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# Protection of Cultural Heritage against the Effects of Climate Change Using Autonomous Aerial Systems Combined with Automated Decision Support

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***Abstract*****—**The article presents an ongoing work in research projects such as SCAN4RECO or ARCH, both funded by the European Commission under Horizon 2020 program. The former one concerns multimodal and multispectral scanning of Cultural Heritage assets for their digitization and conservation via spatiotemporal reconstruction and 3D printing, while the latter one aims to better preserve areas of cultural heritage from hazards and risks. It co-creates tools that would help pilot cities to save cultural heritage from the effects of climate change. It develops a disaster risk management framework for assessing and improving the resilience of historic areas to climate change and natural hazards. Tools and methodologies are designed for local authorities and practitioners, urban population, as well as national and international expert communities, aiding authorities in knowledge-aware decision making. In this article we focus on 3D modelling of object geometry using primarily photogrammetric methods to achieve very high model accuracy using consumer types of devices, attractive both to professions and hobbyists alike.

***Keywords*****—**3D modeling, UAS, cultural heritage, preservation.

## I. Introduction

THE Cultural Heritage plays an important role in defining the identity of Europe as compared to the rest of the World, influencing the feeling of attractiveness for its citizens as a place of work, living and visiting. It increases also the feeling of togetherness among European citizens. Therefore, the need for protecting and preserving European Cultural Heritage is of extreme importance for combined European cultural wealth.

The European cultural heritage is enormous, with a vast and rich variety of cultural items, ranging from buildings to museum artefacts. These items consist of materials of diverse types, the condition of which deteriorates with time, mainly due to environmental conditions and human actions [1]. This strengthens the need for the effective documentation of the cultural items, so that information about them is easily accessible to researchers and the public. The preservation of objects against the effects of time to be passed unaltered to next generations, are also matters of uttermost importance and have attracted significant focus.

Factors responsible for the deterioration of the state of cultural items, in case of indoor environments, include but are not limited to, humidity, temperature, exposure to light, as well as the effects of human activities, such as the transportation of the items. These factors are eliminated by keeping the cultural items in specifically designed facilities, such as museums and galleries, where environmental conditions are controlled by following specifications established after extensive research. However, there is a lack of research concerning the effect of the environment and the means to eliminate it, in cases of uncontrolled indoor environments. Such cases include objects and artworks hosted in historical buildings and monuments of public access, where people activities are not restricted, as in museums. The increased human activity, in combination with the uncontrolled environmental conditions of such facilities affects the objects of interest in a significantly higher degree, than the controlled environment of a museum. In this respect, several monitoring and simulation technologies can be effectively used in order to assist in the documentation of cultural objects, as well as the evaluation of the effects of the environment on them and the development of procedures to handle those effects, in order to achieve preventive conservation. Optical, infrared, ultrasounds, x-ray and other elaborate sensors can be used to scan an object and create a rich 3D representation of it.

A 3D representation is the most complete way to represent a whole structure of an object. Apart from the shape and appearance of the object, other information, resulting from various sensors, can be integrated in the 3D model, such as the materials of the object and stratigraphy information. Automatic missing part reconstruction techniques can also be adopted, to fill missing parts of the object and make the whole shape of the object available.

A rich 3D representation of a cultural object is also valuable for conservators. The 3D model constitutes an accurate virtual representation of the object and contains information about its materials and its internal condition. It thus allows the conservators to view areas of the object, which are susceptible to damage from external factors, without needing a direct access to the physical item, reducing thus, the amount of intrusion. In addition to the information of the 3D models of the objects in a facility, temperature, light and humidity sensors can constantly monitor the environmental conditions around a cultural item, for the conservation personnel to be aware of fluctuations of these conditions, which may result in the deterioration of the object.

By combining environmental monitoring with continuous

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observation of state of an object, by updating its 3D representation, the conservator can gain an overview of how the state of the item is affected by environmental conditions over time. Such measurements can assist in preventing damage to the items and in designing strategies for better preservation.

An innovative, integrated solution has been developed in the SCAN4RECO project [2] with focus on improved portability and modularity. It offers a cost-effective and automated means of digitizing and analysing the Cultural Heritage objects.

The project aimed to create highly accurate digital models of Cultural Heritage objects, offering at the same time highly detailed view of their geometry and the volumetric assembly, material structure and composition of the materials, offering means of visualisation through visual 3D rendering or multi-material 3D printing.

In the SCAN4RECO project objects have been scanned using various surface and penetrating technologies, with purpose of improving the understand of a diverse and complex nature of materials used, as well as to be able to identify a wide variety of material types. It also helped to better comprehend the processes behind progressing degradation over time and in presence of various factors, ultimately devising context-dependent ageing models for each material used.

Models built originally for single materials were further elaborated and simulated using spatiotemporal methods, taking into account environmental phenomena, thus producing multi-causal degradation rendering for objects built from diverse materials. As a result this made it possible to easier predict and recreate their possible future appearance. On other side, this also offered an invaluable tool for restorations, by using predictive approaches to look back in time to see how the degraded object might have looked originally, certainly to a certain level of reliability depending on the time period and structure of the object at the start of the analysis.

SCAN4RECO facilitates conservation efforts by indicating spots/segments of cultural objects that are in eminent conservation need and require special attention, while suggestions are provided by a Decision Support System (DSS) about conservation methods to be followed.

## II. System Architecture

The SCAN4RECO offers a cost-efficient, portable, integrated system, based on multi-modal and multi-discipline, modular, scalable and open-architecture (presented in Fig. 1) extendable platform that will be able to provide multispectral scanning of a variety of cultural asset (e.g. wall-paintings, painting, metallic objects of various sized, carved marble, statues, etc.) non-destructively. It efficiently processes the multi-sensorial input in such a hierarchical way, to produce VR models of improved quality and information according to the demands of the end-user or the use-case/application itself, utilizing each time a diverse set of sensors. This way the complexity and the quality of the multi-layered and multi-dimensional VR model of the cultural object of interest will vary per demand. An important part of the project focuses on the study and modelling of materials commonly found in a variety of common cultural objects. This way, inter-disciplinary knowledge (e.g. physics, chemistry, history, etc.) is combined with computer science (e.g. spatiotemporal simulation, 3D rendering, DSS suggestions, visualization, etc.).

The ultimate goal will be not only the material identification, stratigraphy revealing and automatic, accurate digital 3D representation and reconstruction of the object in its original state, but also the automatic inference of both previous states (i.e. restoration) and forthcoming state/shape of the object in certain times in the future, leading thus, to a 4D representation in Virtual Reality (VR) where three dimensions represent spatial information (including depth information of possible stratigraphy under the visible surface) and an extra dimension corresponds to temporal changes through simulation.

## III. Photogrammetric 3D Modelling of Cultural Objects

One of the main components of the Scan4Reco system is the 3D scanning of the object geometry. It serves as a pre-requisite for being able to visualize together multiple results from a variety of surface and penetrating scanning of small parts of the object. Those include e.g. multispectral visualization from infrared to ultraviolet, depth scanning like X-ray or Raman, to micro surface variations (roughness) using microprofilometry. Furthermore, object geometry serves also as a reference for simulated prediction of future degradations of the object over prolonged periods of time. Such changes involve both physical erosion of the surface and chemical changes that affect the steadiness of the object surface and give raise to speeding up of the object deterioration. Since such changes occur very slowly, having a very accurate and high-resolution 3D object representation is even more important.

During recent years, the 3D scanning has become an essential part of a common approach to digitization of cultural heritage, both for preservation purposes and for making it wider accessible to scholars and the general public. High-resolution 3D recordings and models of archaeological and historical locations, monuments and structures, arts objects and artefacts enables now anyone to monitor, study, publish, distribute and better understand our shared cultural history. One of the most important characteristics of any digital representation of a cultural object is certainly its physical shape, or in technical terms its geometry, needed to be captured at the highest resolution possible with the most recent technologies available, archive them in their RAW form (i.e. as captured by the sensors), such that subsequent processing can be performed at any later time as digital processing technologies advance. On the other hand, such precise 3D models also enable high-accuracy of reproduction back into a physical form through 3D printing.

Digital 3D models are commonly related to artificial, virtual environments. However, the emerging ability to recreate them as 3D physical objects creates a new demand for new investigations into extra types of information that the digital data need to contain. Recent years demonstrate growing level of damage and destruction to cultural heritage caused not only by massive tourism, but especially during conflicts, through illicit acts of vandalism and terrorism (e.g. in Palmyra), as effects of natural degradation caused by increasing levels of pollution as well as by natural disasters [3]. Other effects include also commercial interests and imperfect restorations leading to the need for re-evaluating the importance of high-resolution replicas. Exact representations are now easier achievable thanks to technological advances in 3D scanning, increasing resolution of imaging sensors, composite photography, advanced in multi-spectral imaging, processing and reproduction techniques.

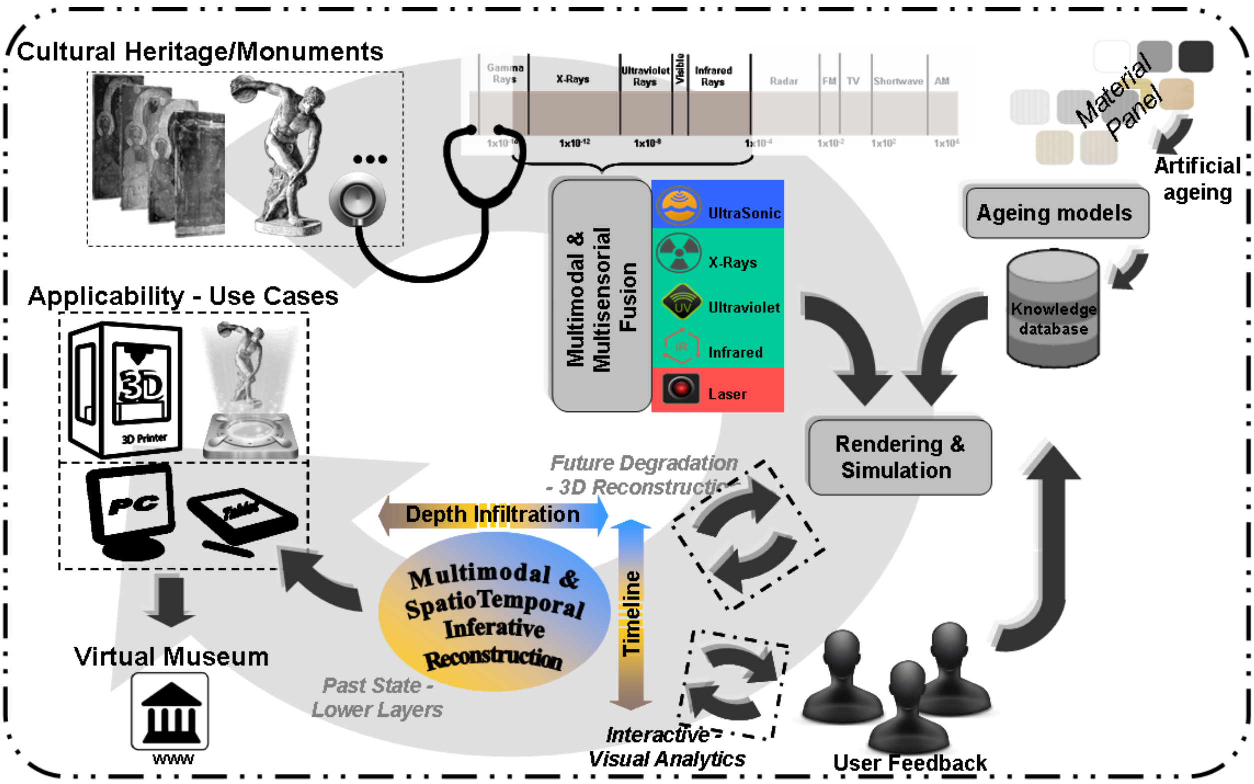


Fig. 1 Conceptual system architecture

Various 3D scanning technologies are in common use, each with their own advantages and limitations. Until recently, time-of-flight methods sprung among community of users fascinated by sensors like MS Kinect [4], Structure sensor [5] and similar ones. Although originally developed as short-range body motion capture devices and targeting immersive gaming, ability to scan the environment using infrared diodes offered ability to capture objects and areas in 3D to level not previously possible. Nevertheless, it become apparent quickly that accuracies achievable cannot surpass millimeters [6] and hence use of such sensors has been limited to personal use rather than professional object scanning. On the other hand 3D photogrammetry, when using high resolution cameras and when taking care of certain rules, may reach amazing levels of precision, such as 57 micrometers as we have managed to reach with 50 Megapixels cameras with even higher accuracies possible if using cameras like Phase ONE, equipped with sensors exceeding 150 megapixels for industrial cameras [7] up to 280 megapixels for NADIR aerial photography [8].

Certainly, with such a diversity of available technologies, a section of the best approach to fit the specific needs becomes a real challenge. None of them is geared to do everything and anything. The time of flight approaches, triangulation, stereoscopy, 3D photogrammetry and other approaches offer different relationships between the real object and its digital representation. Types of 3D data may vary in scale, from topographies of landscapes captures from large altitudes, to taken at close range and sufficiently accurate to represent changes to surface and marks not visible to a naked eye. With digital means they can be visualized to aid in reconstruction and/or monitoring of their condition. Even though there are systems capable of capturing 3D information with colour, there are no 3D scanners yet that would be able to record colour to a standard required to produce an exact digital replica.

Techniques and scanners discussed herein are the most common ones in use for applications dealing with cultural heritage. Therefore, the needs in our projects were twofold, from one side a correct representation of object shape (geometry), from the other one dealing correctly with difficult materials to capture their correct colour and appearance. The focus of this chapter is capturing the global shape, whereby some of the presented commercial technologies show potential for correct representation of object appearance as well.

Photogrammetry or stereoscopic scanning is the technology of making depth measurements from raster photographs. It can be used for quick recording of vulnerable and inaccessible sites. Algorithms like 3D photogrammetry or stereoscopy are ideal for obtaining 3D object representations in situations where it would be either physically impossible (inaccessible locations, conflict zones) or too costly to use higher accuracy laser 3D scanners, or in situations when high-speed recording would be important, such as for 3D scanning people, animals and/or other living organisms, liquids or other fast moving objects. Such methods are also ideal for recording of translucent surfaces, such as alabasters, marbles and transparent materials.

Due to the composite nature of the image capture, colour and form can be extracted from the data. Until recently achieving highest resolution recording of surface for facsimile production and featureless, reflective and dark surfaces was not feasible. However, recent software developments (e.g. by Autodesk ReMake [9], ArTec 3D Studio [10], Pix4D Mapper [11], Agisoft Photoscan [12] and many other ones) it became possible through improvements to photogrammetry technology to become soon the dominant method for recording at risk cultural heritage in 3D and colour. A special version of the photogrammetry is structured light scanning, whereby pre-defined shapes (commonly horizontal and vertical lines) are projected onto the object surface. By analysing the change in line shapes from images captured by the camera, the shape of an object can be determined.

## IV. Automated 3D Modelling System

The photogrammetric 3D modelling provides not only the precise representation of the object geometry, but offers also a reference for positioning partial scans from other modalities. It also captures the object condition at a time that can be then aged artificially through digital simulation. The 3D modelling is done from several 50MPixel raster images taken with high-overlap (more than 70%) on a regular grid, thus providing high number of matching features among many images. The precise positioning and orientation of the camera in three dimensions (repeatable to single centimetres) is achieved by using a computer controlled mechanical arm. Images are then processed either locally (rough model only, due to a limited computational power of the rack PC) and/or using remote processing server where it can take advantage of the high processing power boosted by CUDA cores [13] of the multiple Nvidia GTX 1080TI graphics cards [14].

## V. Experiments

Several technology validations on different types of objects have been performed. The test showing the power of the technology was to 3D scan of a Saint Michael icon from Mount Athos monastery in Halkidiki (Greece). Here the highest resolution commercial camera Canon 5DS-R [15] was used, which incorporates a 50Mpixel CCD sensor. A 20-years old icon has already shown signs of ageing with physical surface deteriorations and discolorations, thus being a suitable subject for high resolution analysis in both 2D and 3D. High resolution images allowed to achieve feature discrimination at accuracy reaching 57 micrometres (Fig. 4).

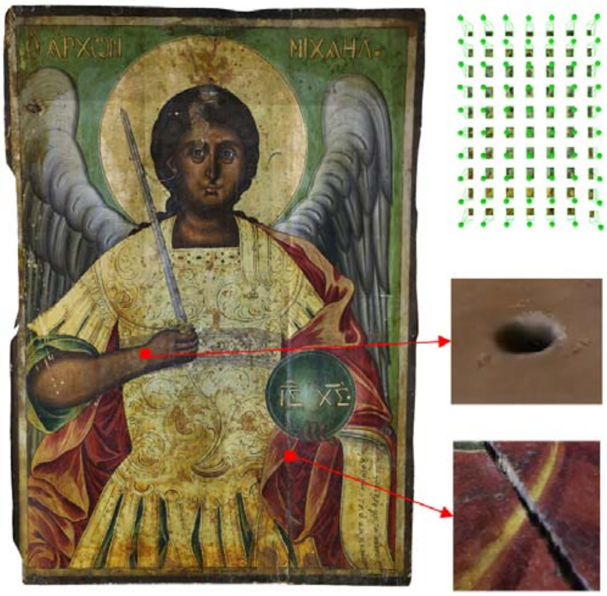

Fig. 2 The 3D model of Saint Michael icon captured with 50MP camera, showing images taken at a regular grid with zooming on the identified holes and cracks to demonstrate the achievable precision

A high-performance PC with i7-3.8GHz processor and dual Nvidia GTX1080 graphics cards allowed to perform the processing in less than 8 hours. A zoom into the selected features of the icon shows the precision of representation of both flat and recessed parts of the object to accuracy reaching 50 micrometres. These experiments show the capabilities for this technology to produce 3D models with accuracies reaching the precision usually required by CH restoration facilities. In our experiments, we have used commercial photogrammetric software, such as Autodesk ReMake [9] (formerly known as Autodesk Memento) and ReCap, Pix4D Mapper Pro [4], AirTek Studio [10] and Agisoft Photoscan [11]. The performance and processing time varied significantly among those applications. After several attempts, we concluded that Autodesk ReMake and Pix4D Mapper were most suited to scanning the types of objects used in the SCAN4RECO projects (painting and icons, as well as metallic 3D objects up to the size of a life size statues) and environments where images were captured (indoor or outdoor, using natural or artificial lighting).

The ReMake application is a comprehensive solution enabling transformation of the reality captured using photographs into high-definition 3D models. Such 3D model meshes that can be further processed to improve geometry, filling in discontinuities, modifications of geometry, measurements of size and volume, re-topology, comparing to other models taken at e.g. different time, as well as optimization of the workflows, all entirely within the same integrated environment. The application handles also reverse engineering as support for design and engineering, for asset creation for AR/VR, film, game, art, for archiving and preserving heritage, digital publishing interactive for Web and mobile experiences. ReMake plays well with Autodesk®

ReCap 360, helping clean up, fix, edit, optimize and prepare the generated meshes from laser scans or photos for downstream use. ReMake simplifies complex processes since it was designed for users who require top-quality digital models of real-life objects but have little or no 3D modelling expertise. The early experiments with Autodesk ReMake in the SCAN4RECO project have shown several advantages, such as smoother edges and cleaner model mesh as compared to Pix4D Mapper, although precision is significantly lower and models lack high object count, yet.

## VI. Extending from Objects to Cultural Areas

The H2020-ARCH project offers technology transfer from dealing with tangible objects to larger spaces whether they are buildings, statues, city areas, archaeological sites etc. This has led to pursuing in SCAN4RECO advanced technological development aimed at transforming stationary laboratory systems to as portable as it was only possible, in many cases small-enough to be deployable on autonomous ground and aerial systems. The latter ones made it possible to capture objects well above the ground level and thus offer new way of analysing their condition and assess risks of their degradation. In doing this, we have considered both natural erosion caused by natural environments, but also speeded up effects from Climate Change, natural events and/or human-borne incidents. Consequently, ARCH pursued means of strengthening the resilience of cultural and historical regions to negative effects of progressing climate change effects as well as other threats, including extreme weather conditions and natural disasters. It also aims to support decision makers in effectively responding to emerging needs of risk areas when deriving strategies for sustainable protection and reconstruction. It pursues also advanced technological developments of means for improved acquisition of relevant information about the condition and state of the cultural heritage as well as data processing algorithms for building a knowledge base to support authorities in knowledge-aware decision making. This includes an information management system for hazard data, captured via existing climate services and novel monitoring techniques leading to provision of simulation models for what-if analysis of the effects of hazards and potential measures, ageing and hazard simulation. As such, it extends 3D modelling and ageing simulations from SCAN4RECO, shown on an example of Saint Giorgio statue in Fig. 3, adding means of monitoring climatic and weather changes that might have direct effect of degradations to cultural heritage objects. Since 3D scanning and monitoring of large areas stretches beyond current capabilities of UAVs, new methods of operating large number of devices simultaneously over areas of interest, as suggested in Fig. 4, are proposed whereby initially flight control is linked to the pilot console (current legal requirement), though applied R&D is directed to fully relay autonomous mission control onto a dedicated embedded computer deployed on UAS itself (ongoing) [16].

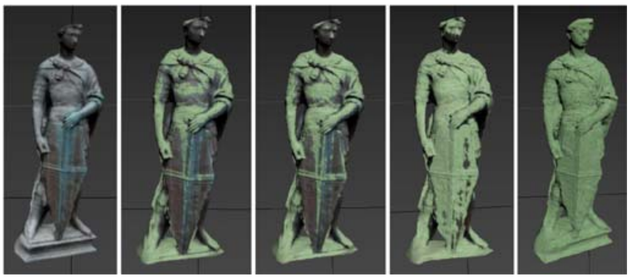

Fig. 3 Simulated ageing of a bronze statue of Saint Giorgio at 5-year intervals

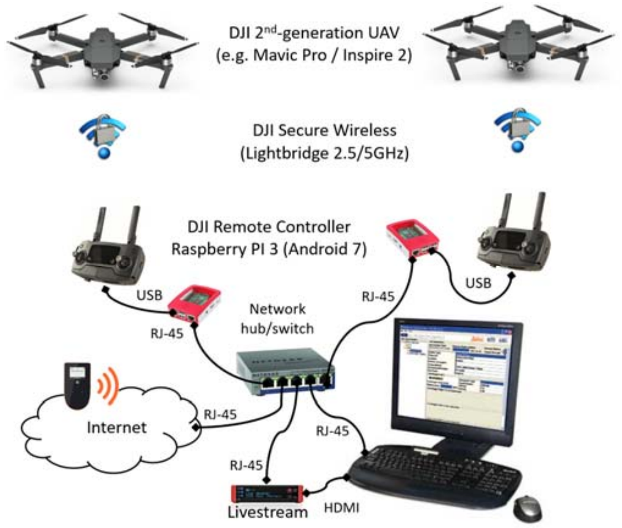


Fig. 4 Autonomous swarm UAS operation for 3D monitoring of large areas

Such a system will enable high level of autonomy in decision making in varying environmental conditions, monitored by e.g. a CIPCast-DSS system by ENEA that collects data from diverse sensors ranging from ground to aerial ones (Fig. 5), especially important during disasters or in cases where instant surveillance of large areas is required.

## VII. Conclusions and Further Work

In this article we summarized the main concepts behind use of 3D scanning/modelling and simulated ageing of cultural heritage objects as proposed in the SCAN4RECO project, taking advantage of autonomous systems for monitoring large objects as well as large cultural areas of e.g. cities, excavations and/or disaster areas, as proposed in the FP7-AF3 [17] project and currently extended in the H2020-ARCH [18] project. The vast amount of research performed in all three mentioned projects could only be signalled in this publication and therefore interested readers are suggested to explore online resources of publications, prototypes, demos and presentations available on the WEB portal of each of the mentioned projects.

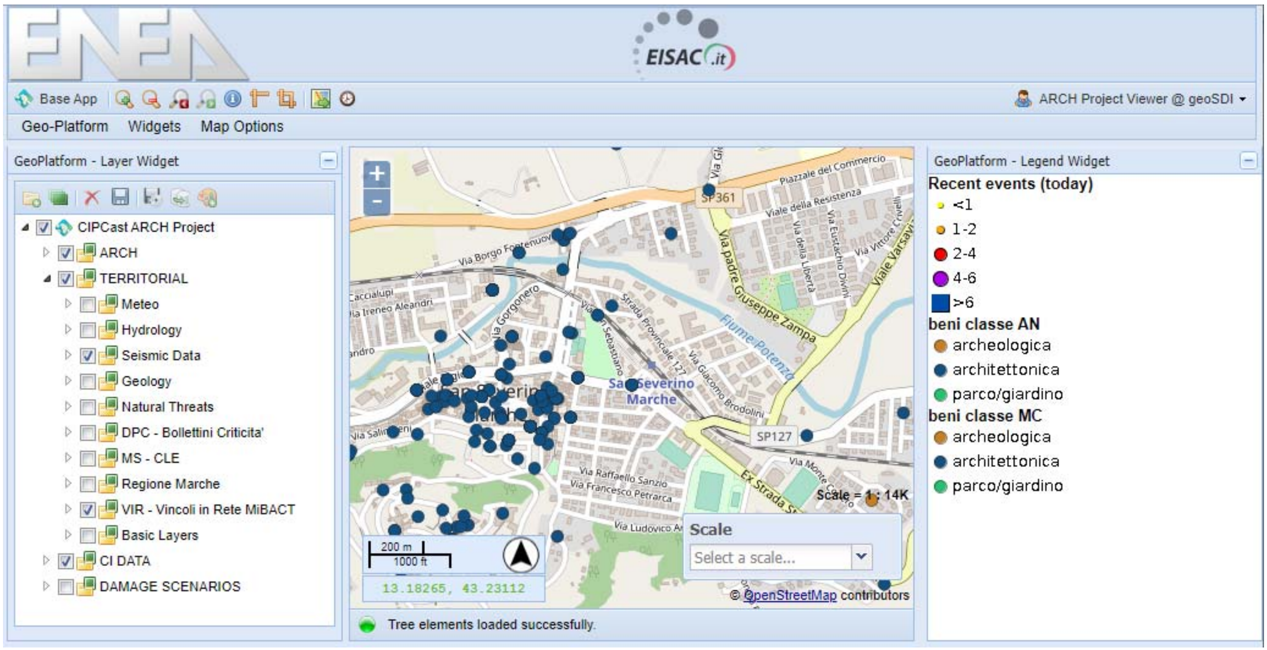


Fig. 5 CIPCast DSS from ENEA used in ARCH project

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## References

[1] Smith, T.F., Waterman, M.S.: Identification of Common Molecular Subsequences. J. Mol. Biol. 147, 195--197 (1981)
[2] H2020-SCAN4RECO project: https://cordis.europa.eu/project/id/665091
[3] Krukowski, A. and E. Vogiatzaki, „*UAV-based photogrammetric 3D modelling and surveillance of forest wildfires*", Workshop on "UAV & SAR: using drones in rescue operations", ISA, Rome, Italy, 29th of March 2017.
[4] MS Kinect sensor: https://developer.microsoft.com/en-us/windows/kinect/
[5] Structure sensor: https://structure.io/structure-sensor
[6] Jeremy Steward, Dr. Derek Lichti, Dr. Jacky Chow, Dr. Reed Ferber, and Sean Osis "Performance assessment and calibration of the Kinect 2.0 time-of-flight range camera for use in motion capture applications", FIG Working week 2015, "Wisdom of the Ages to the Challenges of the Modern World" Sofia, Bulgaria, 17-21st May 2015.
[7] PhaseOne 150MP: https://photography.phaseone.com/xf-camera-system/
[8] PhaseOne industrial 280MP system: https://industrial.phaseone.com/Aerial_System_280MP_System.aspx
[9] Autodesk ReMake (15th of March 2017): https://remake.autodesk.com
[10] ArTec 3D Studio (15th of March 2017): https://www.artec3d.com/3d-software/artec-studio
[11] Pix4D Mapper Pro (15th of March 2017): https://pix4d.com/product/pix4dmapper-pro
[12] Agisoft Photoscan (15th of March 2017): http://www.agisoft.com
[13] CUDA (15th of March 2017): http://www.nvidia.com/object/cuda_home_new.html
[14] NVidia GeForce cards (15/03/2017): https://www.nvidia.com/en-us/geforce/products
[15] Canon EOS 5DS-R camera: https://www.canon-europe.com/for_home/product_finder/cameras/digital_slr/eos_5ds_r/
[16] Krukowski, A. and E. Vogiatzaki, "*Autonomous Aerial Systems in Service of Cultural Heritage Protection from Climate Change Effects*", International Conference on Cultural Heritage (EUROMED'2020), Cyprus, 2-5th of November 2020 (http://euromed2020.eu)
[17] FP7-AF3 project: https://cordis.europa.eu/project/id/607276
[18] H2020-ARCH project: https://cordis.europa.eu/project/id/820999