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DELIVERABLE D.T2.2.1

Manual of good and bad practices for disaster resilience of cultural heritage risk assessment.

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CONTENTS

1. INTRODUCTION

1.1. Objective and scope

Deliverable D.T2.2.1 is developed within the framework of the activity A.T2.2 of WP T2 C*ultural heritage vulnerability in emergency situations*, which concentrates on the critical analysis of local vulnerability and measures in emergency situations for cultural heritage. This deliverable aims at providing a manual with a critical overview of the foremost examples of good and bad practices, learned from experience, in managing risk for cultural heritage located in Central Europe (considering mainly flood, heavy rain and fire due to drought).

More specifically, this document pursues the following objectives:

- To outline past and recent examples of extreme events in Central Europe, highlighting the key aspects and shortcomings of risk management approaches and measures.
- To identify the foremost examples of good practices in managing risks for cultural heritage.
- To determine the target aspect of risk (hazard, susceptibility/exposure or resilience) at which the good practice measures aim together with their feasibility of implementation, impact on CH protection and limitations.
- This deliverable should be read in conjunction with the following documents:
    - D.T2.1.1 which has the scope of highlighting the main problems, barrier and challenges existing at Central European level in the resilience and risk management of cultural heritage facing natural disasters.
    - D.T2.1.3 which 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.
    - D.T2.2.2, which investigates resilience controllable criticalities of cultural heritage suitable for innovative mitigation, providing technical details of specific solutions.

The next section describes the structure of the report.

1.2. Structure of the report

The deliverable D.T2.2.1 *Manual of good and bad practices for disaster resilience of cultural heritage risk assessment* is composed of the following sections: section 2 presents the key aspects and shortcomings of flood risk management measures experienced during past and recent events; also “good” flood risk organisational and operational/technical practices are discussed. Section 3 deals with heavy rain, outlining examples of “bad and good” practices in the management of cultural heritage assets with respect to strong rain and wind including the possible limitations, if any, in terms of feasibility of implementation and impact on CH protection. Similarly, section 4 presents past and recent fire due to drought events with future projections in Central Europe; organisational and operational/technical measures to be taken in case of fire risk in cultural heritage assets are discussed.

2. FLOOD

2.1. Recent events: key aspects and shortcomings

The increasing atmospheric temperatures lead to changes in the frequency, intensity and seasonality of floods due to extreme rain as well as through the melting of ice caps, glaciers, sea ice, ice and snow cover especially in polar and mountain regions [1]. A comprehensive analysis of the impacts of sea-level rise carried out by the Croatian Ministry of Environment and Natural Protection in 2015 [2] shows, for example, that if no adaptation measures are taken, sea-level rise and socio-economic development would increase flood risks substantially during the 21st century. The expected number of people flooded annually in Croatia would increase from initial 17,000 to 43,000–128,000 in 2100 and the expected annual damages from initial US$ 40 million to 0.9 to 8.9 billion per year in 2100. In a similar manner the increasing intensity and frequency of river floods together with the criticalities of town planning in urban environments, especially in historic cities, will considerably increase the severity of impacts of natural disasters on the socio-economic system as well as on the urban fabrics including cultural heritage assets.

Multiscale impact of water action on the historic landscape and objects

In the example, a small damaged bridge and its surroundings as a result of combined water saturation and flow in subsoil layers, typical for a sudden loss of load carrying capacity of clay or washing out of fine sand, and reconsolidation of soils loosened with uplift action. The dam on the right side has been totally destroyed and washed away.

Veltrusy park, bridge (Bohemia/CZ)

Several flooding events hit Central Europe in recent times. Numerous regions suffered from extreme fluvial flooding during which most existing protection measures were overwhelmed and damage totalled billions of Euro, particularly in 2002 (Czech Republic, Austria, Germany, Slovakia, Poland, Hungary, Romania, Croatia) 2006 (Bulgaria, Romania, Serbia, Macedonia, Germany, Czech Republic, Hungary), 2009 (Austria, Czech Republic, Hungary, Poland, Romania, Slovakia, Turkey) and in 2013 (Germany, Czech Republic, Austria, Switzerland, Slovakia, Belarus, Poland, Hungary). Similarly, sea floods due to exceptional tides, storm surge and heavy rain (or combinations of these) occurred in the Adriatic region of Central Europe: in 2008 and 2012 Dalmatia was flooded together with Istria and Kvarner area. The old town of Trogir was flooded together with the centre of Rijeka, as were parts of Pula, Vodice, Šibenik and Zadar. Furthermore, disastrous events occurred also recently: in October 2018 the Slovenian coastal harbour of Piran has been flooded along with roads and streets by the Adriatic Sea waters. The population has been urged to follow the instructions of the Civil Protection and Disaster Relief Administration and other services. Similarly in Venice, the October 2018 flood has been the worst seen since 1966, when floodwaters reached a height of more than 6 feet.

These examples present a vivid picture of what is at stake when natural disasters strike urban areas with significant cultural sites. Past and recent flooding events in Central Europe highlight several key points and shortcomings in the risk management of cultural heritage assets. Analysis of consequences of the fluvial flooding in 2002 occurred in Central Europe reveals that the main causes of structural damage can be subdivided into insufficient communication among responsible authorities as well as among the authorities and citizens, impact of water action on historic materials, structures and sites and inadequate post flood interventions [3]. It also underlines that heritage structures may be severely damaged even by minor flows causing increased moisture in interiors [4].

Underestimation of impact of minor water flows

Rising damp, Veltrusy chateau (Bohemia/CZ)

When drafting a correct flood risk management plan, it is important to take into consideration also events with low intensities. These may, in particular cases, induce considerable damage to cultural heritage assets. Flood water often transports various substances which may cause chemical deterioration or biological infection. In the example on the left, it is possible to see rising dampness and salt efflorescence after a low water depth flood in the Chateau Veltrusy (Bohemia).

Visual impact of structural measures in cultural heritage environments

Troja (Prague/CZ)

Structural measures can have a strong impact on cultural heritage sites. For example, the protective barrier shown in the picture is highly effective during the flood situation; however, it severely changes the context between the river and the historic settlement. In this case, even if only some parts of the wall are immovable, these are still disturbing.

Drdacky highlights how structural measures are sometimes difficult to implement in the case of cultural heritage protection, because they are mostly visible and disturbing, and need not always be cost-effective. This subject needs further research and comparisons should be made with best practice non-structural measures. As far as non-structural measures are concerned, the application of standards to protect cultural heritage from floods may lead to the originality, authenticity and aesthetic qualities and values of historic monuments being compromised [5]. During flood threats emergency measures, such as sand bags and big bags, are often applied to strengthen the flood defences and attempt to prevent breaches. Although these measures are often used there is limited insight in the actual reliability of the measures and their effectiveness in increasing the safety of the flood defences [6].

Evaluation of the effectiveness of emergency measures

Karlín (Prague/CZ)

Some emergency measures provide a relatively fast and cost effective protection against floods. However, their effectiveness can be limited and it should be always taken into consideration for each measure the safe uses that are allowed. For example, the employment of sand bags is successfully applicable only at low depth and slow velocity of water flow.

Dynamic low velocity stream action

Left: Masonry bridge in Hlína (CZ); right: archive of architectural plans NTM (Prague/CZ)

Even when measures are correctly applied, damages might occur due to dynamic action of water. Dynamic low velocity stream action is typically observed inside closed buildings where floated objects move and are displaced, e.g. furniture from one into another room; long lasting actions can even wash out subsoil under foundations or clay mortar from masonry.

Emergency measures hastily applied during the flooding include protective barriers, prompt removal of floating debris from bridges, additional anchors for river traffic and movement of people away from endangered areas. Despite these measures, in several cases cultural heritage assets were considerably damaged including historic structures (churches, synagogues and bridges), public buildings (schools, office buildings and hotels), residential houses and moveable objects in archives, museums as well as private collections. Furthermore, although many cultural institutions in industrialized countries have their own emergency plans, these are mostly fire-fighting and not specifically intended for floods or other types of disasters. Extensive investigations of the damage provide valuable information on flood actions and causes of structural damage. Erosion, hydrostatic pressure, dynamic flow of water and impact of floating objects or debris are identified as principal flood actions on structures; in most cases combinations of the flood actions occurred [7]. Finally, recent experience in Central Europe starkly shows that environmental degradation, the inability to manage fluctuations in the volume of rivers, and other weather-related natural disasters are on the increase in many parts of the world and can destroy precious heritage sites. It also indicates that institutional coordination works quite well, for example at national level, but regional coordination within urban and other geographic areas has been less successful. This will create an active constituency to support preventive measures. As it was evident in Central Europe, the public at large, through their work as emergency volunteers, was responsible for helping to save many treasures, which requires more involvement from the public and acknowledgement about the risks to cultural heritage and the need for investment in protecting heritage from natural disasters [8].

2.2. Good practices

Good practices in flood risk management include all those measures, which are specifically intended to positively impact the resilience of cultural heritage assets. Two groups are considered, namely organisational and operational/technical measures. Each measure is presented with its target aspect of risk (hazard, susceptibility/exposure or resilience) as well as with its feasibility of implementation, impact on CH protection and limitations.

➢ *Organisational measures*

> It is indeed a good practice to develop a comprehensive disaster plan for the sake of making more effective risk reduction strategies.

According to the School of Civil Protection handbook [9], a comprehensive disaster plan should include the following:

- Understanding the hazard (probability of occurrence, type, location, zoning, estimation of intensity and return period). This must be undertaken on the basis of present day and long-term scientific research into causes and events and their monitoring and, also, of an analysis of documentation on past disasters. Information should be published in map form, with computer archiving. All material should be kept in a safe place.
- Understanding other geological, hydrological, meteorological and natural processes and factors – water courses and levels, soil characteristics and sub-surface geology, their behaviour in the event of disaster and their effects on the architectural heritage. Micro-zoning and site effect studies and maps should be produced.
- Incorporating seismic, meteorological, hydrological and geological data into the administration of the architectural heritage and of town and land use planning in order to:
    - Identify and assess the vulnerability of the architectural heritage to hazard (by means of vulnerability and damage graphs and matrices) and assess the risks and the probable damage or loss.
    - Minimise vulnerability by developing and implementing plans for assistance (technical and financial) with the strengthening, repair and maintenance of the architectural heritage.
    - Control proposed alterations to, and the use or change of use of, historic buildings where the risk is already high or might be increased.

- Control proposed alterations to the use of land in the vicinity (local and regional) of major or numerous elements of the architectural heritage, where there is a demonstrable risk created by that land use practice

Understanding the hazard, hydrogeological and natural processes

The behaviour of floods can be studied using physical and mathematical models which help understanding the site effects of predefined flood events. It also helps assessing the effectiveness of proposed structural measures.

Physical model of river basin in Prague - Troja, CZ

Training, practice and exercises

Risk management must include awareness raising and training activities. These should be carried out in a participatory manner, involving different stakeholders.

Practice: wrapping paper and books after simulated flood; right, assembling barriers

- Training and preparing staff, including those from the civil defence and all other public services in the country, according to local law, in recording, salvage and emergency repair, shoring, propping and emergency protection methods and practice, and in the implementation of security measures to counter theft, arson and other criminal activity. This must include the publication of technical advice, of reconnaissance maps, inventories, surveys and regular practice and exercises.

- Encouraging and controlling the quality of maintenance and repair of historic buildings by the initiation of action plans, in co-operation with local communities and individual owners/occupiers.
- Preparing plans and priorities for salvage, removal, storage and emergency conservation work of movable property.
- Identifying and marking buildings of special interest.
- Preparing and implementing plans and priorities for full restoration in the aftermath of a disaster.
- Ensuring that there is an adequate supply of materials for protection, conservation and restoration.
- Ensuring that emergency teams of specially trained conservation professionals (architects, engineers, surveyors, planners, archaeologists and historians), craftsmen and builders as well as responsible members of the local communities are identified and trained for action.
- Monitoring, evaluating and improving the "disaster plans".

Cultural heritage mapping, identification and state of conservation

Damage identification using mobile devices (MONDIS project)

The mapping and identification of the CH assets at risk is one of the essential steps in risk evaluation and management. Knowing the location, characteristics and conditions of objects allows better planning and prioritisation. Modern ITC solutions can help to easily record and process a vast amount of data.

- *Operational/technical measures*

Measures for the protection of the architectural heritage against natural disasters should begin with the development of specifications and guidelines for the assessment and upgrading or strengthening of historic buildings. It is imperative that any works intended to improve the resistance and resilience of a building do not result in an unacceptable intervention into or loss of the special interest of the building. In order to achieve this goal, it is important to ensure complete survey and recording, and detailed inspection and understanding of the historic building, as well as its structural system and constructional materials and techniques, its evolution and history and its conservation.

Operational/technical measures fall into two categories:

1) site specific – maintenance, improvement and emergency works to the historic building or object (the first two are undertaken on a regular or planned basis and the third, although prepared in advance, is undertaken at the time of a disaster);

2) site general – local or regional control of, and alteration to, land use patterns and local or regional preventive measures and works (to be planned and implemented as part of a co-ordinated programme to minimise the frequency of specific disasters, such as flooding, avalanches, mudflows and landslides).

► Site specific

- Good maintenance is the single most effective means of reducing the amount of potential damage or loss. Therefore, it is essential that quality maintenance work, undertaken on a periodic basis after regular inspections (on a cycle of at least five to ten years) and employing traditional and compatible techniques and materials, be advised and specified.

Good maintenance for resilience building

Bridge with sphinx, Veltrusy (Bohemia/CZ)

Good maintenance is key to the correct performance of structural components and materials in the event of disasters. In the picture left, a well maintained small stone bridge sustained total immersion in water during the 2002 flood in Bohemia without substantial damage and its resilience consisted only in periodic, quality maintenance (e.g. drying and surface cleaning).

- All alterations intended to improve resistance or resilience must be agreed by the authorities for the architectural heritage, which should produce technical guidelines, after undertaking experimental, analytical and comparative research into: a) the resistance of historic structures and materials; b) historic concepts and methods of improving resistance; c) the behaviour of different structures and materials – timber-frame, rubble or ashlar masonry, earth structures, etc.; d) the implications and likely behaviour of building defects, both intrinsic and extrinsic, in the event of a disaster; e) the evaluation of previous "modern" strengthening practice and techniques; f) the assessment of different levels of disaster intensity and of the frequency of occurrence.

Improvements should comply with the following conditions:

a) the degree of works proposed should not result in the total or partial impairment of the special interest or integrity of the historic building; b) the existing structural systems and materials are retained, respected and enhanced, if necessary; c) traditional materials and techniques are preferred; d) if new materials and techniques are proposed these should be compatible with the existing ones, durable and reversible, as far as is practicable; where these conditions cannot be met, alternative proposals should be commissioned and evaluated; e) each building and any proposed works are assessed on their own merits and that works will be undertaken on the basis of performance requirements, not according to a prescribed code, with due consideration given to the possibility of improved and more sensitive methods in the light of technological development; f) the proposed works are designed according to realistic probability assessments of disaster occurrence and intensity, and graduated according to different levels of risk.

- The opportunity to undertake works to improve resistance should always be investigated and the work implemented before a building is considered for a major programme of repairs or of alteration and extension. Existing inappropriate or unauthorised forms of construction, extension or alteration should be removed, where possible, by the use of legislative and financial measures. All improvements and strengthening work should be fully documented and allow for long-term review, with the aim of establishing international standards.

Preparedness or immediate safety works: balancing water forces

Temporary plastic foil containers filled with water prevent floor damage due to buoyancy and flow away movements in case of lightweight houses.

- Preparation for emergency action in the event of a disaster should identify the specific action to be undertaken. It is essential to co-operate with other authorities, both civil and military. Provision should be made for:
    - Fire-fighting and protection against water damage.
    - Immediate safety works of shoring and propping.
    - Closure and supervision to ensure protection against land and water flows, air-borne debris, adverse weather and criminal activity.

- Marking important objects and structures.
- Clearing debris, taking care to record in situ and to recover movable and displaced or fragile objects.
- Emergency conservation work and removal to a safe place of important, movable, displaced or fragile objects.

Clearing debris

Clearing debris and mud it is fundamental after flooding. In this example, a historic masonry house with a deep layer of mud on the first floor after total immersion in slowly flowing water (Prague, August 2002).

House Loskota II (Prague/CZ)

- Full recording, preferably by photogrammetry, of damaged structures.
- Reinstatement of fire and safety equipment, the provision of emergency power supplies and adequate transportation. For the long term, a full survey and inspection of the damage must be organised in order to plan, develop and implement restoration, repair and conservation of the architectural heritage.

► 2) Site general

Territorial protection through the use of barriers

Left: Base wall of the protection barrier along the Danube (Spitz, Austria) ;

Right: Efficient protection in Prague during high water (CZ)

Protection barriers can be very useful in preventing flooding of large areas along the river banks. In particular after the floods in early 2000s, such structural measure has been implemented along major rivers throughout Central Europe. It requires complex works and it is usually time consuming and expensive. However, it provides an increased level of safety and, under particular circumstances, it helps avoiding catastrophic losses.

The work should follow the identification of those elements of the architectural heritage most at risk from preventable disasters, such as flooding, avalanches and landslides. In these cases, prevailing land use practices – agriculture, forestry, communications, industry and general development – should be assessed and remedial measures undertaken in order to minimise the risk. Particular attention should be paid to deforestation, soil abuse and degradation, and the use of, and alterations to, ground and underground water. In certain circumstances, physical prevention works must be planned and implemented. These should include: levees, dykes, dams, tree screens, consolidation of slopes and diversionary barriers.

3. HEAVY RAIN

Due to climate change extreme weather events are becoming more frequent. Such events are often characterized by: 1) above average high precipitation sums and intensities for both time of year and for the given region, 2) a duration of several days, and 3) by a relatively large area impacted by the precipitation [10]. Significant and serious floods of major Central-European rivers are related with heavy precipitation events in connection with specific conditions in the river basin, primarily snow melt in the winter and spring and possibly increased preceding soil saturation in the summer. Significant damage coincides often with heavy rain conditions at the site and/or at upstream locations and it occurs with particular intensity near confluences or lower plain territories along the river. The amount of damage is often strongly correlated with unreasonable designation of new construction in such endangered regions [11].

Further flooding, heavy rain is often accompanied by medium to strong wind action and fluctuating or extreme temperatures. Rainwater penetration into building envelopes might induce quite unevenly distributed high moisture content zones consequently posing the danger of durability problems to cultural heritage assets and, in combination with other factors (e.g. freezing/melting temperature, salt action, cracks etc.), could even undermine the structural integrity and stability of building components. Flooding and rainwater constitutes therefore the main threats to CH protection associated with heavy rain.

3.1. Recent events: key aspects and shortcomings

A wider literature review suggests that heavy precipitation events have become more intense and more frequent in Europe on average, but there are important differences across regions, seasons, time periods, heavy precipitation indices and underlying datasets. Studies generally agree that heavy precipitation has become more intense in northern and north-eastern Europe since the 1950s, even though not all changes are statistically significant. Owing to limited data availability, only a few studies have focused on large regional scale assessments of sub-daily precipitation. A recent review study concludes that extreme sub-daily precipitation events have generally increased in Europe, even in regions with decreases in mean rainfall, but there is large variability across regions, seasons and event durations [12]. The damage associated with heavy precipitation often originates from sub-daily localised heavy precipitation events, which can lead to costly flash floods. Many recent heavy rain cases in the Central European region, occurred in particular during the first decade of the 2000s (summer 2002, 2006, 2010, 2013 etc.). For example, after days of rain and heavy thunderstorms in May and early June 2010, large parts of eastern Central Europe were affected by flooding. The main focus of the flooding was in southern Poland, but the Czech Republic, Slovakia, Hungary, Croatia, Bosnia and Herzegovina, Bulgaria and southern and eastern Germany were also affected. Precipitation occurred in several phases, with by far the highest recorded amount in the middle of May. The cause of this heavy rain was a quasi-stationary upper-air low combined with a specific cyclone pathway, strong temperature contrasts, copious water vapour and orographic effects. As a result of dyke-building in recent years, the extent of the damage was limited; nevertheless, there was considerable damage to farmland and there were also fatalities [13]. In addition to the bad practice highlighted in section 2, which refers primarily to the problem of flooding, past experience exposes other shortcomings specific to heavy rain events, including: alterations of the drainage capacity of the environment surrounding a CH object (e.g. roads); the use of inappropriate materials for solving a durability issue; the hygric properties of the assets which become inappropriate for withstanding the increase in rain loads; incorrect design or lack of intervention (e.g. in the case of an undersized drainage system for example) and finally the lack of maintenance which induces unhealthy structural conditions.

Finally, it should be also added that heavy rain is likely to become more frequent in the future in Europe, with changes in extreme precipitation depending on the region [14]. Projections show an increase in heavy daily precipitation in most parts of Europe in winter, by up to 35 % during the 21st century. Heavy precipitation in winter is projected to increase over most of Europe. In summer, an increase is also projected in most parts of Europe, but decreases are projected for some regions in southern and south-western Europe.

Changes in drainage capacity of originally unpaved roads in heavy rain situations

The extensive use of asphalt and cement as paving materials for roads can, in particular cases, induce dramatic changes in the paths of rainwater streams and lead to sudden failures. In this example, repeated heavy rain periods induced the washing off of soil underneath the asphalt and consequently the collapse of the road. Asphalt roads have a considerably lower water permeability capacity than older unpaved tracks and such aspect should be closely considered especially in situations in which asphalt can be avoided (e.g. pedestrian roads)

Collapse of a pedestrian road section due to soil removal by rainwater (Baranya Co./Hungary).

3.2. Good practices

Good practices in heavy rain penetration risk management are outlined below. Each measure is provided with clues on its target aspect of risk (hazard, susceptibility/exposure or resilience) as well as on its feasibility of implementation, impact on CH protection and limitations.

➢ *Organisational measures*

Good practices in strong rain risk management include all those measures which optimise the resilience of cultural heritage in the context of rainwater related actions. More specifically such measures are aimed at solving two main categories of issues: problems related to flooding due to heavy rain and issues connected to rainwater penetration into building components and ground soil.

- Understanding the probability of occurrence of heavy rain, location, zoning, estimation of intensity.
- Understanding other geological, hydrological, meteorological and natural processes and factors.
- Investigating the performance of original or altered building materials and components, such as wall assemblies, undergoing heavy rain situations and the combination with other environmental and intrinsic factors (e.g. temperature, salts, damage to building component etc.).

Investigation of the performance of building components/interventions against excessive rain penetration

In the perspective of improving the resilience of cultural heritage assets against heavy rain, it is important to investigate the performance of historical building components under strong rain loads as well as to evaluate the effectiveness of possible interventions. In the picture left, a rain penetration test of masonry pillars in the "Vincenc Strouhal" climatic wind tunnel in Telč, CZ. This is used to study rain penetration and its mechanical effects.

Brick masonry testing of wind-driven rain (CET, Telč, CZ).

- Training and preparing staff, including those from the civil defence and all other public services in the country, according to local law, in recording, salvage and emergency repair, shoring, propping and emergency protection methods and practice, and in the implementation of security measures to counter theft, arson and other criminal activity. This must include the publication of technical advice, of reconnaissance maps, inventories, surveys and regular practice and exercises.
- Encouraging and controlling the quality of maintenance and repair of historic buildings by the initiation of action plans, in co-operation with local communities and individual owners/occupiers.
- Preparing plans and priorities for salvage, removal, storage and emergency conservation work of movable property.

- Identifying and marking buildings of special interest.
- Preparing and implementing plans and priorities for full restoration in the aftermath of a disaster.
- Ensuring that there is an adequate supply of materials for protection, conservation and restoration.
- Ensuring that emergency teams of specially trained conservation professionals (architects, engineers, surveyors, planners, archaeologists and historians), craftsmen and builders as well as responsible members of the local communities are identified and trained for action.
- Monitoring, evaluating and improving the “disaster plans”.

➢ *Operational/technical measures*

> Monitoring is important to assess the effectiveness of measures as well as to evaluate the correct performance of structure and building materials during heavy rain events. In particular it is suggested to monitor the moisture content in building materials along with early warning systems for situations of heritage relevance; it is also important to monitor water table changes and soil saturation to avoid soil subsidence and washing off due to heavy rain.

- Inspection and maintenance to ensure tightness of building envelope and correct performance of drainage systems.
- Protection of building components, details and artwork with shelters, barriers or coatings.
- Treatment of building materials to prevent excessive water penetrating or soaking into material.
- Design and implementation of adequate drainage systems ensuring that water is carried away rapidly and effectively (outlets, adequate, unblocked gutters, etc.).
- Carrying out architectural improvements (details, cornices, etc.).
- Replace originals by replicas.
- Improve the anchoring of the features of the building envelope (roofing, façade).
- Strengthen the structure and/or provide additional supports to the whole structural system.

Design and implementation of adequate drainage systems

Existing drainage systems should be surveyed and repaired on a periodic basis. New systems, or parts of them, should be carefully designed to allow for the increased rain loads, in case the existing system is deemed not sufficient. In this example, drain pits have been added to the system in order to stop the flowing of water downhill (notice the erosion of the ground due to rain before interventions).

New drainage system of a baroque church (Pécs, Hungary).

4. FIRE DUE TO DROUGHT

The current high level of loss of historic buildings to the effects of fire is a cause for significant concern. By increasing the awareness of the issues involved and promoting the adoption and utilisation of appropriate fire-fighting measures, this can be combated and reduced. Indeed, historic buildings represent a finite resource, and their loss to the effects of fire is an issue of extreme importance, encompassing economic, political and cultural aspects of societies.

4.1. Recent events: key aspects and shortcomings

Historically, firefighting has been a feature of architectural design. Ornamental ponds that served as landscape features provided firefighting water supplies near mansion houses, and various devices were contrived to effect escape from buildings in an emergency. But essentially primitive ladders, hoses and pumps, sand buckets, and water bucket chains were relied upon to control any fire that broke out. The alternative was to let the fire burn itself out, leading to the loss of building and contents [15]. Nowadays, the threat of fire in buildings is rapidly increasing, due to climate change. Drought and desertification are becoming more and more relevant phenomena that must also be taken into account. A study conducted on the protection of CH against natural disasters highlights that in the period from 1978 to 1995, for example, there was an extreme lack of precipitation. Many buildings, including CH objects, suffered from foundation displacement, and subsequently from heavy cracking on the upper structure [16]. In Central Europe, climate change will probably increase drought frequency, duration and severity, and this will affect agriculture, biodiversity, forestry, energy production, tourism, and more general the availability of water resources. A study based on 411 climatological stations across Austria (excluding the Alps), the Czech Republic and Slovakia over the period 1961-2014 shows that the number and intensity of droughts are already increasing in parts of Central Europe, especially north of the Danube River, the north-western Czech Republic, and the south-eastern corner of Slovakia. This trend is not due to a decrease in precipitation. It is due to an increase in the evaporative demand of the atmosphere, driven by higher temperatures and global radiation. The observed drying trends are most pronounced during the April–September period and at low elevations (below 600 m) [17]. All these factors are expected to increase therefore the hazard of fire due to drought and the consequent loss of cultural heritage assets.

Visual impact of fire-fighting systems

World Heritage Church (Wojanow/Poland)

The visual impact of fire-fighting systems is quite variable depending on its type and location within the building. Often such systems have an acceptable impact on the overall appearance of building components. In the picture left, for example, it is shown a nozzle for high pressure mist fitting harmoniously in the context in which it is placed. In other cases, particularly in hidden spaces, systems can be more intrusive. This is seen in the picture right, which shows water supply pipes in the roof space of the World Heritage Church, Wojanow (Poland).

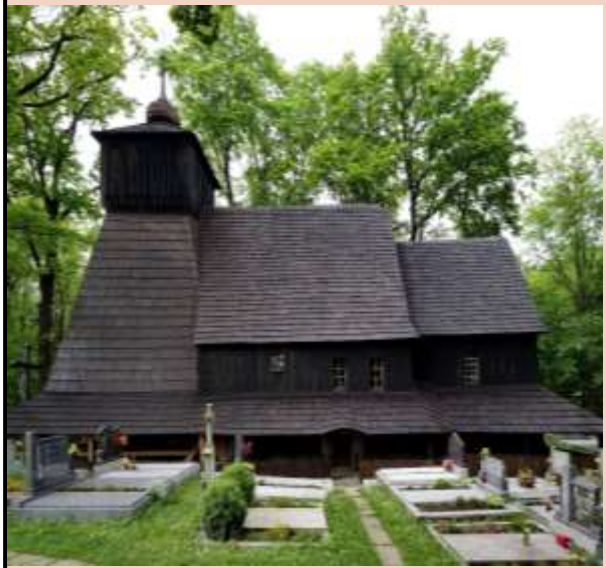
Recent fires due to drought occurred with a catastrophic impact on the countryside, forests, historic towns and complexes or buildings around Europe (latest being in Greece, 2018). They have highlighted the main shortcomings concerning the protection of cultural heritage against such disaster. In the context of this document, it is worth it to discuss only those aspects of drought the can be optimised, modified and intervened on. In principle fire-fighting systems are considered efficient and compatible for utilisation in historic buildings; however they might prove to be less appealing in sensitive contexts where they are too visible and result in an excessive impact on the original appearance of cultural heritage objects. This is largely because the engineering design profession and manufacturers do not think laterally about the conservation issues that are involved. As a result suppliers tend to offer limited options in the choice of available equipment. Equally, architects and designers do not fully understand the complexities and sensitivities of the issues involved and, in consequence, the internal appearance of important buildings frequently suffers as a result of insensitive detailing. Although retrofit detection schemes are considered and implemented, more often than not, a holistic approach is left unresolved - with the building being offered little or no suppression protection. To be more effective, the need is for owner, architect, engineer, contractor and supplier to be more in tune with the degree of risk, and the physical and aesthetic attributes of what needs to be protected [15].

The drought periods create suitable conditions and situations for accidental fires, for example during construction and repair works, or for arson activities especially for an intentional destruction of wooden architecture. Such a combination of natural climate phenomena with man-made harming is one of the ever increasing trends which it is difficult to predict and prevent. Moreover, intentionally initiated fire is also used to remove a protected monument for development reasons. In such cases the fire extinction actions must follow rules decreasing the damage and enabling resilience with safeguarding the majority of heritage substance [18]. Here is also important a fast protection of the burnt structures.

Lack of crime prevention

Horní Maršov (CZ)

Nowadays, most of cultural heritage objects are still lacking protection against acts of vandalism and theft. Specifically connected to fire, it should be mentioned that arson is one of the most frequent crime offence against cultural heritage. In this example, left Chateau Horní Maršov (Czech Republic) damaged by fire started on several places under the roof due to activity of a group of arsons (August 2018). Below, left wooden church in Guty (Moravia) restored before fire (2014); on the right, the church totally destroyed in 2018.



Guty,(Moravia/CZ)

Negligence

Many fires start due to negligence of users or workers typically employed for repair and restoration or construction works. In the picture on the left, a medieval roof framework destroyed by fire during repair intervention.

Pernštejn Castle, CZ

4.2. Good practices

Good practices in fire due to drought risk management include all those measures which are specifically intended to positively impact the resilience of cultural heritage assets. Two groups are considered, namely organisational and operational/technical measures [9]. Each measure is presented with its target aspect of risk (hazard, susceptibility/exposure or resilience) as well as with its feasibility of implementation, impact on CH protection and limitations.

➢ *Organisational measures*

For each historic building a named member of staff or of the household, with deputies, must be made responsible for fire safety. This fire safety manager, who might also be responsible for security and health, should initiate and oversee all aspects of the fire prevention or mitigation strategy or plan, in liaison with the fire brigade staff and with professional advisors (architects, surveyors, engineers, planners, specialists on historic buildings) and representatives from the insurance companies. The strategy should be subject to constant rehearsal and review, and records of all activities should be made. The main objective is to reduce the risk by undertaking systematic fire prevention. A balanced series, or optimum choice, of organisational, technical and physical measures should be employed.

Specifically, the strategy will seek:

- To assess the risk of outbreak of fire, to minimise that risk and to prepare a plan of action in the event of a fire.
- To ensure safe and orderly means of escape for all occupants.
- To protect the historic structure and to prevent the fire from spreading.
- To establish a staff structure with clearly defined responsibilities in the event of a fire.

Monitored practice drills

As for any other type of hazard, practice drills and rescue exercises should be periodically carried out involving a number of different stakeholders commonly involved with cultural heritage protection as well as the civil society, whose active participation in case of disaster can significantly increase the resilience of the assets.

Göttweig Monastery exercise, Austria (DUK University)

- To train and educate staff in fire-fighting and evacuation procedures, and in the implementation of salvage priorities and plans, including regular and monitored practice drills.
- To prepare and maintain documentation on the layout of the premises, including detailed plans which indicate the location of fire-fighting facilities, of means of escape routes, and of fragile, important and valuable structures and fittings.
- To ensure that the uses of the building are consistent with safety requirements.
- To encourage good housekeeping and maintenance standards in order to reduce the risk of ignition.
- To ensure that fire safety systems are correctly maintained and operational.
- To ensure that the building and its curtilage are not subject to either arson or vandalism.
- To keep records of protection activities and to evaluate the effectiveness of the strategy.

The nature of fire prevention and mitigation strategy can neither be fixed nor prescribed by rigid codes of practice. It must be flexible and in each case fire safety measures should be implemented which guarantee the necessary means of escape, whilst at the same time not impairing the character and value of, or inflicting damage upon, the historic building. Individual strategies will vary but in each case the emphasis will be on prevention, preparation and vigilance rather than on provisions requiring structural alterations.

All structural alterations and the installation of mechanical, electrical or other systems associated with prevention, detection and fire-fighting must be agreed with the authorities responsible for the architectural heritage. The aim is to minimise the amount and effect of “passive”, physical, structural or preventive works in the interest of the historic building or artefact. A systematic approach which treats each case and building on its merits and which employs a flexible package of organisational and technical measures will reduce the need for major physical works, while, at the same time, meeting the safety legislation and requirements. Essentially, this represents a strategy of vigilance and prevention, coupled with early detection and the orderly application of evacuation and fire-fighting procedures.

➢ *Operational/technical measures*

- The sources of ignition should be identified and eliminated or minimised.
  - All parts of the building should be kept clear of waste and rubbish. In particular, attics, basements, stairwells and areas under stairs, cupboards and empty storerooms should be inspected regularly, cleared of unnecessary material and kept clean.
  - Cleared strips or zones in grassland, heath or forest areas should be provided, if acceptable in aesthetic terms.
  - Electrical installations, circuits and equipment should be regularly tested, properly maintained, utilised and overhauled. Circuits should not be overloaded and faulty equipment and wiring should be replaced. It is advisable that main cable and fuse boxes are located in a separate fireproof room or area.
  - Naked flames from heat and light sources such as candles, torches, gas lighting and open fires or stoves should be avoided. Where their use is to be permitted, there should be careful monitoring, strict control and the provision of safety guards when unattended. The provision of suitable fire-fighting equipment nearby is essential.
  - Only trained workmen should be allowed to undertake maintenance, repair and improvement work on historic properties. They should be made aware of the importance of the building or its fittings and should be supervised by a senior and responsible member of staff. Smoking should be banned and hot-work (blowlamps, cutting, welding, etc.) should be allowed only if there is no alternative. Any acceptable hot-work should be subject to a permit which identifies responsible parties, and allows control of the nature, location and duration of the work and which ensures that combustible materials are removed or protected. In addition, extinguishers and alarm systems must be provided and the work supervised and monitored at all times, with provision for checks for a period after the work is completed.
  - Lightning conductors (arresters or rods), properly designed and maintained, should be fitted.
  - Chimneys should be swept regularly. All hearths, flues and ducts should be maintained in a sound condition. All cookers, heaters and boilers should be serviced regularly, be kept clear of combustible materials and be provided, where appropriate, with fire and safety guards. Kitchens, plant and boiler rooms should always be provided with suitable fire-fighting equipment and the rooms should not be used for storage.
  - Smoking should be discouraged in historic buildings or confined to specific fire-protected rooms or areas, installed with fire-fighting equipment and alarm systems.
  - Provisions should be made against arson and, in particular, premises and their curtilages should be secure against unauthorised entry. Temporary staff and visitors should be vetted and supervised, and flammable and waste materials kept out of reach.

- Fire detection and alarm systems should be installed. The bare minimum should be fire bells or an electrically operated system. Preferably, automatic and active fire detection systems should be installed and connected to an alarm centre and to the local fire brigade. Each individual detector should be identifiable and the systems should be provided with the ability to monitor faults and false alarms. Smoke, heat and flame detectors can be installed and connected to alarm centres either electrically or by radio-link. The casings for the detectors should be unobtrusive, as small as possible and adapted in shape and colour so as not to impair their historic setting. In some cases (thatch or timber-cladding, for example) external heat detectors might be recommended. In all cases, detectors and alarms must be properly and regularly maintained and responsible staff trained to understand and handle the systems.

- Fire-fighting facilities should be provided and maintained.
    - Firefighting by staff or occupants should be encouraged with the provision of regular and monitored programmes of awareness and training. Premises should be fitted with fire buckets and hand-held extinguishers which must be suitable for both general and special risks. Extinguishers should be inspected and overhauled on a regular basis.

Implementation of automatic fire-fighting systems

Automatic fire-fighting systems are extremely important in protecting cultural heritage assets from fire. These should be carefully designed and implemented in order to minimise the impact but at the same time ensure that the necessary level of safety is provided. In the pictures: (above) automatically starting high pressure mist sprinklers in action, (below) water gun with automatic starting of operation upon signals from sensors of the electronic fire signalization system.

    - Automatic fire-fighting systems should be installed wherever possible if it can be proven that the risk would be reduced, but only where there is likely to be little or no impact on the special interest of the historic buildings. Attics and roof spaces, spires and towers on churches could be possible locations inside buildings. However, the danger of collapse or decay following operation must be carefully assessed. Industrial, commercial, transport and military premises might be capable of greater intervention than domestic properties. The installation of devices on roof ridges (particularly on thatch, grass, reed or straw) and on cornices could be considered. In dense urban areas, dry sprinkler systems in narrow gaps on facades will assist in preventing the spread of fire in urban areas. The use of copper pipes with hidden joints should be encouraged. Modern fast-response sprinkler systems, based on zone signalling, should be employed. Regular maintenance, with the identification and elimination of faults, must be undertaken. The use of sprinkler systems, particularly in areas of fragile construction, containing delicate fabrics, panelling, furniture, works of art, and so on, and in unventilated areas, must be carefully assessed.

   - Access at all times for the fire brigade is vitally important. Roads and access points should be made and maintained wherever possible. In historic gardens and landscapes the maintenance of “green ways” might suffice. Fast and reliable routes between fire stations and historic buildings and centres should be identified and reported on maps. Water supplies should also be identified, including all main water sources: wells, reservoirs, storage tanks and water towers, ornamental canals, ponds and lakes, swimming pools and natural sources such as rivers, streams and lakes. If there is no ready and nearby supply, then consideration should be given to the establishment of such or to the provision of an emergency storage tank of adequate capacity, suitably located, hidden or disguised. Immediate access to, and within, the building should always be reviewed and improved, for example by creating roof hatches and by ensuring that doors can be unlocked and opened.

- In some circumstances, in particular in relation to the provision of a safe and adequate means of escape, physical alterations might prove necessary. These might include:

   - The enclosure of stairwells, where appropriate, and protection of the means of escape.
   - Alternative ways of protecting the means of escape, such as air overpressure systems, to prevent the penetration and spread of smoke and flames.
   - The installation of smoke vents and hatches, which will also allow improved access for fire-fighting.
   - Lobbies, with new partitions incorporated around existing features.
   - Adequate fire-resistant doors including self-closers, fire-stops and intumescent strips to doorways.
   - The application of intumescent paint and other finishes to panelling or cast iron columns, for example.
   - The installation of automatic emergency lighting and signs which are independent of the normal electricity circuit.
   - The construction of barriers where they would not detract from the character of the building, for example in undivided roof spaces, and by the reinstatement of missing partitions The approach adopted should begin with a package of “soft”, non-intrusive measures, with the application of “hard”, intrusive measures only where all other measures are obviously inadequate and jeopardise human life and the architectural heritage.

- After a fire the following action should be taken:
   - The minimum of making safe in order to allow inventory-taking, salvage and rescue work.
   - Valuable artefacts and fittings, including those either dislodged or in danger of collapsing, should be recorded in situ and then carefully removed, under the supervision of conservation specialists, to a safe place for urgent conservation measures.
   - Emergency inventory-taking by appropriate means, at least plans and photographs, but photogrammetric surveying is to be encouraged.

- Damaged roofs should be covered temporarily, for example, with tarpaulins, and the property secured against unauthorised personnel and theft.
- Residual water should be removed by mechanical and physical methods (suction pumps, sponges, cloths, etc.) and the building should be thoroughly dried by the maintenance and improvement of ventilation and, where possible, by the use of dehumidifiers.
- Investigation, by non-destructive techniques, of hidden structure and fabric must be undertaken and the installation of hygrometers should be considered.
- All alarm systems and fire-fighting equipment should be reinstated.
- Any further structural works, including proposals for restoration and repair, or for demolition, must only be undertaken after full consultation with, and the approval of, the authorities for the architectural heritage.

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