Danube Transnational Programme
Living Danube Limes

Sustainable Conservation of Danube Limes Sites

PROJECT OUTPUT T3.3

Title Sustainable Conservation of Danube Limes Sites — Final version 12/2022

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Project ID DTP3-1-359-2.2

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1. Introduction

1.1. General remarks

The aim of this deliverable is to propose principles for standard measures to protect the cultural heritage in question against the effects of natural disasters as well as against excessive wear and tear by tourism or man-made hazards´ impact. The proposed measures concern cultural heritage not housed in museums, except in the specific case of measures against the effects of earthquakes on museum collections. Therefore, it does not consider specific procedures for inspection and protection of buildings or modern shelters. Exceptions include ruins integrated in structures of contemporary buildings. The elaborated documents for the inscription of the Frontiers of the Roman Empire – The Danube Limes on the World Heritage list under the UNESCO protection contains partial and mostly general appropriate suggestions of such a protection for the concerned parts in Austria, Germany, Hungary and Slovakia. They are included in the Management plan proposals, and they are well applicable in the parts of the Danube Limes (DL) in the other project partner countries, i.e. Croatia, Serbia, Bulgaria and Romania. However, the general character of the suggested measures is not sufficient for adoption of detailed and effective operational activities safeguarding cultural heritage from damages and loss in critical situations and from slow deterioration processes due to climate change in Europe.

1.2. Background principles

The topic of protection of cultural heritage against impact of natural as well as man-made hazards has been studied for decades. In the recent years an interest in this subject intensified due to emergence of new dangers related to climate change and global challenges. However, the basic approach to mitigate their impacts remains and includes four pillars: i) regular inspection and careful maintenance of the historical stock & improved land use planning and management, ii) raising awareness and regular coordinated training, iii) international cooperation and availability of funding, and, iv) legislative support. They are commented in the subsequent paragraphs. There is further remarkable a tendency to combine measures aiming at an increased resilience of cultural heritage which is considered as effective preventive protection approach. The concept of resilience indicates the capacity of a system to withstand shocks or in other words the ability of a system to absorb changes without a transition to a different state. Danube Limes heritage assets are complex systems with context-specific characteristics and a limited adaptability. The resilience of this heritage environment must take into account the resilience of individual DL heritage elements together with their interactive, dynamic, emergent and adaptive roles. The resilience of complex DL heritage systems to the impact of natural and man-made disasters can be improved by means of three basic approaches: i) preventive protection, ii) adaptation and iii) resilience preparedness. Preventive protection measures can be cost demanding, not always feasible and they 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 (ruin) 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 ruins may 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 ruins 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. In the case of DL has a limited applicability and can be applied mostly in land use measures. 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 suggested to be a core strategy for the LDL project, presenting a clear potential to be cost effective at ensuring high benefits. Increasing resilience requires understanding the critical elements of a CH system, which is a fundamental task, which ensures the development of a resilience and risk management approach tailor-made for the CH system considered. The next paragraphs provide a definition of such critical elements, outlining the most relevant categories, which should be considered for improvement of resilience of DL heritage.

Example of well conserved and maintained Roman ruin (Carnuntum, Austria)

2. Damaging threats and damage mitigation strategies

The standards are designed with the following threats in mind: Natural hazards and disasters, including climate change – e.g. floods, harsh weather events, erosion, temperature fluctuations, landslides, biotic damage. Threats intentionally damaging human activities – e.g. illegal prospecting and "mining" in archaeological sites, vandalism. Excessive tourism or unsuitable visitor traffic, tourist vandalism – e.g. “souvenirism”. Global development challenges mostly caused by the effort for the economic performance of the monument – e.g. inappropriate interventions (beautification, inadequate reconstruction, etc.), change of context, change of use or management in the area (including the river).

2.1. Natural hazards

2.1.1. Floods

According to the data provide by the LDL Project partners, some sites especially in Hungary (Dunafalva – Contra Florentiam Lugio 1. Kikötőerőd and Kölked Hajlok-part – Altinum segédcsapat tabor) are endangered with fluvial floods, however, similar situation is likely in the lower Danube sites in Serbia, Bulgaria and Romania. The hazard is clearly documented with various recent studies, e.g. the recent ESPON map of the flood events with the return period of 100 years[1]. Long sections of the DL are in zones with a danger of river floods affecting significant areas. Former studies proved that some areas experienced floods in much faster return periods and the climate change influence further shortens the return period, especially in the Central Europe, and increases also the flash flood hazard. The danger is further increased with a possibility of occurrence of ice floe dams, which may rise the water level in flood planes. Therefore, flooding is considered a serious problem namely for the DL sites in a close vicinity to the river.

2.1.1a Conservation strategies in relation to floods

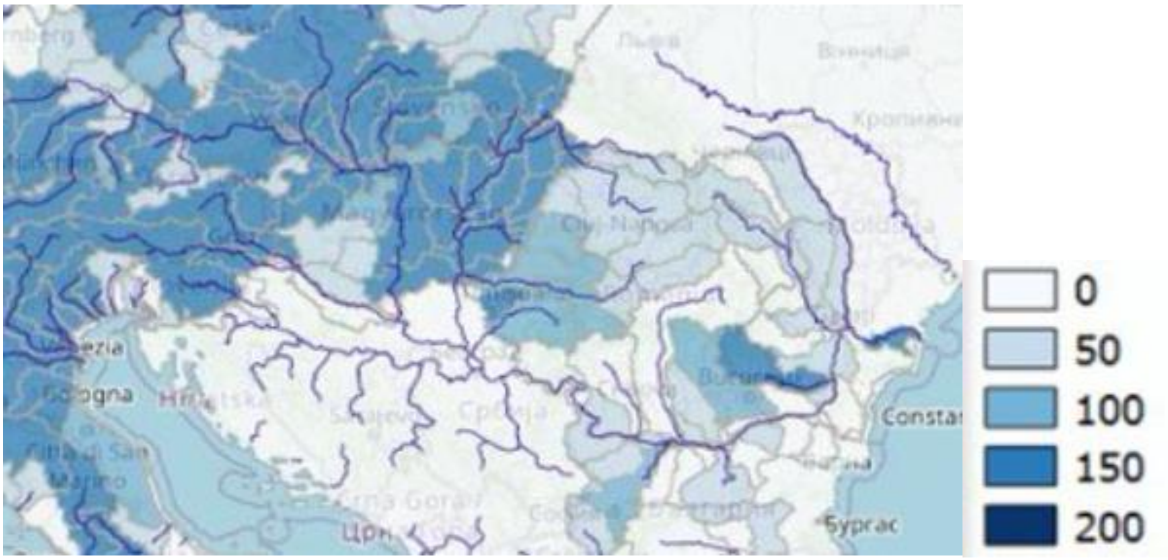
The recent experience shows that so called territorial protection is the most effective measure in case of sites. Territorial protection may include technical measures, e.g. stable or temporary barriers as well as land use and land cover modifications. Technical measures are rather expensive and not always applicable in situations where the context between the site and the river represents a heritage value worth to be preserved. However, along the upper Danube the measures with a high protection level have been adopted. The level of flood protection is given by the estimated design return period of the maximum flood event that the defence measures are able to cope with.

Territorial protection is mostly ensured with combined stable and temporary (mobile) barriers, which are important best practice examples. In Austria during the last 10 years very effective flood prevention measures were implemented (partly with mobile elements) along DL risk areas and a very effective forecasting system has been installed accompanied with a monitoring system to react within a very short time. In Slovakia, the protective

[1] www.espon.eu/sites/default/files/attachments/ESPON-TITAN_Scientific%20Report-Annex%201_Hazards%20Analysis.pdf

embankments with a minimum of HQ 100 are built along the Danube River near the DL part and high water is restrained in inundation areas between the embankments.

Careful flood protection policy has been adopted in Hungary where a modern flood prevention system which has been developed since the second half of the 19th century saves certain structures of the Danube Limes from harm that are on the protected side. The flooding of these can occur in extraordinary cases, about once every fifty years. The remains in the flood plain, primarily bridgeheads, fords and signal towers are subject to inundation once or twice a year. They cannot be protected from floods also due to possible occurrence of ice dams. Rehabilitation is considered in the case of these remains if they are of outstanding significance, otherwise the conditions that have developed through regular flooding are simply maintained. The Hungarian management plan considers planting of protective forest strips along the river as well as modifications of river channel aimed at creation of a larger room for flood water. The modifications must be materialized carefully taken into account possible damage of the buried heritage during trees planting or due to



destructive action of the roots.

Estimated design return period of flood defences in years. (Source Copernicus EMS).

River banks are further endangered by undermining and water stream erosion which may even initiate local landslides. Some protective shore stabilization can be applied in small and well delimited areas when justified with a possible loss of outstanding heritage.

Large landslide in Dunaszekcső 30-35 meters of the river bank broke away along a 300 meter long section and slid down about 10 meters in 2008, taking with it more parts of the Roman fort of Lugio.

Individual ruins – free standing or integrated in recent buildings – are usually sufficiently robust to withstand flood forces and actions, provided they have stable foundations. In fragile situations the foundations can be protected against underscoring with reinforcement of the surrounded surface, e.g. with pavement.

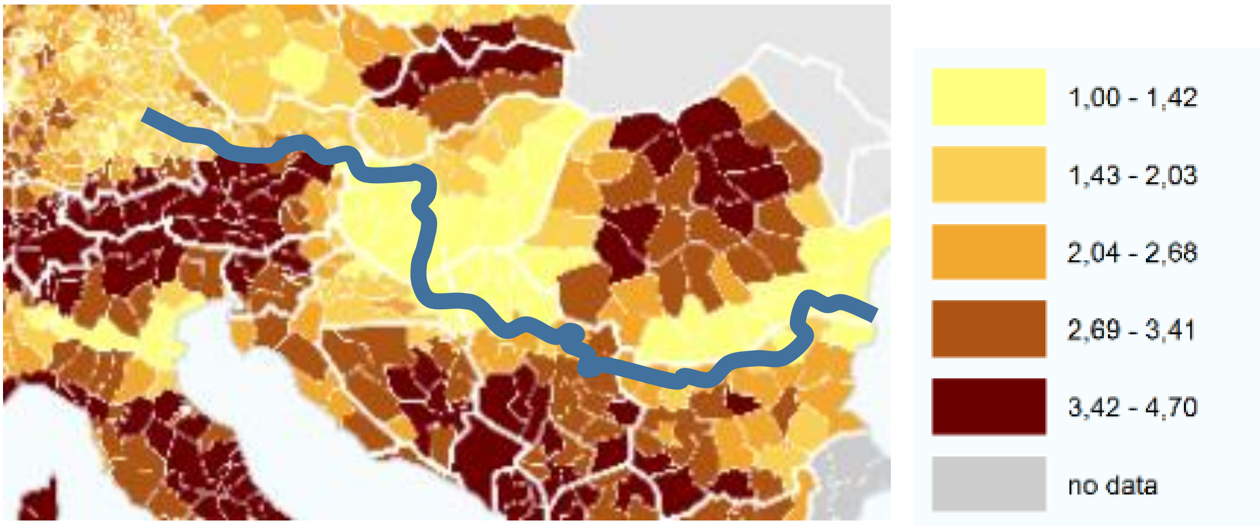
Sufficiently robust free-standing ruins (Kostol).

Expensive protection barriers have reasonable return period of the investment, which is demonstrated in the figure above where the estimated design return periods of flood defences in years are shown. However, fast erection of temporary protecting barriers as well as evacuation requires regular training of emergency teams. In the sites without barriers planting of protective forest strips along the river as well as modifications of river channel aimed at creation of a larger room for flood water.

Example of a night evacuation exercise with packing and transport of objects of art from endangered gallery on the bank of river Vltava (Prague, Czech Republic)

2.1.2. Landslide

Landslides are a very widespread natural hazard in the DL territory, even though they affect very localised areas, but large enough to generate substantial damage to archaeological sites. They may be triggered by floods and earthquakes and thus create an important part of the combined hazards.



Landslide map shows the mean landslide susceptibility based on the JRC European Landslide Susceptibility Map (ELSUS 2) which takes into account topographic information (elevation, slope angle), shallow sub-surface lithology, land cover, and more than 149.000 landslide events. ELSUS v2 classifies landslide susceptibility in five classes (1= very low; 2= low; 3= moderate; 4= high; 5= very high) at a resolution of 200m x 200m. To present landslide susceptibility at NUTS3 average for each NUTS3 area was calculated. Therefore, the five classes of the map above do not coincide with the classes of ELSUS v2 (Source: ESPON TITAN 2020).

DL line passes NUTS3 regions with low to moderate average landslide susceptibility. However, just along the Danube the landslide danger is quite high. The Hungarian management plan informs that below Budapest there is a high river bank along the right side of the Danube. The riverbank is made of loess soil, and according to evidence from old maps and records, significant pieces of the loess river bank occasionally break off into the Danube. In 1860 at Dunaszekcső one million cubic meters slid away, as well as two million cubic meters in 1965 at Dunaújváros and another million cubic meters in 1970 at Dunaföldvár. The most recent spectacular slide took place on the 12th of February 2008 and affected the Dunaszekcső fort that had unfortunately been damaged previously as well. 30-35 meters of the river bank broke away along a 300 meter long section and slid down about 10 meters, taking with it more parts of the Roman fort of Lugio as well as cultural layers preserving significant archaeological evidence. The landslide excludes the possibility for excavations. The inspectorate of mines with jurisdiction registers the areas in danger of landslides. Therefore, the necessary information is available to the management organizations. The remains of the Roman fort (Lugio) lying within the territory of Dunaszekcső was not included in the World Heritage nomination due to the existing geological threat.

2.1.2a Conservation strategies in relation to landslide

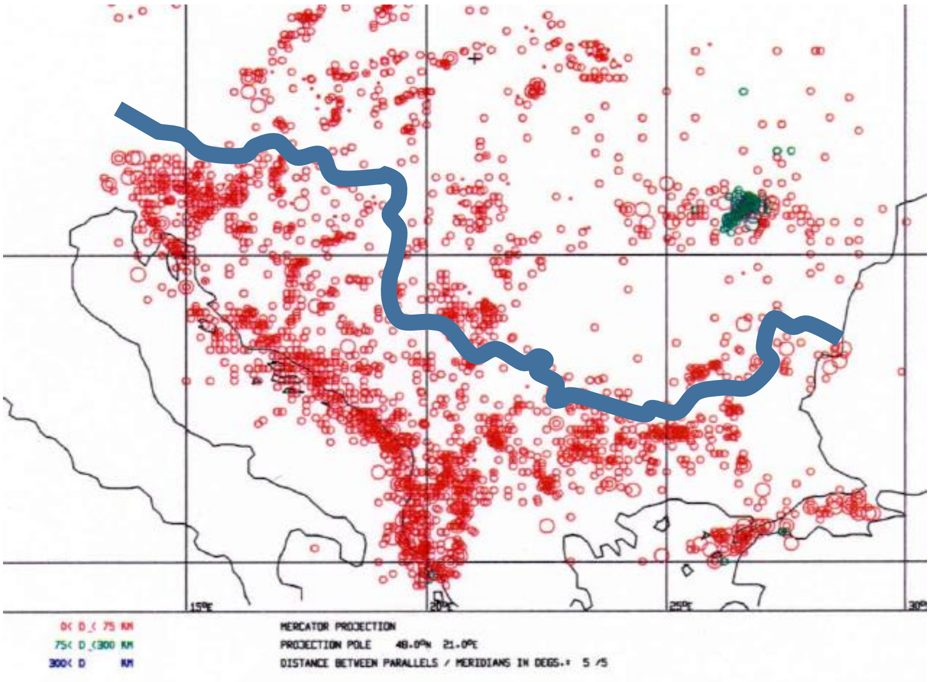
The further movement of the river towards the west and the increasing flood levels as a result of climate change and river regulation could bring about landslides in different areas along the Danube in the long term. It is necessary to perform <u>annual monitoring</u> on the loess areas, and the limes remains that may land up being endangered must be given increased attention, ensuring every means for the prevention of damage.

Studies of landslide activities show that the trigger factors are the rainfall amount at the day of landslide as well as the total rainfall for previous two weeks. However, also other factors must be taken into the evaluation, especially the soil type (at least sandy versus cohesive, or soil permeability) and the slope inclination. In general, slopes with medium inclination (15°-30°) are the most problematic. Slopes with a smaller inclination are usually stable due to small shear stresses acting in the ground (with the exception of slopes with pre-existing slip surfaces, where residual friction angle has been reached). On the other hand, it turns out statistically that slopes with higher inclination than about 35° are usually also stable. If such a slope was susceptible to failure, it would have already failed in the geological history.

Therefore, rain water must be removed as quickly as possible from the landslide prone areas and the toe of critical slopes must be protected against harming geotechnical interventions (e.g. notches).

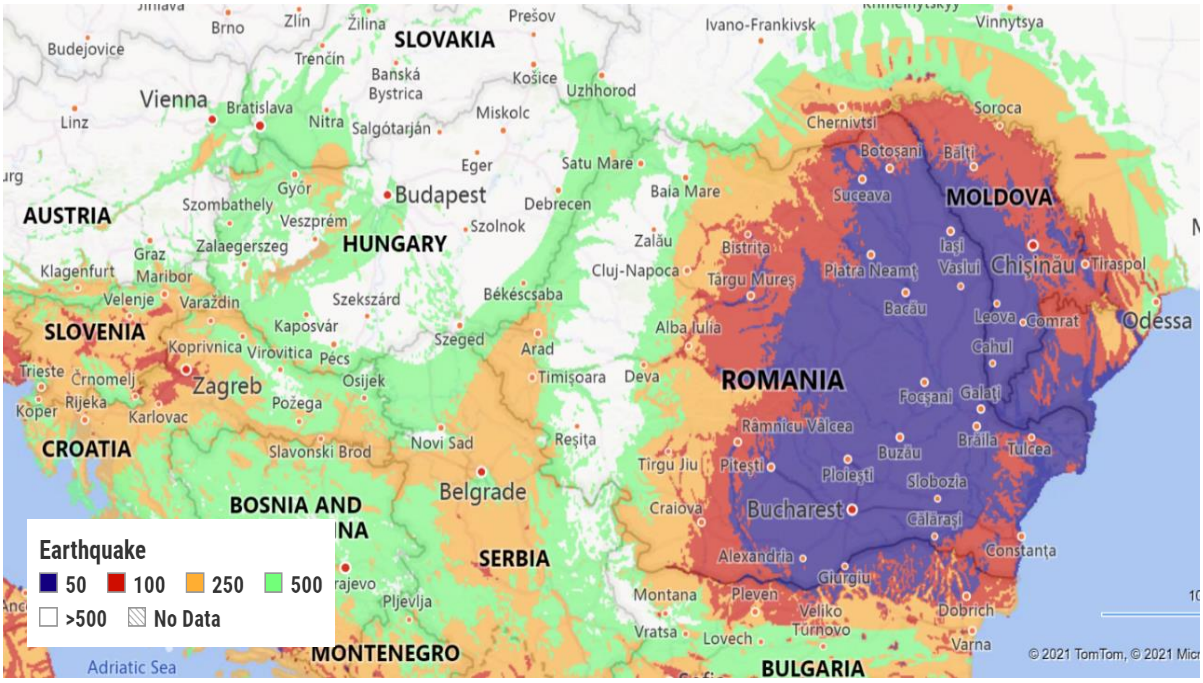
2.1.3. Earthquake

The Limes touch seismic prone zones and there is a historic experience with earthquake induced damage, e.g. in Carnuntum. The area includes two different zones with different seismic activity and severity. Three maps illustrate the statement. The first shows a review of seismic events in the area in the course of 2300 years, which illustrate the territorial extent of recorded cases. The second map presents areas with likely return periods. And the last map shows intensity of recorded seismic events. The data shows that the earthquake hazard is present on the DL territory with a rather high probability of occurrence.

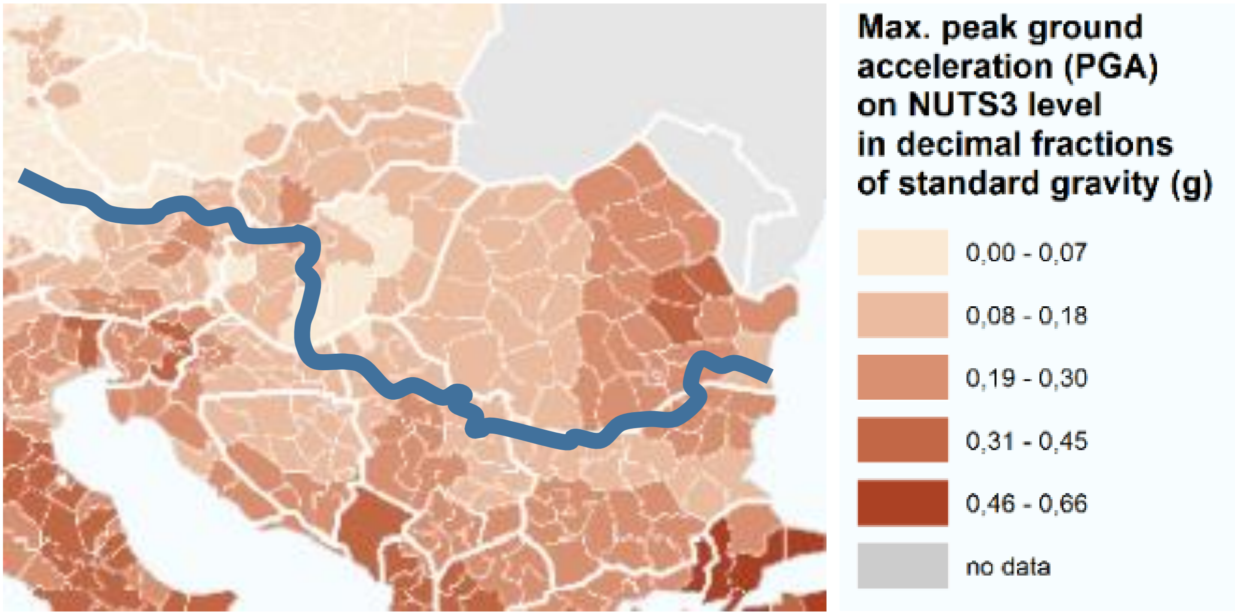


Review of seismic events along the Danube in the period from 342 BC to AD 1990[2].

[2] BGR - Seismic hazard assessment - Earthquake Catalogue of Central and Southeastern Europe (bund.de)



Map of seismic activity with areas of similar estimated return periods in the years for earthquake events. (Source FM Global Worldwide Earthquake Maps)



Map of maximum peak ground accelerations in the DL territory. (Source ESPON TITAN 2020).

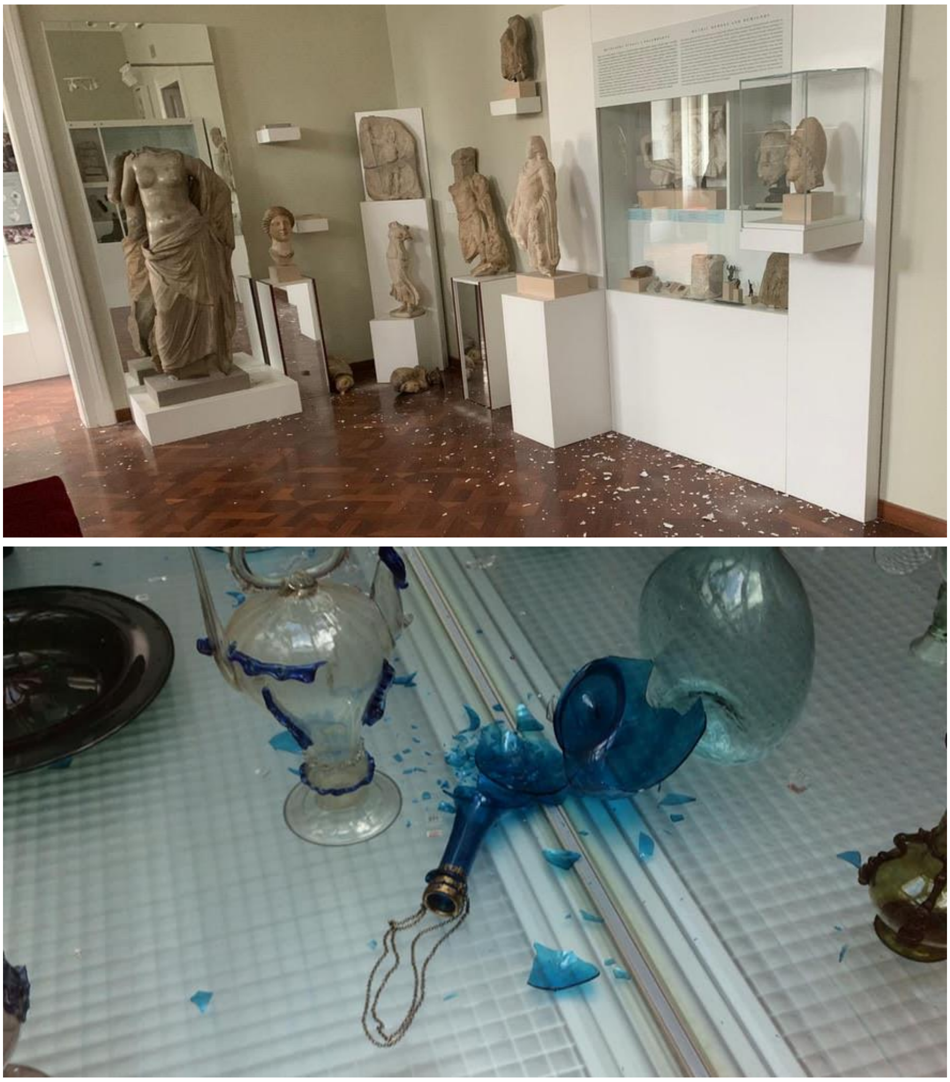
In Hungary, several minor quakes may occur annually, but the strength of these does not exceed 2.5 on the Richter scale. Earthquakes that cause more significant damage occur every 15-20 years, and serious earthquakes occur every 40-50 years. According to records, the Danube River Valley has been hit by earthquakes numerous times, including Komárom in 1763, 1783, 1806 and 1851, and Dunaharaszti in 1956. Most recently, there were minor earthquakes at Érd and Mohács in 2010, and at Oroszlány near the Danube and Németkér near Paks in 2011. The earthquakes – even the quakes of minor strength – can primarily endanger DL parts that are in poor technical condition and those with standing walls.

2.1.3a Conservation strategies in relation to earthquake

The threat from minor earthquakes can be prevented through the improvement of the technical condition of the remains. The quakes of greater strength can also cause significant damage to DL parts that are underground but prone to erosion or those found in wet soils made up of loose particles, and this cannot be prevented.

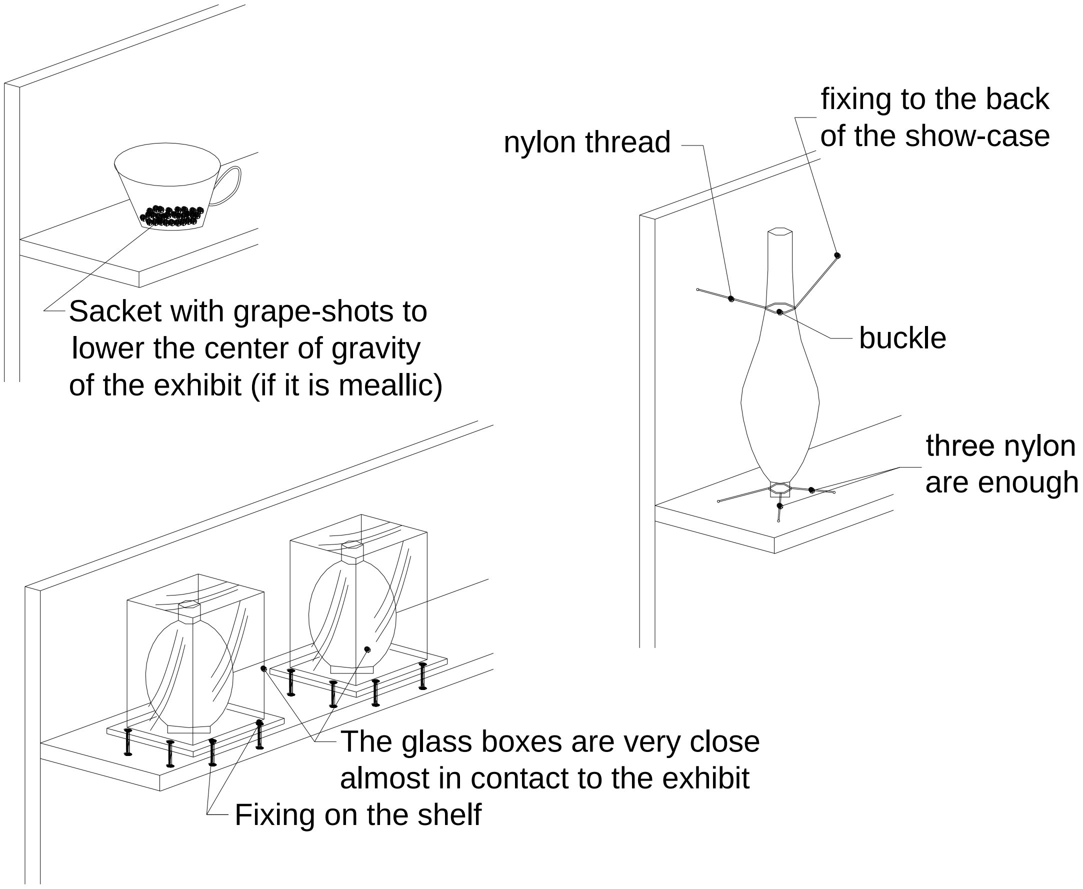
Earthquake induced damage in archaeological sites in the area under discussion is mostly limited to the loss of stability and overturning of free-standing ruins. Partial disintegration or breaking of long stone elements may happen. It is almost impossible to prevent such damage, however, the defects are usually repairable using the anastylosis approach, provided that the heritage structures were well documented.

More damage on antique artefacts has been observed in museums when the objects were not adequately fixed against overturning or falling down from the shelves. This typically concerns free standing sculptures, vessels and various artefacts placed on shelves or stands.



Earthquake caused damage in a museum – overturning and breaks of fragile objects and sculptures.

Aesthetically acceptable fixing of fragile objects helps to prevent damage and loss. Movable cultural heritage inside damaged buildings (e.g., in museums), can also be lost, not only during the earthquake, but also when they are incorrectly removed and transported away from the buildings.



Possible fixing of vessels on museum shelves resistant against overturning – design and drawings T. Sali.

2.1.4. Weathering

Weathering effects involve namely action of radiation, heat, water, air, wind and air pollutants. They affect cultural heritage mostly in a synergic way and occur in both the exterior and the interior spaces. The simultaneous action of temperature and water in repeated freezing/thawing cycles is a typical example of a situation very dangerous for wet porous brittle and quasi-brittle materials. The interacting influence of temperature and moisture causing repeated and uneven volumetric changes results in material deterioration and propagation of defects. In combination with abrasive particles, the wind can cause remarkable surface erosion, (e.g. on monuments in sandy deserts). However, they are numerous other examples, e.g. moisture and deposition mechanisms, wind + water + pollutants penetrating as weak acids into materials.

Weather damage has been observed on some ruin walls (crumbling of materials - Százhalombatta-Dunafüred – Matrica vicus és fürdő), on roads (via praetorian in Dunaújváros Öreg-hegy – Intercisa segédcsapat tábor, vicus és katonai fürdő) and there is expected damage from freezing and soil erosion due to heavy rains. One hundred freeze-thaw cycles is reported in Hungary.

Loss of building elements, loss of integrity due to weather and neglected maintenance (Bosman)

Surface degradation and biofilm on Roman masonry. Melted snow or rain damages masonry with unmaintained top covers which must be kept sufficiently tight. Running water further stains walls and supports grow of bacteria or algae. (Autern, Austria)

2.1.4a Conservation strategies in relation to weather action

Exposed remains, typically ruins are deteriorated by cyclic or repeated action of weather agents. Water in all forms is the most detrimental, therefore, the remains should be kept in conditions which reduce penetration of water into porous materials on one side but also enable appropriate evaporation (drying) on the other side. This is achieved by integral pointing of masonries preferably with lime based mortars and/or by protective sacrifice lime paints if acceptable from the conservation policy point of view.


Masonries suffer in mortar joints which need repair of re-pointing.

Intensive salt efflorescence should be reduced with desalination treatment because salt crystallization also quickly degrades porous materials and composites, e.g. masonry walls.

Salt efflorescence appears typically after drying of previously wetted walls.

Windstorms may potentially destroy free standing slender ruined walls or damage other parts of the site with falling trees. Falling prone ruins or trees should be anchored against a strong wind action.

Heavy rain can not only cause flood situations but also surface erosion and pavement destruction, therefore appropriate water disposition from the archaeological site must be well designed and the water channels kept clear and in perfect condition.

Degradation due to temperature fluctuations (freezing/thawing cycles or just frost) in combination with precipitation and wind can be significantly reduced by means of seasonal covering with temporary shelters. Shelters must be properly designed with natural ventilation and microclimate preventing growth of bacteria, algae or fungi.

Example of temporary winter shelters of sculptures.

2.1.5. Biotic damage

Biological elements in archaeological sites can have both protective and damaging effects. In the same way, climatic influences can damage those protective elements and, on the contrary, support harmful ones. The protection functions can be reasonably exploited at land use planning and agricultural activities.

Climate change namely the global warming generate new situations promoting propagation of new invasive species of plants which create a difficult problem in some sites, e.g. such a situation was reported in Carnuntum. Invasive plants are those which are non-indigenous in the territory and have a high ability of fast colonization of new sites. Expansive species are indigenous plants, however, similarly fast propagating and creating rather large populations. They involve many herbs and also trees e.g. Rubus, Sambucus nigra. Nevertheless, their effect is manageable. Examples of invasive plants represent e.g. Locust tree (Robinia pseudoacacia) which is the most spread introduced tree in the Central Europe, Tree of heaven (Ailanthus altissima) is a very aggressive sub-tropic plant colonizing rather warm areas and its future propagation is dependent on the climate change.

The Austrian management plan describes the following situation. Animal and plant pests damage remains above and below the surface, although to differing degrees. Roots that extend deeper or animals that burrow may have a damaging impact on remains that are underground and that are generally better protected. They do not have an impact worthy of mention on the construction materials; instead they endanger the stratigraphy and the finds enclosed, therefore disturbing the original archaeological conditions. However, their impact is always limited. Similar to this, the damaging impact of birds that nest in the loess banks and animals that settle in the riverbed of the Danube is minor. The remains above the ground surface, (even those that have been conserved), may be endangered by plants that have aerial roots, mosses and lichens through splitting and cracking effects.

Invasive species: Tree of heaven (Ailanthus altissima) – left, Locust tree (Robinia pseudoacacia)- right.

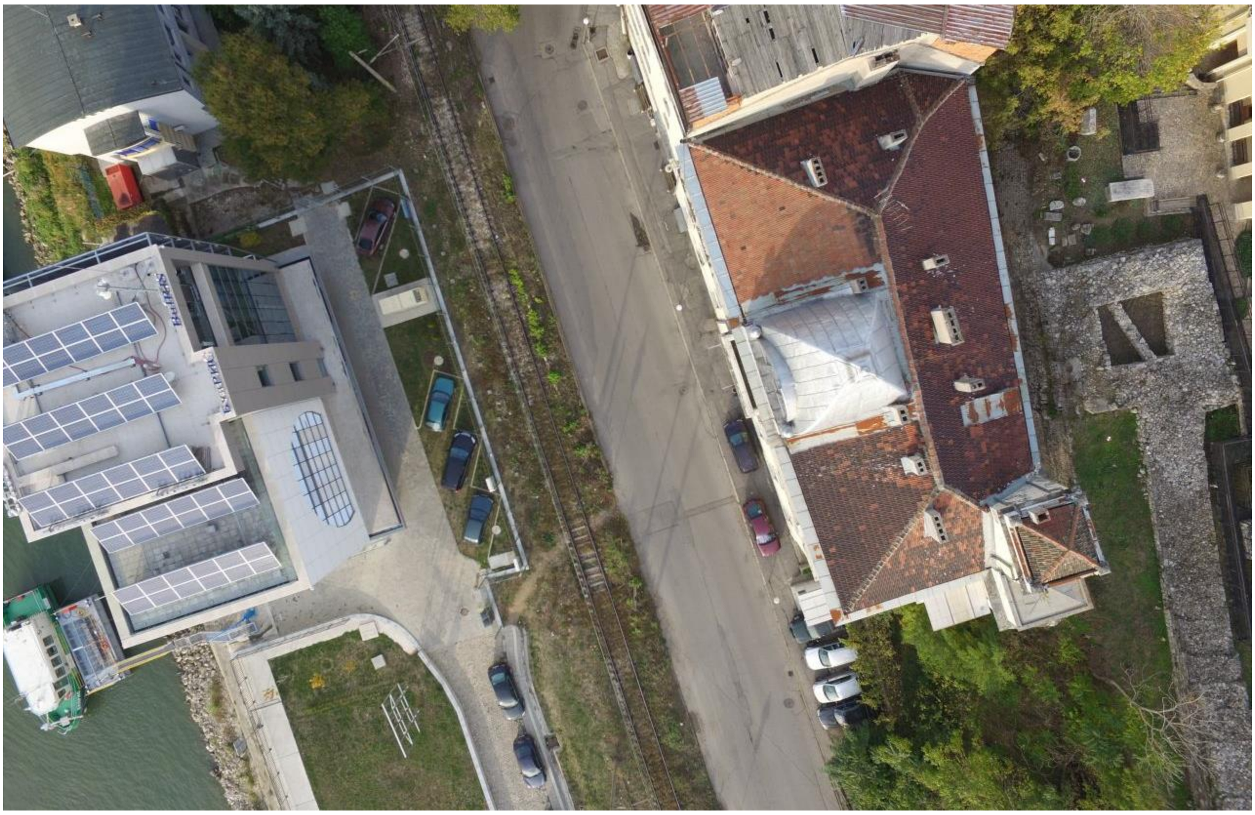
2.1.5a Conservation strategies in relation to biotic dangers

Mitigation of the effects above require regular periodical inspection and monitoring of the site with immediate rectification of the found defects or problems. Specific maintenance and care procedures should be adopted which are tailored for specific sites and situations.

According to the recent experience, the preventive best practice includes mainly increasing the share of human labour in the fight against the spread of non-native and invasive, or. expansive plant species as well as in combating the spread of plant pests (e.g. branches and strains of conifers, fungal diseases, leaf-eating pests, parasitic plants). Human labour is necessary at elimination of young invasive tree shoots and self-seeding, e.g. young acacia or young ailanthus, management's priority is to prevent especially new plantings of alianthus and reduce existing ones in valuable areas.

2.2. Man-made hazards

Man-made dangers in archaeological sites are typically associated with the mode of their management, modes and intensity of their exploitation and use, (which is closely connected to tourism or visitors´ behaviour), policies and financial support of their protection and unwanted or intentionally destructive human interventions (e.g. terrorism). Widely observed phenomena are illegal prospecting and "mining" in archaeological sites and vandalism, which includes also graffiti. Further damage is seen in the site spoiling with the trash left by previous visitors, defacing, removal of stone materials, metal detecting and excavations by “treasure hunters”.



Development pressure in large cities impact context and accessibility of Roman monuments (Ruse, Romania)

2.2a Conservation strategies in relation to man-made hazards

Successful mitigation of man-made damage requires profound knowledge of the relevant criticalities which may further serve as a basis for design of appropriate preventive and protective measures. They lay mostly in development of the local, regional or national management tools directing and fostering not only the site management but also public awareness rising and collaboration. Management plans of the DL sites consider some approaches which could be presented as good practice examples.

It is supposed that relevant information, on the-spot communication and awareness raising of residents and institutions surrounding the sites (e.g. tourist facilities) will reduce graffiti impact.

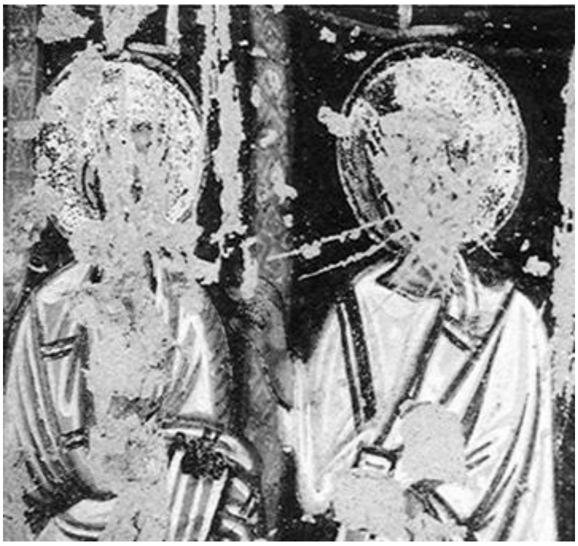
In Austria, special attention is paid to identification of criticalities which could facilitate intentional damage. On the basis of the Hague Convention of 1954 with its protocols of 1954 and 1999 as the legal basis for the protection of cultural property, (currently) an evaluation of all DL parts with regard to their endangerment (the deliberate destruction of cultural assets as a terrorist act, natural disasters such as flooding, and Man-made disasters) is running. This evaluation corresponds to a preparatory action to be carried out in peacetime together with the Austrian Armed Forces and gives an assessment of the value of the individual DL parts.

The prevention of vandalism includes watching the area, regular cleaning, repair or replacement of equipment that has been damaged and install vandalism-proof public furnishings. An alerting the management body to damage to the DL part or its protective structure can be the duty of either the local community watch, the rangers or the nature conservation patrol, (which is in Hungary supported by law).

Damage from metal detecting and illegal excavations can be reduced by more frequent and regular watching the site. There started also a closer cooperation of the archaeological institutions with the amateur treasure hunters, which decreases this negative impact. For example, in the Czech Republic a Portal of Amateur Collaborators and The Register of Independent Finds of the Archaeological Map of the Czech Republic was launched in April 2021, which attracted 1500 amateur prospectors.

2.3. Impact of tourism

There is a common opinion in all management plans that the Danube Limes archaeological sites do not represent a significant tourist attraction with a high number of visitors, except of some museums, and the damage caused by mass tourism is therefore not characteristic of the excavated, exhibited parts of the limes. However, some typical threats have been identified. For example, vandalism (as above graffiti, defacing, “souvenirism” with taking away pieces of stone or ceramics), climbing or walking on unstable or sensitive sections of the monument, which may cause their partial destruction or soil erosion with instability consequences.

Climbing of sculptures or ruined walls or graffiti and ravage of pictures

2.3a Conservation strategies in relation to tourism

In the present situation appropriate planning of visitors´ access, especially the routes and the paths in the vicinity of remains reduces soil erosion dangers. Reasonable and conservation tolerable barriers preventing climbing or walking on unstable or sensitive sections of the monument are recommended. Furnishing the site with visitors-friendly infrastructure – e.g. information tables, toilet facilities, drinking water fountains, litter bins etc.

In specific cases or in case of massive growing of visitor numbers, surveillance or guarding may be necessary or even erection of fences with the visitors regulation.

Typical erosion due to action of visitors.

Fenced area with information panels (Zeiselmauer, Austria)

Furnished site with surveillance, tourist facilities, information tables etc. (Carnuntum)

2.4. Global challenges

2.4.1. Land use, agriculture and forestry

The majority of the DL sites, over two thirds, are not built-up and they are mostly used for agricultural cultivation of various modes from the pasture to grain or corn growing on the arable land or forestry. It seems that modern agriculture represents the most serious threat for the heritage in the Danube valley. Namely if it disturbs the soil to a depth of more than 30 cm, (e.g. planting grape vines or other special cultures), or if it involves the planting of vegetation with fundamentally different root systems, (e.g. afforestation), if it opens the integral ground surface and creates a danger of erosion, (the ploughing of fields and pastures) or if it fundamentally alters the water consumption or chemical composition of the land, (irrigation or chemical protection of plants).

The unbuilt areas further attract development pressures especially in surroundings of settlements. There are some sites not protected by approved land use plans.

Also mining activities pose some danger for the DL heritage. Fortunately, only one site from the list, Zwentendorf is situated very close to a raw material mining area, but the mining activities and spatial extension are fixed in a mining plan which is approved and monitored by the public administration (Province of Lower Austria).

2.4.1a Conservation strategies related to land use, agriculture and forestry

The agricultural activities need to be carefully checked, and if a danger is present the mode of cultivation must change. Because of a particular threat of erosion even in flat situations, the DL areas under the plough need careful continuous monitoring. Alteration of the type or method of cultivation, for example develop grass or meadow instead of woody plants, can also be important means for preservation and protection that must be employed as a management tool when possible.

Example of well-developed cultivation of land in forest with Roman masonry ruins – the surrounding is covered with regularly maintained meadow (Windstallgraben, Austria)

Similarly well maintained site in a forest.

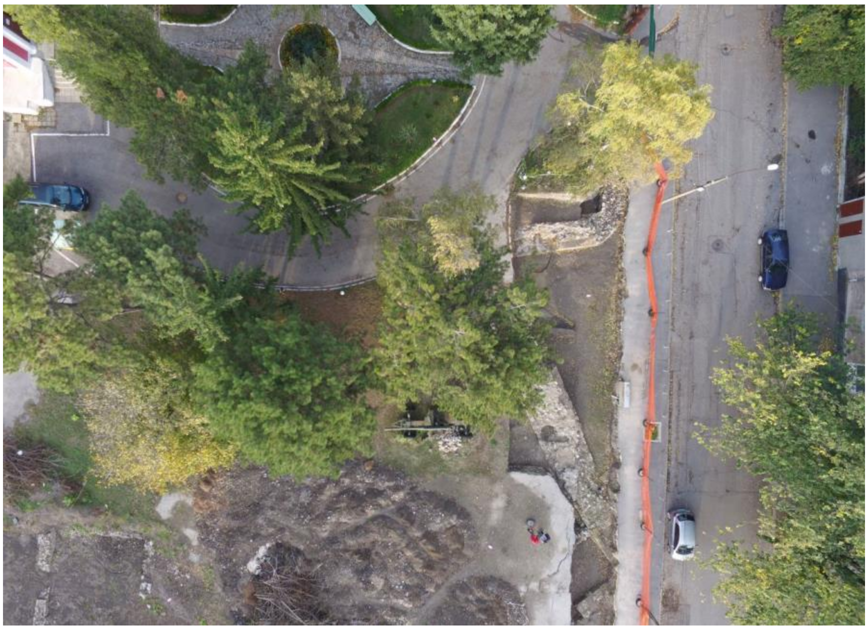
In particular, on those sections of the limes parts where building remains, the paths of roads and the remains of ditches can be found. In situations when a compromise between a utilization, which would damage the monument and the interest in its preservation is not otherwise possible, the land should be left unused. Such an approach is recommended in Bavaria provided public funding is available or any other institution, which has an interest in the protection and conservation of The Danube Limes in Bavaria. Another best practice example is recommended in Austria and consists in special agreements with the farmer ensuring a sensitive ploughing (no deep ploughing) to minimize the impacts on the DL heritage parts. Such an agreement not allowing deep ploughing has been signed for the site in Enns. Moreover, intensive information and discussions with the farmers strengthen the awareness for the cultural heritage.

Protection and conservation of the landscape simultaneously further saves the surroundings of the DL parts from inappropriate construction activities and adverse effects on its visual appearance. This also serves to preserve the monument's characteristic features.

2.4.2. Construction and infrastructure

Damage may also occur especially in places where parts of The Danube Limes are affected by construction projects, e.g. the construction of new roads or railways, industrial complexes, houses or quarrying and facilities for the production of energy. Experience in Bavaria has shown that facilities for renewable energy can endanger the public's perception of the World Heritage. Wind turbines in particular can compromise The Danube Limes appearance if they are located within a close view of the monument, or if they appear in a close perspective from the monument.

Even though DL parts situated in settled areas are well respected in the communal plans, (e.g. in Austria), small scale threats resulting from the necessity to connect existing buildings to water, gas, power, and sewage lines cannot be excluded. Similar problems of malfunctions of underground utilities with frequent needs of repair is present in Slovakia (gas, water, sewerage).



Aerial view of a dense mixture of Roman ruins and modern paved roads (Ruse)

2.4.2a Conservation strategies related to construction and infrastructure

The management plans indicate that protection of known remains of the DL in the settled areas must be effectively improved. In order to achieve this, local authorities should develop and implement comprehensive planning guidelines, such as land use plans or relevant bylaws, as early as possible.

All underground works in the DL properties require permission and an authorized supervision of the relevant institutions.

Example of integration of Roman archaeological remains in a modern city infrastructure with urban presentation and interpretation of the monument (Vindobona, Austria)

3. Regular inspection

3.1. Why

Regular inspection with specific condition survey of Donau Limes sites serves to monitoring of their physical stability and sustainability features. Physical inspection of structural health concerns all categories of vulnerability to the damaging or harming effects and represents a basic condition for properly and in-time maintenance of historical tissue and prevention of damages and failures. The scope and procedure of the regular inspection is generally oriented to checking of historical materials and structures irrespectively to a probable deteriorating or damaging action mainly for economy reasons.

3.2. When

The management plans envisage regular periodic inspections, however, without any description of the procedures. It is expected that the inspections will take care for monitoring preservation of heritage values decisive for the inscription on the World Heritage list. The inspections should be scheduled and carried out also with an aim to identify possible deterioration symptoms for early safeguarding interventions. Usually regular inspections are carried out once a year. A good time to conduct a regular inspection is the spring months. In the event of an emergency situation, the inspection is always after it subsides and after any remedial interventions have been carried out. For intensively visited places, it is advisable to carry out an inspection even after the end of the tourist season to assess the need to repair any critical wear or erosion before the onset of winter.

3.3. Specific situations

If need be, long term continual monitoring of development of found defects or site conditions may be adopted, e.g. typically the movement of cracks in masonry or the ground water table fluctuations.

3.4. How

There are several guidelines available for such an inspection on built heritage, which can be used for museum buildings, which is out of the scope of this report[3]. For the case of Donau Limes heritage, the recommendations are presented below. Periodic inspections usually do not require any special aids or facilities and are carried out by visual survey. In cases of observation of fault development, more frequent or continuous monitoring is carried out by installing measuring sensors. For regular inspection, it is advisable to make a site plan with marking and labelling of structures and objects that will be regularly monitored. For each object, it is necessary to prepare its basic documentation with a description of its shape and

[3] Drdácký, M., Adámek, J. Rukověť stavební diagnostiky / Händbuch für Baudiagnostik, chapter in the book „Příručka revitalizace – Sanace a zachování církevních staveb / Revitalisierungsleitfaden – Sanierung und Erhalt kirchlicher Bauten“. St. Pölten: Diözesanarchiv St. Pölten, 2016, pp. 56-91. ISBN 978-3-901863-47-9 or Surveys and inspections of buildings and associated structures (B.P.Clancy et all). IStructE, London, 2008.

dimensions, the materials used, the conditions of foundation or stability, possible integration into recent structures, the history of interventions and the initial state.

When describing the condition, particular attention should be paid to possible defects and malfunctions. Their location and description are useful to document both in drawing and photography. Regular inspections then record changes compared to the initial state of the basic documentation. At archaeological sites of the DL, it is practical to monitor the terrain and its stability, including rainwater drainage and land cover, masonry remains rising above the surface, historical paths and possible floor residues.

The conduct of inspections is facilitated by tables, in which the findings are recorded and which at the same time ensure the completeness of the inspection.

3.5. Site terrain and stability monitoring

3.5.1. Rain water drainage

Water is the main factor that can threaten the stability of the terrain in the locality. Therefore, during the regular inspection, rainwater drainage measures must be carefully checked and kept clean and functional.

Rainwater channels must be checked and kept clean and functional

3.5.2. Land cover and agricultural cultivation

Mode of agricultural cultivation must be carefully monitored. Further, the land cover which helps to keep the surface integrity and prevents soil erosion must be examined and the found shortcomings repaired. Critical areas are in the vicinity of ruins or other exposed remains connected through the "wild" paths deliberately generated by visitors. Occurrence of invasive species and signs of damaging animals.

3.5.3. *Terrain shape*

Any change in the terrain shape must be recorded, especially after floods, and their cause explained. It concerns depressions which may signal washing-up of fine subsoil particles or clay shrinkage due to deep drying as well as buckles caused by wet clay swelling or frost effects. Periodical geodetic terrain shape monitoring might be introduced in cases of uncertainty of reasons or future progress of these defects.

3.5.4. *River or stream banks*

Banks in contact with the river deserves a special attention because of an increased risk of occurrence of local landslides or gradual draining away.

3.6. Masonry ruins

Most of the exposed monuments are ruins and remnants of buildings free-standing or connected to the recent masonry of contemporary buildings. For these remains, it is necessary to examine the condition of the material and the condition of the structure, or foundations.

3.6.1. *Masonry mortars*

Mortars are composite materials containing various types of binders and sands. In the DL masonries, ancient mortars as well as modern mortars from repair, grouting and pointing are present. Their degradation can be assessed with monitoring the loss of material cohesion. It can be measured with a simple and cheap method using so called *peeling test*, when a usual Scotch tape is stuck on the surface and the amount of the released material is measured[4].

3.6.2. *Masonry stones*

Natural stones show different weather resistance and their weathering is manifested in a wide range of defects. For the description of the defects and damage, it is recommended to use the terminology given in the ICOMOS Glossary https://www.icomos.org/publications/monuments_and_sites15/pdf/Monuments_and_Sites_15_ISCS_Glossary_Stone.pdf. For the degradation rate, the above mentioned *peeling test* can be applied[5].

3.6.3. *Masonry bricks*

Donau Limes ancient masonries typically contain burnt clay bricks. They are sensitive to deterioration due to frost and salt action. Degradation phenomena are similar to those which can be observed at the stone surface, therefore the same observation methods are to be applied. The surface quality can be checked by *scratch tests*.

[4] Drdácký, M., Lesák, J., Niedoba, K., Valach. J.: Peeling tests for assessing the cohesion and consolidation characteristics of mortar and render surfaces, Materials and Structures, Volume 48, Issue 6 (2015), 1947-1963.
[5] Drdácký, M., Lesák, J., Rescic, S., Slížková, Z., Tiano, P., Valach, J.: Standardization of peeling tests for assessing the cohesion and consolidation characteristics of historic stone surfaces, Materials and Structures, Volume 45, Issue 4 (2012), pp. 505-520. DOI 10.1617/s11527-011-9778-x

3.6.4. Masonry structures

For the masonry structure assessment, a visual survey of the condition of the outer surfaces of the walls provides an overall picture of the stability of the ruin (building) and consists of the following steps.

- Inspection of all wall surfaces and record of found cracks - their size (width, depth and length), position, character, course, or age.

- Detailed inspection of masonry joints, window or other openings with a focus on deviations from vertical or horizontal (*use of a spirit level*).

- Detection of signs of movement of the ruin (building) as a whole.

- Inspection of walls on the both surfaces with checking verticality and buckling.

- Record of possible wall deflection from the vertical. Does the whole wall or just the surface layer deviate?

- Detection of other signs of different settlement and local *(e.g. after a flood, activity of animals)*.

- Checking the verticality of corners and pillars.

- Checking the condition of grouting - changes in arrangement, performance of grouting.

- Checking presence and extent of rising moisture and salts - efflorescence and salt failure, especially in the foot masonry.

- Checking presence and extent of biotic agents and damage – bacteria, algae, lichens, plants.

- Checking of presence of water traps – small depressions, lacunae etc.

- Checking of signs of vandalism

- Non-structural damage, which includes e.g. soiling of surface with dust, crusts, excrements of birds or their nests has also impact on the maintenance works and should be a subject of inspection.

3.6.5. Masonry foundations and surroundings

Recording of possible disturbing or endangering elements or signs in the vicinity - trees, drainage ditches, subsoil movement, etc.

3.7. Pavements and roads

3.7.1. Pavements

Several important items: the integrity of the surface layer, adequate flatness of the surface and pavement, the presence of harmful biotic agents (e.g. weeds, roots), appropriate water run-off channels.

3.7.2. Stairs

In some situations, communication equipment includes stairs or handrails, which must comply with appropriate safety measures and be regularly inspected.

3.8. Structural protection measures

3.8.1. Shelters

Some sites have shelters protecting the archaeological remains. Rules for their inspection are more complex than the recommendations above and they are out of scope of this manual. However, there are recommended temporary seasonal shelters, which also need inspection. Here the anchoring must be checked as a system including the structures, which provides supports. There should be also checked the health of trees which can damage shelters. From the weathering point of view the surface layers and elevated moisture are of the great importance. The tightness of the envelope against penetrating water or snow, (at reasonable diffusion characteristics), and the damp rise structures and voids must be carefully checked.

3.8.2. Protection barriers

Permanent protection barriers, for example earth dams or concrete walls, must be checked for their integrity and tightness. Elements for temporary barriers must be kept clean and ready for fast application. The structural parts are stored in covered closed warehouses protected from damage. Anchor holes in foundations must be kept clean.

3.9. Specific survey

An exceptional step is a possible proposal to carry out an additional special survey or a recommendation to carry out some immediate intervention (timely repair, static temporary support, etc.).

Survey of large ruins may need application of supporting tools (ladders or platform). It is recommended to rectify found deficiencies immediately. (In the picture the small trees growing on the wall).

4. Regular maintenance

4.1. Background

Regular maintenance represents one of the most important strategies against damages and failures. Unfortunately, the regular maintenance is almost neglected in conservation practice and it is guilty for the majority of failures of built heritage. Lack of regular maintenance causes material decay and loss of mechanical characteristics decisive for structural resistance to acting forces or environment actions. It also influences substantially the subsequent measures listed below. The maintenance action is usually initiated as a result of the regular inspection or it can be carried out really regularly on a basis of maintenance plans, which is a better and recommended standard approach. The maintenance action in most cases does not need design work or even an engineering supervision. It can rely only on skills of properly trained craftsmen, which substantially shortens the time to action and prevents development of a defect into a more serious damage or even a failure. A maintenance guide is a useful tool and should combine tips for inspection with recommendations how to fix an identified problem. Regular maintenance significantly improves life cycles of historical materials and objects. It prevents development of serious damages from weathering action and prolongs time between restoration works.

Maintenance of heritage objects and sites DL consists in periodical actions recommended or required for individual types of heritage assets and in actions, which are consequence of inspection findings. The same typology division as in the previous paragraph is kept, however, only the masonry ruins are treated in a deeper detail.

4.2. Maintenance tips

4.2.1. Site

Undeveloped areas require routine care appropriate to the nature of the land use. Agricultural management is governed by agro-technical needs, grassy areas without use can be grown as flowering meadows with double haymaking or more often mowed lawns. Further interventions are based on the requirements arising from periodic inspections. In particular, it is a matter of supplementing the cover for protection against soil erosion, sowing or over-sowing of bare areas or thinly grassed areas, securing the banks, threatened by the danger of local landslides or undermining.

In fenced areas and fields with landscaping, the usual gardening maintenance of flower beds, shrubs and trees is added. Furthermore, regular cleaning and disposition of biological waste and garbage left by visitors.

4.2.2. Masonry ruins

For the maintenance of building residues, it is desirable to develop a **maintenance plan** for individual buildings. This plan contains an introductory part with identification data for the entire archaeological site, ie name, location, ownership data, the administrator with the names of the responsible persons and their contacts. Furthermore, information on regular inspections and the persons who perform them.

The object-oriented part of the maintenance plan contains the object or element identification. The plan is further subdivided into activities arising from general maintenance needs or legislation (e.g. electrical wiring or equipment inspections), and activities or work required to correct deficiencies identified by inspections. Corrective and preventive interventions are good to classify according to urgency and necessary expertise. An example of good practice is to arrange the plan in a table, (see below), where the individual sections contain the following information.

Site							
Address							
Type							
Owner(s)							
User							
Responsible manager							
Date of the basic issue							
Author(s)							
Dates of maintenance plan updating							
Object identification		**Ruin of a watchtower – Inventory Nr. 5**					
Periodic actions							
Description of work	Place on the object	Planned date	Date of execution	Expertise required	Priority	Estimated / real cost	Conditions /comments
e.g. repointing of the degraded joints in masonry	*all sides*	*April 2024*		*skilled bricklayer*	*high*	*5000 EUR*	*See the "Maintenance manual", p.12; dry weather; scaffolding*
Non-scheduled actions							
Description of work	Place on the object	Required date	Date of execution	Expertise required	Priority	Estimated / real cost	Conditions /comments
e.g. filling of lacunae after a fallen stone	*western facade*	*by MM/YYYY*		*skilled bricklayer*	*high*	*1000 EUR*	*essential need for a compatible stone, mortar and implementation; ref. 2021 inspection report*
Object identification		**Next ....**					

Object identification. This part contains the basic data on the location of the subject of intervention. It is further refined with specification of the elements or parts of the construction to which the relevant actions relate. Their location (place) may be supported with designation in the drawing or photograph.

Description of work. It specifies the maintenance work, physical conditions and the method of execution. The description should be as accurate as possible. For specific tasks, it is appropriate to prepare a maintenance manual with the necessary recipes, recommended or prescribed materials, instructions for implementation, or drawings, which explain the required tasks and their location on the object. This also applies to repair work, where the instructions then form an appendix to the maintenance manual. This simultaneously creates documentation that can be advantageously used in evaluating the success and longevity of the intervention for further planning.

Planned date / Date of execution. Time related inputs define in the schedule planned and record the really completed action. Planned date is derived from the periods of recommended maintenance published in literature or on empirical experience with the operation of the object and the life of individual elements or modifications. It further takes into account the legally prescribed intervals of implementation (tests and revisions). It may include also works of repair of degraded parts based just on the experience of a skilled and properly trained craftsman. For non-scheduled actions the required date refers to the date suggested in the inspection report as an optimum period for a repair intervention preventing development of a heavier damage.

Expertise required. Maintenance as well as preventive conservation works may be efficiently carried out by stake holders, ("do-it-yourself" mode), skilled craftsmen or professional restorer. Specific actions solving defects identified by inspection campaigns may require engineering design of resilience increasing works, e.g. strengthening against earthquake impact of geotechnical measures preventing landslide.

Priority. It expresses the level of urgency of individual maintenance tasks with regard to the condition, expected rate of deterioration progress or probability of development of future negative consequences for the heritage asset.

Estimated / real cost. A cost estimate is usually based on experience from former interventions or detailed calculations or offers of contracted works.

Conditions / comments. The field is reserved for other information on conditions important for the repair or maintenance materialization, e.g. necessity of a close cooperation with the competent state monument care authority, (e.g. approvals, surveillance), requirement of specific license for the contractor, required weather conditions or facilities. There is a space for references to the inspection reports, photography documentation, restoration reports etc.

Well maintained masonry ruins with simply fixed top covers and repointed joints made of lime based mortar. The gravel pavement is easy to maintain and does not retain rainwater (Bad Deutsch Altenburg)

4.2.3. Pavements and roads

Regular maintenance of roads and remnants of historic pavements or floors can prevent their damage and subsequent major repairs. Proper road maintenance consists primarily of regular surface cleaning, including drainage systems, timely repair of individual damaged areas and renewal of the surface layer at threshing floor type surfaces. For paving and stone stairs, missing or severely disturbed paving stones, including joint filling, must be added immediately. Regular maintenance of pavements and roads is recommended with a yearly period, the removal of grass or plants from joints or surface layers then as soon as possible after their emergence.

Well maintained road pavement (Bacharnsdorf)

Best practice ideas for the maintenance collected in the Interreg CE "RUINS" project are added here[6].

[6] https://www.interreg-central.eu/Content.Node/RUINS/D.T1.1.1-Report-on-state-of-art-final-version-4-copy.pdf

5. Preventive conservation

5.1. Conditions for damage mitigation

Design of measures mitigating the adverse effects of various situations, loads and conditions is based on knowledge and analysis of experienced or estimated damage and failures of historic objects suffered from disasters or other loads. A wide variety of historic structures and materials as well as the scope of possible damage make designing of widely applicable measures and methods difficult. Therefore, an approach of generalization based on ranking of historic structures, elements and situations according to their sensitivity to the man-made and natural disaster effects has been developed. It groups the endangered cultural heritage into vulnerability categories, (see an example for flood situations). In the case of DL heritage the variety of endangered stock is fortunately rather limited which simplifies the process of such a classification, in contrast to architectural heritage, for example.

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 - origination of cracks or even shifting structural parts. Bowing of wooden floors. No dangerous loss of strength and load carrying capacity reduction.	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 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	

Example of ranking of heritage buildings and structures in relation to the flood situations. It contains columns describing the object characteristic, experienced damage, examples of objects or structures and preventive measures further highlighted with traffic light colours indicating priorities.

The majority of DL assets have a form of archaeological sites with remains and artefacts buried or re-buried in soil. Their physical vulnerability is mostly robust with exemptions in cases of erosion situations or inappropriate agricultural or forestry use. The only exposed remains consist in ruins or ruined walls integrated in non-Roman buildings. So, the remains are composed of stone, brick or combined masonries. Their physical vulnerability involves grades from robust and stable entities to fragile and prone to heavy damage or even loss, depending on the material and masonry composition and the type of hazard.

Special attention must be paid to structures or buildings erected as shelters of archaeological remains. They deserve a complete care as any other contemporary building, as indicated above with relevant references.

5.2. Preventive protection

Preventive protection typically includes technical measures. It is cost demanding, not always feasible and it can sometimes lead only to partial benefits in case of some natural disasters, such as for example in the case of threat of landslides. Preventive protection can be designed and implemented at territorial, building (ruin) 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.

The archaeological site is protected against high water with an earth dam, (an example from Iža in Slovakia)

Preventive protection of ruins may present greater advantages when implemented using temporary measures, which are removable after the event. Temporary quickly erectable barriers are typically used in such an approach. They need storage space and regular training of dedicated rescue troops, usually fire brigades.

Example of a training exercise of erection of a temporary barrier against flood (Stein, Austria).

Material protection of heritage assets in open air is almost always irreversible, however, for individual immovable artefacts or ruins could be very effective. More considerate or even now material intervention can be applied on historic masonries covered with shelters.

Conserved of historic masonry with hard mortar and compact crown structure (Iža, Slovakia)

Closed permanent museum like shelter protecting Roman masonry ruins (Stari Kostolac)

5.3. Adaptation

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. In the case of Danube Limes has a limited applicability and can be applied mostly in land use measures.

Reconstructions of the anastylosis type can be considered as adaptation when they include application of measures increasing resistance against threating environment and forces.

Example of adaptation of Roman ruins for higher resilience against natural disasters (Capidava Fortress, Romania)

5.4. Resilience

5.4.1. Criticality based resilience

In order to determine an effective resilience and risk management plan, it is fundamental to individuate the critical elements, which substantially affect behaviour of cultural heritage objects. A critical element can be defined as a controllable 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 archaeological site conservation standard, which can be easy to use and accessible also to non-technical stakeholders, a simplified categorisation of critical elements has been proposed in the Interreg CE project "ProteCht2save" and used for design of a manual for stakeholders[7]. Examples are presented here:

Criticality	*Typical damage*	*Situation examples*
Changes in subsoil characteristics that affect the stability of cultural and natural heritage.	Decreased anchoring of tree roots; buoyancy effects loosen the subsoil and may cause differential settlement or uplift of buildings or their parts, subsequently tilting or cracking masonries. *The permanent anchoring of a pine tree near the castle in Ravello (I). →*	
Resilience focused measures		**Engineering assessment and design**
Preventive	*During disaster*	*After disaster*
Only local and partly effective measures are possible and economically justified. They involve e.g. additional anchoring of trees against the combined action of wind and a change in subsoil.	Anchor trees with superficial root systems.	Drain the area and restore natural soil moisture and compactness.
Relevant hazards	**Floods; Heavy rain; Frost periods; Combined hazards**	

[7] M. Drdácký, R. Cacciotti, I. Kopecká: Drdácký, M., Cacciotti, R., Kopecká, I.: Cultural Heritage resilience - A manual for owners and managers. ITAM AV ČR, 2020, 45 p., ISBN 978-80-86246-50-5, eISBN: 978-80-86246-63-6

Criticality **Danger of surface erosion due to flushing rain water along slopes.**	*Typical damage* Destruction includes erosion of soil, damage pavements of roads, may initiate mud flow and avalanches. *Reinforcement of subsurface layer with geonet, prepared for planting grass layer. →*	*Situation examples* 
Resilience focused measures		**Do-it-yourself if possible**
Preventive	*During disaster*	*After disaster*
Permanent consolidation or enrockment and pavement of slopes and banks. Protection with grassed geotextiles and/or bushes and trees	Creation of temporary capacity water run off drainage channels and dikes, e.g. using sand bags.	Repair of damage on the pavement and enrockment of slopes as well as on capacity water run off drainage channels and dikes.
Relevant hazards	**Floods – river, flash, tidal; Heavy rain**	
Criticality **Combined weathering effects – typically frost after intensive wetting. A danger associated with late autumn floods or heavy rain.**	*Typical damage* Material disintegration due to repeated freezing. *Situation presents sculptures of a porous stone protected with winter covers against wetting. →*	*Situation examples* 
Resilience focused measures		**Do-it-yourself if possible**
Preventive	*During disaster*	*After disaster*
Installation of winter covers after intensive wetting or generally before winter.	Protective foil wrapping of frost sensitive objects, typically stone, stucco, terracotta and artificial stone sculptures.	Remove the temporary winter covers, repair minor damage which might occur due to cover microclimate and restore protection surface treatment.
Relevant hazards	**Floods; Heavy rain; Frost periods; Combined hazards**	

5.4.2. Managerial criticalities and measures

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. Naturally, management plans of DL heritage assets exploit to a large extent general legislative instruments ensuring protection of their heritage values as well as tools for land use planning, disaster management and access regulations and control. They create a strong and stable base for design and adoption of managerial measures. However, it is well known that in the management practice the available legislation has not been fully or effectively applied due to various obstacles or human failures, which set a group of managerial criticalities. They typically include e.g. the lack of knowledge or information, negligence (lack of maintenance), inadequate decision making, poorly designed emergency or post-disaster plans, missing funds and similar. 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. An example again taking advantage of the Interreg CE project "ProteCht2save" is presented here.

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 based on plans and handbooks
PP1	**No maintenance schemes for CH at risk**	Minor damage might be experienced due to long-term effects of malfunctioning control systems (e.g. drainage) and protection systems (monitoring, early-warning)	Proper maintenance is missing inducing in some cases bad functioning of protection systems, drainage, regular survey etc.	Regular inspection and maintenance; Awareness and knowledge raising and sharing; Allerting 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 non-maintained heritage. Complex, at times impossible recovery.	No resilience and risk management plans are enforced	Site planning must include 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

The example concerns management issues related to cultural heritage protection planning. Here the following criticalities are typical: i) No resilience and risk management plan, ii) Lack of specific emergency procedures related to evacuation or rescue, iii) No maintenance schemes for CH at risk. Managerial criticalities are further analysed in other groups, namely information on CH assets, funding, knowledge and awareness, policy and regulations. In this group of criticalities, the following measures are recommended: Land use planning which includes risk management; Regular inspection and maintenance including issue of maintenance plans and handbooks; 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. The Table arrangement serves as a decision supporting tool for identification of priorities and highlighting possible preventive measures safeguarding heritage assets.

5.4.3. Physical criticalities and measures

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 there exists a wide range of historic structures and materials, and also a wide range of types of damage. This makes it difficult to design general and widely applicable measures and unified methods. Therefore, the physical critical elements are to be analysed considering a ranking of historic structures, elements and situations according to their sensitivity to the effects of weather and natural disasters.

5.4.4. Typical physical criticalities in masonries

<u>Cracks in masonry</u> are a very common phenomenon which tells a lot about the structure, for example, about the possible origin of the cracks:

• settling (drop) / lifting - *manifested in masonry mostly by <u>sloping cracks</u>, inclining at an angle of about 45 ° above the fallen part - the fall usually causes the leaching of fine parts of the soil with water or settling of insufficiently compacted soils, or drying of clays by lowering the groundwater level, trees), lifting is often caused by trees, frost or watering and subsequent swelling of clay soils*;
• temperature and volume changes - *manifested mostly by <u>vertical cracks</u> in the masonry (at the interface between the sunlit and non-sunlit part of the building (especially at the towers)*;
• shrinkage of the material - *usually only in the plaster as a network of <u>fine cracks</u> (craquele)*;
• overloading - *manifested by crushing of the material - mostly stone elements of the pillars with a network of dense small vertical cracks and breaking of the edges in the load joints*;
• corrosion of walled iron and steel elements, e.g. ties - *<u>star cracks</u>, tearing of elements*;
• degradation of masonry - *loss of shear strength of mortar*.

If the cracks are severe (they penetrate to a great depth, penetrate the entire wall, appear suddenly) and their causes are not obvious, long term monitoring of their behaviour should be proposed.

Non-structural damage, which includes e.g. soiling of surface with dust, crusts, excrements of birds or their nests has also impact on the maintenance works and should be a subject of inspection.

Example of masonry degradation and biological soiling (Sacidava, Romania)

Example of combined weathering and vandalism damage

6. Conclusions

As we state above most of greenery have to be removed from the site with ruins. This includes e.g.: sowing or over-sowing of bare areas or thinly grassed areas, mowing and line-trimming of grassed sites on earthworks of archaeological significance with walk-behind or small ride-on mowers, removal of trees causing a problem or potential problem for site stability, involve possible grazing, which should not result in damage to any archaeological features.

The walls of historic ruins are very specific. Their construction types are not typical today. It forces both designers and contractors to properly prepare substantive and technical content before starting a repair. In addition to the complexity of repair procedures, it is also important to respect the historical value and perform treatments only in accordance with the conservation policy or issued guidelines. Due to the specificity of the buildings and the application of formerly common and diverse solutions to their construction, each case and object should be treated individually. Based on local surveys, interviews with users, and analyses of the documentation collected, it was found that it was not possible to create a widely applicable repair or maintenance algorithm.

7. Acknowledgement

The Manual was produced as a part of the project Valorising cultural heritage and fostering sustainable tourism by LIVING the common heritage on the DANUBE LIMES as basis for Cultural Route within the framework of Interreg Danube Transnational Programme.

About the project:

Living Danube Limes is an EU funded Interreg Danube Transnational Programme project and focuses on connecting, enlivening, researching, preserving and highlighting the Roman Danube Limes as transnational cultural heritage of enormous significance, in order to create a sound foundation for a future European Cultural Route.

Acronym: Living Danube Limes

The programme specific objective is: SO 2.2 Foster sustainable use of natural and cultural heritage and resources.

This project has a total project budget of 3,151,121.20€, funded by ERDF, IPA II and ENI-MD.

Duration: 01.07.2020 - 31.12.2022

Lead Partner: University for Continuing Education Krems, Danube University Krems, Austria

Published by Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences. Prague 2022.