WHITE PAPER AP11
TECHNOLOGIES FOR CULTURAL HERITAGE USE AND PRESERVATION

EXECUTIVE SUMMARY

This is a summary of the first white paper on the activities carried out by the nine Institutes of the DIITET Dept. contributing to the area “Technologies for Cultural Heritage (CH) Use and Preservation”.

On 10 May 2018 the DIITET Director appointed a two-person panel for writing the white paper. A first draft was completed on May 17th and distributed for comments and inputs to the researchers of the involved Institutes. All those inputs were incorporated in a second draft, updated through a participatory process and revised into this version, submitted to the DIITET Director on June 12th.

The opportunities offered by modern technologies for the use and preservation of tangible and intangible cultural heritage are practically unlimited. DIITET's contributions have been organized according to three main themes of Cultural Heritage - documentation/diagnosis, representation and dissemination - whose interdisciplinary nature requires a collaborative approach that can go beyond our departmental Institutes. The state of the art of these relevant areas is therefore presented in the 1st chapter, further detailing the status of these areas by means of several topics.

The 2nd chapter describes activities and results in each topic, making explicit notice to the DIITET institutes where the activity is taking place.

The 3rd chapter presents the current impact at scientific, industrial, social and political level, considering both national and international perspectives, through: CH conservation and restoration projects; participation to expositions and museum installations; collaboration with companies; social impact projects; collaborations with international institutions.

The 4th chapter describes some emerging research challenges.

The article ends with a conclusion chapter and two annexes: the list of reference persons and a description of further aspects or data (relevant facilities, list of personnel, details about active projects, videos, and images).

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1. STATE OF THE ART OF THE RELEVANT SCIENTIFIC AREA

The opportunities offered by modern technologies for the use and preservation of tangible and intangible cultural heritage are practically unlimited. DIITET's contribution addresses three of the main themes of cultural heritage - documentation/diagnosis, representation and dissemination - whose interdisciplinary nature requires a collaborative approach that can go beyond our departmental Institutes.

1.1 Documentation

This section presents the scenario of methodologies and technologies (HW and SW) for digitizing the shape characteristics or the material/surfaces properties, or for diagnostic analysis of the conservation status, up to sampling intangible CH assets - a mandatory first stage for any computer-assisted management of CH assets.

Small-Large Scale Digitization

Active 3D scanning systems based on laser or structured light offer extreme accuracy and data sampling density. Modern photogrammetric solutions (3D from standard 2D images) offer now performances near to the ones of active scanning. Other 2D digitization solutions via flat scanners, Reflection Transformation Imaging (http://culturalheritageimaging.org/Technologies/RTI), panoramic/360 images or videos are now widely available. Besides "visual aspect", digitization technologies can exploit non-visible bands of the spectrum or other kinds of radiation, thus providing information about the history and the present status of a CH object and allowing to access the object without invasive analysis.

Processing algorithms and tools for the efficient production of high-quality digital models reached a very good status (with both commercial and open source solutions), even if the automatic ingestion of high-resolution digital data into archival museum systems is not yet a fully consolidated practice.

Materials and Conservation Status Sampling

CH applications require instruments for sampling the *reflection properties* of the surfaces (e.g. color, hyperspectral imaging data or bi-directional surface reflection models) or for investigating the *chemical* and *material composition* of artworks by analyzing their interaction with suitable probing radiations (hyperspectral imaging, imaging spectroscopy, X-ray, ultrasound, laser induced fluorescence, etc.). All these technologies should be as non-invasive as possible and should sample both the surface and the inner layers. The results help understanding the execution technique, assessing the conservation status and supporting the restoration.

Miniaturization and cost reduction make also possible to disperse a number of sensors on the surface of an artwork, to sample the environmental and conservation conditions over time and transmitting data to a remote data integration and visualization unit, thus improving risk-based decision-making processes for preventive conservation actions.

Drones-assisted inspection

Unmanned vehicles, or *drones*, working either in air or underwater, improved considerably our sampling capability. These devices offer advantages in speed, safety and cost of acquisition, also allowing the user to inspect areas that are difficult to be accessed. They also allow extending the sampling scale and scope (from satellites to small drones) and allow performing cost-effective and regular monitoring of CH sites.

1.2 Data Representation and Understanding

The sampling technologies available produce data in multiple formats, which have to be mapped to a common space and treated in an integrated manner. Moreover, data and metadata have to be archived;

technology supporting data sharing and efficient multi-modal searches should be provided, to make those data the basic building blocks for consultation and reuse for study and further processing purposes.

Data Mapping and Archival

The many different classes of sampling devices and/or multimedia resources make data integration a very complex problem in managing tangible and intangible heritage, as those resources cannot be analyzed in isolation. Therefore, we need technologies for *mapping* all those data in a common space, documenting them with *metadata*, and supporting permanent *archival.*

Knowledge management is fundamental to foster the interoperability and re-use of information among actors having different cultural background and skills, which usually deal with cultural resources separately. Knowledge models formalized in ontologies provide a valid semantic base for annotating resources and correlating different complex data (in term of heterogeneity of content, number of documents and media typology) related to a specific product over time.

Data Search and Exploration

Features search, a basic component of any data management system, has already been applied to the CH field, providing effective solutions and solving similarity queries over large archives of visual data. Indeed, querying by images helps both in education and research and enables the exploration of inter/intra cultural relationships.

An interesting example is the Google platform (https://artsandculture.google.com) to search CH collections, which indicates how advanced search mechanisms could be used to explore and interact with large Museum collections. However, multimodal and content-based visual search of CH collections is still at its infancy.

Computer-based simulation

The availability of innovative mathematical models, numerical methods and information technologies makes possible the structural analysis of historical buildings through of numerical codes. Whereas numerical simulation, which supports the choice and design of strengthening operations, structural health monitoring, relying on the measurement of deformation and environmental vibrations of structures, allows to assess their behavior over time.

1.3 Dissemination

Annotated CH resources and visual data have a great potential for dissemination to the public and supporting museum and tourist applications. Intense research is active on those themes and great opportunities are open for technological transfer.

On-line Data Visualization

Data visualization has a leading role in both data analysis tasks and for the presentation to the public (including design of museum installations or for didactical uses). The specificity of CH applications suggests high-profile requirements in terms of accuracy and resolution of the 2D/3D representation. The research efforts are focused on the design of efficient and performant SW solutions for rendering those data at interactive rates, keeping data quality and accuracy as unaltered as possible.

The *web* became the main channel for data distribution and search; this is also true for CH applications and has created the need of revising the visualization technologies, taking into account data transmission needs, view-dependent rendering and on-demand transmission of the data.

Virtual, Augmented and Mixed Reality

Interactive fruition of data is now possible by accessing the web with mobile devices, as well as by using specialized visualization devices, very useful for applications in museums, archaeological sites and historic urban contexts.

Virtual Reality (VR) technology has recently been revitalized with the introduction of high quality and low-cost head mounted displays. *Augmented Reality* (AR) technologies also offers intriguing capabilities for adding knowledge/information in a very natural manner using mobile devices.

The current activities also concern the design of effective *interfaces*, based on either gestural input or tangible interfaces, allowing untrained users to navigate easily the virtual/augmented worlds, as well dialoging with the environment.

3D Fabrication

Technologies able to transform a 3D model in a physical instance have also boomed in the last decade, thanks to the huge interest in industrial applications (Industry 4.0). This raised also a lot of interest in CH, to either populate museums expositions with static and enhanced/sensorized replicas, to support restoration projects, or to improve the impaired people perception experience.

Serious Games

Computer games with educational purposes are becoming popular as a funny way to engage the public into an active state of learning rather than to receive information passively, through several factors as storyboard, graphics, usability, collaboration/competition mechanisms and interaction devices.

Serious Games have the potential to recreate accurately an historical setting, providing a holistic experience including sounds (spoken language, traditional music), aesthetic elements, folkloric and religious events, and giving the opportunity to practice behavioral codes and habits through in-game tasks, thus offering a strong contribution to preserve the intangible heritage.

2. CONTRIBUTION TO THE RELEVANT SCIENTIFIC AREA

CNR activities and results in relevant areas are here presented, following the organization in topics presented in the previous chapter and making an explicit reference to the DIITET institutes where they are taking place.

2.1 Documentation

Small-Large Scale Digitization

[INM]

- Innovative and unique tool for remote sensing and applications to the territory and related resources based on multispectral investigation (102 investigative bands) with the fine radiometric discrimination (up to 0.02 micron push) typical of the MIVIS sensor used for aero-transported remote sensing (spatial resolution up to 3 m x 3m).

[IREA]

- Synthetic Aperture Radar systems (SAR) on satellite platforms for 3D reconstruction and long-term monitoring of deformations on large areas;
- Georadar and holographic radar for high-resolution imaging of underground and inner parts of structures and artworks (detection/characterization of defects and construction modalities, buried/hidden ruins), used in Pompeii and Herculaneum.

[ISTI]

- Active (laser-based, structured light, ToF, RGBD) and passive (structure from motion, photogrammetry) methodologies for 3D digitization.
- Design of 3D digitization systems and of the required post-processing software algorithms and tools.
- Intense algorithm design activity, producing many innovative solutions and a leading open-source tool for sampled data processing (MeshLab, http://www.meshlab.net), distributed worldwide, with around 400.000 downloads/year, considered as a major resource by the CH community).
- Contribution to the design of innovative technologies for Reflection Transformation Imaging (RTI) acquisition and processing.

Fig. 1 - Example of hyperspectral image scanning at the Picasso Museum (Barcelona, Spain).

Fig. 2 - Example of digitization results, at the small and large scale.

Materials and Conservation Status Sampling

[IFAC - METEORS group]

- Optical-fiber coupled LIF spectrometer for in situ measurements aiming at characterization of biofilms
- Fluorescence LIDAR imaging systems (4D data: 3D hyperspectral fluorescence images and fluorescence lifetime) for the remote diagnostics on monumental surfaces.
- Integration of 3D models and fluorescence hyperspectral images.
- Studies on the effects of low-fluency laser radiation on mural paintings.

[IFAC - SABeC group]

- Design and assembling of hyperspectral imaging devices
- Optimized dedicated software and data processing procedures, including image-cubes mosaicking, new methods for pigment identification and mapping, visualization, and archiving of the results.

[INM]

- Development of contactless *vibro-acoustic* techniques and devices for the structural decay processes diagnostic of painted surfaces (frescoes, glazed ceramic tiles, panel paintings).
- Development of an *Audio Frequency - Acoustic Imaging (AF-AI)* technique providing frequency resolved acoustic images of paintings.
- MIVIS hyperspectral data (0.43-12.7 micron) processing to automatically characterize and quantify elements and materials in geographically identified areas
- Development of reproducible methodologies on a large scale, with cartographic restitution, as well as the integration of some other data (remote sensing, cartographic, ISTAT, etc.) in GIS and WebGIS.

[IREA]

- Development of optic fiber sensors for in-situ distributed monitoring of deformation and/or temperature on long distances with high spatial resolution
- Experience in THz imaging (to sample overlapping layers and delamination phenomena) and spectroscopy.

[ISTI]

- Digital processing and analysis of multispectral images of ancient documents to highlight their status of conservation and help possible material restoration plans.
- Deployment of sensor networks to monitor the structural health of historical buildings.

Drones-assisted inspection

[ISTI]

- An inter-laboratory facility to design and use drone-based technologies, including a drone setup to capture data for 3D reconstruction and monitoring crack patterns in historical buildings.
- An embedded card allowing the drone to self-locate during the survey.
- SLAM-based methods to improve the pilot front-end experience, including real time visualization capabilities, and to support the drone navigation self-awareness. The 3D model of a cultural heritage asset is thus made accessible on-line, along with the acquired and processed data describing its structural status, experimented in Pompei.

[ITC]

- Combined use of drone and multicamera system for realizing 3D model using SfM techniques, experimented on an historical village.

2.2 Data Representation and Understanding

Data Mapping and Archival

[IASI]

- Analysis of multi-dimensional data for visualizing the temporal changes of urban artefacts and monuments over time by investigating the variables that are not directly observed, depending on their own characteristics and the impact on the environment.

[IFAC]

- Development of a new hyperspectral image data processing focused on the identification and mapping of spectral features of selected pigments/dyes
- Providing access to the corpus of digital data sets through a unique and user-friendly web platform specifically designed for museum professionals, aimed at facilitating exploitation of massive and structured data sets (CRISTINA - *CNR Retrieval of Images from hyper-Spectral data Through Interactive Network Access*).
- Several spectral databases, produced by analyzing in the UV-Vis-IR ranges diverse artists' materials and techniques, freely accessible on the web.
- Web-site prototype for visualizing and accessing spot reflectance measurements and hyperspectral imaging data (http://www.ifac.cnr.it/durer) developed with the Uffizi Gallery.

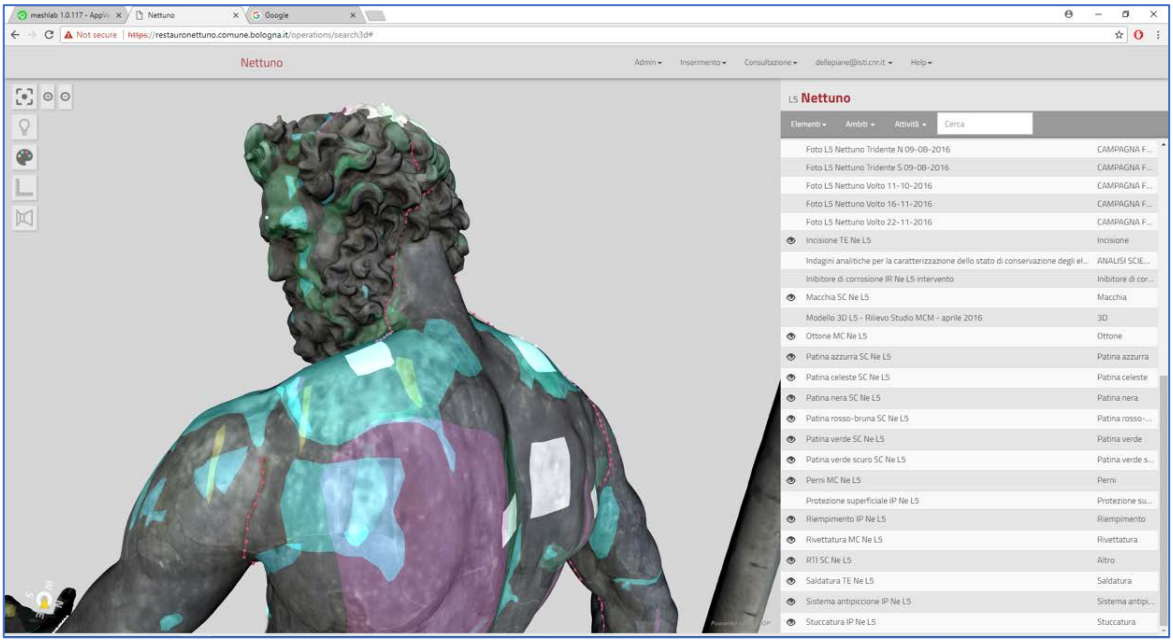

Fig. 3- Example of an archival system designed to support restoration documentation.

[IMATI]

- Knowledge management system based on a) semantic enrichment of metadata to increase the level of description (semantics, workflow provenance, quality); b) data integration, according with the Linked Data principle of the web as “global space”, with the study of algorithms for the semantic analysis of resources and methods to explore such datasets.
- Methods and tools to support the whole 3D annotation pipeline (format for 3D annotated models; annotation transfer across models) and shape analysis workflows (feature detection and characterization - patterns, decorations, and style traits).
- Dashboard platform including a novel automatic processing pipeline, based on the IMATI GRAVIfix library, which prepares 3D models for ingestion in curatorial and analysis systems (repairing, simplification, data organization).

[ISTI]

- Design of tools for the virtual restoration of damaged documents to help paleographic analysis.
- Design of systems to support data documentation and integration, including also features for mapping data on a common representation space and providing visual analysis functionalities, applied to the restoration of the Neptune Fountain of Bologna, developed for ISCR, Bologna University and Bologna Municipality in 2017. It allows restorers to work cooperatively through a web-based documentation system, where all the data are mapped, indexed and searched over the 3D digital representation of the artwork surface, supporting the creation of technical drawings and maps directly on the skin of the artwork. It is a very first example of restoration documentation implemented in real-time on a web-based 3D system.
- Design of systems supporting the documentation and analysis of archaeological findings by a mobile device allowing the automatic shape recognition performed on a remote archive and its documentation on the remote archival system.

Data Search and Exploration

[IMATI]

- Multimodal information systems, tailored for museums and tangible/intangible CH collections, integrating innovative search and browsing paradigms to support users in information discovering.

- Methods for automatic feature extraction (visual/mood attributes or keywords) and for semantic annotation- from text, images, 3D, audio, video related to tangible and intangible resources - allowing users to query the art collections based on their visual or semantic content.
- Development of methods libraries to index, retrieve and classify 3D models focusing on multimodality and query formulation mechanisms (*data search and retrieval or similarity queries* over large archives of visual data, recognition based on global characteristics, salient parts/features, and also properties related to color or and textures).

[ISTI]

- Searchable CH object repositories (metadata schemas, administrative and descriptive metadata plus additional entities for searching on both contents of and relationships between the archived documents);
- Tools for the extraction of semantically significant visual descriptors (features) to support visual search paradigms;
- Systems supporting cross-media search on raw digital content (text queries to retrieve relevant non-annotated visual digital content).

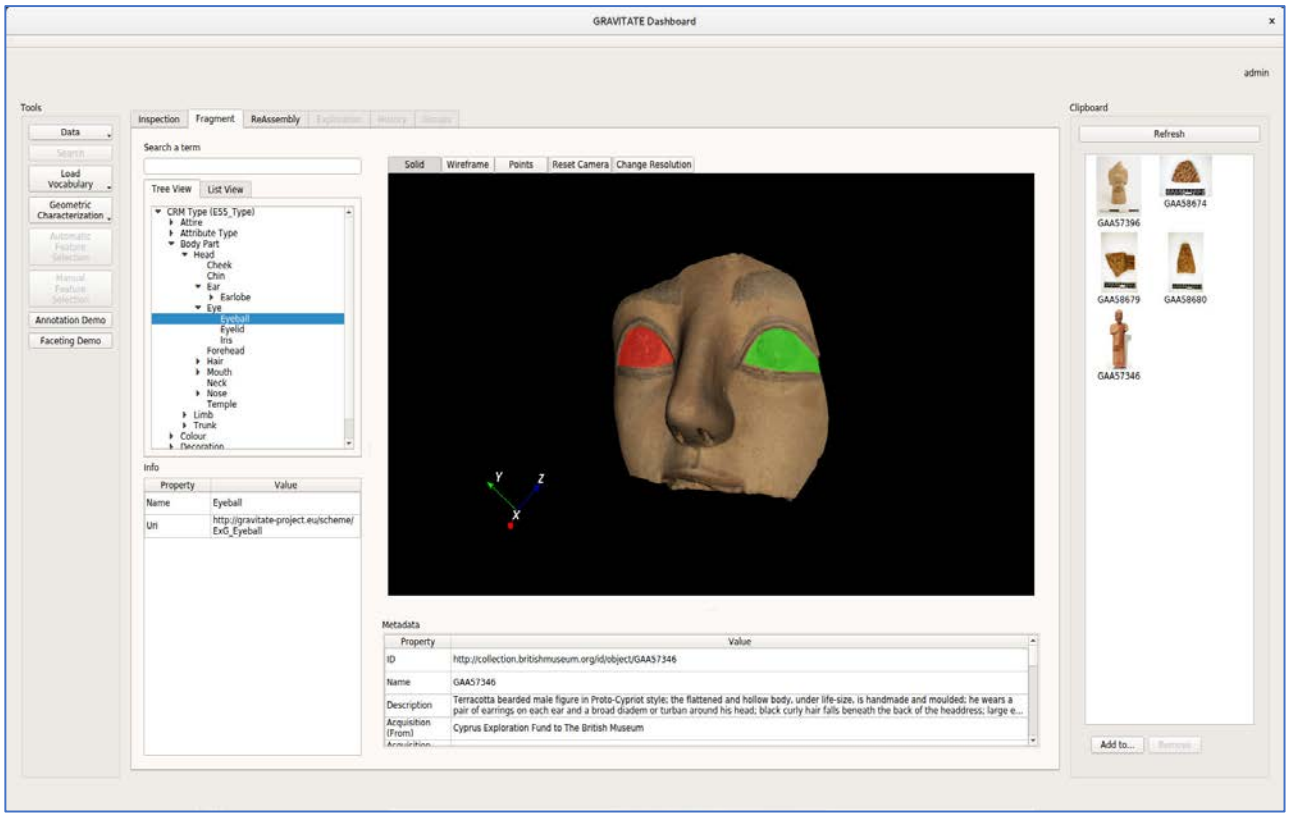

Fig. 4 - Example of semantic annotation taken from the Gravitate Dashboard.

Computer-based simulation

[ISTI]

- Development of mathematical models and software for the structural analysis of ancient masonry constructions. In particular, the Finite Element (FE) code NOSA-ITACA (freely available at www.nosaitaca.it) allows for modeling the nonlinear behavior of masonry constructions under static and dynamic loads, by taking into account the material's inability to withstand tensile stresses.
- Numerical strategies for FE model updating, aimed at calibrating a FE model of a structure in order to match numerical and experimental results, and damage detection techniques

[IAC]

- Mathematical models and simulation tools for the study of chemical and biological damages, such as degradation on porous stones caused by salt crystallization, contact with iron compounds, and for the description/prediction of the flow of incoming/outgoing visitors in outdoor/indoor areas, including parking points of the museum area.
- Image processing for automatic degradation detection (alterations and colorimetric/geometrical properties) and for restoration of digitized copies of archive material.

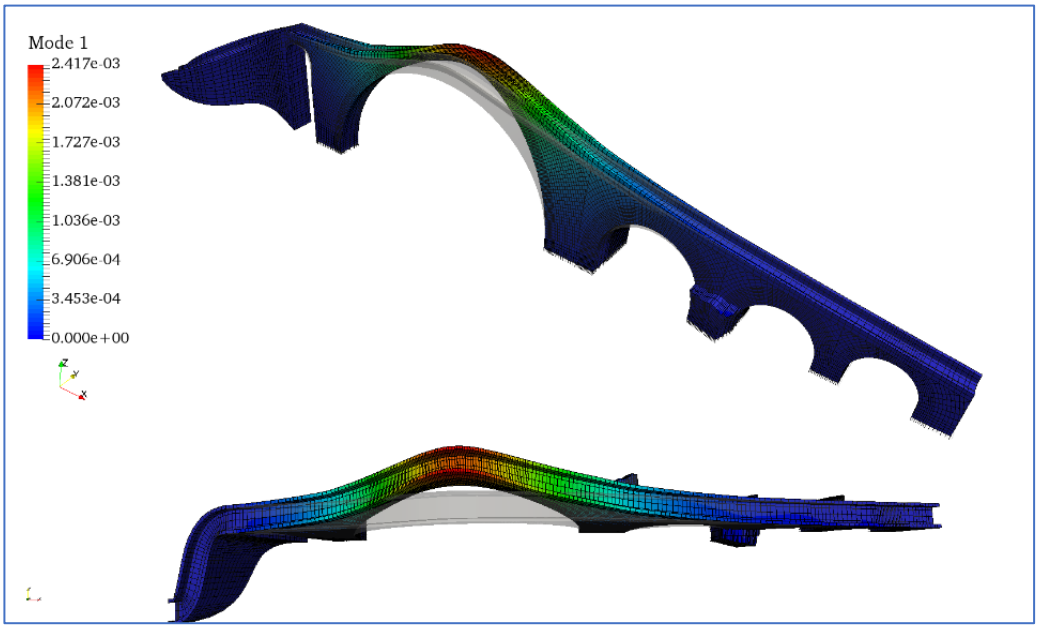

Fig. 5 - FEM results produced with the NOSA- ITACA code while studying the Maddalena Bridge (Borgo a Mozzano, Italy).

2.3 Dissemination

On-line Data Visualization

[IMATI]

- Visualization tools providing users with a compact overview of the available data, in order to mine properties and relations among data and to achieve a correct interpretation of the results, using thematic paths to support a personalized exploration of the archive.

[INM]

- Methods for the implementation of WebGIS Platforms, characterized by immediacy and ease of use, aimed at non-expert users, enabling to share information in real time, allowing the management of the multiplicity of information / data, and making complex evaluations (e.g. for monitoring and control of the land).

[ISTI]

- *3DHOP* (3D Heritage On-line Presenter), an open-source platform for supporting users in the publication and visualization of 3D content on the web; it includes an extremely efficient web-based rendering engine (multiresolution encoding, data compression, progressive transmission, view-dependent rendering), different interaction approaches and sophisticated visual data analysis features. It counts hundreds of users and thousands 3D content published on the web.

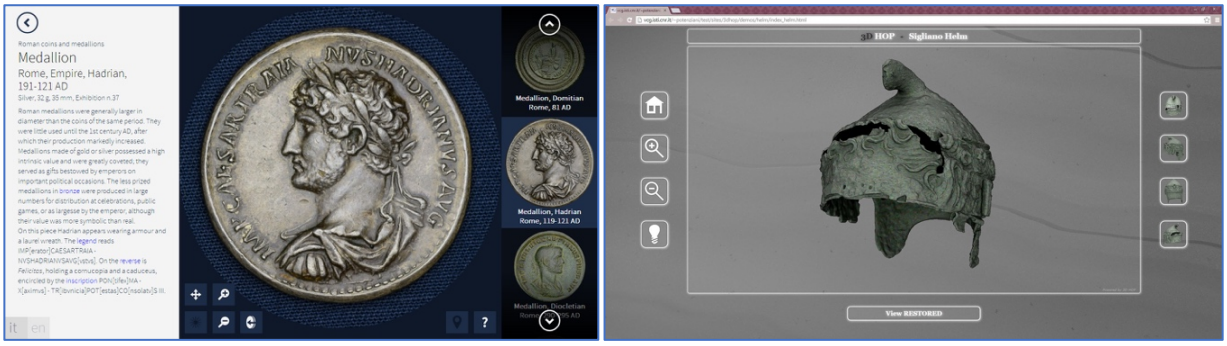

Fig. 6 - Some examples of web-based visualization of 2D-RTI and 3D data.

[ITC]

- Development of multimedia interactive map based on a single HTML page using AJAX, with a client-side control mechanism using jQuery components and open data format GeoJSON. The user can select a landmark viewing its multimedia content previews in as scrolling window or in a gallery; landmarks—visualized with multi-shape markers using unambiguous colors—could be filtered through their categories and types, accessibility status and time line, thus improving the system usability (www.itc.cnr.it/ba/map).

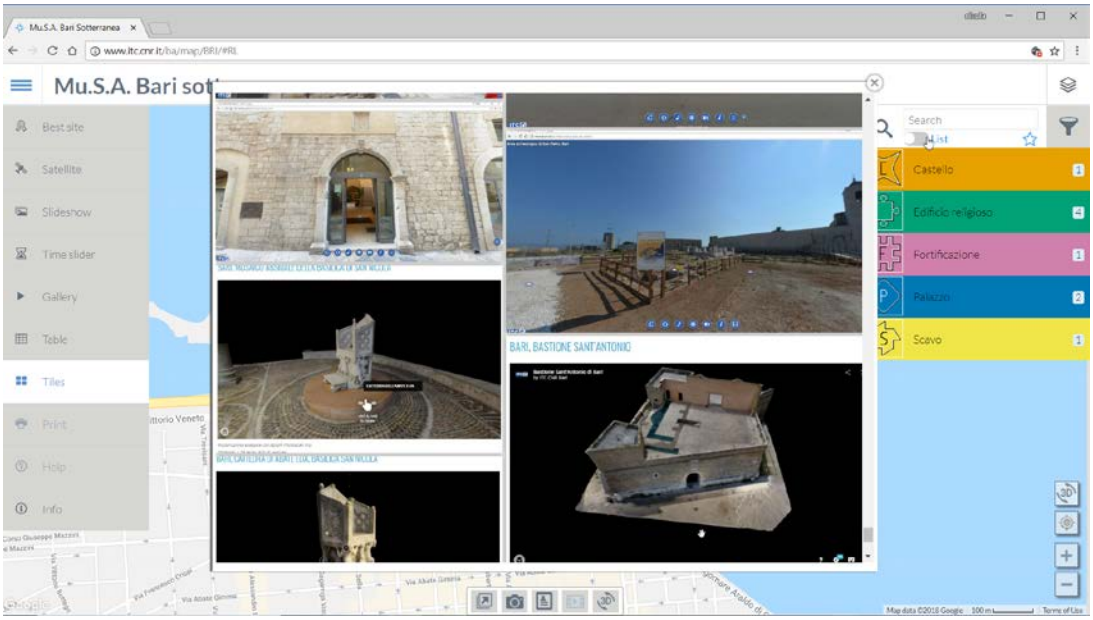

Fig. 7 - Example of multimedia interactive map (http://www.itc.cnr.it/ba/map/BRI).

Virtual, Augmented and Mixed Reality

[IASI]

- Methodological approaches and innovative technology (App Based Indoor/Outdoor, Proximity Analysis, Efficient Path Profiling, Augmented reality) that while not renouncing the rigor of historiographic research, improve learning, access and use of CH

[ICAR]

- Augmented reality, virtual reality and body tracking technologies solution development.
- Design of “touchless”, multi-degrees-of-freedom user interfaces, for both virtual and augmented reality applications, by using depth sensors and/or RGB cameras, relying on algorithms to filter depth data and to increase the precision of distal pointing and of skeletal tracking.

- Conversational chatbots based on knowledge-graphs.
- Usability evaluation campaigns, both considering qualitative and quantitative data.

[ISTI]

- Experience with modern VR/AR technologies applied to interactive presentation of CH assets on land/museum and underwater. Use of head mounted displays to enable an augmented presentation of 3D printed replicas.

3D Fabrication

[ISTI]

- New solutions for the production of resin copies by molding, thus reducing cost and increasing production speed.
- 3D fabrication technologies for the design of artistic reproductions.

Serious Games

[IMATI]

- Study of the game mechanics having an impact on learning in the context of CH, focusing on the representation of 3D worlds in role-playing games and 3D setting and immersive technologies to facilitate engagement, a feeling of presence in the digital environment, empathy with the game characters and learning.

Fig. 8 - 3D fabrication as an option to close the loop: *physical - digital - physical*.

3. IMPACT

Participation to major CH conservation and restoration projects

Research labs contributing to AP11 have been partners or technology providers in a very large number of conservation and restoration projects, collaborating with primary conservation institutions, such as:

- Istituto Superiore per la Conservazione e il Restauro - ISCR, Rome [ISTI, IAC]
- Opificio delle Pietre Dure - OPD, Florence [IFAC, ISTI]
- Venaria Reale, Torino [IFAC]
- CH Superintendencies and Museums (Galleria Accademia Firenze, Uffizi, Museo San Marco Firenze, Opera Primaziale Pisana, Galleria Borghese Roma, Museo di Archeologia Ligure, Archivio storico della Fondazione Ansaldo) [IFAC, IREA, ISTI, IAC, INM, IMATI]
- Archaeological sites: Pompei [IREA, ISTI], Ercolano [IREA], Casale di Balsignano [ITC]
- Museums abroad: Museum Picasso, Barcelona, Spain [IFAC], Gallery of Art Washington DC, USA [IFAC], British Museum, London, UK [IMATI], Cyprus Museum [IMATI], Guggenheim, New York, USA [ISTI], Museu Nacional d'Art de Catalunya, Barcelona, Spain [ISTI]
- Historical city centers: Gubbio, Matera [IREA], Cetinje (Montenegro), Matera, Siracusa, Tirana (Albania) [ITC]

Participation to expositions and museum installations

- Museo Archeologico Nazionale di Napoli (MANN) – Co-organization of the hybrid, real-virtual exhibition “I Campi Flegrei, Oltre il Visibile”, July 27 – November 10, 2016; Design and implementation of three systems: i) Interactive multi-projection of the Omphalos Apollo statue; ii) holographic reproduction of statues with touchless control of the light source; iii) interactive exploration of ancient books [ICAR]
- Exhibition “Il Bello o il vero” - Napoli, Complesso Monumentale San Domenico Maggiore, February 3 – June 6, 2015 – Design and implementation of a system for the interactive visualization of 3D reconstruction of statues [ICAR]
- “Alchemy by Jackson Pollock”, Temporary exhibition, Guggenheim Venice, Italy (2015) and Guggenheim Museum, New York, USA (2017) [ISTI]
- Museo delle Ceramiche di Grottaglie [ITC]

Collaboration with companies (technology transfer)

- [IFAC – SABeC] SABeC group selected in 2016 by SPECIM Spectral Imaging Ltd. (Oulu, Finland) as a pilot laboratory to test and check the IQ prototype performances in the Cultural Heritage fields.
- [IMATI] Collaboration with Softeco, for the project on the Ansaldo Foundation business Industrial Heritage archival Archive
- [ISTI] Contract with HP (US branch) for right of use of ISTI VClab 3D graphics libraries.
- [ISTI] Long-lasting collaboration with TEA-Sas, Catanzaro, Italy, for a series of European and National projects on analysis, virtual restoration and archival of digitized CH assets, such as paintings and ancient/degraded documents.
- [IAC] collaborated with Fratelli Alinari photographic archive in Florence for the development of novel digital restoration tools
- [IREA] collaborates with Leonardo and e-GEOS for the development of a ICT platform for effective resilience of CH based on the synergic use of several sensing technologies.

Social Impact Projects

- [ITC] “Vi.S.T.A. Virtual and Social heritage Tour Application” project for developing and testing an integrated technological system for virtual and social touring of artistic and cultural heritage managed by the “Polo Museale” in Apulia Region.

Collaborations with international institutions

- CNR colleagues [IMATI, ISTI] have been regularly invited to the workshops organized by the EC for discussing the themes of forthcoming calls (e.g. **ICT and Cultural Heritage Workshops** organized by CNECT, G2 and held in Luxembourg in 2016 and 2017). Participation to these events was by invitation only (selected experts).
- CNR leads the **EUROGRAPHICS Working Group on Graphics and Cultural Heritage** and is regularly present in the program committee of the yearly associated EUROGRAPHICS workshop on Graphics and Cultural Heritage (GCH). The 2018 edition will be in Vienna, Austria (Visual Heritage 2018, http://2018.visualheritage.org/)
- CNR has been among the organizing partners of the IEEE Digital Heritage 2013 and Digital Heritage 2015 conferences, a large event attracting >500 registered participants (R. Scopigno Co-Chaired the IPC in 2015).
- IFAC-CNR is actively involved in running the international Infrared and Raman Users' Group (IRUG), which is dedicated to the support and professional development of its members by providing a forum for the exchange of infrared and Raman spectroscopic information and reference spectra for the study of the world's cultural heritage (www.irug.com, M. Picollo chair for Asia-Australia-Oceania).
- CNR colleagues are involved into the program committee of many international conferences concerning ICT & CH themes (e.g. the European Geoscience Conference, where several sessions are devoted to CH since 2010; IEEE VSMM; EG GCH; CAA; Digital Heritage; etc.).
- R. Scopigno [ISTI] is Editor in Chief of the ACM Journal on Computing and Cultural Heritage.
- CNR colleagues are members of Editorial Board (Editor in Chief and Associate Editor) of HERITAGE, an open access journal of MPDI

4. EMERGING RESEARCH CHALLENGES

- Novel methodologies for the integration and correlation of *multi-sensor data* to perform multiscale, multi-resolution and multi-depth analysis to provide enhanced understanding and to support risk-based decision-making. Advancements of artificial intelligence algorithms for visual analytics and data characterization.
- Novel portable solutions for 3D acquisition of objects with not-cooperative surface reflection properties.
- Miniaturization of complex *diagnostic instruments* and related costs reduction, e.g. using technologies based on fluorescence and reflectance hyperspectral imaging systems; design of systems based on radiofrequency electromagnetic field for contactless disinfection of artifacts from molds and lichens.
- New ways of accessing and exploring *archival resources*, overcoming cultural barriers and data types differentiation, exploiting semantic to link resources; innovative methodologies for the *annotation* and *browsing* of resources (visual and textual searches); exploiting CH knowledge models codified in ontologies to allow a search for concepts; semantically annotated 3D models.
- Automatic methods to characterize and even discover *similarities in style*, supporting a more effective exploration of digital collections; associations between pieces which can be part of different collections; identification of common production patterns.
- Long-term, continuous structural health monitoring and real-time damage detection techniques, data-driven analysis, algorithms for improving efficiency and reliability of numerical codes for *structural analysis*.
- Moving from an artefact-oriented to a context-oriented perspective in the modelling, representation and management of CH data and information.
- Integration of *gesture/tangible/speech interaction* and *augmented/virtual reality*, dialoguing with IoT sensors and optimizing user interaction capabilities; development of sensorized, active replicas to support AR applications.
- Extending GIS or BIM technologies to support the specific needs of CH *built environments*, addressing documentation, representation, mapping, modelling and promotion of assets.
- Development of tools with interfaces *accessible for all*, with the aim to support schools, stakeholders and small communities in acquiring and sharing knowledge on minor/local assets using low-cost devices and open data repositories, boosting the sense of belonging to a common cultural heritage of local communities.
- Development of GIS technologies for Cultural Heritage and built environment, addressing at the same time documentation, representation/mapping/modelling and promotion of assets, focused on network patterns among territorial markers and minor resources, performance enhancement criteria and ‘towing strategies’ on a regional scale.

5. CONCLUSIONS

This paper presents the technologies for the use and conservation of cultural assets developed in the last few years in the Project Area #11 (AP 11) of DIITET. Some of these technologies have been designed focusing on the needs of potential users, ranging from experts (*art historians, curators, conservators, conservation scientists, restorers, archivists)* to general users (*museum visitors, students, public*).

The current state of AP11 is quite good as far experience, critical mass and national/international visibility are concerned. Some facts and figures substantiate this assessment.

AP 11 is contributed by several institutes (we list a detailed list of the personnel involved in Appendix 2) and has reached a considerable critical mass, with **376 PM** contributed by 80 researchers (see the data presented in Annex 2); these PM correspond to 34 research units at full time, which is the size of an average CNR Institute. We consider these figures as a *considerable critical mass* dedicated by CNR to the theme ICT & CH. The estimated personnel cost is 1.590.000 Euro (this total is computed by taking into account only the cost of the permanent staff, since the staff with temporary contracts is financed by external projects).

Another important indicator is the capability of a research domain (and the researchers involved) t*o secure funds on competitive research project calls*. Appendix 2 presents the list of the research projects active to date, all of them financed by external competitive calls). We are proud for the number and quality of those projects. The total of the funds secured on those competitive calls is **6.031.000 Euro** on an average 3 years duration (thus, 2.010.000 Euro per year).
Assuming the estimate above of the human power dedicated, activities in AP11 return a *multiplier factor* of **226%**. This figure is higher than the average CNR and demonstrates the value and profitability of the research on ICT & CH done at CNR.

The themes in AP11 are therefore *active*, presents *open issues* for basic research in ICT, and are backed by a domain, which is an excellent field for assessment and dissemination of new technologies. Moreover, this is a domain where CNR is already fulfilling very well his third-mission role (especially towards CH institutions, museums and in applications oriented to tourism). Impact over industry is still limited (due to the scarcity of resources dedicated to the management and fruition of CH at the national level, which still do not make this domain very attracting for companies); but all indicators show that this situation could change shortly, especially for a country like Italy so much involved with tourism and cultural industry.

PROJECT AREA 11: TECHNOLOGIES FOR THE USE AND PRESERVATION OF CULTURAL HERITAGE S

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