subject to provincial legislation, the speed of implementation is affected largely by the fact that legal and technical standards differ from province to province	Broad range of stakeholders leads to slow or un-coordinated approaches to apply contemporary safety-precautions and risk disaster mitigations instruments; no clear rules about the responsibilities are often reported	Strengthening the administrative power of responsible authorities to enforce measures to reduce risks; Coordination among levels of authorities
Reg3	**Lack of building codes dedicated to CH**	Heavy damage is expected due to natural disaster and climate change related effects as well as to improper codes not specifically addressing CH	Rules regarding renovation of heritage buildings can be very strict creating an obstacle for risk management strategies; in some cases cultural heritage lacks a	Concept of performance requirement introduced in building codes; Participation of heritage experts in policy making

			specific approach	

PHYSICAL CRITICAL ELEMENTS

1.Flood

- F0 Flood-resistant structures
- F1 Structures made of materials with a high volumetric change due to moisture – typically i) timber structures and elements, ii) combined structures made of materials with different moisture expansion, iii) some soils
- F2 Structures made of materials that lose their strength to a great extent when subjected to moisture – typically i) dried brick (adobe) masonry, ii) masonry with clay mortars (with a low lime or cement content), iii) decayed timber structures and elements, iv) infill subsoil and fine particle subsoil
- F3 Structures susceptible to partial damage due to flooding – typically i) timber parts prone to uplifting and floating away, ii) large bridges, iii) pavements
- F4 Structures and elements vulnerable to overall collapse or displacement due to flooding – typically i) small bridges and walkways, ii) free-standing walls, iii) light, improperly anchored objects (summer houses, etc.), iv) small dams.

The impact can be reduced using various measures applicable in the identified categories: make regular inspections of structural health (all categories); make emergency plans and establish guidelines (all categories); install an early warning system and provide information systems (all categories); prepare technical measures against flooding – permanent measures or easily-installable temporary measures (all categories); provide temporary strengthening and additional supports (F2, F3, F4); take measures to decrease loads (dismantle bridge parapet walls, make openings to balance the water pressure) (F3, F4); improve the anchoring of sensitive structural parts into supporting structures (F3, F4); remove floating objects and "dams" from the stream (F3, F4); publish guidelines for "after the flood" activities, e.g. prevent damage due to rapid material disintegration, rapid salt crystal growth, pollution and climatic effects, etc. (all categories).

Rank	Type	Flood Vulnerability	Examples	Preventive measures and priorities
F0	**Flood-resistant structures and buildings**	No structural or material damage apparent during and after flood. Typical impacts: water saturation and high moisture of materials and structures, soiling, infection by microorganisms, unhinged doors and similar.	Robust objects made of water resistant materials (e.g. granite or similar stone, metals, good stone masonry, concrete).	No hard measures necessary – only some recommended preparedness facilitating cleaning and drying after the flood,
F1	**Structures made of materials with a high volumetric change due to moisture**	Damage associated with volumetric change – usually irreversible – change of shape, cracks, and deflections. Spalling of surface layers. Moisture expansion may cause damage of masonry –	i) timber structures and elements, ii) combined structures made of materials with different moisture expansion – e.g. combined timber – masonry objects, iii) some soils	Prevention of contact with water – if possible (plastic wrapping, protective coats etc., creation of dilation gaps between timber and masonry,; evacuation of moveable

		origination of cracks or even shifting structural parts. Bowing of wooden floors. No dangerous loss of strength and load carrying capacity reduction.		objects.
F2	**Structures made of materials that lose their strength to a great extent when subjected to moisture**	Materials fast degrading and losing their mechanical characteristics due to high moisture or water saturation which induces significant reduction of load carrying capacity of structural elements or subsoil and may cause fatal failures during flood or after it.	i) dried brick (adobe) masonry, ii) masonry of burnt bricks or some sensitive stones (sandstone) with clay mortars (with a low lime or cement content), iii) decayed timber structures and elements, iv) infill subsoil and fine particle subsoil.	Critical structural elements require assessment of their load carrying capacity by professionals and the structures usually need temporary supports or permanent strengthening before flood situations.
F3	**Structures susceptible to partial damage due to flooding**	Damage is very sensitive to the condition of such objects. Partial loss of cultural heritage is a consequence of water action.	i) timber parts prone to uplifting and floating away, ii) parts of large bridges, namely parapet walls or piers, iii) pavements	Regular inspection and repair of found deficiencies; Provide temporary strengthening and additional supports; Take measures to decrease loads (dismantle bridge parapet walls, make openings to balance the water pressure); Improve the anchoring of sensitive structural parts into supporting structures; Remove floating objects and "dams" from the stream.
F4	**Structures and elements vulnerable to overall collapse or displacement due to flooding**	Sudden failure and overall collapse of elements due to the static and/or dynamic actions of water.	i) small bridges and walkways, ii) free-standing walls, iii) light, improperly anchored objects (summer houses, etc.), iv) small dams	

2.Fire due to drought

- H0 Fire resistant structures with low fire load
- H1 Fire resistant structures with high fire load
- H2 Fire destroyable structures and buildings in settlements
- H3 Fire destroyable structures and buildings in country side
- H4 Fire destroyable structures and buildings in forests
-

The impact of fire can be reduced using various measures applicable in the identified categories: evacuation of moveable heritage (all categories); installations of monitoring and early warning systems (all categories); installation of automatic extinguishing systems in interiors (all categories) and exteriors (H2, H3, H4); creation of fire stopping protective belts (buffer zones) around the structures or buildings (H3, H4).

Rank	Type	Fire Vulnerability	Examples	Preventive measures and priorities
H0	**Fire resistant structures with low fire load**	Minor, aesthetical damage can be experienced in the building/structure after fire, which due to the low fire load can have only a short duration of reduced	i) Unfurnished buildings whose components such as floor structure, ceilings and roof structure are not made of inflammable	Evacuation plan for moveable heritage assets and installation of monitoring and early warning systems as well as automatic

		intensity.	materials. ii) Structures not made of inflammable materials	extinguishing systems in interiors
H1	**Fire resistant structures with high fire load**	Considerable damage to contents and minor damage to building components as well as doors, window frames	Furnished buildings/structures whose components such as floor structure, ceilings and roof structure are not made of inflammable materials	Installation of automatic extinguishing systems in interiors and early warning systems.
H2	**Fire destroyable structures and buildings in settlements**	Significant damage to building components such as floor and roof structures. Heavy damage or loss of ceilings, doors/windows and decorations as well as furniture and moveable objects. Possible deformation of metal building components.	Structure/building in urban area whose components are made of inflammable materials (e.g. timber floor and roof structural system, half-timbered structures) or made of materials susceptible to deformation at high temperature	Installations of monitoring and early warning systems; Installation of automatic extinguishing systems in interiors and exteriors
H3	**Fire destroyable structures and buildings in country side**	Heavy damage to building components such as floor and roof structures. Complete loss of ceilings, doors/windows and decorations as well as furniture and moveable objects. Possible deformation of metal building components.	Isolated structure in rural area whose components are made of inflammable materials (e.g. thatched roof for vernacular buildings) or made of materials susceptible to deformation at high temperature	Installations of monitoring and early warning systems; Installation of automatic extinguishing systems in interiors and exteriors; Creation of fire stopping protective belts (buffer zones) around the structures or buildings
H4	**Fire destroyable structures and buildings in forests**	Collapse of the structure/building or partial collapse due to failure of floor or roof structure or excessive temperature induced deformation of components.	Isolated structure in forests whose components are made of inflammable materials (e.g. log house) or made of materials susceptible to deformation at high temperature	Installations of monitoring and early warning systems; Installation of automatic extinguishing systems in interiors and exteriors; Creation of fire stopping protective belts (buffer zones) around the structures or buildings

3.Wind

- W0 - Wind resistant structures and elements
- W1 - Vibration prone elements and structures – typically i) windows and window glazing, and ii) architectural elements (e.g. pinnacles)
- W2 - Wind releasable elements – typically roof coverings
- W3 Structures susceptible to partial wind damage – typically i) roofs, ii) windmills, iii) tall sculptural works
- W4 Structures and elements vulnerable to overall collapse due to wind action – typically i) free-standing walls and elements (attic gables, walls of ruins, fencing walls, chimneys, menhirs, poles, etc.), ii) light and tall buildings (towers, timber houses, etc.) and iii) trees.

The impact can be reduced using various measures applicable in the identified categories: make regular inspections of structural health (all categories); carry out long-term monitoring of structural health (W3, W4); install warning systems (only in special cases of W3, W4); carry out regular maintenance (all categories); change the tuning of structures or elements (W1); Improve the anchoring of the building envelope (roofing, facade) (W2); improve the anchoring of sensitive structural parts into the supporting structures (W3); change the effect of wind on the element or building (make changes to the wind flow conditions) (W1, W2, W3); strengthen the structure and/or provide additional supports for the whole structure (W4).

Rank	Type	Wind Vulnerability	Examples	Preventive measures and priorities
W0	**Wind resistant structures and elements**	No detectable damage after wind, even for significant actions. No or controlled vibration and no material/element release is experienced	Elements and structures made of sound materials whose shapes do not allow major vibration. Also proper anchoring avoids releasing of materials and elements	Ensure regular inspection and maintenance to evaluate the good conditions of the structure and its elements
W1	**Vibration prone elements and structures**	Detectable vibration of elements and structures occasionally associated with localised damage such as micro cracks and deformations	i)Windows and window glazing ii) architectural elements (e.g. pinnacles)	Change the tuning of structures or elements
W2	**Wind releasable elements**	Loosening, dislocation or missing elements after wind action	Roofing material such as tiles, shingles etc.	Improve the anchoring of the features of the building envelope (roofing, facade)
W3	**Structures susceptible to partial wind damage**	Visible damage to the structure and elements due to wind action. This damage needs fast and costly repair as usually can lead to additional deterioration of the building and its contents (e.g. in case of roof leaking or missing)	i) roofs, ii) windmills, iii) tall sculptural works	Improve the anchoring of sensitive structural parts into the supporting structures; Long-term monitoring of structural health is recommended; If possible, intervene on the wind flow conditions; Consider, in cases of significant loss expected, to install warning systems.
W4	**Structures and elements vulnerable to overall collapse due to wind action**	Building components and/or structures expected to collapse due to wind action.	i) free-standing walls and elements (attic gables, walls of ruins, fencing walls, chimneys, menhirs, poles, etc.), ii) light and tall buildings (towers, timber houses, etc.) and iii) trees.	Strengthen the structure and/or provide additional supports to the whole structural system; Install warning systems

4.Heavy rain

The surfaces of building elements and structures (including decorations) exposed to rain are divided into five categories:

- R0 Sheltered from rain

- R1 Partly exposed to rain and/or moderate rainwater runoff – typically vertical surfaces moderately exposed to winds
- R2 Exposed to rain and/or heavy rainwater runoff – typically i) roofs, ii) inclined surfaces of sculptures, iii) vertical surfaces exposed to prevailing and strong winds
- R3 Complex shapes with horizontal surfaces – typically i) Cornices, ii) Balconies, iii) Decorative architectural elements
- R4 Complex shapes with water traps – typically roof and façade details

The impact can be reduced using various measures applicable in the identified categories: make regular inspections of structural health; carry out long-term monitoring of structural health (selected); install warning systems (typically in moisture-sensitive roof lofts and timber); carry out regular maintenance; ensure that water is carried away rapidly and effectively (outlets, adequate, unblocked gutters, etc.); prevent water penetrating or soaking into material (coatings, barriers, etc.); provide protection against excessive rain penetration (shelter, coatings, etc.); carry out architectural improvements (details, cornices, etc.); replace originals by replicas.

Rank	Type	Heavy rain Vulnerability	Examples	Preventive measures and priorities
R0	**Weather resistant structures and elements sheltered from rain**	No detectable damage after heavy rain.	Elements and structures made of sound materials whose shapes minimise rain exposure	Regular inspection and maintenance to evaluate the good conditions of the structure and its elements
R1	**Structures and elements partly exposed to rain and/or moderate rainwater runoff**	Occurrence of occasional and localised moisture areas (moist stains). Depending on moisture storage and transport capacities of the materials moisture can be lowered to natural content without damage. Monitoring is required to assess such case.	Vertical surfaces moderately exposed to winds	Prevent water penetrating or soaking into material
R2	**Structures and elements exposed to rain and/or heavy rainwater runoff**	Material degradation. Occasional high moisture in porous materials leads to a series of durability problems such as disintegration, crumbling, biological colonisation, unhealthy conditions for occupants.	typically i) roofs, ii) inclined surfaces of sculptures, iii) vertical surfaces exposed to prevailing and strong winds	Prevent water penetrating or soaking into material; Carry out long-term monitoring of structural health
R3	**Complex shape structures and elements with horizontal surfaces**	Almost permanent high moisture in building materials which might lead to significant durability problems. The prolonged presence of rainwater in the material could affect the mechanical properties of the materials and lead to structural damage	typically i) cornices, ii) balconies, iii) Decorative architectural elements and edges, corners, protuberances or subtle elements fixed to massive parts	Ensure that water is carried away rapidly and effectively (outlets, adequate, unblocked gutters, etc.); Provide protection against rain penetration
R4	**Complex shape structures**	Extended damage to porous building materials due to permanent high	typically roof and façade details made of sensitive material,	Ensure that water is carried away rapidly and effectively

	and elements with water traps	moisture content. Structure or it parts not possible to be used by occupants due to unhealthy environment. Structural damage is expected due to long-term degradation of material properties	foundations and lower portions of vertical elements built in lower level areas prone to water pooling	(outlets, adequate, unblocked gutters, etc.); Carry out architectural improvements (details, cornices, etc.); Replace originals by replicas; Provide protection against rain penetration