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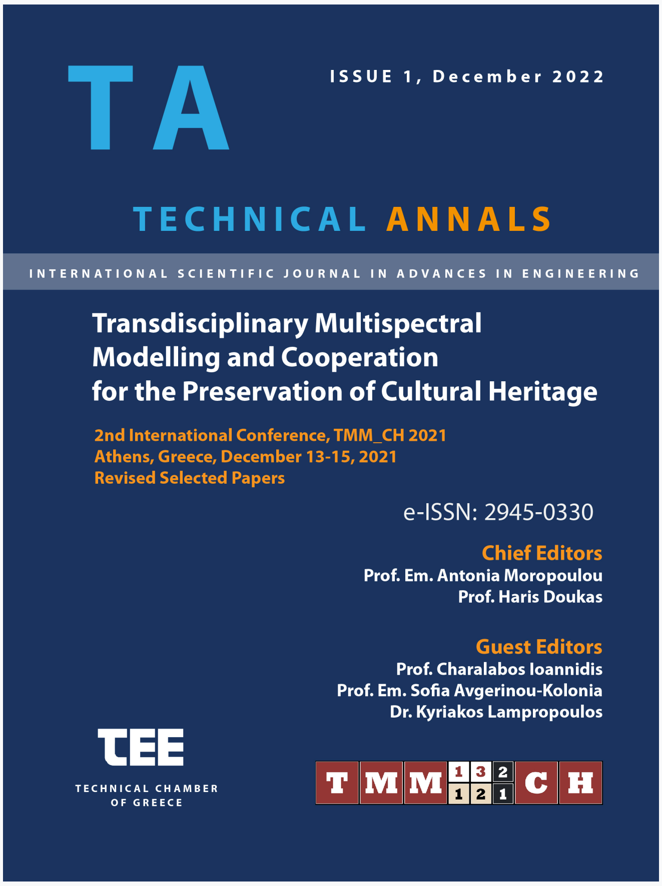

Improved Resilience and Sustainable Reconstruction of Cultural Heritage Areas to cope with Climate Change and Other Hazards based on Innovative Algorithms and Modelling Tools

Kyriakos Labropoulos, Charalampos Zafeiropoulos , Charalampos Zafeiropoulos , Ioannis Rallis , Anastasios Doulamis , Nikolaos Doulamis , Antonia Moropoulou

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Improved Resilience and Sustainable Reconstruction of Cultural Heritage Areas to cope with Climate Change and Other Hazards based on Innovative Algorithms and Modelling Tools

Kyriakos Labropoulos[1] Charalampos Zafeiropoulos[1] Ioannis Rallis[1]
Anastasios Doulamis[1] Nikolaos Doulamis[1] and Antonia Moropoulou [1]

[1] National Technical University of Athens,
klabrop@central.ntua.gr, irallis}@central.ntua.gr,
amoropul@central.ntua.gr, mpampiszafeiropoulos@mail.ntua.gr,
adoulam@cs.ntua.gr, ndoulam@cs.ntua.gr

Abstract. Our proposed framework aims to efficiently train a network of fellows on the field of the resilience of Cultural Heritage (CH) areas and historic cities against Climate Change (CC) and other types of hazards. Towards this direction, the proposed framework aims to introduce a research framework for downscaling the created climate and atmospheric composition as well as associated risk maps down to the 1x1 km (historic area) scale, and specific damage functions for CH materials. Applying atmospheric modelling for specific CC scenarios at such refined spatial and time scales allows for an accurate quantitative and qualitative impact assessment of the estimated micro-climatic and atmospheric stressors. Our proposed framework will perform combined structural/geotechnical analysis of the CH sites and damage assessment under normal and changed conditions, based on the climatic zone, the micro-climate conditions, the petrographic and textural features of building materials, historic data for the structures, the effect of previous restoration processes and the environmental/physical characteristics of the surrounding environment. The data coming from installed monitoring system will be coupled with simulated data and will be further analysed through our data management system, while supporting communities' participation and public awareness. The data from the monitoring system will feed the Decision- Support-System (DSS) so as to provide proper adaptation and mitigation strategies. The produced vulnerability map will be used by the local authorities to assess the threats of CC (and other natural hazards), visualize the built heritage and cultural landscape under future climate scenarios, model the effects of different adaptation strategies, and ultimately prioritize any rehabilitation actions to best allocate funds in both pre- and post-event environments. To train the fellows, our approach will make use of extensive workshop and training sessions, as well organise summer schools.

Keywords. Cultural Heritage, Climate change, Hyperspectral data, Data Management System, Visualization, Monitoring

1. Introduction

Recent studies highlight the potential impact of Climate Change (CC) and geo-hazards (such as landslides and earthquakes) on historic areas hosting Cultural Heritage (CH) sites and monuments[1], which in turn yield significant adverse impacts on economies, politics and societies. The deterioration of CH sites is one of the biggest challenges in conservation; aspects such as building technologies/materials, preventive measures and restoration strategies, resilience and adaptation methodologies must be considered[2]. Up today there is no specific process towards understanding and quantifying CC effects on historic areas; combined with the limited strategies on CC-related issues, it becomes difficult to assess quantitatively and qualitatively the impact of various climatic and other parameters on the CH sites[3]. These issues form an integral part of the necessary support that should be provided to governmental bodies and cultural authorities to properly adapt their policies, in the short and long term, towards deploying sustainable mitigation plans and providing efficient reconstruction of the CH parts that have been damaged.Finally, the absence of communities' participatory approaches to the overall planning of the historic areas is a main challenge to tackle.

The proposed framework aims to efficiently train a network of fellows on the field of the resilience of CH areas and historic cities against CC and other types of hazards. The network aims to use proper modelling tools and methods, innovative technologies (terrestrial and satellite imaging for wide-area inspection, advanced machine learning techniques, etc.) to deliver an integrated platform for resilience assessment of CH areas, addressing multi-hazard risk understanding, better preparedness, faster, adapted and efficient response, and sustainable reconstruction of historic areas [4]. The proposed frame- work will take into account the local ecosystems in the areas of interest, mapping out their interactions and follow a truly sustainable reconstruction approach at technical, social, institutional, environmental and economic levels [5]. To this end, it will incorporate active communities participation, support new business models based on the concept of a "load-balancing" economy, (using an algorithm that acts like a "reverse proxy", distributing client traffic across different companies within the same sector) and offer financial risk-transfer tools (parametric insurance,Catastrophe-CAT-bonds) that can ensure the immediate funds' availability to fuel timely build-back-better efforts.

2. Related Work

Protection of the Cultural Heritage monuments from Climate Change and other types of hazards, assessment of their condition and restoration actions are research areas of great interest. Moreover, their impact on social systems plays a significant role in sustaining the economy. At European level, there exists significant efforts in understanding and quantifying Climate Change effects on the built environment and on heritage assets in particular, introducing and utilizing a wide range of scientific techniques, analyses and assessment approaches [6 – 17].

A series of significant scientific challenges regards the effective assessment of the state of preservation of the cultural heritage assets, the diagnosis of their deterioration mechanisms and the prevailing environmental phenomena that cause damage to the surfaces and the structure of the heritage assets, as well as the evaluation of the detrimental effect of past inefficient protection or rehabilitation interventions [19]. The role of non- destructive testing in providing crucial information to address these challenges is becoming more valuable, especially as the technological advancements enable non-destructive data to be fully integrated in a 3D approach of understanding the structure and the impact of the environment on the asset [20], [21]. In [21], the authors exploited infrared thermography to diagnose materials decay taking into account different historical periods.This approach is used as a tool in the diagnostic level, for the detection of invisible superficial cracks or/and disparities, as well as the revelation of moisture presence within structures. In [22], the authors introduced a fuzzy clustering approach for extracting the local variance feature from an image. This method applied to define the transitional features implementing hybrid segmentation. In [17], the authors proposed a framework to boost the development of efficient Climate Services in Europe, by supporting research for developing better tools, methods and standards on how to produce, transfer, communicate and use reliable climate information to cope with current and future climate variability. In [18], the authors develop regional networks that will connect actors of the wood mobilization value-chain from forest owners to relevant regional authorities but also forestry industry to cover and find answers to the main challenges in the field, especially the sustainability of the wood mobilization. In [11], the authors presented the total reported economic losses caused by weather and climate-related extremes over the period 1980-2017 amounted to approximately EUR 453 billion (in 2017 Euro values).

There are also ongoing similar projects for the resilience of cultural heritage areas against climate change. In [14], the team applied the circular economy principles to cultural heritage adaptive reuse for achieving environmentally, socially, culturally and economically sustainable urban/territorial development. In [15], the team's mission was to create an ecosystem of Citizen Observatories to help move citizen science into the mainstream and demonstrate COs as a valuable component of managing environmental challenges and empowering resilient communities. Therefore, several key instruments applied to target, connect and coordinate relevant stakeholders: fostering communities of practice to strengthen and consolidate the current knowledge base of COs and expand the geographical reach to different target groups via several toolkits. In [23], the team will develop a disaster risk management framework for assessing and improving the resilience of historic areas to climate change and natural hazards. Tools and methodologies will be designed, in collaboration with the four European municipalities (Bratislava, Camerino, Hamburg, and València), for local authorities and practitioners, the urban population, and national and international expert communities. In [24], the project will provide the tools needed to understand the effects of climate change, extreme weather conditions, the ravages of time and intense geological phenomena on cultural heritage monuments in Greece, Italy, Norway and Spain (representing different climatic zones).

3. Our proposed approach

Our proposed framework will coordinate the existing expertise and research efforts into a collaborative plan to offer a comprehensive Transfer of Knowledge (ToK). The multi- scale approach to ToK, teaching, research and skill share will be able to encompass the full range of methodological advancements that are otherwise only available at high- class individual research centres across Europe. In our proposed

Table 1. Research projects, milestones and mitigation plans

Climate Change approaches	Year
FP7-ERA-NET - Cofund network: ERA4CS- European Research Area for Climate Services [17]	2016-2021
JPI Climate - Joint Programming Initiative Connecting Climate Knowledge for Europe Strategic Research and Innovation Agenda [16]	2016-2025
DG ECHO - Overview of natural and man-made disaster risks the European Union may face [6]	2017
European Environment Agency (EEA) - Economic Losses from Climate-Related Extremes [11]	2017
CLIC - Circular models Leveraging Investments in Cultural heritage adaptive reuse [14]	2017-2020
WeObserve - An Ecosystem of Citizen Observatories for Environmental Monitoring [15]	2017-2020
ROSEWOOD - European Network of Regions On SustainablE WOOD mobilisation [18]	2018-2020
SINCERE - Strengthening INternational Cooperation on climatE change Research [13]	2018-2022

framework, we have adopted for each research pillar an iterative research methodology, in a way to minimize all the possible risks (training management) and guarantee a smooth running of the framework.The research methodology is divided into four main phases, based upon the PDCA Model (Plan-Do-Check-Act).

Phase 1: Definition-and Analysis of Requirements. This will take place at the beginning of each research step. Requirements will be defined in respect to the resilience and risk assessment of CH areas and historic areas against CC and other hazards, and in close collaboration with the well-known members of the project

Figure 1. Iterative Research Methodology For Each Research Step

Phase 2: Research. It is responsible for introducing the main research components of each WP. More specifically, it includes identification and exploitation of best available technologies, anticipating a risk and contingency plan in case that the designed or adopted technology is not able to fulfill requirements of Phase 1 and introduce objective benchmarking tools the for evaluation of the research tools.

Phase 3: Implementation. It regards implementation aspects and system integration issues. During this phase collective intelligent framework able to integrate the entire distinct component together in a common final integrated platform will be established. All previous results are interlinked together. On one hand previous phases' and research steps' outcomes are integrated, and on the other hand platform's architecture and research shortcomings are detected and surpassed, to stay aligned with our approach's objectives and timeline.

Phase 4: Validation, Dissemination, Outreach and Feedback. Validation will be accomplished using the benchmarking metrics derived from the research phase and the recommendations as well as consultations of the end-users. Dissemination and outreach activities are designed in a way to ensure maximal impact and contribute to the relevant CH policies, by covering the full chain, ranging from research, academia, industry, policy makers and CH stakeholders to general public (including pupils). Throughout the different tasks in each segment of this approach, there are interrelations between different phases, to guarantee that the main research objectives will be addressed and realized to the maximum extend.

3.1. Strategic Objectives

Our approach deals with 8 Scientific and Technical Objectives (STOs). The first STO refers to reliable quantification of climatic, hydrological and atmospheric stressors. Our proposed framework will propose existing numerical modelling tools in the targeted historic areas in order to cover interactions from short to the longterm. This data will estimate indicators for the potential impacts of CC on historic areas at a local level, in- cluding aspects created by their longterm exposure on air pollution and micro-climatic conditions. Lastly, a Land Surface model will be proposed to account the impact of climate and atmospheric composition on soil surface parameters. As a result the model will quantify the structural and thermophysical impacts on the structural elements.

Second STO refers to multi-Hazard modelling which will cover single, cotemporaneous and cascading hazards. Moreover, inundation maps will be provided for specific catchments by using hydrological modelling for various precipitation capacities. As for seismic hazards, they will be quantified based on their seismic intensity levels and their spatial/temporal distribution for the historic areas, via stochastic modelling approaches. Our approach aims to provide input for the relevant regulatory framework, on the load models for climatic actions.

The third STO includes the estimation of Structural and Geotechnical (SG) safety risk of the surveyed structures. This estimation will be achieved via Simulators that exploit monitoring data from various sensors.Besides our partners expertise on SG engineering and on materials' deterioration, the consortium will also assess the current con- dition of structural, non-structural and content components of all buildings in the historic area. These models will validate simplified numerical or reduced-order physical models in order to achieve more accurate assessment of the impact of the climate pressure and geo-hazards. These models will also define related damage/vulnerability functions and capacity thresholds of the aging structure, optimise any reconstruction or retrofitting actions and finally evaluate the response of the structure in the future, for a large number of hazards scenarios with/without the proposed adaptation and mitigation measures.

The fourth STO refer to the environmental and material monitoring including state identification and damage diagnosis. In particular, Computer Vision (CV) and Machine Learning (ML) algorithms will be proposed to exploit sensors some of which mounted on vehicles and drones to get a precise inspection of the selected CH sites. Some of the expected outcomes will be 3D images of the wide area, damage assessment and structure deformation maps, surface material classification and degradation analysis and contour diagrams for the temperature profile. Additionally, spatial-temporal 4D (3D plus time) maps will assess the temporal damages of sites and the impact of the climate on its conditions. Moreover, ML-based algorithms will be used for the assessment of land cover changes in the broader area, and overall estimation of the environmental condition of the CH site. Lastly, each site will obtain integrated conventional sensors (e.g., environmental and structural) and low-cost microclimate-stations.

The fifth STO includes the design of a Cultural Heritage Resilience Assessment Platform and a Decision- Support-System (DSS), enabling communities' participation. This platform will support the implementation of various analysis, modelling tools and damage/vulnerability functions, while obtaining information from various sources (literature, surveys, satellite, etc.) with different levels of granularity (building/block/regional level) together with the associated uncertainties. These tools will be desingned on a Geographic Information System (GIS), based on the interface of an existing open-source hazard assessment software (e.g., OpenQuake) and network simulators (e.g., EPANET, traffic simulators), and using socioeconomic impact analysis tools to produce both quantitative and qualitative loss estimations (e.g. financial loss estimation, reputation impact, morale impact etc.) As a result the platform will enable the simulation of different scenarios offering total risk and impact assessment of hazards on the structural/non-structural components, testing of various risk management approaches, plans, strategies, counter- measures and adaptations for the selected structures, understanding the sensitivity of system assets, structures, and services to various hazards and interdependency due to cascading events.The platform will also help the development risk-based response strategies adapted to specific scenarios and defining efficient standard response procedures. Lastly, this platform will assess and quantify the overall resilience of the CH area with a holistic quantitative approach.

The sixth STO proposes the development of an initial research and training network which will support the development, effective integration and increased utilisation of existing and the proposed framework's innovative technologies and techniques. Our approach will encourage researchers and professionals to go beyond the current state- of-the-art in the relevant application domain, through a multidisciplinary and international approach based on a wide spectrum of technological tools and methods that can contribute to a more effective CH resilience and conservation policy.

The seventh STO includes the provision of a Handbook that presents: a) technical information on sustainable reconstruction of historic areas, b) proper adaptive response strategies for CC and other hazards scenarios, c) post-disaster reconstruction examples, d) practical checklists and references to assist practitioners, field-workers, cities and cultural authorities, etc. in better decision making, e) recovery requirements for various sec- tors, f) information on financial tools to mitigate risk, including a novel set of CH-area- specific insurance-linked securities (e.g., CAT-bonds) designed to cover different degreesof extreme CC and non-CC event severity and g) guidelines and techniques to encourage, facilitate, and develop bespoke reciprocal agreements between same type of businesses for timely service recovery. Last STO refers to build up specific complementary and market-oriented skills to allow the European researchers and professionals to face the new challenge in terms of technology development and future services.

4. Impact of our proposed approach

The main impact of this approach is to form an international and inter-sectorial network of organizations working on a joint research programme in the field of Resilience of CH focused on market needs. The participants will exchange skill and knowledge, which will allow them to progress towards key advances in different techniques, and have a better understanding of the research culture in different countries and sectors.Technically, our proposed framework is expected to have a significant impact on a variety of technological aspects (tools and algorithms) related to the capturing, visual computing, animation, interaction, collaboration, visualization, and interoperable metadata description, all in the context of European framework of Copernicus, Galileo, CH, etc. The expected technological impact is of paramount importance given that our approach will address a series of previously unexplored beyond the state-of-the-art areas that however have recently emerged as high value scientific objectives in research frameworks outside Europe. Moreover, the proposed framework promotes a unique think tank in the field of CH eliminating the cultural, political, linguistic but more importantly the geographic boundaries that sometime delay the materialization of new ideas into practical applications. The focus however of this pioneering think-tank is to execute in an intradisciplinary fashion so that geographic and other boundaries reverse into advantages of new "added value" pan-European co-laboratories.

4.1. Research Collaborations

There are two categories of research collaborations during our approach. The first category aims to achieve transfer of knowledge between research institutions and to improve research and innovation potential at the European and global levels. In particular, the high quality of this approach will allow researchers to fully explore such high-end technology capabilities and better comprehend the benefits of their use. This will allow individuals from different scientific and technical fields to integrate their knowledge and practical expertise for the benefit of the end-users.

Our approach is designed to (i) make research careers more attractive to the new generations; (ii) make early stage researchers more attractive candidates for their future employment positions by creating very specific skills requested by the market and (iii) improve the skill and technical background expertise of staff engineers already employed in the industry. This approach will hence ensure significant impact on the key skills, career prospects and employability of all its candidates. Each individual researcher will gain immediate and longer-term benefits of the proposed research and training programme in terms of enhancing skills in technology and interpretation methods. The programme is envisaged in a multi-disciplinary framework that will allow researchers to foster their creativity. Through the mobility actions, our approach will provide exceptional opportunities to have a complete and in-depth hands-on experience on scientific instruments and software required for monitoring the major risk affecting the CH and historic areas. A well-structured work plan makes an effective connection between academia and the private sector with actions such as training seminars (complementary skills) that will be organised and implemented by SMEs. Network-wide events and individual projects will broaden the researcher's background knowledge in similar research areas. Researchers will become familiar with a wide range of research methods related to this subject. The network-wide events will also encourage researchers to develop or strengthen other complementary fields of expertise such as management skills, writing projects proposal, team working and leadership skills. Researchers will be actively involved in the integration of new and traditional techniques of archaeological sites monitoring mapping in different environments, thereby broadening the traditional academic research training setting and eliminating cultural and other barriers to mobility.

The second category refers to research collaborations resulting from the intersectoral and/or international secondments and the networking activities implemented. Firstly our approach aims to foster already existing collaborations within consortium. In particular, the members of the Knowledge Alliance have participated in several joint experi- mental research efforts in the field of ICT-aided protection of CH assets. This approach forms the most suitable framework for amplifying on-going collaborations between its consortium members. Moreover, the commitment and the expertise of the consortium as well as the proposed research training, guarantee sustainable use of the results and future successful cooperation.Secondly, our approach plans to create and maintain long-lasting collaboration between the participants. Generally, the knowledge and skills acquired during this approach will contribute to significant collaborations between enterprises and academic/research institutes which will last long after the end of this approach. All the participants have strategic interest into collaborative efforts towards improved resilience of CH and historic areas. On the one hand, the enterprises are seeking for new technological toolkits arising from the fields of CC and hazards modelling and tools, innovative CV/ML techniques and tools, digitization and visualization. Additionally, the academic institutions anticipate to enormously benefit from their interaction with the private sector in terms of optimizing RD and aligning it to real-world needs.

Last but not least the project intends to strengthen the competitiveness of the participating enterprises and institutes. The economic value of CH has been studied on the national, regional and local levels. National studies often contain comparisons with other countries. There are also studies providing data by sector, such as museums, and studies of the economic impact on a micro level, providing assessment on the level of separate heritage institutions, such as museums, libraries, archives or sites. The literature review has identified that the economic value of CH is currently assessed using conventional and well-known economic impact models. Among other subsectors within the cultural industry sector, CH is not assessed as an explicit subsector or branch but, rather, as a cross-cutting prerequisite for economic development, particularly for the tourism industry and job creation. Such evidence based on the interconnection between CH and the emerging research of the creative industries sector is a recent phenomenon. The consortium aims to conduct a specialized business analysis to predict potential revenues on different types of target users (CH researchers, visitors of the historic areas and the wider public of the areas)

4.2. Improvement Of The Research And Innovation Potential

4.2.1. Regional CC maps

The proposed framework will advance the partners capacity for reliable downscaling of climate simulations and extraction of robust climate indicators in the local- to site-scale. By enabling access to an extensive database of high-resolution (12km) RCM simulations as driving climatology, a set of novel approaches for the assessment of climate and micro-climatic effects in very small scales will be evaluated and validated. In the framework of the assessment of climatic stresses on CH sites, the relevance and representability of primary climate parameters (time-series) and compound indicators for local-scale applications will be evaluated. The assessment framework will integrate a two- way (meso/micro-scale) coupling scheme in a completely new area of application, namely the determination of flow fields in these scales related to the CH sites, as well as the transport and deposition of air pollutants under specific, realistic scenarios of climatic stress.

4.2.2. Hyper/Multi-Spectral Imaging

The proposed framework innovates on integrating ground multi/hyper-spectral imaging analysis techniques on automating the diagnosis of the current assessment status of a CH monument/historic area site. This exploits the concept that different materials and/or decay phenomena are depicted on spectral bands using different signatures and thus allowing discriminant analysis. During this approach, the multi/hypespectral imaging analysis is carried out at different temporal instances to get results about degradation rates and potential acceleration phenomena that are caused due to CC and environmental impacts.

4.2.3. Data Management Systems (DMS)

Having already gained a significant experience in the data management and big data technologies, the consortium aims to build upon these and expand this knowledge to another application domain that is the preservation of CH. Our approach aims to increase the odds of developing a novel DMS that will enter the relevant market and enhance our service portfolio.

4.2.4. Visualization Systems

The proposed framework will advance products to support enhanced 3D geospatial datasets, which will make them unique for this application. This new kind of knowledge will benefit to the large community of its product users, in different domains ranging from crisis management, civil security, to the general industry, to better understand and exploit the dynamic dimension, as well as other degrees of freedom, of geographic sites. It will also enable the community of developers to create new applications supporting massive dynamic geospatial datasets.

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5. Conclusion

This work provided a short introduction of our approach which propose a framework for the field of the resilience of Cultural Heritage (CH) areas and historic cities against Climate Change (CC) and other types of hazards. Such techniques has the potential to encourage governmental bodies and cultural authorities to deploy sustainable mitigation plans and provide efficient reconstruction of the CH parts that have been damaged. The proposed framework is expected to improve people's knowledge, providing them with training sessions and summer schools and allowing them to fully explore high-end tech- nology capabilities and better comprehend the benefits of their use.

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