Big Earth Data for Cultural Heritage in the Copernicus Era

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Abstract Digital data is stepping in its golden age characterized by an increasing growth of both classical and emerging big earth data along with trans- and multidisciplinary methodological approaches and services addressed to the study, preservation and sustainable exploitation of cultural heritage (CH). The availability of new digital technologies has opened new possibilities, unthinkable only a few years ago for cultural heritage. The currently available digital data, tools and services with particular reference to Copernicus initiatives make possible to characterize and understand the state of conservation of CH for preventive restoration and opened up a frontier of possibilities for the discovery of archaeological sites from above and also for supporting their excavation, monitoring and preservation. The different areas of intervention require the availability and integration of rigorous information from different sources for improving knowledge and interpretation, risk assessment and management in order to make more successful all the actions oriented to the preservation of cultural properties. One of the biggest challenges is to fully involve the citizen also from an emotional point of view connecting "pixels with people" and "bridging" remote sensing and social sensing.

Keywords Big data · Digital archaeology · Remote sensing · Data integration · Cultural heritage management

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Introduction

In the last 20 years, remote sensing (RS) along with big data and information and communication technologies has radically changed the current cultural heritage (CH) scenery and future prospects. The digital data and tools nowadays available for CH enable us to get rich and detailed information from heterogeneous data sources, for example, earth observation (EO), sensor networks, digital libraries, web data service, social networks and IoT (Internet of things) with specific reference to cultural heritage, using sophisticated and complex systems that replaced the simplest traditional ones to cope with big data challenges from the storing to the processing, mining, integration and interpretation.

Big data has emerged in the past few years providing opportunities to improve and/or enable research and decision support applications with unprecedented value for digital CH and archaeology. The possibility to fast analyse relatively large, varied and rapidly changing huge quantities of data has sped up the work during the diverse phases of application ranging from survey, mapping, documentation, exploitation and monitoring at diverse scales of interest, moving from small artefacts to architectural structures and landscape scale.

There is, therefore, no doubt that EO big data will significantly change the scientific approach, data analysis and methodologies as well as discoveries of unknown archaeological sites and the visualizations of the results to also engage attractively citizens into the human past and its contemporary legacies.

Scientific big data has a number of characteristics, including complexity, comprehensiveness and global coverage, as well as high degree of integration with information and communication technology which will provide a great contribution to those approach to the study of the human past, as *processual archaeology* (Patterson 1989) modelled using scientific method, to find and make clear the (theoretical) general laws of cultural growth in the way that societies responded to their environments.

Big data will bring together perspectives coming not only from cultural heritage but also from the creative arts, design, software development and social science transforming the current approaches and moving from single discipline to multidisciplinary and interdisciplinary approaches.

The latest generation of satellite sensors opened up a frontier of possibilities providing ever-closer and more comprehensive look at the earth's surface, with the potentiality to inform us about present and past human activity.

Moreover, augmented and virtual reality makes possible to integrate virtual restoration with the current status of the historical buildings, ancient environment reconstruction also including anthropological aspects and mapping past flora and fauna (Gabellone et al. 2017; Pescarin 2015).

One of the most important points is that all of these technologies are available at different costs for different purposes and needs. Even with a small budget, it is possible to implement very effective solutions. For example, by satellite optical imagery available from Google Earth (Luo et al. 2018) or using a small "drone", equipped

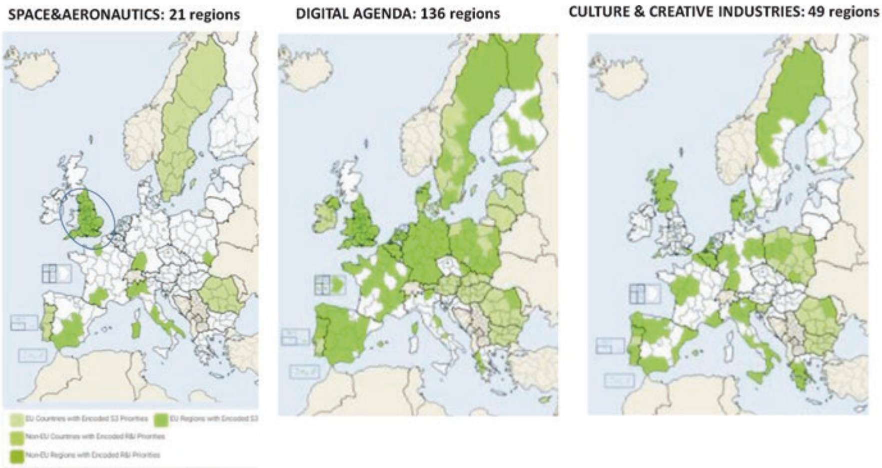

Fig. 1 Smart specialisation platform: regional priorities. (Image source: EYE@RIS3 tool, EC) AU2

with GPS and digital camera remotely controlled (Campana 2017), it is possible to carry on detailed surveys, operational monitoring activities of complex structures and areas of archaeological interest (Masini et al. 2018a, b). Moreover, the growing AU1 availability of free data and open access software tools, with particular reference to Copernicus initiatives, enhances a powerful link between in situ investigations and EO data, research and operational services thus offering a new opportunity for the exploitation of big earth data also addressed to the social benefits and economic development of culture and creative industries (see Fig. 1).

Therefore, the new and emerging challenges are the dissemination of data, the interoperability, the costs, the simplicity in use and the speed of applications, to make them open and understandable to everybody and useful for operational monitoring and preservation of CH properties. Focussing on this strategic challenge, as also highlighted in the 2030 Agenda and relative Sustainable Development Goals (SDGs), it is important to remind that the factors that most of all threaten cultural heritage sites are among the others: social/cultural uses of heritage, use/modification of cultural properties, physical resource extraction, local conditions affecting physical fabric, transportation and utilities infrastructure, urban sprawl, pollution and biological resource. In other words, today cultural heritage is (according to UNESCO) “increasingly threatened with destruction not only by the traditional causes of decay, but also by changing social and economic conditions which aggravate the situation with even more formidable phenomena of damage or destruction” (from the general conference of the UNESCO in Paris from 17 October to 21 November 1972). To face these drawbacks, the increasing involvement of citizens and their awareness on the importance of preserving CH along with a continuous monitoring in terms of type and extent of adverse changes over time is essential for supporting planners and decision-makers as also highlighted in the framework of 2030 Agenda and SDGs, with particular reference the sustainable exploitation and preservation of CH (see Albert 2017).

The main issue of great importance for supporting the evolution processes in a "sustainable development" approach is the availability of information on past and current conditions to estimate potential future scenarios. In this context, big earth data (also available free of charge), with particular reference to Sentinel missions (http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4) and services (https://www.copernicus.eu/en), can be fruitfully used for (i) improving knowledge and documentation of cultural heritage sites, (ii) monitoring and planning purpose, (iii) recording ongoing trends and (iv) estimating natural and anthropogenic risks at a detailed level. Moreover, the availability of free-of-charge satellite imagery and services represents a cost-effective mean for obtaining useful data and reliable information that can be easily and systematically updated for the whole globe and, therefore, can fruitfully be adopted for developing reliable and accurate SDG indicators for the monitoring of the achievements of the identified goals.

Copernicus

The Copernicus programme, financed by the European Community and managed by the European Space Agency (ESA), thanks to a wide range of technologies, from satellites to terrestrial, marine and aerial surveying systems, provides operational data and services information (for a wide range of application areas) in a complete, open and freeway. Copernicus has opened the season of big geospatial data (https://cordis.europa.eu/news/rcn/128882_it.html) that are strategic for the development of services for decision support in various application contexts with a view to sustainability.

There are four pillars, on which Copernicus is founded: (i) the spatial component (satellites and associated ground infrastructures), (ii) in situ measures (aerial and terrestrial measures), (iii) harmonization/standardization of data and (iv) services for users. The Copernicus services are based on information from a constellation of dedicated satellites, called "Sentinels", and dozens of other satellites, the so-called participating missions. This information is supplemented with data obtained from in situ (i.e. local) sensors. In particular, the spatial component related to the constellation of dedicated satellites consists of various Sentinel missions with the following objectives.

- Sentinel-1 provides monitoring services for terrestrial and marine areas with radar images. The first Sentinel-1a satellite was launched on 3 April 2014.
- Sentinel-2 provides high-resolution optical images for terrestrial services (e.g. monitoring of vegetation, soil, inland waters and coastal areas). Sentinel-2 can provide useful information in cases of emergency.
- Sentinel-3 provides services for the global monitoring of terrestrial and oceanic areas.
- Sentinel-4 will provide data on atmospheric composition.

Table 1 ▪▪▪ AU3

Sentinel missions	Number of satellite	Mission
Sentinel-1	4 satellites	Synthetic aperture radar (C band) mission designed to monitor sea ice zones, the Arctic environment and the risk of land-surface motion as well as generate forest, water and soil mapping
Sentinel-2	2 satellites	Optical mission with a multispectral instrument mainly for agricultural applications such as crop monitoring and management, vegetation and forest monitoring (e.g. leaf area index, chlorophyll concentration, carbon mass estimations), monitoring land cover change for environmental monitoring, observation of coastal zones (marine environmental monitoring, coastal zone mapping), inland water monitoring, glacier monitoring and ice extent and snow cover mapping. Burnt area mapping and fire severity estimation
Sentinel-3	3 satellites	Multipurpose mission with multiple instruments, mainly for sea-surface as well as sea and land ice topography, sea- and land-surface temperature, ocean- and land-surface colour, seawater and inland water quality and pollution monitoring, land use change monitoring, forest cover mapping, fire detection, marine and general weather forecasting, snow cover monitoring, measuring earth's thermal radiation for atmospheric applications and last but not least for overall environmental and climate monitoring and modelling.
Sentinel-4	*Sentinel-4* will be placed on geostationary Meteosat	Monitoring of the composition of the atmosphere for air quality, stratospheric ozone and solar radiation as well as climate monitoring
Sentinel-5	*Sentinel-5* plus Sentinel-5 precursor are carried on the polar-orbiting MetOp	Monitoring of the composition of the atmosphere for air quality, stratospheric ozone and solar radiation as well as climate monitoring

- Sentinel-5 provides Sentinel-4 in the provision of atmospheric composition data.
- Sentinel-6 will contribute to the precision altimetry missions (see Jason-2 satellite lens).

Table 1 summarizes the Sentinel missions and their main applications, but obviously it is expected that the integration and complementary use of diverse data source and services will provide improvements in cultural heritage monitoring and management.

Copernicus marked the beginning of a new era in earth observation. The first Sentinel satellites have been launched, and a huge amount of data (big earth data) is now available throughout the globe together with other information (such as weather forecasts at different space/time scales, pollution and air quality forecasts, etc.). The amount of data that is now being created and stored globally is enormous and is constantly growing.

The constellation Copernicus has changed the paradigm with which the citizen is related to the spatial datum, because it is open access, available to all. Therefore, space is a huge opportunity for a society, today, that evolves very quickly and offers challenges and opportunities. In the light of recent sensor developments and data availability, innovative models and methodologies are needed for data analysis and the integration of different information, as well as new strategies for the exploitation.

However, despite the increasing availability of data, information and forecasts on the one hand and the increasing impact of natural and artificial disasters, the monitoring and documentation activities have been limited to date.

Therefore, there are important challenges and opportunities related (i) to the extraction of information, (ii) to the integration of different data sources, (iii) to the efficient management and (iv) to technology transfer.

Copernicus is, therefore, an important element for scientific progress and the development of European industrial capacities and generates opportunities for innovation by allowing not only the improvement of existing monitoring and control systems but also and above all the development of new applications and services with high added value (known as "downstream" sector).

Copernicus portfolio services (https://services-portfolios.copernicus.eu/) provide around 1092 operational products (http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Services_overview) which are essential information for the 6 main Copernicus domains: ocean, land and atmosphere monitoring, emergency response, security and climate change that are another critical issues for both CH and SDGs. Moreover, the evolution of services and products is part of the Copernicus initiatives ranging from the research activities to the set operational services up. Nowadays, diverse Copernicus services "have reached different degrees of maturity. Some were already declared operational several years ago (in 2012 for the Land Monitoring Service and the Emergency Management Service – Mapping, in 2015 for the Atmosphere Monitoring Service and the Marine Environment Monitoring Service) while others were declared operational more recently (in 2016 for the Border Surveillance and Maritime Surveillance components of the Security service and in May 2017 for the Support to External Action component) or are still in their development phase (Climate Change Service)".

All the Copernicus services are based on information from Sentinel satellites (shown in Table 1) and from the so-called "participating missions, supplemented with data obtained from in situ (i.e. local) sensors and aerial/drone survey. In sections "Copernicus Satellite Data and Cultural Heritage" and "Aerial Data for Cultural Heritage" a brief overview on satellite, aerial data for CH is provided, in order to highlight that the capability to extract information from data is linked with the capability to integrate data and info available from diverse sources to transform data into knowledge.

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Copernicus Satellite Data and Cultural Heritage

Even if still today the applications of RS data in operational disaster management and monitoring are still difficult tasks, the recent improvements in EO (including both active and passive sensors from satellite, aerial and in situ technologies) offer data which can enable new applications specifically for the documentation and assessment of heritage sites. To this aim, a dedicated workshop was organized by EU on 01/09/2017 (http://ec.europa.eu/growth/content/copernicus-cultural-heritage-workshop-0_en) which focussed on the characterization and mapping of Copernicus capabilities and existing solutions over user needs and the identification of potential solutions to effectively support cultural heritage. The workshop aimed to (i) "identify the main user requirements for space-based applications associated with the preservation and management of cultural heritage assets" along with (ii) opportunities for standardization taking into account "what is already being done in some European countries, with risk assessments associated to each cultural asset also taking account of environmental risks". AU5

The use of satellite data for CH has more paid great attention worldwide, due to the following aspects:

(i) The improvement in spectral and spatial resolution reveals increasing detailed information for CH purposes.
(ii) The synoptic view offered by satellite data helps us to understand the complexity of CH investigations at a variety of different scales.
(iii) Satellite-based digital elevation models (DEMs) are widely used in CH for several purposes to considerably improve data analysis and interpretation.
(iv) The availability of long satellite time series allows the monitoring of hazard and risk in CH sites.
(v) Remotely sensed data enable us to carry out both inter- and intra-site prospection and data analysis.

Nowadays, in some fields, as urban sprawl (see Fig. 2), land degradation, fire, drought, flooding and extreme weather events disturbances, biological risks, etc., remote-sensing-based techniques are promptly ready for an operational use in natural heritage monitoring and risk assessment, whereas for other applications it is necessary to improve the capacity in the use of satellite data to monitor the state of conservation of cultural heritage. For example, Sentinel-1 is a SAR in C band and, therefore, provides useful data for monitoring and mapping urban deformation and land subsidence, as well as for detecting structural damage and/or underground construction thus improving risk estimation and safety and at the same time contribute to reduce economic loss.

SAR enables us to overcome some limitations of optical imaging providing (i) all weather acquisitions (ii) at any time of day or night and (iii) capable to "penetrate" (to some extends) vegetation and/or soil depending on the antenna wavelength, surface characteristics (ice, desert sand, close canopy, etc.) and conditions (moisture content). SAR has shown the great potential for site CH monitoring and as well as

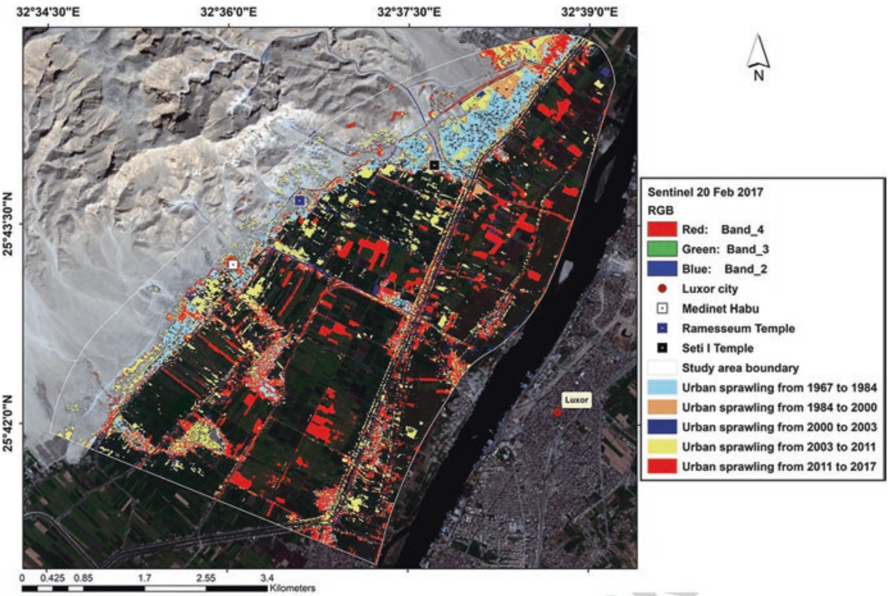

Fig. 2 Urban sprawl 1984–2017 automatic detection around the Luxor (Egypt) archaeological area (in Elfadaly et al. 2018)

for landscape archaeology and the detection of buried or emerging archaeological remains (Chen et al. 2014, 2016, 2018; Stewart 2017). Although several achievements have been made in recent years, the SAR remote sensing is still today underexploited for CH.

The availability of Sentinel-1 free of charge for all can really make the difference in the next future, being that over the years, one strong limitation in the use of SAR satellite data has been the difficulty in accessing to the data and the complexity of processing. Moreover, new promising applications of data integration include the use of SAR with other remote-sensing methods including optical data, in situ acquisition as well as aerial survey (Lasaponara et al. 2017).

The availability of high-resolution satellite data has been so rapidly growing that new problems have arisen mainly linked with methodological aspects of data analysis. In this context, the main concern is the lack of correspondence between the great amount of remote-sensing images and effective data processing methods capable to integrate data from diverse sources (EO and traditional data), to reliably enhance and to automatically process the data. Presently, the great amount of services including climatic ones along with multisensor data from Copernicus missions will suitably support new promising applications for the preservation of CH that is today one of the topics of great economic and social significance, so that, for the first time, culture was included in the 2030 Agenda for Sustainable Development. Therein culture was recognized as a “driver of economic, social and environmental development as at the heart of humanity, shaping human beliefs, hopes and interactions" (https://www.iccrom.org/transforming-our-world-iccrom-and-2030-agenda-sustainable-development). Among the 17 SDGs of the 2030 Agenda, 8 are relevant to culture heritage preservation, and the current and future challenge is to provide member states with particular reference to Middle East area "with the tools, knowledge, skills and enabling environments to preserve cultural heritage in all its forms, for the benefit of all people". In this context, it is important to highlight that cultural heritage and historical landscape especially, where heavily influenced by human activities, have to be systematically monitored and accordingly managed to be preserved. In the past decades, many countries across the world have been involved and are today experiencing an increasing frequency and impact of disasters, such as extreme hydrometeorological events, most probably related to climate change, floods, landslides, earthquakes, volcano eruptions, fires, uncontrolled urbanization and air pollution (Lasaponara and Masini 2017). In order to face with the increasing frequency and adverse impact of disasters, it is necessary to set up systematic monitoring activities and tools to identify issues and changes that can destroy or deteriorate heritage increasing its vulnerability. This may require the use of heterogeneous data essential to identify the major threats as well as to reconstruct the historical landscape and to compare it with the current one, in order to detect remains of the past, analyse the transformations and detect ongoing changes and potential threats.

Aerial Data for Cultural Heritage

A wide availability of digital technologies, acquired from passive and active aerial sensors, as multi-hyper-spectral sensors, SAR and laser scanning, historically had provided data and information useful to address manifold strategic challenges, thus opening a new horizon for many application fields including CH and archaeological investigations also addressed to virtual 4D modelling, augmented reality, etc.

Aerial Archaeology

Historically, aerial photography has been the first remote-sensing tool extensively used for digital archaeology for surveying emerging archaeological remains as well as for detecting underground archaeological structures through the reconnaissance of proxy indicators, generally known as "soil", "crop" and "shadow" marks (Wilson 1982).

Crop marks are linked to the presence of buried walls and/or filled ditches in vegetated areas. They produce local variations in moisture and nutrient content and, consequently, in the growth of vegetation, which can be revealed by differences of height or colour in crops (Evans and Jones 1977) 8; Masini and Lasaponara 2017). AU6 Using multispectral and hyperspectral images, crop marks can be detected by spectral variations in specific channels more sensitive to vegetation (as near-infra-

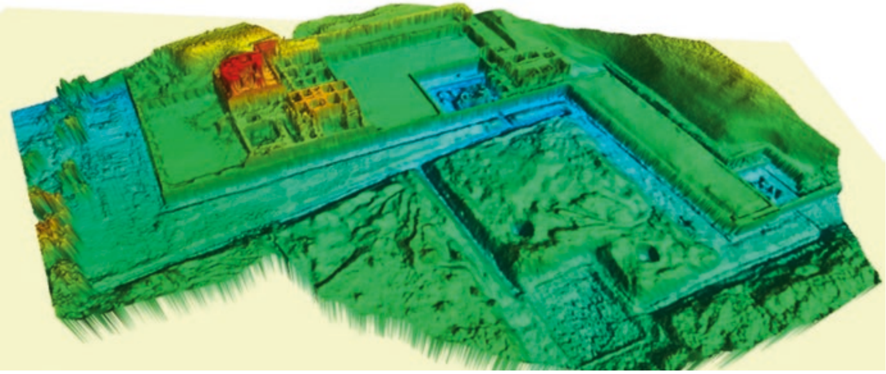

Fig. 3 3D model of Acclawasi palace in Pachacamac (Peru) obtained by structure from motion applied to images taken from a drone

red) or spectral indices (i.e. mathematical combinations of different spectral channels) as NDVI (Doneus et al. 2014; Agapiou et al. 2016).

Damp marks occur when there is presence of archaeological deposits, such as buried walls, filled ditches and pits, etc. They induce local changes in the drainage capability of the soil and can be revealed by changes in colour or texture exploiting spectral variations in specific channels more sensitive to moisture or spectral indices (i.e. mathematical combinations of different spectral channels) as NDVI, NDWI, etc. AU7

Finally, shadow marks are micro/medium microtopographic relief linked to archaeological remains, as artworks, platforms, ditches and shallow remains, and they can be revealed by the presence of shadow (Fig. 3). AU8

The visibility of the traces of archaeological interest appearing as (in many cases subtle) crop/weed, soil and shadow marks has a great intra- and inter-year variability due to changes in crop types and phenology, soil moisture content and other surface parameters (Masini et al. 2018a). Additionally, the visibility of microrelief depends on many factors, such as off-nadir viewing angle of the collected imagery, time of image acquisition, view geometry, sun angle (microtopographic relief variations are more visible in early morning or late evening) and surface characteristics; in particular, the presence of vegetation can completely cover the microrelief. These limitations can be overcome by (i) UASs and (ii) airborne laser scanner (ALS), also referred to as light detection and ranging (LiDAR).

Currently, a LiDAR survey could be carried out by using two different types of ALS sensor system: (i) conventional scanners or discrete echo scanners and (ii) full-waveform (FW) scanners (Doneus and Briese 2006). The first delivers only the first and last echo, thus losing many other reflections. The second is able to detect the entire echo waveform for each emitted laser beam, thus offering improved capabilities especially in areas with complex morphology and/or dense vegetation cover (Fig. 4).

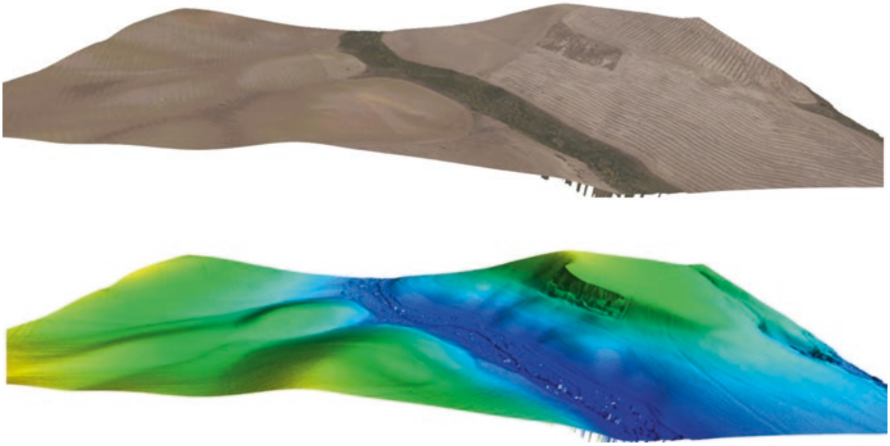

Fig. 4 Airborne laser scanning survey aerial photo (up) and DTM (bottom) obtained after the removal of vegetation cover along a river

ALS systems are generally made up of different components which contribute to the final accuracy of the range data. All the components should be accurately calibrated and integrated.

Nowadays, ALS is regarded as a well-established tool used for archaeology and cultural landscape studies. The majority of published studies are based on data collected by conventional ALS, for the management of archaeological monuments, landscape studies and archaeological investigations to depict microtopographic earthworks in bare ground sites and in forested areas (Canuto et al. 2018; Chase et al. 2011, 2017; Doneus et al. 2008; Evans et al. 2013). AU9

LiDAR sensors are also mainly powerful tool for investigating archaeological heritage in densely vegetated sites (as wooded areas, rain forests, etc.). ALS can penetrate vegetation canopies and model accurately underlying terrain elevation. The discoveries of Evans et al. (2013) in Angkor and of Chase in Belize (Chase et al. 2011) demonstrate the effectiveness of this technology for archaeological research (Fig. 5).

LiDAR provides direct range measurements mapped into 3D point clouds between a laser scanner and earth's topography. The high detail of the digital terrain models allows us a precise characterization of geomorphological features and the identification of relief linked to human activity. The interpretation of LiDAR products aimed at identifying potential traces of cultural interest is based on the visual criteria and the degree to which the features appeared anthropogenic versus non-anthropogenic: shape, pattern, texture and shadow, as in the case of passive data (from the panchromatic to multispectral and hyperspectral imagery). To this aim, it is crucial (1) to process the point clouds and classify terrain and off-terrain objects by applying adequate filtering methods, in order to obtain very accurate DTM; (2) to "manipulate" the DTMs with appropriate techniques of visualization, such as Sky View Factor, Openness, Local Relief Model (Hesse 2010; Zakšek et al. 2011;

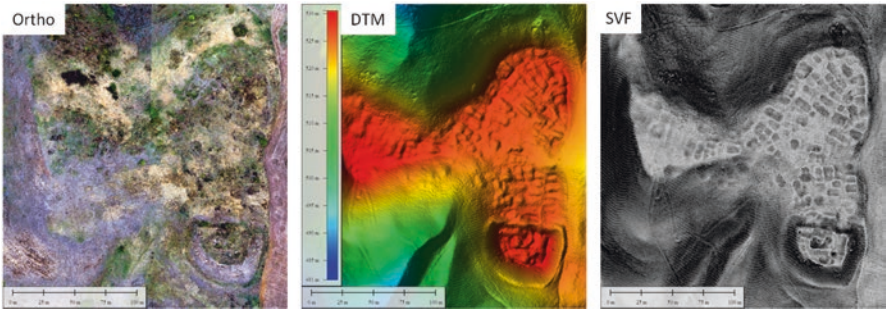

Fig. 5 LiDAR-based investigation of the mediaeval village of *Yrsum* near Matera (Southern Italy) founded in the eleventh century and abandoned in the fifteenth century. The microrelief visible from the DEM derived from LiDAR (middle) is more significant in respect of the crop marks of the optical image (left). The Sky View Factor map (right) allows to extract in an automatic way the urban shape of the village

AU10

Doneus 2013), aimed at emphasizing changes of topography, discontinuities of the landscape, platforms and any kind of earthworks attributable to the human work. In some cases the post-processing based on visualization techniques is fundamental to understand the urban shape of settlements and to identify the main building phases (Lasaponara et al. 2009, 2010; Masini et al. 2018b)

UAV Systems

The increasing technical developments of aerial sensors in terms of miniaturization and data quality offer an invaluable opportunity and at the same time pose several challenges related to the acquisition, processing, integration, analysis and interpretation and above all standardization of the diverse data acquisition and processing steps in order to ensure full operational applicability. Undoubtedly, compared to traditional aerial survey, the unmanned aerial vehicles (UAVs) offer several advantages, particularly low cost and ability to cover large areas in a short time (Campana 2017) under a wide range of wind and weather conditions.

In particular, drone is also useful for aerial thermography (Casana et al. 2014), for which it is mandatory to capture imagery in a short window of time when the contrast in thermal inertia is highest between the target and the background, generally sunrise or sunset. In addition, to reduce the possible changing in thermal values due to difference in the superficial/environmental characteristics, the area under investigation should be surveyed in a time as short as possible.

Moreover, the low altitude of UAV operations along with the improved technical imaging systems enable very detailed surveys with spatial resolution significantly higher compared to those obtained from satellites or manned aircraft. For this reason, drone is especially useful in archaeology before, during and after excavation. In particular, (i) before the excavations, detail achieved by drone photography and derived results including orthophoto and DEM allows us to identify potential archaeological proxy indicators and (ii) during and after the excavations provides fast and detailed surveys for documentation related both to the advancements in the excavation virtual reconstruction, etc.

Additionally, the rapid response of UAV imaging systems has received a lot of attention also for CH risk monitoring and post disaster damage assessment.

The recent continuous technological developments in UAV platforms, sensors and image processing techniques have resulted in a rapidly increasing use of these platforms and sensors for remote-sensing applications with new potential in cultural heritage. UAV platforms equipped with sensors for RGB, multispectral, hyperspectral and thermal imaging, as well as with laser scanning, miniature RADAR and passive microwave radiometers, have demonstrated high capability in traditional CH research fields and significant research opportunities in novel UAV-based applications. This is opening up a vast new area of opportunities in remote sensing for cultural heritage for the survey, mapping, monitoring and management. Additionally, UAVs have been traditionally used to test new sensors or integration of instruments, and the continuous improvements in data processing techniques as well as the development of ad hoc processing workflows devised for the specific application issues will allow us to address novel research questions.

Final Remarks: Integrating EO and Social Science New Frontiers of Earth Observations

The preservation of cultural heritage is a pressing issue, especially for the territories subjected to a long period of human action that has adversely influenced both environment and landscape, producing a significant deterioration of archaeological features and alteration of historical landscape, so that for the first time, culture was included in the 2030 Agenda for Sustainable Development, including 17 Sustainable Development Goals (SDG) to transform our world. Therein culture was recognized as a "driver of economic, social and environmental development as at the heart of humanity, shaping human beliefs, hopes and interactions" (https://www.iccrom.org/transforming-our-world-iccrom-and-2030-agenda-sustainable-development). Among these 17 SDGs, 8 are relevant to culture preservation, and the current and future challenge is to provide member states with particular reference to Middle East area "with the tools, knowledge, skills and enabling environments to preserve cultural heritage in all its forms, for the benefit of all people".

The today available digital tools, with particular reference to Copernicus initiatives, make possible to characterize and early understand the state of preservation of cultural properties to identify ongoing changes and assess the effectiveness of conservation and management strategies also addressed to "preventive restoration", namely, systematic strategic maintenance planned according to the real status of the cultural properties before its deterioration.

The different areas of intervention for CH require the availability of rigorous information for study and documentation, protection and conservation, monitoring, risk assessment and management. In particular, the structural, environmental and microclimatic monitoring is a crucial activity for preserving an important part of the CH to assure a proper conservation of buildings, statues, frescoes, paintings, artworks and also ancient books, tools and artefacts. It is important that management strategies will include the systematic monitoring of structural and environmental parameters as a crucial activity for preserving CH. The full exploitation of data provided by diverse sensors (from aerial, space and ground acquisition) and the usage of 3D models, acquired from airborne and terrestrial laser scans, impose the integration of all the available information (in digital and not digital format).

AU11

Remote sensing is particularly useful in providing regular and repeated imagery (even for less accessible areas), of unparalleled importance for monitoring the effects of climate change, urban and rural development, degradation, damage from disasters or voluntary destruction, etc. For countries with fledgling sites and monument records, EO provides the only cost-effective means for CH monitoring and preservation as well as for locating and defining archaeological sites and landscapes.

Space technologies have multiple potentialities serving numerous applications in the cultural heritage ranging from the documentation and monitoring to the management and preservation. One of the most important steps for all the diverse applications is the information extraction and the interpretation. The final results are generally useful information depicted as beautiful pictures that have also the potential to show complex phenomena as paintings or pieces of art. This suggests the possibility of wide dissemination showing to end users and citizens (in museums or schools and other public spaces) the results of the researches using a simple but very effective language as the images are.

Therefore, the main challenge is to (i) fully involve the citizen also from an emotional point of view in the process on monitoring and preservation of cultural properties and landscape and (ii) better exploit the EO and advanced data processing methods to assess and monitor both natural and man risks affecting CH at different scales of intervention, from landscape down at a single building view, with particular reference to Copernicus missions and services. Remote sensing is a key tool for the knowledge, management, monitoring and preservation of cultural and natural heritage, but at the same time the challenge is to fully involve the citizens also from an emotional point of view in the process on monitoring and preservation of cultural properties and landscape.

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