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RESULTS PACK ON CULTURAL HERITAGE

Heritage at Risk: EU research and innovation for a more resilient cultural heritage

Research and Innovation

EDITORIAL

HERITAGE AT RISK: EU RESEARCH AND INNOVATION FOR A MORE RESILIENT CULTURAL HERITAGE

Neglect, pollution, natural hazards and climate change are all playing their part in the damage to cultural heritage. This non-renewable resource, in all its diverse physical forms, needs safeguarding for future generations. EU-funded research projects, including those showcased in this new CORDIS Results Pack, have been carefully investigating the preservation and the sustainable management of these valuable assets to increase their overall resilience. Innovative solutions and techniques, assessment systems, mitigation strategies, risk management models, disaster prevention, quick damage assessment, ICT tools and guidelines have been some of the major results successfully delivered by both FP7 and H2020 projects in the field of cultural heritage.

Cultural heritage has a universal value for us as individuals, communities and societies. Rather than being static, heritage evolves through our engagement with it and our heritage has a significant role to play in building the future of Europe. All these factors feed into the European Union's decision to make 2018 the European Year of Cultural Heritage.

The cultural heritage of the European Union is a rich and diverse mosaic of cultural and creative expressions: our inheritance from previous generations of Europeans and our legacy for those to come. It includes natural, built and archaeological sites, museums, monuments, artworks, historic cities, literary, musical and audiovisual works, and the knowledge, practices and traditions of European citizens.

This richness is not just something we have to preserve, it also gives back in the form of economic growth, employment and social cohesion. Cultural activities and artefacts offer us the potential to revitalise urban and rural areas and promote sustainable tourism.

Our heritage: our children's inheritance

EU research projects have been carefully investigating the preservation and sustainable management of vulnerable artefacts and sites. Innovative solutions and techniques, assessment systems, mitigation strategies, risk management models, disaster prevention, quick damage assessment, ICT tools and guidelines have been some of the major results successfully delivered by FP7 and H2020 projects on cultural heritage.

While how to go about preserving artefacts and sites is primarily the responsibility of Member States, the EU focusses on safeguarding and enhancing Europe's cultural heritage through a number of policies and programmes, such as support for research.

Some of the projects presented in this brochure achieved results that include advanced social and technical solutions. Others have developed guidelines and recommendations for experts and policy-makers. All these results will contribute to increase the resilience of heritage sites facing disasters, climate change, mutating environments and conditions etc.

Contents

History lessons for a more resilient future

A wide-ranging EU-funded analysis of rural Western European societies, spanning a period of 500 years, has identified common characteristics that make some societies more resilient against disaster than others.

The COORDINATINGforLIFE (Coordinating for life. Success and failure of Western European societies in coping with rural hazards and disasters, 1300-1800) project has found that while rising inequality in itself does not necessarily lead to higher vulnerability, the presence of intermediary groups is often crucial.

Village communities, water management organisations and charities, for example, have historically played a key role in helping societies to prevent and recover from disasters. But with the decline of these middle groups their success in this dwindled. Moreover, the project has shown that when rises in material inequality are not addressed by way of institutional changes, societies do become more vulnerable.

Another key finding has been that while some groups have proven to be highly vulnerable to hazards, others have always managed to escape the 'storm'. "It is therefore not societies that are hit by a disaster, but very specific groups within society," explains COORDINATINGforLIFE project coordinator Professor Bas van Bavel from Utrecht University in the Netherlands. "We feel this approach could be a vital antidote against too much of a focus on systemic vulnerability."

Durable societies

Launched in 2014 and due for completion in 2019, the COORDINATINGforLIFE project has focused on Western Europe in the period between 1300 and 1800. Comparative analyses over this timespan have been carried out to try and identify what determines resilience. Today, societies around the world will likely be confronted with more disasters in the coming decades, particularly as a result of climate change.

"This makes it crucial to better understand why some societies appear able to prevent hazards from becoming disasters or, if disasters happen, to cope with them and quickly recover," says Prof. van Bavel. "There is also a growing consensus that relying on technological solutions and material resources alone will not suffice."

Prof. van Bavel points out that wealthy and technologically advanced countries are not spared disasters, as demonstrated all too clearly by the Fukushima disaster in Japan. This is why answers are increasingly being sought in the organisational capacities of society. "We know very little, however, about what these capacities are, and why they sometimes are successful in facilitating recovery and sometimes not," says van Bavel.

"It is not societies that are hit by a disaster, but very specific groups within society"

History as a laboratory

The approach taken by the project has been to consider history as a living 'laboratory', where historical records can be analysed to test hypotheses. The long historical perspective of the project has enabled the team to compare widely differing cases and achieve insights into the relative performance of these societies.

"Another interesting element of this project is that it combines history and historical methods with insights and expertise from economics, geography and climatology," says Prof.

van Bavel. “Our work has relevance for scholars working in the natural sciences, including the fields of climate change and epidemics. A key aim has been to enrich their understanding of present risks by adding an historical perspective.”

The project team is currently working on a textbook entitled ‘History and Disasters’ – aimed at a wide audience of scholars from all disciplines, students and practitioners – and is developing links between historical research and current policy. This is being achieved not only through disseminating findings, but also through direct contact.

“Project members are actively involved in networks on current climate change research and policy and contribute to briefing documents aimed at academics, NGOs and government agencies,” says Prof. van Bavel. “Moves to integrate historical knowledge into present-day flood protection schemes have already resulted in active collaboration in a Belgium-Dutch Estuary Restoration project (the Hedwige-Prosperpolder project), as well as several targeted presentations. In the longer term, this may result in a tech-transfer project, provisionally labelled ‘Building with nature and history’.”

Project	**COORDINATINGforLIFE - Success and failure of Western European societies in coping with rural hazards and disasters, 1300-1800**
Hosted by	Utrecht University in the Netherlands
Funded under	FP7-IDEAS-ERC

Malta: a case study in the rise and fall of civilisations

Evidence from ancient cereal pollen samples, erosion and tree felling has given EU-funded scientists the clearest picture yet of the complex and hidden history of ancient Malta. The findings could help us understand how cultures become sustainable, or collapse.

Humans arrived in Malta at least 700 years earlier than previously thought, the ground-breaking Fragsus (Fragility and sustainability in restricted island environments: adaptation, cultural change and collapse in prehistory) project has revealed. "Malta experienced two or three episodes of colonisation, possibly with gaps in human occupation of as much as 1 000 years," says project coordinator Professor Caroline Malone, from Queen's University Belfast in the UK. "This was never suspected before. In fact, little research has been directed towards understanding why colonial experiments fail or succeed on small islands."

This was a key objective of the Fragsus project, which has examined the impact of the first human settlements on Malta to assess the rapidity of deforestation, erosion and degradation. The results have sparked great interest in Malta, where tourism forms a critical element of the economy. They could potentially boost the conservation of valuable heritage sites on the heavily urbanised and populated islands. Over a quarter of the islands are already under concrete.

"Malta has some of the most distinctive archaeology in Europe, which has never been fully appreciated"

The project has also involved around 100 students in on-site excavation work and led to five ongoing PhDs, helping to ensure that Fragsus' work will continue into the future. A follow-on Marie Curie-funded project will now use project data to better understand Malta's ancient past.

Uncovering Malta's past

When Malta was first colonised in the 6th millennium BC, pristine soil and forest covered the landscape, but within centuries the landscape was bare and under intensive cultivation. A temple culture emerged out of this precarious environment, which was sustained over centuries. "There is something about small geographic spaces that gives rise to intense, complex social states," says Prof. Malone. "Think of Cyprus, or Easter Island." Some 2 500 years after the first settlement however, this unique and isolated socio-economic system apparently collapsed.

"Malta has some of the most distinctive archaeology in Europe, which has never been fully appreciated," explains Prof. Malone, who has spent more than 30 years pioneering excavations on the islands. "The rapid rise in population density, wealth and with it the destruction of the island's heritage and landscape made a pressing case for further investigation."

The team set itself some ambitious questions. For example, how did a very small island community in prehistoric times manage to sustain complex life over millennia and were the monumental temples instrumental in the process of sustaining cultural life? The Fragsus project also sought to identify the socio-economic or environmental failure at the end of the island's temple culture, which may have caused society to collapse or to drastically change.

"We tackled these questions through archaeological surveys and excavations as well as soil extractions containing ancient pollens and invertebrates," she explains. "The project has been a melting pot of ideas. We also analysed dietary and DNA data from a large burial complex to provide a human dimension to archaeological evidence." Finally, radiocarbon dating helped the team to build a robust chronological "calendar" of time and change on the islands.


© Fragsus

Fragile past, fragile future

Some of the findings of the project, which ended in April 2018, are on show at an exhibition at the National Museum of Archaeology of Malta in Valletta. This show encapsulates the project's ambition of raising awareness of Malta's unique and little-understood ancient past, which in many ways echoes current environmental predicaments on the densely populated and urbanised islands.

"We hope archaeological approaches will be transformed," says Prof. Malone. "We have highlighted the importance of gathering DNA samples and shown that this can be done in southern Europe, where previously it was thought that heat damage made this impossible."

Project results will continue to be published for some time to come, while digitised human remains can be used in further studies. "Our hope is that Fragsus will have a lasting impact on conservation work in Malta, and that this will be accelerated in the future," she adds.

Project	**Fragsus – Fragility and sustainability in restricted island environments: adaptation, cultural change and collapse in prehistory**
Coordinated by	Queen's University Belfast in the United Kingdom
Funded under	FP7-IDEAS-ERC
Project website	http://www.qub.ac.uk/sites/FRAGSUS/

Cultural heritage given platform to cope with climate change

An innovative ICT platform will provide decision-makers with vital information to help them prioritise cultural heritage investments and act decisively to strengthen the resilience of sites against climate change.

The impressive diversity of cultural heritage assets in Europe, together with a range of different climatic regions, creates a complex picture that requires different adaptation policies for conservation. The EU-funded HERACLES (HEritage Resilience Against CLimate Events on Site) project has sought to address these challenges by developing a modular IT platform system that allows for customisation suited to different needs and standards.

The platform collects and integrates multisource information – including satellite imagery of heritage sites – to support informed maintenance and conservation decisions. The HERACLES project brings together information gathered from multiple sources, notably end users, in a kind of crowd sourcing cultural heritage exercise.

Context analysis, site health analysis and risk analysis feed into the platform, which then delivers historic data, thematic maps and 3D models. Conservationists and archaeologists can use these outputs to gain access to run analyses that take into account climatic change impacts and develop specific models for monitoring and mitigating these risks. The platform will be commercially available to cultural heritage decision-makers upon project completion in April 2019.

"We want to create a more culturally conscious society"

"What makes this platform unique is that it can provide a huge amount of data that is targeted to specific site needs," explains project coordinator Dr Giuseppina Padeletti from the National Research Council in Italy. "To the best of my knowledge, there is nothing like this currently available." Other platforms for example might provide data that can only be used in specific circumstances.

On top of this, the HERACLES project also aims to raise awareness of the need for climate change resilience within the cultural heritage sector, a complex domain that involves so many social, political and expert actors and issues. "We want to create a more culturally conscious society," adds Dr Padeletti.

Putting findings into practice

All work has been validated at two challenging cultural heritage sites – the historic town of Gubbio in central Italy and Heraklion on the Greek island of Crete. These sites were selected because they exemplify the threats posed by climate change to cultural heritage.

"We began by studying the key problems affecting both of these sites, with the aim of developing generalised methods and solutions that are applicable across Europe," explains Dr Padeletti. "We also wanted to select two sites where people live and work, and which are part of the fabric of daily life."

Gubbio, located in a seismic region in Umbria, is a beautiful Medieval town built into the side of a mountain. Like many medieval towns, it is ill-equipped to deal with high intensity rainfall, which can cause landslides and erosion. In Heraklion on the Greek island of Crete meanwhile, rising sea levels and intense waves threaten the sea fortress of Koules, while high winds and salty air are corroding the 4 000-year-old Palace of Knossos, home of the mythical Minotaur and one of the finest examples of early Mediterranean civilisation.


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The team confirmed that climate change poses an existential threat in numerous ways. For cultural sites, this can mean monuments being swept into the ocean due to rising sea levels and more intense storms or being gradually eroded due to heavy rains and landslides. No matter where a cultural asset is, the effects of climate change are present.

Building up resilience

The HERACLES project has also sought to raise awareness about cultural heritage being an integral and vital part of European daily life. "There is a strong social and economic aspect to cultural heritage," notes Dr Padeletti. "Local people often feel incredible attachment to the cultural heritage that surrounds them and often depend on heritage sites for economic revenue through tourism. In this respect, historic towns are living assets that the inhabitants feel motivated to protect."

At the same time, Europe has experienced serious economic crises that have led to spending constraints and tightened public investments. Cultural heritage is not always viewed as a priority by governments. In this respect, the HERACLES platform will help decision-makers to prioritise restoration and development work. New methodologies and protocols on identifying sites in need of climate resilience have also been developed and are now freely available on the project's website.

As the project enters its final year, Dr Padeletti is looking forward to collecting more data and further refining the platform. Providing access to targeted data on climate change resilience will help to ensure that future generations are able to enjoy our shared European heritage in places such as Gubbio and Heraklion.

Project	**HERACLES - HEritage Resilience Against CLimate Events on Site**
Coordinated by	National Research Council in Italy
Funded under	H2020-ENVIRONMENT and H2020-SECURITY
Project website	http://www.heracles-project.eu/

Cooperation key to tackling cultural heritage threats

While Europe's rich and varied cultural heritage is increasingly at risk due to human action and climate change, cooperative EU-funded actions have shown that pooling national resources can strengthen resilience and achieve results that benefit everyone.

Three projects, all funded through the HERITAGE PLUS (ERA-NET Plus on Cultural Heritage and Global Change Research) project, have successfully applied space technology to monitor the vulnerability of cultural heritage, produced practical manuals on threats for use by governments, global organisations and NGOs, and developed new tools to cost-effectively preserve Europe's cultural treasures. These EU-funded projects underline the value of bringing together expertise and resources from across Europe to protect our shared European heritage.

HERITAGE PLUS is an ERA-NET Plus action coordinated by the Joint Programming Initiative on Cultural Heritage and Global Change (JPI CH). It receives top-up funding from the European Commission to support transnational research projects on topics such as tangible cultural heritage and developing new methodologies, technologies and products for assessing, protecting and managing historical and modern artefacts, buildings and sites.

"The HERITAGE PLUS initiative enhances European excellence and competitiveness by developing current knowledge on the challenges facing cultural heritage, to forecast its future change"

Ms Cristina Sabbioni, one of the JPI CH coordinators, explains, "The HERITAGE PLUS initiative enhances European excellence and competitiveness by developing current knowledge on the challenges facing cultural heritage, to forecast its future change. This is done based on mainstreaming political decisions and on environmental dynamics to understand the impact on tangible, intangible and digital cultural heritage."

Eyes in the sky

One such project is Prothego (PROTection of European Cultural HEritage from GeO-hazards), which has, for example, introduced satellite monitoring techniques to analyse geo-hazards at UNESCO World Heritage sites across Europe. These sites, from archaeological complexes to historic town centres, are often impacted by natural hazards such as extreme weather, all of which have been worsened by climate change and human interaction.

"A comprehensive picture of sites affected by geo-hazards has not been made available," explains Prothego project coordinator Daniele Spizzichino, from the Italian Institute for Environmental Protection and Research. "This lack of information means that vulnerability assessments of cultural heritage have been neglected."

Low impact monitoring techniques using satellites have the potential to spot vulnerabilities early and save money on post-disaster recovery. A key outcome of this project has been the successful application of new space technology to the cultural heritage sector, capable of monitoring surface deformation with millimetre precision. Over 400 UNESCO World Heritage Sites in Europe were analysed and data integrated with existing databases of geo-hazards. This enables the project team, working closely with partners such as the UK's Natural Environment Research Council and the Cyprus University of Technology, to identify and rank the most critically endangered cultural heritage sites over the whole of Europe.

"The Prothego project successfully brought cultural heritage conservation and earth and space sciences together," says Spizzichino. "New potential markets for low impact monitoring techniques have been identified and promoted. Our hope now is that the Prothego approach will be enlarged and implemented across all European cultural heritage (not just to UNESCO WHL)."

Understanding threats to CH

The HeAT (Heritage and Threat) project has also addressed gaps in our understanding of threats facing cultural heritage, something that can limit effective policy-making and intervention.


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The project sought to address this situation through: a systematic analysis of threats across different geo-cultural locations; producing practical manuals for use by governments, global organisations and NGOs; and holding small thought-provoking exhibitions to popularise some of its findings.

"For example, a number of books have been published that document threatened and contested heritage sites in Romania and Poland," says project coordinator Ingolf Thuesen from the University of Copenhagen in Denmark. "A web-based platform to better understand and visualise the destruction of cultural landscapes via map overlays was developed, as well as a short film on the impact of dam building projects in the Near East and Egypt on cultural heritage."

Achieving a deeper understanding of processes that lead to the destruction of cultural heritage will help policy makers to develop more proactive strategies. A publication entitled 'Conflict and Culture' will be launched together with a travelling exhibition in late 2018. "Although project findings will provide scholarly insights, we also aim to share our results with non-academic circles and close the gap between heritage research and heritage policy, decision-making and knowledge," adds Thuesen.

Preserving archaeological landscapes

The CLIMA (Cultural Landscape risk Identification, Management and Assessment) project meanwhile has focused on tackling threats to Europe's rich archaeological landscape. A practical and affordable multi-task tool providing decision makers with risk and warning maps of sites has been developed, along with a commercial service for monitoring degradation and planning preventive conservation activities. The tool makes extensive use of processed satellite data and ground-based data.

"The CLIMA project is a demonstrator of a specific technology and a specific approach to cultural heritage preservation," explains CLIMA project coordinator Stefano De Angeli from Tuscia University in Italy. "The service model is based on continual monitoring and risk forecasting, which triggers preventive restoration interventions instead of having to wait for far more expensive rehabilitation actions when it is too late. We believe this model has the potential to be extended to hundreds of sites across Italy and Europe." Protection of archaeological sites and landscapes will also have a favourable economic impact on surrounding regions, which often depend on tourism.

"A key lesson from this project has been the importance of close communication between partners," says De Angeli. "We were able to bring in disciplines like earth observation remote sensing, which have not to date been fully exploited. This has enabled us to make significant advances in our understanding of archaeological cultural landscapes."

Project	**HERITAGE PLUS – ERA-NET Plus on Cultural Heritage and Global Change Research**
Coordinated by	Ministry of Cultural Heritage and Activities and Tourism in Italy
Funded under	FP7-ENVIRONMENT
Project website	http://www.jpi-culturalheritage.eu/ec-projects/heritage-plus/

Ensuring that Europe's cultural heritage can weather climate change and natural hazards

Researchers with the EU-funded STORM project are building new technologies and processes to better protect and preserve Europe's cultural heritage against the threats of climate change and natural hazards.

Europe's cultural heritage is extremely exposed to climate change and natural hazards, which threaten its integrity and may compromise its sustainability. In the last four decades, numerous European institutions have carried out preventative strategies aimed at protecting the EU's cultural sites. Although all of these initiatives had prevention and public policy at their core, none addressed the issue of 'what to do next'. The EU-supported STORM (Safeguarding Cultural Heritage through Technical and Organisational Resources Management) project is considering that next step.

"The project started with the great ambition of building a common motivation framework among a wide group of varied competences. After the first period of STORM, we know that the methodology could work and now it is time to apply it in the field"

Putting prevention into practice

STORM uses the valuable information on prevention gathered during previous projects to create practical tools to safeguard Europe's cultural heritage. By making the processes user-focused and citizen-centred, STORM is bringing a new level of awareness about protection and prevention.

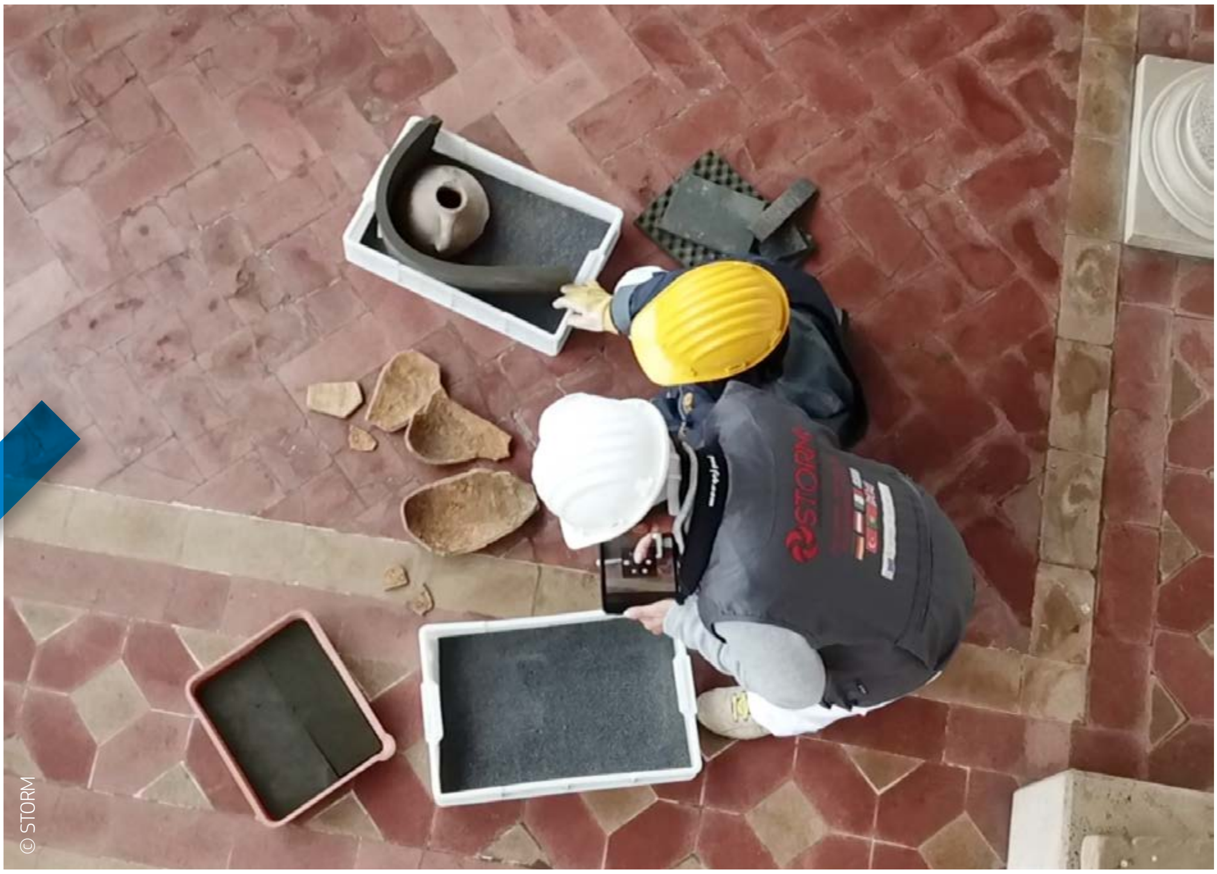
"STORM proposes a set of novel predictive models and improved non-invasive and non-destructive methods for surveying and predicting environmental changes, and for revealing threats and conditions that could damage cultural heritage sites," says Project Coordinator Dr Silvia Boi.

The project studies how different vulnerable material, structures and buildings are affected by extreme weather events, using a range of site-specific sensors and damage assessment tools.

"For example, our work at the site of the Bath of Diocletian used atmospheric monitoring to assess the impact of contaminants on the monument and microclimate monitoring aimed at the conservation of archaeological and monumental heritage." The project also conducted structural analysis of the monument, using a 3D laser scanner at different times and different places at the site, to provide data on vibrations caused by road and underground traffic. They assessed the environmental conditions and compared the arising data with meteorological parameters.

STORM uses intra fluorescent and wireless acoustic sensors along with survey and diagnosis technologies, including LiDAR and UAVs. In the next stages of the project, crowdsensing and crowdsourcing techniques will be put in place. These will offer applications and services over an open cloud infrastructure, resulting in a collaborative platform for collecting information and enhancing knowledge. Shared data will enable the development of processes and sustainable methodologies to safeguard and manage European cultural heritage.

Crowdsourcing information will be used during the Quick Assessment process when intervention is needed in the case of sudden hazards. It will ensure that the right actor is sent to the site at the right time. Those involved will be rigorously identified and selected during the trial scenarios definition and some exercises will be planned to evaluate the results of the response.



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Crowdsensing will be used to collect data on the specific hazards that are threatening the pilot sites. Volunteers such as tourists and students, along with those more expert, will be invited to upload certain data, including text and images. The project can then use this material to inform its activities.

From testing to in-field application

The STORM system is currently being tested in Italy, Greece, the UK, Portugal and Turkey. According to Dr Boi, the results from these five pilot sites will provide a consistent set of guidelines, best practices and lessons learned about the usage of the STORM technologies. This includes ground-based sensors and the damage assessment technologies, as well as situation awareness, risk assessment and management services to quickly detect and effectively mitigate natural hazards and climate change threats.

"It is every government's duty to assure the preservation and valorisation of national heritage, through the development of policies that are effective and inclusive. Policies need to contribute to raising awareness among local communities and institutions about the conservation of their heritage," says Dr Boi.

Current regulations and directives on the impact of climate change on cultural heritage, and national emergency plans, are not sufficient to cover the needs assessed by STORM. "There were weaknesses in specific directives provided by authorities, which creates a jeopardised situation in almost all the countries involved in the project," she explains. At the end of STORM, policy recommendations will be released to show a feasible pathway to improve the response.

"The project started with the great ambition of building a common motivation framework among a wide group of varied competences," says Dr Boi. "After the first period of STORM, we know that the methodology could work and now it is time to apply it in the field."

Project	**STORM – Safeguarding Cultural Heritage through Technical and Organisational Resources Management**
Coordinated by	Engineering Ingegneria Informatica S.p.A. in Italy
Funded under	H2020-ENVIRONMENT and H2020-SECURITY
Project website	http://www.storm-project.eu/
Video	https://bit.ly/2IlvNoc

Getting smart about cultural heritage

Researchers with the EU-funded SmARTS project have developed low-cost, easy-to-use devices for mapping, monitoring and analysing the surfaces of historical and archaeological artefacts.

New advances in open source and low-cost software and hardware mean new opportunities for analysing and preserving our shared cultural heritage. The EU-funded SmARTS (Smart technology for analysis and monitoring of Cultural Heritage materials) project is taking advantage of this new technology to produce low-cost, easy-to-assemble, easy-to-use and fully customisable devices for mapping, monitoring and analysing surfaces of historical and archaeological artefacts and structures.

"Free, open source software and hardware represent the core of a sustainable approach to cultural heritage conservation," says principal investigator Mainardo Gaudenzi.

"The use of smart technology, such as that being developed in the SmARTS project, is potentially a fast and reliable response to the lack of economic resources that many cultural heritage projects face," adds project coordinator Dr Judit Molera.

A range of devices

From a practical point of view, SmARTS is developing a range of devices for the inspection, monitoring and analysis of cultural heritage materials. Each device is based on free and open hardware and software and the principles of economic sustainability.

"We are developing devices that are scientifically reliable and fully comparable to off-the-shelf-devices," says Gaudenzi. "In fact, many of these devices are already being used by cultural heritage operators, technicians and professionals in general."

For example, the project designed a robot capable of using a non-destructive and non-invasive approach – paramount to handling the fragile surfaces so commonly found in the field of cultural heritage. The robot, which is equipped with an imaging system and a mini spectrophotometer, is already being used to analyse surface morphology and the colours of one of the largest collections of Catalan modernist hydraulic tiles. According to Gaudenzi, the data acquired has proven very useful in conservation and restoration actions.

The project also developed a range of data loggers for preventive conservation in museums, art galleries and historical archives. "We prototyped temperature, relative humidity and dew point data loggers, as well as devices for monitoring ultra violet and both visible and infra-red light irradiation," explains Gaudenzi. "These prototypes have been validated in both laboratory and real environments, and the excellent results have led to the design of other devices suitable for real time and remote monitoring in typical cultural heritage environments." Once finalised, the prototypes will be used by Barcelona's National Museum of Art of Catalonia (MNAC).

The principle target of these devices is not customers, but proactive end-users. "We don't just provide economically sustainable technology, we provide technology that can be easily assembled and disassembled and re-shaped, adapted, customised, enhanced and, finally, re-shared," explains Gaudenzi. "That's why we love to define our

"The use of smart technology, such as that being developed in the SmARTS project, is potentially a fast and reliable response to the lack of economic resources that many cultural heritage projects face"

technology not as end products, but as prototypes that are always in progress."

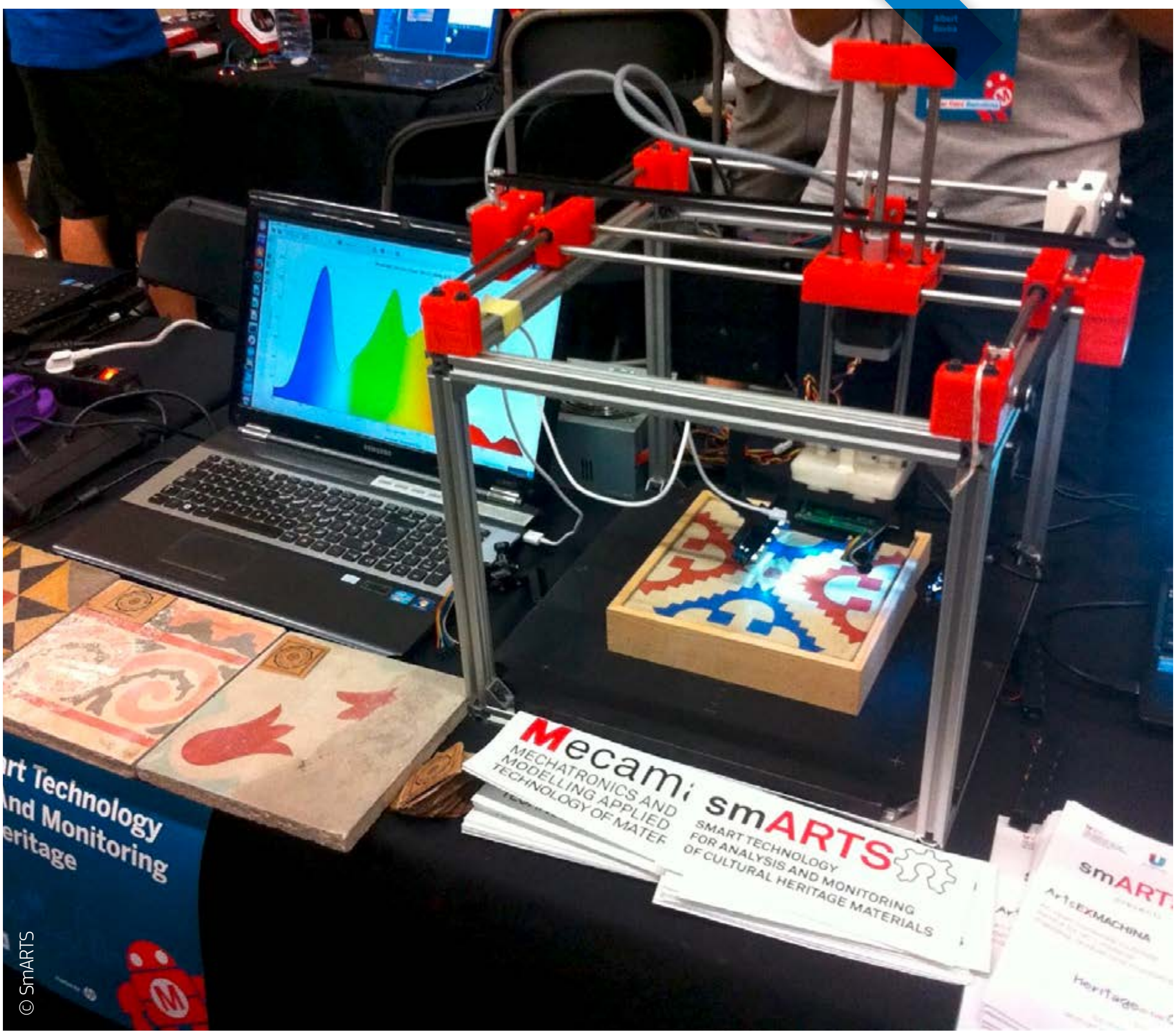
A convergence of technology

All-in-all, the SmARTS project is demonstrating the possibility of providing technological solutions capable of overcoming the idea of exclusivity and closeness and embracing the concepts of circularity and inclusion. "We strongly believe in the potential of knowledge-sharing," concludes Molera.

"We are firm believers that the convergence of technology acceleration, hyper-connectivity, and open and free access to data and technology, when combined with the global movement of citizen scientists, can represent a key factor in achieving truly sustainable development."

The project has successfully started collaborations with a number of museums, foundations and private companies. To keep this momentum going, researchers are currently looking for new funding opportunities at both the national and international levels.

Project	**SmARTS – Smart technology for analysis and monitoring of Cultural Heritage materials**
Coordinated by	Balmes University Foundation in Spain
Funded under	H2020-MSCA-IF
Project website	http://mon.uvic.cat/mecamat/smarts/



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New radiocarbon dating techniques reveal secrets of early Saharan civilisation

Latest research reveals that the Sahara was much more densely populated in the pre-Islamic era than previously believed. Findings now show that oasis settlements played an important role and that trade was developed alongside the spread of irrigated agriculture.

The key questions that arise from research into the desert region of North Africa concern the nature, sophistication and connectedness of the first oasis communities in the Sahara. The traditional view, fostered by the legacy of modern colonial government in North Africa, is that the Sahara was lightly populated apart from a few wandering nomads in the pre-Islamic age.

The EU-supported TRANS-SAHARA (State Formation, Migration and Trade in the Central Sahara (1000 BC – AD 1500)) project has challenged that position by exploring several key themes: trade, settlement type and economic activity, technological change, burial rites and identity, and migration.

"The TRANS-SAHARA project has re-oriented the future agenda of study of Saharan history and archaeology, with important implications not only for scientific study, but also for the national identity of Saharan and Maghrebian countries"

Ground-breaking discoveries despite severe constraints

The impossibility of conducting field research in the Libyan Sahara as a result of the 2011 civil war meant the project used satellite image analysis and targeted radiocarbon dating of mudbrick settlements to gather part of its data. "This enabled a dramatic expansion in knowledge of pre-Islamic oasis settlement in several Libyan oasis zones; with global publicity for the discovery of hundreds of towns and villages of the 'lost' Garamantian civilisation," explains lead researcher Professor David Mattingly.

The results clarify the scale and sophistication of Garamantian society, which, says Prof. Mattingly, began around 1000 BC. In the period AD 1-600 it arguably constituted the first pre-Islamic state of the central Sahara.

Development around oases earlier than thought

More recently, Moroccan fieldwork, starting with satellite mapping and follow-up ground visits to collect dating evidence (including another substantial suite of radiocarbon dates), has revealed a similar pattern of precocious oasis development. This, the project believes, is linked to other markers of social change (metallurgy, hierarchy and complexity). "The development seems to have occurred at a later date, beginning in the first half of the first millennium AD, with the region becoming influential in the formation of powerful Islamic states in the early medieval period," Prof. Mattingly explains.

One of the most remarkable discoveries of the Moroccan fieldwork was the discovery of a type of tomb with painted funerary chapels used for ancestor worship. So far TRANS-SAHARA has established a corpus of 20 painted human figures (such as the illustration), providing a remarkable window into desert society, dress, accoutrements and aspects of ritual and belief.

Prof. Mattingly intends to take these findings further, "We plan to excavate further tombs in a future phase of the project. Another of the Moroccan settlement sites has yielded a remarkable dossier of hundreds of engraved rock art images: mostly of horses with mounted warriors, seemingly linked to a horse cult of some sort. We believe that discoveries like these will help the Moroccan authorities develop visitor attractions/museums in the study zone."

Pioneering dating techniques provide a clearer idea of context

The greatest challenge to the historical archaeology of the Sahara has been the lack of chronological precision. Numerous archaeological sites are known for the historical context being entirely lacking. The TRANS-SAHARA project has pioneered a method of dating mud architecture using radiocarbon (AMS) methods on organic inclusions in mudbrick.

This has proved extraordinarily useful in providing clearer dates for a wide range of sites spanning the pre-Islamic and Islamic eras. A total of c. 200 AMS dates were funded by the ERC, providing an entirely new framework for oasis development across the Sahara. He adds, "If our dating approach is extended to further sites, the regional trajectories of development will become clearer."

Fostering collaboration to create new approaches

As well as meeting its scientific objectives, the project served to advance the careers and intellectual development of a cohort of early career researchers. The conferences fostered working relationships and collaborations that went beyond the core project, some of which are ongoing.

"The TRANS-SAHARA project has re-oriented the future agenda of study of Saharan history and archaeology, with important implications not only for scientific study, but also for the national identity of Saharan and Maghrebian countries," Prof. Mattingly explains.

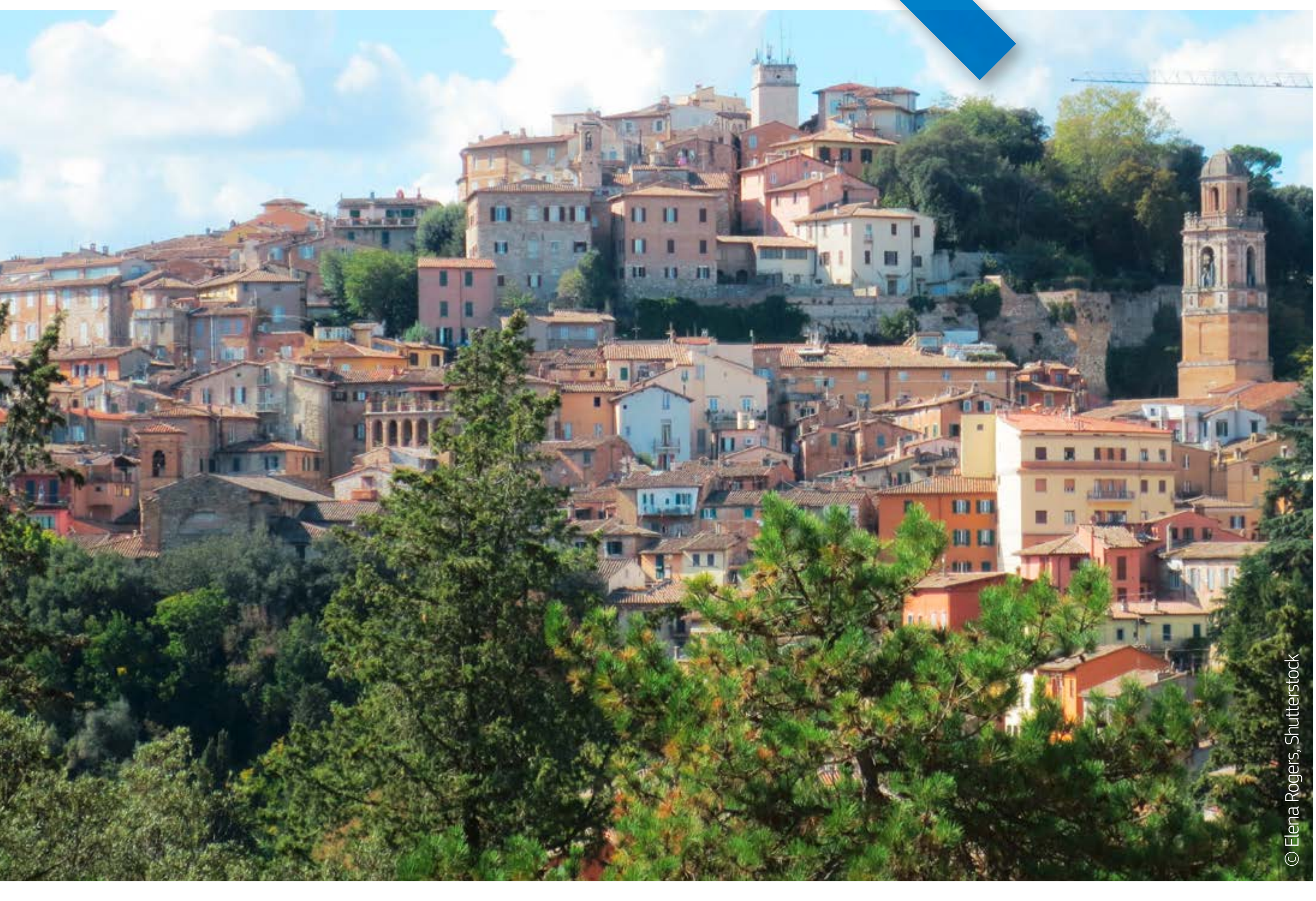
Project	**TRANS-SAHARA: State Formation, Migration and Trade in the Central Sahara (1000 BC – AD 1500)**
Hosted by	University of Leicester in the United Kingdom
Funded under	FP7-IDEAS-ERC
Project website	https://www2.le.ac.uk/departments/archaeology/research/projects/trans-sahara-project

Novel methods in 3D reconstruction can offer heritage preservers and curators new insights

Most existing solutions for urban modelling generate dense geometric models that are accurate and visually faithful, but that come with no structural or semantic information. As a result, applications that often require structured scenes cannot readily use them.

Large-scale cultural heritage scenes are not just complex 'shapes', they are hybrid scenes composed of both free-form shapes (land, trees) and myriads of objects that have structural relationships and semantic meaning (such as walls, roofs, façades). One category of existing solutions generates faithful city models enriched with structural and semantic information, yielding meaningful levels of detail. However, producing these city models requires many labour-intensive modelling and editing operations to assign semantic labels to data, then to reconstruct.

The EU's TITANIUM (Software Components for Robust Geometry Processing) project tackles the problem of 3D reconstruction and simplification of data gathered from raw geometric



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measurements, as well as related conversion methods specifically tailored to 3D urban modelling. Raw data are 3D point clouds either measured by laser scanners or generated by dense photogrammetry algorithms (which convert a set of photos into 3D point clouds with colour attributes).

As lead researcher Dr Pierre Alliez, based at the Institut National de Recherche en Informatique et Automatique (INRIA) in France, explains, "From existing research prototype algorithms, our goal is to develop a software demonstrator for geometry processing and 3D urban modelling, in order to facilitate the pre-commercialisation of novel software components for the Computational Geometry Algorithms Library."

"Although our research directions remained within the field of computer science, we enlarged our focus to topics commonly tackled within the fields of robotics and computer vision"

Pioneering novel formulations

On robust shape reconstruction, Dr Alliez explains the project pioneered novel formulations based on the theory of optimal transportation. This involves input geometric measurements (raw point sets) as discrete measures (a distribution of masses). The reconstruction problem is reformulated as a mass transportation problem between the said masses and reconstructed surfaces.

"Spatially-variable noise, increasingly common in low-cost geometric sensors, is handled via a novel automatic scale selection approach, which relies on the sole assumption that the inferred shapes are manifolds of known dimension." The project chose these methodologies because they offer unrivalled resilience to noise and outliers.

Regarding the enduring problem of robust shape approximation, TITANIUM developed a novel approach that reduces the geometric complexity of a shape, while remaining within a tolerance volume and providing topological guarantees. "This approach best illustrates our initial goal to devise methods that can take defect-laden data as input, and yet provide guarantees as output," says Dr Alliez. He adds, "Although our research directions remained within the field of computer science, we enlarged our focus to topics commonly tackled within the fields of robotics and computer vision."

Societal benefits

Societal benefits of the project include the potential for supporting sustainable urban design, since computational engineering also applies to simulations of physical phenomena at the scale of entire cities. The impact of the proposed demonstrator will be significant in applications where geometry acquisition and processing play a central role (e.g., geographic information systems, computational and reverse engineering).

Dr Alliez explains, "Our industrial contacts have told us that the process of converting raw data into defect-free models ready for simulation is by far the most labour-intensive part of the design cycle (accounting for 85 % of time spent vs. 15 % for the simulation). Our demonstrator has the potential to significantly reduce the duration of this process, offering increased economic competitiveness."

The project's findings can also feed into conservation work. Detecting and enforcing structural relationships translates into the detection of near adjacencies and canonical relationships, followed by their reinforcement by quantisation into exact relationships. Structure and semantic information are then used to recover levels of details. "This would improve the scanning of either a historical site or an entire collection whose pieces are possibly disseminated," says Dr Alliez.

Going forward, TITANIUM's results can lead to the development of the concept of collaborative digitisation and active digital resources. In the context of a multidisciplinary collaboration, the objective is to design hybrid systems in which communities (via social networks) and networks of sensors cooperate.

Project	**TITANIUM – Software Components for Robust Geometry Processing**
Hosted by	INRIA in France
Funded under	H2020-ERC
Project website	https://team.inria.fr/titane/pierre-alliez/

New insights into how the great Gothic vaults were constructed helps restorers of the future

The question of how medieval architects communicated their fantastically complex designs for some of Europe's most beautiful Gothic vaulting has perplexed researchers. Now a hands-on approach provides insights that will help conservationists.

When it comes to the fantastically intricate design of Gothic vaulting and ribbed arches, we have had very little knowledge of how architects communicated with master masons. The few sketched-out plans that exist, such as that for a part of the Cathedral of Strasbourg, show a surprising lack of written instruction and even measurements are missing. With the architect in a different place to the building site itself, the question that has baffled researchers in this domain is: how did such complex structures make it from two-dimensional drawing to the great, three dimensional vaults that captivate us today?

"These projects have enabled us to gain a deeper understanding of the principles of the geometric design and how the instructions for producing their single stone elements were formulated. These insights will feed into the conservation practices of the future"

Finding the answer was the primary goal of the EU-funded REGOTHICVAULTDESIGN (Design Principles in Late-Gothic Vault Construction – A New Approach Based on Surveys, Reverse Geometric Engineering and a Reinterpretation of the Sources) project. As project coordinator Dr David Wendland explains, "Until now our knowledge has been mainly based on sources which, in some aspects, appear incomplete. The innovative approach of the project consists in formulating hypotheses on the design directly from the built artefact, with a working method not common in surveying until now."

Although an interesting conundrum in its own right, the question also feeds into restoration and maintenance: good conservation practice benefits from the ability to draw on original techniques.

Exploring techniques of medieval master masons

The stonemasons' knowledge was shared orally, in lodges and workshops. One such workshop, which was involved with the building of Strasbourg Minster from the 12th to 16th century, is still up and running. Historically accurate stonemasonry techniques are taught there today, which made the workshop a logical participant in Dr Wendland's research.

To establish how the master masons of 500 years ago went about their work, and to work out how they instructed the cutters to size the stones with such geometric precision, Dr Wendland and his team reverse engineered, among many others, the ribbed vaulting of St Anne's church in Annaberg, and the Palace of Meissen, Germany.

"These structures are extremely complex in their geometry, with complicated meshes of ribs soaring along three-dimensional curves and intersecting on multiple levels at the keystones," says Dr Wendland, who was based at the Technical University of Dresden, Germany.

One technique the project employed was to create a large expanse of plaster surface (10x15 metres), which was formed into a 'tracing surface' at the University of Dresden. Tracing floors were a standard technique used at the time and researchers were keen to replicate the process, using only squares, compasses and rulers.

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A drawn out process

Using the tracing floor and the instruments the original masons would have employed, the team drew out the pattern for the vault at Meissen. "Representing the three dimensional on a flat plane was a real challenge," Dr Wendland explains. Once the design was mapped out on the plaster, the researchers compared the pattern with the dimensions discovered through their survey of the original vault.

Copper templates, referred to in some manuscript descriptions of the task, were used to transfer flat designs to the three dimensional stone carving. "We tested our theory using gas blocks as they are easy to carve and allowed us to carry out rapid trials," he says. However, their system proved to be robust and the work moved onto quality stone quite quickly.

21st century master masons, 500 year-old know-how

Academic research was not the sole aim of the two projects. Of equal importance to the Franco-German team was the dissemination of 'living knowledge'. To that end, apprentices at the stone masons' workshop were involved in the carving. As Dr Wendland puts it, "The knowledge of the historical procedure in planning and setting out is now available for anyone working on the restoration of historic vaults. Involving young professionals in this is vital if the information is to be transmitted."

He goes on to explain that the idea behind the whole project is not only to rediscover and understand historical techniques, but to incorporate them into current restoration practices. "Restorers should at least have the option of using historical setting-out, planning and cutting techniques."

Long-term research with even longer-term goals

The team's work was carried out over the lifespan of two EU-supported projects. Building on the processes explored by REGOTHICVAULTDESIGN, which focused on surveying, the second phase, called REGothicVaultElements (Late Gothic vaults and their complex stone members: Recovering historical design procedures, implementing knowledge in restoration practice), concentrated on replicating construction techniques.

"These projects have enabled us to gain a deeper understanding of the principles of the geometric design and how the instructions for producing their single stone elements were formulated. These insights will feed into the conservation practices of the future," says Dr Wendland.

Project	**REGOTHICVAULTDESIGN - Design Principles in Late-Gothic Vault Construction - A New Approach Based on Surveys, Reverse Geometric Engineering and a Reinterpretation of the Sources** **REGothicVaultElements - Late Gothic vaults and their complex stone members: Recovering historical design procedures, implementing knowledge in restoration practice**
Hosted by	TU Dresden in Germany
Funded under	FP7-IDEAS-ERC
Project website	http://late-gothic-vaults.eu/
Video	https://bit.ly/2KRU7I6

New insight into natural slate solves roofing market's problems

Many historic buildings throughout Europe were built with slate, yet little is known about these building rocks used for roofing. An EU initiative shed important light on this stone, and proposed solutions to some of the European roofing slate industry's pressing issues.

Since the dawn of time, slate has been the most important natural stone and virtually the only one used for roofing. However, there is a lack of knowledge about this valuable material, in contrast with the abundant scientific literature for other stones such as marble or granite.

The EU-funded TOMOSLATE (New uses for X-ray tomography in natural building stones: Characterization, pathologies and restoration of historical and recent roofing slates) project aimed at "filling the knowledge gap, while identifying the main problems of the roofing slate industry in Europe and providing answers," says principal project investigator Dr Víctor Cárdenes. The characteristics of roofing slate were examined using X-ray micro-computed tomography (MCT), together with other analysis techniques.

Novel methods to tackle roofing slate industry problems

"Today, no standard classification exists for the different varieties of roofing slate," notes Dr Cárdenes, a researcher at Belgium's Ghent University. The roofing slate industry uses commercial names, instead of the petrological denominations for each rock. This leads to overall confusion about the nature and characteristics of roofing slates. TOMOSLATE characterised and classified the existing roofing slate lithotypes. According to Dr Cárdenes, this is the first ever classification of roofing slates to be performed anywhere in the world.

The project defined the pathologies that affect roofing slates in order to propose a methodology that mitigates the incidence of weathering on the stone. "This is vital to preserve Europe's architectonic heritage," stresses Dr Cárdenes. The method to prevent iron sulphide oxidation

"This is the first ever classification of roofing slates to be performed anywhere in the world"

– the main weathering culprit – is based on a new concept. Instead of applying a chemical product to the roofing slate during the production chain, this innovative technique is employed when the slate on the roof begins to show oxidation. A protective coating paint is applied using a spray can. The approach is easy to use and environment friendly.

TOMOSLATE analysed the standardised tests applied to roofing slates. "These tests are mandatory for the roofing slate market," he adds. "However, they can be optimised to improve the information obtained from assessments."

Dr Cárdenes says that the project also yielded an unexpected result. The use of MCT on slates highlighted a pyrite framboid population. Measuring and analysing these populations in a fast and reliable way has opened up new line of research which has important implications for other fields of geology, including palaeoecology and ore mining.

Unlocking the mystery of what roofing slate actually is

"TOMOSLATE will help the roofing slate industry, builders and architects to better understand their products," explains Dr Cárdenes. When he and others visited slate quarries and gave talks at dedicated conferences, the overall impression was that nobody really knew exactly what roofing slate was. Some producers didn't even know what kind of stone they were quarrying.

"We now have greater awareness of a very important natural stone that's used abundantly in Europe and the rest of the world," concludes Dr Cárdenes. Ultimately, TOMOSLATE outcomes will revitalise the economy of European slate-producing areas because of the added value given to their slates.

Project	**TOMOSLATE - New uses for X-ray Tomography in natural building stones: characterization, pathologies and restoration of historical and recent roofing slates**
Coordinated by	University of Ghent in Belgium
Funded under	FP7-PEOPLE

Putting together the pieces of Europe's cultural heritage puzzle

Researchers with the EU-funded IPERION CH project are working to establish a European research infrastructure dedicated to the conservation, interpretation and management of our unique cultural heritage.

From prehistoric cave paintings to medieval churches, from Renaissance sculptures to modern graffiti – Europe's cultural heritage is world-renowned. Yet despite its trove of cultural treasures, Europe's reputation in heritage science is not at the same level. One reason for this is the fact that heritage science is often left to individual Member States. As such, each European country is focused on its own research, using its own state-of-the-art facilities and academic institutions. However, to ensure that Europe's cultural heritage gets the attention it deserves, there needs to be a collaborative, European-wide approach to heritage science.

The EU-funded IPERION CH (Integrated Platform for the European Research Infrastructure ON Cultural Heritage) project is working to integrate these national efforts and to connect experts from across Europe. "By opening up world-class facilities to a wider number of researchers and academics, we hope to foster more collaborative work


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and to strengthen Europe's reputation in heritage science," says Project Coordinator Luca Pezzati.

The field of heritage science embraces a wide range of research disciplines, each of which supports the various aspects of tangible and intangible cultural heritage conservation, interpretation and management.

A viable research community

For example, if your research team is restoring a church in Italy, you might benefit from using specific analytical tools or the opportunity to consult with a similar restoration project. However, unless these tools and experience can be found in Italy, you probably won't be able to access it. "A constant challenge for researchers in this field is that cultural heritage is so fragmented," explains Pezzati. "The tools and information that a researcher might require are all too often dispersed in archives or institutions located across Europe."

For Pezzati and his colleagues, the answer to the challenge of fragmentation is infrastructure. "The IPERION CH infrastructure will provide access to all services, instruments and expertise from participating institutions via one central access point," he says. "For us, it's all about achieving better coordination among institutions and creating a viable research community for European heritage science."

Ready access

Currently, IPERION CH is comprised of 23 partners from 12 Member States, along with one in the US. These partners include a range of leading cultural research centres, laboratories, museums and universities. Through one of the project's three central platforms, heritage scientists can now readily access 19 leading facilities. For example, the MOLAB platform provides researchers with access to mobile laboratories. This allows them to perform their research *in situ* and not have to move fragile works of art or precious archaeological pieces to a laboratory – essential to ensuring the safety of the objects being examined. Other available platforms include FIXLAB, for large-scale facilities, and ARCHLAB, for archiving technical and scientific data.

"By opening up world-class facilities to a wider number of researchers and academics, we hope to foster more collaborative work and to strengthen Europe's reputation in heritage science"

In addition to making better use of European knowledge and expertise, the IPERION CH project also aims to raise awareness about the social and economic importance of protecting our cultural heritage. "When it comes to funding programmes or research priorities, cultural heritage is rarely in the headlines," says Pezzati. "One of the reasons we want to create this infrastructure is to raise the profile of this field."

An ongoing process

Because of projects like IPERION CH, heritage science is beginning to be viewed at the same level as more traditional scientific disciplines. "Building up heritage science is a slow process, and this project is just one step towards our objective," says Pezzati.

Once complete, the IPERION CH research infrastructure will feed into the European Research Infrastructure for Heritage Science (E-RIHS). This ambitious infrastructure project, which is currently in its preparatory phase, aims to integrate cultural and natural heritage research, connecting researchers in the humanities and natural sciences and fostering a trans-disciplinary culture of exchange and cooperation.

Project	**IPERION CH – Integrated Platform for the European Research Infrastructure ON Cultural Heritage**
Coordinated by	National Research Council of Italy
Funded under	H2020-INFRA
Project website	http://www.iperionch.eu/

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