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Climate change-induced disasters and cultural heritage: Optimizing management strategies in Central Europe

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ABSTRACT

Due to climate change, it is foreseen that the frequency and magnitude of extreme climate events such as heavy precipitation, flooding and drought will increase throughout Europe. In recent times, numerous areas suffered from disasters that produced significant damage to cultural heritage. Although different risk management strategies are currently enforced in Central Europe, there still exist many challenges that undermine their effectiveness. This study reviews the necessary points to be addressed for strengthening existing management strategies within the region and the characteristics of potential resilience building measures. It presents feasible and tailored ICT solutions (e.g. a web GIS platform) and decision support tools (e.g. a manual for cultural heritage resilience and a handbook on transnational rescue procedures) for the protection of cultural heritage against floods, heavy rain and fire. These tools result from the Interreg Central Europe project ProteCHt2save, concentrating on risk assessment and sustainable protection of cultural heritage in changing environments. The proposed measures are tested at pilot sites and successfully integrated in local risk management plans. Future work is also proposed for further implementation of the results.

1. Introduction

Central Europe (Fig. 1), as identified by the European Commission, is a vast region which comprises nine Member States including Austria, Croatia, the Czech Republic, Hungary, Poland, Slovakia and Slovenia, as well as eight Länder from Germany and nine regions from North-East Italy (Central Europe Programme, 2020). Being located at the heart of Europe and having been the stage for relevant social and political changes throughout history, this territory has remarkable cultural heritage significance featuring a large stock of assets ranging from monuments and historic districts to landscapes and collections (Central Europe Programme, 2014). In the context of the built environment, cultural heritage represents a non-renewable resource both in terms of socio-cultural and economic uniqueness (Leissner and Fuhrmann, 2015). Thus, evaluating its risk is mandatory in order to identify all possible solutions for protecting and transmitting our tangible and intangible knowledge, culture and traditions to future generations.

As highlighted by Fatorić and Seekamp 2017, in the last decades several research works focused on the impact of climate change on cultural heritage, with particular insights on the European context (Bonazza et al., 2009a, 2009b, 2017; Ciantelli et al., 2018; Gómez-

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Bolea et al., 2012; Grossi et al., 2008, 2011; Sabbioni et al., 2012). Due to climate change, it is foreseen that extreme events such as heavy precipitation, flooding and drought periods will occur more frequently throughout Europe (UNESCO, 2007, EEA, 2019, Trnka et al., 2016). Heavy rain, for example, is likely to become more frequent in the future, with conspicuous changes in extreme precipitation depending on the region (IPCC, 2012). Furthermore, climate change will probably increase the frequency, duration and magnitude of droughts, with considerable effects on a variety of social and economic sectors, including agriculture, health, tourism, and energy production (EU, 2020a). In recent times, numerous Central European regions suffered from extreme fluvial flooding during which cultural heritage was strongly hit, most existing protection measures were overwhelmed and damage totaled billions of euro (Drdácký, 2010, Holický and Sýkora, 2010), 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, particularly in 2008, 2012 and 2018 affecting historic towns, monuments and collections (Hinkel et al., 2015). Indeed, the effects of extreme climate on cultural heritage protection are quite remarkable (Drdácký and Slížková, 2012). As shown in Fig. 2, the most commonly observed damages might vary considerably depending on the characteristics of the event and of the assets involved. Among others, the following damages are often reported:

- At site level, it can be primarily observed erosion, soil displacement, earth deposition, forest or park damage and individual trees damage.
- At building level, the main effects include material degradation, roof and façade damage, primary and secondary structural damage.
- At object level (i.e. movable heritage), it can be recorded widespread damage to furniture and musical instruments, to objects of art, to books and paper, to glass and ceramic objects and to family heritage.

Experience exposes further factors determining the magnitude of the impact of climate change on cultural heritage. The presence of alterations in a building, or materials which become inappropriate for withstanding the increase in climate loads can strongly influence the performance of built heritage. For example, excessive water penetration into building envelopes due to extreme precipitation and strong wind (as well as due to porosity of historic materials), might induce quite unevenly distributed high moisture content zones consequently posing 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 (Cacciotti, 2020). The incorrect or lack of intervention and the lack of maintenance may also contribute significantly to amplify the projected

Fig.1. Map showing the location of the Central European region (blue).

Fig.2. Examples of damages: top left, flooding in historic centre (photo: Drdácký); top right, heavy rain damage in Klingfurth (photo: Austrian Armed Forces, 2009); bottom left, erosion and partial collapse of dry stone walls in the Island of Filicudi, Aeolian Archipelago (photo: Sardella); bottom right, water damage to half-timbered wall (photo: Cacciotti, 2015).

effects of climate-change-induced disasters.

In Central Europe, in order to reduce the impact of climate change , a series of risk management strategies for cultural heritage protection is currently enforced (ProteCHt2save Deliverable D.T2.1.1, 2018). These strategies are commonly grouped into three main categories:

1) *strategies aimed at improving preparedness for cultural heritage as well as at risk prevention and mitigation*: including, among others, training and awareness raising (e.g. seminars and lectures, media campaigns etc.) as well as documentation activities such as mapping, inventories and databases, records and registers of heritage structures.
2) *Strategies focusing on the response to disaster or emergency:* including highly specialized training courses, on-site disaster simulations and access routes planning for emergency vehicles.
3) *Strategies intended to return to pre-event operations*: including measures taken to overcome physical, social, environmental and cultural losses, aligning with the principles of sustainable development and measures for rebuilding in a better way in order to avoid or reduce future disaster risk.

Although many of these measures are nowadays securely enforced, recent observations prove that within the region a number of challenges that impair the implementation of resilience building strategies still exists (ProteCHt2save Deliverable D.T2.1.1, 2018). Risk management needs to continuously adapt to the variability of climate patterns, the worsening of extreme events and the increasing vulnerabilities of exposed assets (Sardella et al., 2020, Sesana et al., 2020). Indeed, the dynamic nature of risk imposes the enforcement of adequately flexible measures able to prevent, cope with and recover from natural disasters.

The present article unveils recent research stemming out from the three-year experience gained from the Interreg Central Europe ProteCHt2save project (ProteCHt2save, 2020), aimed at setting the framework for the optimization of risk management strategies in Central Europe. The project focuses primarily on the development of feasible and tailored solutions for building resilience of cultural heritage applying an integrated and transnational approach with the aim of implementing regional and local strategies on preparedness measures and evacuation plans in emergency.

This paper is composed of the following main sections:

- Section 2 reviews the characteristics of risk management strategies currently enforced, highlighting their challenges, perceived issues and barriers as well as the opportunities for resilience building.
- Section 3 presents the main solutions and tools proposed in this research for the optimization of cultural heritage protection in the context of climate change scenarios.

- Finally, section 4 summarizes the main conclusions from the study, outlining in addition a proposal for future work and scaling-up of its results.

2. Resilience building in Central Europe for cultural heritage protection: Challenges and opportunities

In Central Europe, risk management strategies are the result of extensive learning and adaptation processes, based on the experience from real disasters, involving a series of minor and major adjustments. These adjustments can be grouped as follows (ProteCHt2save Deliverable D.T2.1.1, 2018):

- Changes to the legal and administrative framework: implementation of inventories such as lists of cultural heritage assets; strengthening the administrative power of responsible authorities to enforce measures and to reduce risks; formal recognition of the relevance of risk assessment in town and regional planning; introduction of the concept of performance requirement in building codes governing the design and implementation of interventions on built heritage.
- Changes to finance and budgeting: provision of adequate and quickly accessible resources for cultural heritage protection; obligation to create financial reserves in the budgets of local governments; facilitating the insurance of cultural heritage buildings and objects.
- Improvement to education and training programs.
- Optimization of preventive and post-disaster documentation and mapping.
- Improvement of resilience and awareness of communities through early warning systems, drills and simulations.

Nevertheless, relevant research underlines that in the whole Europe multiple challenges still impact the effectiveness of cultural heritage protection and its implementation (Bonazza et al., 2018). From a recent survey (ProteCHt2save Deliverable D.T2.1.1, 2018), it is evidenced that, among these challenges, the ones that are perceived the most in Central Europe are the following (Table 1):

1. Information on cultural heritage assets: one of the most critical issues related to cultural heritage management is the lack of data. In fact, often no information concerning cultural heritage assets is available and their location, conditions and values are unknown. Furthermore, at times information may be available but incomplete, obsolete or not validated by verifiable sources. Lack of or incomplete/unverified data obstacles the correct evaluation of risk and it prevents the implementation of adequate measures.
2. Funding for cultural heritage protection: the lack of funds or limited accessibility to financial resources for maintenance and protection are commonly reported together with the lack of funding from investors, low budgets of private owners and no resources for the rescue of cultural heritage; furthermore onerous and long procedures of application for financing and conservation works and low participation of public administration in co-financing further exacerbate this issue.
3. Knowledge and awareness related to cultural heritage management: the lack of knowledge concerning protection, maintenance and administration procedures constitutes the most harmful condition for cultural heritage assets. Similarly, low or no awareness among stakeholders involved in the management of such assets, is underlined as a challenge for implementing adequate risk prevention and mitigation strategies. Inappropriate awareness raising, in particular for the civil society and local authorities, significantly affects the resilience of communities inducing a profound adverse impact on cultural heritage protection.
4. Cultural heritage protection planning: the lack of appropriate planning related to risk management is often reported. Missing evacuation and rescue plans for example, a common condition for unlisted cultural heritage assets, are particularly deleterious and strongly affect the ability to absorb the shock of disasters without major consequences. Furthermore, due to inadequate planning the lack of coherent action and cooperation between the various levels of cultural heritage management leads to a slow or uncoordinated implementation of protection measures without clear indications of responsibilities among stakeholders.
5. Policy and regulation for cultural heritage management and care: inappropriate policies and incompatible regulations impede the proper management and care of cultural heritage assets. In some cases the ownership of cultural heritage buildings is not regulated; properties owned jointly by the municipality and the state, for example, impose additional financial burdens to the local authorities, which are asked by the state for advanced funding schemes. In addition, in some cases cultural heritage protection lacks a specific approach. Building regulations, for example, can be often not flexible enough or disregard completely cultural heritage, thus preventing the implementation of appropriate protection measures.

In addition, as unveiled by another study (ProteCHt2save Deliverable D.T2.1.1, 2018), further drawbacks inhibit the development of harmonized risk management policies in the region. Fig. 3 shows the percentage of ProteCHt2save pilot sites reporting disabling

Table 1
Survey: perceived issues related to cultural heritage protection, reported at pilot sites in Central Europe.

Perceived issue	Czech Republic	Austria	Italy	Poland	Croatia	Hungary	Slovenia
1.Information	•			•	•		
2.Funding	•		•	•			•
3.Knowledge & awareness	•				•		
4.Planning	•	•			•	•	
5.Policy & regulation				•	•	•	•

conditions for transnational cooperation. In particular, the following issues can be highlighted:

- Differences in the recognition of the status of national heritage artifacts or sites resulting from various cultural background and various regulations.
- Heterogeneous technical standards and legal regulations such as for example compensation regulations or criminal and financial responsibilities.
- Divergent levels of equipment, training and of expertise could cause problems for the transnational cooperation in the protection of cultural heritage.
- Differences in terms of land use, settlement and economic structures, accessibility, and ecological challenges, as well notable differences in political and administrative structures (Central Europe Programme, 2014).
- Use of languages other than English, in particular at local and regional scales, preventing knowledge sharing and information processing at a Central European level.

However, despite the presence of serious challenges, potential opportunities and solutions for resilience building should still be found in transnational efforts and cooperation. The reasons for this, as observed by Hörnström et al., 2012, are embodied by four types of 'added value' conveyed by transnational initiatives: the first added value refers to organizational and policy learning; learning and dissemination processes enable to frame common issues in a territorial perspective, allowing stakeholders to work at new scales and in new types of networks. The second added value consists in finding solutions to common problems; this encourages the engagement of local and regional actors and it mobilizes political participation. The third added value concerns the achievement of critical mass; the pooling of resources required to create common potential in a specific area is of extreme importance, particularly in sparsely populated areas and smaller communities. The forth added value consists in the formation of administrative and institutional structures, which define a reference framework for building future cooperation and strengthening.

In this research, transnational cooperation is exploited as the catalyst for improving the protection, management and sustainable use of cultural heritage. The next section presents the proposed optimized risk management strategies and their main goals.

3. Optimized risk management tools for cultural heritage protection in climate change scenarios

As mentioned in the introduction, the results presented in this paper are based on the activities of the ProteCHt2save project. The main goal is constituted by the formulation of feasible and tailored solutions for building resilience of cultural heritage to floods, heavy rain and fire.

The risk management tools outlined in this paper stem out from a participatory and multi-disciplinary approach, involving ten partners from seven Central European countries (namely Czech Republic, Croatia, Slovenia, Hungary, Poland, Austria and Italy), including three partners from the academic and research fields and seven partners being local authorities and regional development agencies directly or indirectly managing the case studies and therefore contributing to the pilot study. The tools developed exploit an integrated and transnational methodology with the aim of implementing regional and local strategies on preparedness measures and evacuation plans in emergency. A "management spiral" approach is employed investigating three levels of spatial scale: site or territories, building or complex of buildings, materials and artifacts. The current knowledge on climatology and vulnerability of cultural heritage is critically elaborated and harmonized in order to suggests and setting up policies and recommendation at local and regional level. Through an action learning process and feedback evaluation with pilot sites, the developed tools are defined and their adoption by the local authorities involved in the pilot study is fostered. In order to define a proposal for optimized risk management measures, a four-step procedure is implemented: elements for possible optimization of strategies are individuated at local focus group meetings (participants include managers of pilot sites, crisis management units, policy makers, researchers, local community, police, local

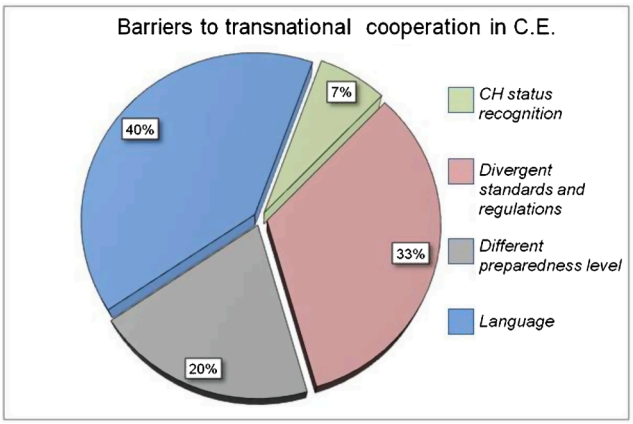

Fig.3. Survey: percentage of partners reporting elements disabling transnational cooperation in Central Europe.

associations) , national and regional events and through surveys of local social networks; participated design of resilience measures is then carried out, based on data gathered during the initial phase, involving expert and non-expert actors; afterwards, pilot actions selected on the basis of risk prone areas and cultural heritage vulnerabilities are used to implement and assess the developed strategies and testing of the optimized strategies proposed is conducted (including cultural heritage sites, structures and artifacts); finally these measures are used to improve the existing disaster risk management plans and policies at the local and regional levels exploiting the involvement of authorities in the whole process. The transnational character of the proposed solutions ensures their transferability to other regions in Central Europe.

It should be underlined that the focus of the proposed measures is intentionally stressed on soft or non-structural resilience (Proag, 2014), as opposed to the hard one, involving physical strengthening of structures or institutions. Hence, all measures presented are concerned with the management, operation and governance of cultural heritage rather than with structural and material interventions. In particular, the protection strategies here considered as optimal and resilient are those enabling an active engagement in disaster prevention of non-expert stakeholders (e.g. owners and managers), those enhancing knowledge sharing and awareness raising and finally those fostering periodic monitoring and continuous maintenance. The final objective is, starting locally, to stimulate wider institutional change at higher levels, possibly up to policy making.

The strategies outlined in this section include ICT solutions (inventory and maps) and tools (decision support tool, handbook on transnational rescue procedures) for the protection of cultural heritage. They are purposely designed to achieve the following goals (Drdácký et al., 2007):

I) Awareness raising. Gathering, evaluating and disseminating good practice examples as well as bad ones in order to exploit the full potential of experiences, in the perspective of defining an appropriate cultural heritage protection strategy.

II) Identifying and marking stock at risk. Lack of appropriate knowledge related to the cultural heritage stock at risk is one of the most widely mentioned drawbacks and shortcomings in relation to effective protection of cultural heritage against natural and human-made hazards. In this perspective appropriate documentation, inventorying and mapping should be developed. Data provide tangible support for making adequate decisions and for correctly monitoring the effectiveness of implemented measures as well as for post-disaster analysis and recovery (Romão et al., 2016; Romão and Paupério, 2019).

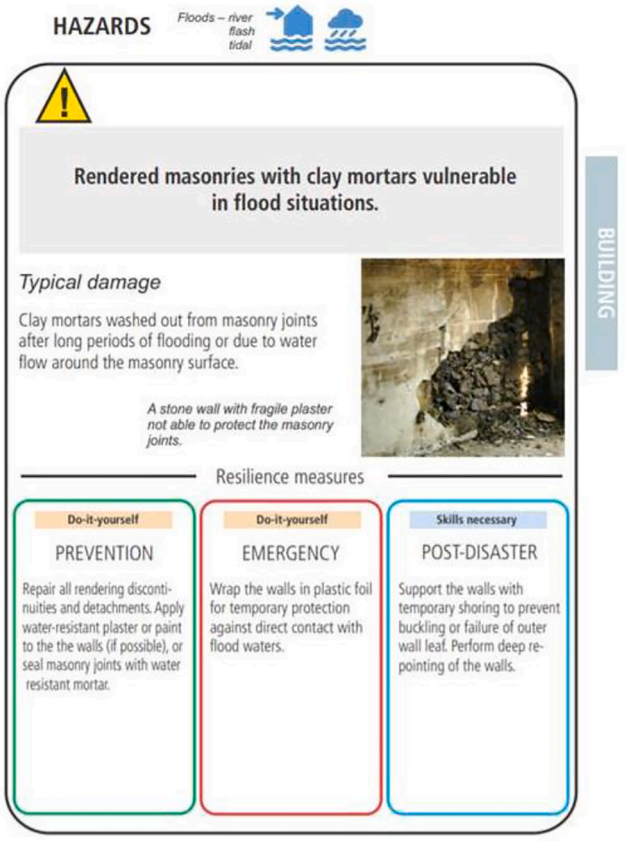

Fig.4. Example of criticality card found in the manual.

III) Education and training. Resilience building must consider educating and training professionals to participate in coordinated actions. For specific cultural heritage assets, rescue tasks, good supervision and in-situ decision making by specially trained professionals could surely reduce losses due to inappropriate interventions.
IV) Exchange of knowledge & experience. Harmonized recommendations focusing on a range of problems, from data collection, damage assessment and evaluation, inventory and mapping of hazards and stock at risk to the creation of thematically-oriented Geographic Information Systems, warning systems and similar management tools, is highly required in order to make progress in combating natural disasters. These standards would further support the development of technical standards for prevention and mitigation of damage from individual or multiple hazards.

3.1. Cultural heritage resilience Manual: Improving data gathering, knowledge sharing and community engagement (goal II and IV)

The Cultural Heritage Resilience manual (Drdácký et al., 2020) is a pocket size booklet available in English and seven other national languages (Czech, German, Croatian, Polish, Italian, Hungarian and Slovenian), intended mostly for on-site use. Its primary aim is to endorse the involvement of citizens and the general public in ensuring better preparedness of local communities concerned with crisis situations, in particular natural disasters. It provides advice to lay users, such as heritage owners, on how to inspect and assess the vulnerability of their properties while enabling them to identify criticalities that can be treated to reduce the impact of catastrophic events. The information provided includes instructions related to measures that can be implemented in various disaster scenarios: (i) pre-disaster prevention measures, (ii) emergency measures, and (iii) disaster recovery measures and activities that can contribute to improving disaster preparedness. The goal of the manual is twofold. Firstly, it strives to raise awareness about the fragility of cultural heritage and the need to protect it adequately against climate-change-induced disasters; secondly, it aims to optimize the resilience of cultural heritage by spreading basic knowledge of appropriate risk mitigation strategies.

The manual is composed of the following sections: section 2 introduces the notions of cultural heritage risk, vulnerability and resilience and introduces the concept of criticality, section 3 summarizes the main issues (referred to as criticalities) related to cultural heritage vulnerability and discusses how these can be mitigated by means of resilience building measures, section 4 presents concluding remarks on use of the manual and its limitations.

This manual considers three main criticality groups relating to the physical scale at which an assessment is carried out: site, building and moveable heritage. Each criticality is presented on a separate card (Fig. 4) containing the following information: the hazard scenario related to the criticality considered (i.e. floods, heavy rain and drought); a description of the criticality; typical damage resulting from the criticality and the occurrence of a disaster; recommended resilience measures distinguishing between preparedness, emergency, and post-disaster scenarios. Each measure is provided with a color-coded label: *do-it-yourself*- relates to those measures which can be performed by the owners themselves; *skills necessary*- individuates measures that require the involvement of skilled labor and should not be performed by the owners themselves; finally *engineer required*- indicates those measures that require professional assessment prior to implementation.

Fig.5. Knowledge sharing (e.g. evacuation exercise, left) and community engagement (risk management planning, right) are supported by the manual (photos: Cacciotti, 2019).

This manual is to be used in preliminary vulnerability assessment of cultural heritage assets and should be employed as a reference only. It is supplementary to the institutionally provided civil protection tools aimed at increasing the resilience of assets having cultural and historical value and which are threatened by critical scenarios or have been hit by natural or human-made disasters. It is intended primarily for the owners, administrators or users of such cultural heritage properties and objects, but also it provides useful information and advice to citizens and institutions in crisis, especially civil protection rescue teams and their auxiliary units (Fig. 5). The manual focuses solely on floods, heavy rain and drought hazards; its scope is limited to the presentation of the foremost examples of lessons learnt from past Central European disasters. In addition, a purposely simplified approach to risk assessment is proposed for the sake of endorsing the active engagement of heritage owners in resilience building strategies. With this in mind, it is strongly recommended to seek professional advice before making any decisions and carrying out any measures that may further undermine the preservation of the asset. Lastly, the manual does not take into account synergic effects that may derive from the co-existence of multiple criticalities in a cultural heritage system – the combined effect being greater than the sum of individual effects. Therefore, in such cases, seeking expert analysis of property conditions is advised.

This tool fosters bettering monitoring and reporting critical issues related to cultural heritage protection, it stimulates continuous maintenance of immovable heritage objects and it raises awareness regarding the susceptibility of cultural heritage to climate change through community engagement. It directly addresses the perceived issues of lack of information, lack of knowledge as well as inappropriate cultural heritage protection planning, outlined in section 2.

3.2. GIS tool for central europe: Strengthening knowledge sharing and enabling risk evaluation (goal II and IV)

The ProteCHt2save Web GIS Tool for Hazard Mapping (WGT) aims at assessing risk prone areas and “hot spots” where multiple concurrent hazards lead to potential impacts on cultural heritage in Central Europe (Sardella et al., 2020). It has been designed mainly to support policy and decision makers in the identification of hazard areas and vulnerabilities for cultural heritage in Central Europe exposed to extreme events linked to climate change, particularly heavy rains, flood and fire due to drought periods.

The online tool visualizes in an interactive way hazard maps of Central Europe, with high spatial resolution. Specifically, maps with spatial resolution of 25X25 km for historical observation have been elaborated for both climate extreme indices and variables, considering the time slice 1987–2016. In addition, maps with spatial resolution of 12X12 km referring to future projections of heavy rain, flooding, drought and extreme heat are provided. Specifically, changes of temperature and precipitation and of climate extreme indices are available for 2 future 30-year periods (2021–2050 & 2071–2100) with respect to the reference historical one (1976–2005) and under Representative Concentration Pathway scenarios RCP4.5 (stabilization) and RCP8.5 (pessimistic).

The obtained maps describe how and where possible changes related to the specific climate risk index or climate variable selected

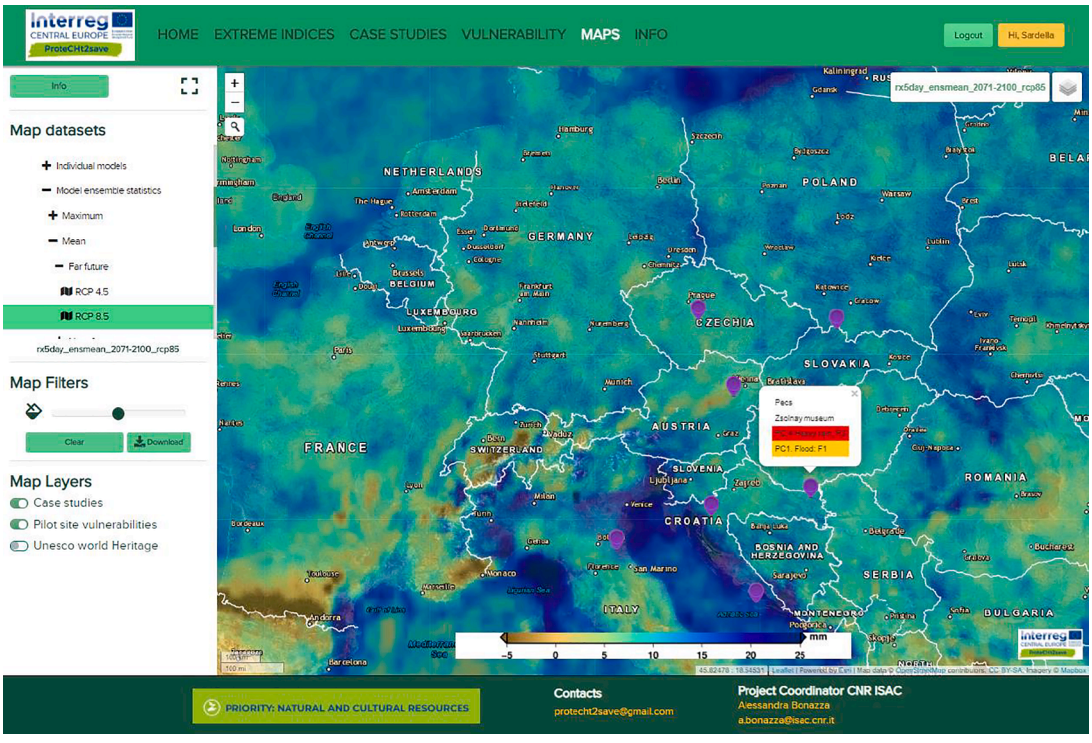

Fig.6. ProteCHtsave WGT map: climatic projection simulation related to mean of model ensemble statistics of the Rx5day climate extreme index under RCP 8.5 scenario for far future (2071–2100) with a spatial resolution of 12x12 Km.

affect/will affect the area of Central Europe and its heritage in the specific period, with particular reference to pilot case studies. In order to summarize in a more easily understandable way the results obtained by mapping the extreme indices using different models, a model ensemble statistic was carried out. The maps (Fig. 6) provided constitute a significant tool for the development of measures and strategies of preparedness with short-term and long-term perspective aiming at the protection of cultural heritage and landscape, urban/territorial planning and risk management in emergency.

It is possible to access the WGT on the official web site of the ProteCHt2save project clicking on the Web GIS Tool button (https://www.protecht2save-wgt.eu/).The web page of Web GIS Tool (WGT) for Hazard Mapping is composed of 6 pages and a registration is required for the access. On the home page general information of the project and the introduction to the WGT are available. In the "Extreme Indices page", the climate extreme indices selected for the project, internationally accepted by the scientific community for representing change in climate extreme, such dry spell or intense precipitation, are indicated. In the "Case Studies page", a description card of each pilot is available with more technical information. On the "vulnerability page", the critical elements in the resilience both physical and managerial for local vulnerably of cultural heritage are reported. The WGT allows to load climate hazard maps through a suitably designed filter and has been designed and implemented with applications and cartographic bases open source, user-friendly, tailored to work efficiently across all major desktop and mobile platforms and further developable on the basis of specific user requirements.

Finally, based on a robust scientific methodology, this tool allows for the first time an identification of risk prone areas for cultural heritage in Central Europe exposed to extreme events linked to hydro meteorological changes. Indeed, the idea is to provide climate related hazard maps together with a qualitative evaluation of vulnerability at pilot sites. This represents an initial step towards the inclusion of a vulnerability data layer in the tool with the intention, with future research, to combine it with hazard and finally evaluate risk (Figueiredo et al., 2020, Sevieri et al., 2020, Copping, 2002). The tool specifically tackles the perceived issues of lack of information and knowledge concerning cultural heritage assets, as presented in section 2. Short-term and long-term scenarios at high spatial resolution up to the end of the 21st century are available and further upgrading with inclusion of additional hazards and cultural heritage categories is possible. Furthermore, a high range of applications to sectors not only specifically dedicated to the cultural heritage protection and a potential use from different target of stakeholders (e.g. public authorities, scientific community, insurance sector, civil protection) is feasible.

3.3. Transnational CHRT guidelines: Optimizing preparedness and awareness raising (goal I, II, III and IV)

Cultural Heritage Rescue Teams (CHRTs) are a tool that allows, depending on its composition and focus, for awareness raising, identifying and marking cultural heritage at risk, education and training, as well as exchange of knowledge and expertise. The underlying idea of a CHRT is that only through cooperation between heritage specialists and emergency responders the efforts for cultural heritage protection can be optimized. The international example is the Italian national "Task Force in the framework of UNESCO's Global Coalition Unite4Heritage" (UNESCO, 2019). Following the massive wanton destruction of cultural heritage in the 21st century, the General Conference of UNESCO adopted at its 38th session in Paris in 2015 a strategy on the "reinforcement of UNESCO's action for the protection of cultural heritage and the promotion of cultural pluralism in the event of armed conflict" (UNESCO, 2015); and Italy responded. The "Blue Helmets for Culture", as the team members were soon called, consist of military personnel (officers from the Italian Carabinieri Command for the Protection of Cultural Heritage – Commando Carabinieri Tutela Patrimonio Culturale) and civilian experts from the Italian Ministry of Cultural Heritage and Activities and Tourism from the different thematic fields necessary for successful protection of cultural heritage (Parrulli, 2019, Rush, 2019, Schramm, 2019).

The basic idea is that CHRTs, installed on national or international level, are able to bridge the gap between heritage side and emergency responder side. Practical handbooks on how to prepare cultural heritage for calamitous events and how to treat affected material are readily available online (i.e. Tandon, 2016, 2018; UNESCO, 2017), but the potential for successful cooperation is often neglected, and the necessary interfaces often are not developed. By specifically selecting CHRT members for their expertise and by

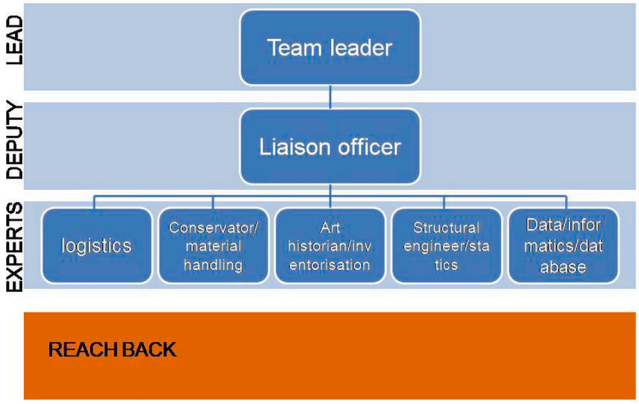

Fig.7. A possible organizational structure of a Cultural Heritage Rescue Team.

adding knowhow on how the other side, i.e. heritage or emergency responder, operates, CHRTs can be the interfaces making successful interventions in cultural heritage protection possible, from preparedness to recovery measures (Schramm, 2019).

CHRTs established on a national basis have the benefit of nationally defined standards, a common language, easy training possibilities and the tailoring to the national needs and the nationally established consortium of emergency responders. International or at least transnational CHRTs may include a broader variety of knowhow and expertise, a wide range of experience, and have the hypothetical benefit of being more readily deployed or requested on an international scale. On the other hand, an international CHRT might have to harmonize different training and equipment standards, cope with different languages and possibly distances that make team training challenging. In both national and international set up, docking to already established systems and joining forces might facilitate the establishment of CHRTs. On European level the Emergency Response Coordination Centre (ERCC) as the heart of the EU Civil Protection Mechanism might be a possibility (Kaiser, 2019; EU, 2020b).

A set of transnational CHRT guidelines, developed by international experts, is proposed in ProteCHt2save; the setup suggested in these guidelines was tested by seven pilot actions in the respective partner countries (Kaiser, 2019). This tool provides useful information for cultural heritage managers and first responders for establishing resilient emergency and recovery procedures. On organizational level, a CHRT needs a team leader, a deputy and a number of subject matter specialists, whose expertise could range from education and training to archaeology, art history, statics, conservation-preservation to data management, logistics and informatics (Fig. 7). In order to function during calamitous events, the CHRT should not only be able to draw on an extended reach back organization for support, but be a well organized body in which the single members know each other, know about the expertise and the modes of operation of the single team members, as well as about certain peculiarities. Training together is not only necessary for acquiring more proficiency and expertise in cultural heritage related tasks, but also for knowing how the team functions and thus enabling a successful deployment at all. Training of the individual members is as important as training as a team. Training for individuals should at least consist of basic knowledge on health, safety and security during operations and first aid in general (Fig. 8). The CHRT members need to be able to handle their equipment correctly and to connect to the other entities around by different communication media. They need to understand the decision-making process the first responders work with and how to best integrate their knowledge into the strict system, which is made for working under high pressure and in little time. In addition, they need to be proficient in working with the CHRT's core material, threatened or damaged cultural heritage. This includes the documentation, handling, packing, moving and storing of cultural heritage; emergency inventories, how to treat which material, how to pack and move it without causing (more) damage. In addition to that there are a few topics the CHRT members have at least to understand: command and control issues in order to make the team governable and functioning, public relation and media issues, logistics and the legal framework in which the CHRT operates, which will be different in every single country. These issues can be taught and trained on-site or off-site, meaning that some of the topics need a hands-on-approach and are best dealt with on a cultural heritage site with dummy objects (documenting, handling, packing, moving, storing, equipment training), while some of the others can be taught in a class room or even on-line (command and control, PR awareness, logistics, legal issues, health and safety), whereas first aid can be taught anywhere as long as it is done practically (Rush, 2017, Kaiser, 2019, Spadari, 2019).

In order to allow for offsite training and awareness raising, ProteCHt2save developed a second tool, related to Cultural Heritage Rescue Teams, but also the overarching topics of climate change induced threats to cultural heritage and preparation for natural calamities. "Vltava Rising" is an educational video game developed for mobile devices in which the player is the head of CHRT that needs to assess the threats posed by flood to cultural heritage in Prague and, the moment the situation allows for no other means, coordinate the evacuation of the movable heritage and the on-site securing of the immovable heritage (available for free on Google Play and App Store; Articulated Python, 2020).

CHRTs address the perceived issues of lack of knowledge & awareness, inappropriate cultural heritage protection planning and inadequate policy and regulations, as presented in section 2. Their impact on resilience of cultural heritage is three-fold. First, CHRTs are able to raise the awareness for the necessity of preparedness in cultural heritage protection. They achieve this by proactive

Fig.8. Cultural heritage protection training exercise TRITOLIA18 together with emergency first responders (photo: DBU/Schramm, 2018).

cooperation of their members with cultural heritage institutions and with emergency responders. In many of the Central European countries that collaborated in ProteCHt2save, cultural heritage protection is a topic, which is not wide spread, and especially not within emergency responders which are likely to be asked for assistance in the case of natural disasters threatening cultural heritage (DUK, 2019). Secondly, when training and educating (themselves and others) at cultural heritage sites CHRTs are able to identify cultural heritage at risk and thus highlight needs for preparedness in order to enhance the resilience of the cultural heritage in question, thus preparing it and its curators for calamities that hopefully never occur. Thirdly, by cooperating on a transnational scale, CHRTs exchange knowledge and expertise, thus crossing borders for transnational cooperation and good practice learning in order to overcome the challenges climate change poses to the management of cultural heritage in Central Europe and beyond. The analysis on existing plans on managing cultural heritage in emergencies (DUK, 2019) has shown that existing measures to prepare cultural heritage for safeguarding during natural catastrophes a) depend on the country in question, b) are manifold and diverse, and c) in most countries analyzed would profit from a coordinated approach, based on the international good practice. The guidelines for CHRTs and the mobile training and awareness-raising app are to be seen as inspirational first step for entities enhancing the resilience of cultural heritage in Central Europe.

4. Conclusions and future work

In disaster-prone and heritage-rich contexts, such as the Central European one, appropriate risk management represents a vital element for ensuring the correct protection of cultural heritage assets.

The analyses carried out in this study show that different challenges to the development of optimized cultural heritage protection strategies are still perceived as relevant. These cover aspects of risk management that vary from information, funding, knowledge and awareness to planning, policy and regulation. In addition, further drawbacks in current practices and local procedures are unveiled. These include divergences in technical and legal frameworks, differences in the availability of resources and expertise as well as language barriers, which might compromise the sharing of specific documentation related to cultural heritage. Multidisciplinary and participatory efforts, conveyed in the ProtecCHt2save project, are employed for overcoming such limitations and for endorsing the development of resilience building strategies. Thanks to its benefits and the acquired knowledge and exchange of experiences among regions, transnational cooperation is proven to be pivotal for determining feasible solutions and policies aimed at an improved protection, management and sustainable use of cultural heritage.

It is underlined that, for the sake of strengthening and optimizing existing risk management strategies, more than on susceptibility reduction, the primary goal should focus on soft resilience building. Additionally, it is found that resilience measures should focus mainly on raising awareness, identifying and marking stock at risk, promotion of education and training, as well as on enabling exchange of knowledge and experience. Optimal, resilient protection strategies therefore are those enabling an active engagement in disaster prevention of non-expert stakeholders, such as owners and managers of cultural heritage assets, those enhancing knowledge sharing and awareness raising and finally those fostering periodic monitoring and continuous maintenance.

The main results of the research include a web GIS platform for hazard mapping and other decision support tools such as the manual for cultural heritage resilience and the handbook on transnational rescue procedures. The WGT, based on a robust scientific methodology, allows for an identification of risk prone areas for cultural heritage in Central Europe exposed to extreme events linked to hydro meteorological changes. It also offers potential for applications to other sectors. The manual fosters bettering monitoring and reporting critical issues related to cultural heritage protection, stimulating continuous maintenance of immovable heritage objects and raising awareness regarding the susceptibility of cultural heritage to climate change through community engagement. CHRT guidelines raise the awareness for the necessity of preparedness in cultural heritage protection, at the same time identifying cultural heritage at risk.

Concluding, the results represent a substantial breakthrough for setting an appropriate methodological framework in Central Europe for improving risk mitigation strategies related to climate change induced disasters. The measures presented represent very helpful decision support tools for different stakeholders and constitute an initial step for enhancing the resilience of cultural heritage in the region. Additionally, it should be highlighted the potential applicability of the proposed tools, such as the Cultural Heritage Resilience Manual and the CHRTs guidelines, to regions other than the one investigated, especially where similar hazards and heritage construction types can be found. Future work should concentrate on a number of improvements making feasible a wider application of the methodology and results presented in this paper. In particular, additional research should concentrate on further developing and testing the validity of the tools, particularly in preparedness and emergency situations. Furthermore, scaling-up should be also investigated in order to elaborate a comprehensive and standardized approach at European level. In this context it should be mentioned that the results here discussed are currently being capitalized in the STRENCH project, which foresees concrete actions to be undertaken for further testing and developing the protection measures and strategies and for integrating cultural heritage in national and regional plans for disaster risk reduction by fostering a proactive cooperation among actors involved in the decision- making process.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Python, A., 2020. Vltava Rising. accessed 13 November 2020. http://www.vltavarising.com/.
Bonazza, A., Sabbioni, C., Messina, P., Guaraldi, C., De Nuntiis, P., 2009a. Climate change impact: Mapping thermal stress on Carrara marble in Europe. Sci. Total Environ. 407 (15), 4506–4512. https://doi.org/10.1016/j.scitotenv.2009.04.008.
Bonazza, A., Messina, P., Sabbioni, C., Grossi, C.M., Brimblecombe, P., 2009b. Mapping the impact of climate change on surface recession of carbonate buildings in Europe. Sci. Total Environ. 407, 2039–2050.
Bonazza, A., Vidorni, G., Natali, I., Ciantelli, C., Giosuè, C., Tittarelli, F., 2017. Durability assessment to environmental impact of nano-structured consolidants on Carrara marble by field exposure tests. Sci. Total Environ. 575, 23–32. https://doi.org/10.1016/j.scitotenv.2016.10.004.
Bonazza, A., Maxwell, I., Drdácký, M., Vintzileou, E., Hanus, C., Ciantelli, C., De Nuntiis, P., Oikonomopoulou, E., Nikolopoulou, V., Pospíšil, S. et al., 2018. Safeguarding cultural heritage from natural and man-made disasters a comparative analysis of risk management in the EU. European Union, Brussels, Belgium.
Cacciotti, R., 2020. Brick masonry response to wind driven rain. Eng. Struct. 204, 110080. https://doi.org/10.1016/j.engstruct.2019.110080.
Central Europe Programme, 2014. Project Stories from the Central Europe Programme-Cultural Heritage and Creative Resources. accessed 10 November 2020. https://www.interreg-central.eu/Content.Node/6-cultural-final.pdf.
Central Europe Programme, 2020. Orientation paper- Transnational Cooperation Programme Central Europe 2021–2027. accessed 10 November 2020. https://www.interreg-central.eu/Content.Node/discover/CENTRAL-EUROPE-Orientation-Paper-1.pdf.
Ciantelli, C., Palazzi, E., Von Hardenberg, J., Vaccaro C., Tittarelli, F., Bonazza, A., 2018. How can climate change affect the UNESCO cultural heritage sites in Panama?. Geosciences (Switzerland) 8, .
Copping, A., 2002. The development of a fire safety evaluation procedure for the property protection of parish churches. Fire Technol. 38 (4), 319–334.
Drdácký, M., Binda, L., Herle, I., Lanza, L.G., Maxwell, I., Pospíšil, S., 2007. Protecting the cultural heritage from natural disasters. Study of the European Parliament, https://www.europarl.europa.eu/RegData/etudes/etudes/join/2007/369029/IPOL-CULT_ET(2007)369029_EN.pdf (accessed 20 November 2020).
Drdácký, Miloš.F., 2010. Flood Damage to Historic Buildings and Structures. J. Perform. Constr. Facil 24 (5), 439–445. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000065.
Drdácký, M., Slížková, Z., 2012. Structural strategies and measures for reducing flood action on architectural heritage, in Brebbia, C.A. (Ed.), Risk Analysis VIII, WIT Transactions on Information and Communication Technologies, Vol 44. WIT Press, Southampton, UK, pp. 249-259.
Drdácký, M., Cacciotti, R., Kopecká, I., 2020. Cultural heritage resilience- a manual for owners. Prague, Czech Republic, ITAM CAS http://www.itam.cas.cz/miranda2/export/sitesavcr/utam/sys/galerie-download/ManualEN_03.07.2020_RGB_final.pdf.
DUK, 2019. Report on analysis of existing plans on managing cultural heritage in emergencies. accessed 27 October 2020. https://www.interreg-central.eu/Content.Node/D.T3.1.1-Report-on-analysis-of-existing-plans-on-managing-cu.pdf.
EU, 2020a. How will be affected. (accessed 10 November 2020).
EU, 2020b.European Union/ECHO, European Civil Protection and Humanitarian Aid Operations, last updated 04/05/2020 https://ec.europa.eu/echo/what/civil-protection/emergency-response-coordination-centre-ercc_en (accessed 09.08.2020).
Fatorić, S., Seekamp, E., 2017. Are cultural heritage and resources threatened by climate change? A systematic literature review. Clim. Change 142 (1-2), 227–254. https://doi.org/10.1007/s10584-017-1929-9.
Figueiredo, R., Romão, X., Paupério, E., 2020. Flood risk assessment of cultural heritage at large spatial scales: Framework and application to mainland Portugal. J. Cult. Heritage 43, 163–174. https://doi.org/10.1016/j.culher.2019.11.007.
Gómez-Bolea, A., Llop, E., Ariño, X., Saiz-Jimenez, C., Bonazza, A., Messina, P., Sabbioni, C., 2012. Mapping the impact of climate change on biomass accumulation on stone. J. Cult. Heritage 13 (3), 254–258. https://doi.org/10.1016/j.culher.2011.10.003.
Grossi, C.M., Bonazza, A., Brimblecombe, P., Harris, I., Sabbioni, C., 2008. Predicting twenty-first century recession of architectural limestone in European cities. Environ. Geol. 56, 455–461.
Grossi, C.M., Brimblecombe, P., Menendez, B., Benavente, D., Harris, I., Deque, M., 2011. Climatology of salt damage on stone buildings. Sci. Total Environ. 409, 2577–2585.
Hinkel, J., Vafeidis, A., Lincke, D., Wolff, C., 2015. Assessment of Costs of Sea Level Rise in the Republic of Croatia Including Costs and Benefits of Adaptation, technical report. Ministry of Environment and Natural Protection, Croatia.
Holický, M., Sýkora, M., 2010. Assessment of Flooding Risk to Cultural Heritage in Historic Sites. J. Perform. Constr. Facil 24 (5), 432–438. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000053.
Hörnström, L., Smed Olsen, L., Van Well, L., 2012. Added Value of Cross-Border and Transnational Cooperation in Nordic Regions. Nordregio Working Paper 2012:14, Nordregio, Sweden.
IPCC, 2012. Managing the risks of extreme events and disasters to advance climate change adaptation, Field, C.B., V., Barros, T.F. ,Stocker, D., Qin, D.J,. Dokken, K.L., Ebi, M.D., Mastrandrea, K.J., Mach, G.-K., Plattner, S.K., Allen, M. ,Tignor, and P.M., Midgley (Eds.), Cambridge Univ. Press, Cambridge, U. K.
Kaiser, 2019. Guidelines for Cultural Heritage Rescue Team (CHRT), Interreg Central Europe ProteCHt2save deliverable, (accessed 10 August 2020).
Leissner, J., Fuhrmann, C, 2015. Final public report- Climate for culture. https://cordis.europa.eu/docs/results/226/226973/final1-publishable-summary-climate-for-culture.pdf (accessed 10 November 2020).
Parrulli, 2019. Interview with Brigade General Fabrizio Parrulli, Commander of the Carabinieri TPC, Rome, 25.02.2019, for Schramm.
Proag, V., 2014. The Concept of Vulnerability and Resilience. Procedia Econ. Finan. 18, 369–376. https://doi.org/10.1016/S2212-5671(14)00952-6.
ProteCHt2save Deliverable D.T2.1.1, 2018. -Identification of barriers / challenges in different Central European Countries on cultural heritage vulnerability. https://www.interreg-central.eu/Content.Node/D.T2.1.1-Identification-of-barriers-and-challenges.pdf (accessed 20 November 2020).
ProteCHt2save, 2020. About the project. (accessed 20 November 2020).
Romão, X., Paupério, E., Pereira, N., 2016. A framework for the simplified risk analysis of cultural heritage assets. J. Cult. Heritage 20, 696–708. https://doi.org/10.1016/j.culher.2016.05.007.
Romão, X., Paupério, E., 2019. An indicator for post-disaster economic loss valuation of impacts on cultural heritage. Int. J. Archit. Herit., .
Rush, L., 2017. The Importance of Training Cultural Property Protection, in: Cultural Property Protection: NATO and other Perspectives. NATO Legal Gazette 38/2017, 80–91.
Rush, 2019. Interview with Dr. Laurie Rush, US Army Fort Drum, 13.01.2019, for Schramm.
Sabbioni, C., Brimblecombe, P., Cassar, M., 2012. Atlas of climate change impact on European Cultural Heritage. Anthem Press, London.

Sardella, A., Palazzi, E., von Hardenberg, J., Del Grande, C., De Nuntiis, P., Sabbioni, C., Bonazza, A., 2020. Risk mapping for the sustainable protection of cultural heritage in extreme changing environments. Special Issue Assessing the Impact of Climate Change on Urban Cultural Heritage. Atmosphere 11 (7), 700. https://doi.org/10.3390/atmos11070700.

Schramm, H., 2019. Integration von zivilenAkteuren des Kulturgüterschutzes in einenEinsatzstab.Master Thesis Danube University Krems, Austria.

Sesana, E., Gagnon, A.S., Bonazza, A., Hughes, J.J., 2020. An integrated approach for assessing the vulnerability of World Heritage Sites to climate change impacts. J. Cult. Heritage 41, 211–224. https://doi.org/10.1016/j.culher.2019.06.013.

Sevieri, G., Galasso, C., D'Ayala, D., De Jesus, R., Oreta, A., Grio, M., Ibabao, R., 2020. A multi-hazard risk prioritization framework for cultural heritage assets. Nat. Hazard Earth Sys. 20 (5), 1391.

Spadari, L., 2019. The Italian Task Force "Unite4Heritage": Earthquake Experience. Presentation 27.02.2019, Accumoli, Module 10 Cultural Property Protection Msc, Danube University Krems.

Tandon, A., 2016. Endangered Heritage. Emergency Evacuation of Heritage Collections. In Tandon, A. (Ed.), ICCROM-ATHAR.

Tandon, A., 2018. First Aid to Cultural Heritage in Times of Crisis. Vol. I: Handbook for coordinated emergency preparedness and response to secure tangible and intangible heritage. Vol. II: Toolkit for coordinated emergency preparedness and response to secure tangible and intangible heritage. In Tandon, A. (Ed.), ICCROM / Prince Claus Fund.

Trnka, M., Balek, J., Štěpánek, P., Zahradníček, P., Možný, M., Eitzinger, J., Žalud, Z., Formayer, H., Turňa, M., Nejedlík, P., Semerádová, D., Hlavinka, P., Brázdil, R., 2016. Drought trends over part of Central Europe between 1961 and 2014. Clim. Res. 70 (2), 143–160. https://doi.org/10.3354/cr01420.

UNESCO, 2007. World Heritage Challenges for the Millennium. UNESCO World Heritage Centre, France.

EEA, 2019. Heavy precipitation in Europe. accessed 20 November 2020. https://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment-1.

UNESCO, 2015. UNESCO Resolution 38 C/48.

UNESCO, 2017. Manual for Contingency Procedures in Historical Archives in the Events of Natural Disasters. General Guide for dealing with Natural Disasters. In: UNESCO and Ministerio de Cultura y Patrimonio del Ecuador (eds.).

UNESCO, 2019. Memorandum of Understanding between the Government of the Italian Republic and the United Nations Educational, Scientific and Cultural Organization (UNESCO). accessed 09 August 2020. https://www.unite4heritage.org/.