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Europe and the Mediterranean:
Towards a Sustainable Built Environment

Edited by Ruben Paul Borg, Paul Gauci, Cyril Spiteri Staines

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SBE 16 Malta

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International Conference

16th March – 18th March 2016

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Sustainable Built Environment Malta

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Diagnostic Integrated Procedures aimed at Monitoring, Enhancement and Conservation of Cultural Heritage Sites

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Abstract. New methods for condition assessment survey of Cultural Heritage based on predictive analysis (diagnostic, conservative, morphometric) and non-destructive procedures (thermal imaging, level of reflectivity, integrated sensors, spectrophotometry, sonic surveys, etc.), supported by economically sustainable technologies and devices, are becoming more and more strategic for monitoring, conservation and regeneration processes. The European Project "INCEPTION - Inclusive Cultural Heritage in Europe through 3D semantic modelling", funded by EC within the Programme Horizon 2020, has the ambition to strongly support the development of a pan-European approach to data usage for better decision making related to preventive interventions and for supporting of site management and sustainable exploitation of assets. Software tools for 3D data processing and applications for maintenance and asset management will be developed within the Project INCEPTION in order to increase cross-sector collaboration and knowledge sharing to achieve the main goals of a sustainable, cost effective, no time-consuming, accurate procedure for diagnosis, monitoring and conservation of cultural heritage.

1. INTRODUCTION

The preservation of our tangible cultural heritage is increasingly closely linked to the possibilities of documentation, condition assessment, monitoring and predictive analysis by means of non-destructive procedures. Cultural heritage is nowadays at risk of loss for several causes, such as pollution, urban sprawl, global warming and climate change, mass tourism, extreme weather events, lack of maintenance and human intervention not respectful of the historical and material values of our legacy.

Protection, conservation and sustainable maintenance of cultural heritage is one of the Europe's priority also as a strategy to exit the current economic crisis and build smart, sustainable and inclusive growth, together with the reduction of the environmental impact and the establishment of business strategies for the economic value of cultural heritage.

Heritage management is a strong interdisciplinary filed and many actors are involved in the complex process that, from the documentation up to the restoration, leads to the preservation, enhancement and sustainable exploitation of assets.

In this framework, the European Commission supports more and more various aspects of European cultural heritage research and promotes excellence in heritage in all its forms, supporting in particular: conservation and ICT technologies, disaster resilience and climate change, energy efficiency in historic buildings, underwater cultural heritage, art, culture and humanities, such as the emergence of a European common identity, transnational dialogue and understanding.

The new agenda for EU Research and Innovation on cultural heritage in line with Horizon 2020 sets out in particular three interrelated objectives:

promoting innovative finance, investment, governance, management and business models which will increase the effectiveness of cultural heritage as an economic production factor;

promoting the innovative use of cultural heritage to encourage integration, inclusiveness and cohesion;

promoting the innovative use of cultural heritage to enable sustainable development of European cultural landscapes, seascapes and environments.

The coming, and the increasing development of tools and technologies for the diagnosis and study of the state of conservation of historic buildings was a turning point in the use of scientific analysis for non-destructive assessment and characterization of structures and materials, making increasingly strategic the integrated survey of morphological and dimensional features together with surface specifications.

In this context, the increasingly widespread use of different methodologies and technologies of three-dimensional survey of cultural heritage opens new scenarios that correlate the achievement of three-dimensional models with high metric-morphological precision and accuracy with mapping of the state of conservation, using the database obtained by the 3D survey as multi-layered digital models able to support multiple visualizations of information and surface specifications. This procedure is supported by several European research projects including "EU-CHIC".

Indeed the EU-CHIC project has demonstrated that there are several methods, tools and techniques to obtain information regarding the cultural heritage. Based on several indicators (e.g. time, costs, level of difficult and number of information collected) the three-dimensional survey of cultural heritage could be considered the most efficient solution.

In the last few years the Department of Architecture of the University of Ferrara developed a series of operational methodologies related to the three-dimensional survey of cultural heritage according to different approaches aimed at different targets and purposes: the 3D metric-morphologic survey in order to achieve 3D databases useful for documenting the geometric memory of historical-architectural heritage; the survey in emergency conditions to estimate the damages and structural assessments, the suggestion and proposal of reconstruction and preservation of the "memory" of the historical artefacts; survey, mapping and verification of unauthorized buildings in historic centres, up to metric surveys integrated with diagnostic methodologies for the conservation of the elevations and surface materials in heritage complexes, buildings and sites.

2. INTEGRATED PROCEDURES FOR DIAGNOSTIC ANALYSIS

Currently projects and interventions related to conservation, preservation, enhancement, refurbishment and reuse of cultural heritage are strictly related to different procedures to assess the state of conservation and general conditions of cultural heritage; starting from an overall documentations and historical researches (including historical construction phases, previous restorations, changes in functions and programs, etc.), visual detection, characterisation of materials and structural conditions, mapping of deteriorations processes and different instrumental diagnostic analysis on the basis of the purposes of the overall diagnostic investigation, the integrated diagnostic survey is the primary tool for decision makers and to define any kind of intervention or management of heritage sites.

Documentation, conservation, retrofitting, enhancement, valorisation and any other kind of interventions addressing the wide range of situations and requirements that cultural heritage presents, need multidisciplinary approaches and many different expertise. New technologies and 3D models interoperability outline new avenues in interoperability and data integration.

As a matter of fact, a specific brunch of the integrated procedures for monitoring the state of conservation toward a sustainable approach to preventive intervention and sites management is related to the "image" or "multi-spectral" analysis; combining 3D metric-morphologic models with mapping and image analysis of architecture surfaces it is possible to exploit useful representations and visualisation of conservative specifications and to extract new awareness and data. Three dimensional representations are an effective tool for studying, detecting and evaluate the transformation of the built environment and its multiple impacts and effects. Three-dimensional models, opportunely processed, not only allow to understand and assess

morphological features, but can also be configured as multi-layered 3D data bases for multidisciplinary purposes, including visual detections of material specifications and deteriorations by means of and high-definition digital visualisations for non-invasive investigations.

Fig 1. Example of 3D integrated survey methodologies applied to thefaçade of the Church of S. Carlo in Ferrara, Italy. The 3D time of flight laser scanner survey has been integrated with digital photographic survey, analysis of conservative specifications by spectrophotometric survey and reflectivity index (DIAPReM Centre, Department of Architecture, University of Ferrara).

2.1. *Diagnostic analysis integrated to 3D data acquisition*

Speed and amount of data are the main characteristics that allow the terrestrial 3D laser scanner survey to act as a useful technology for metric and morphological description of architectures and monumental complexes. The evolution of technology for automatic survey is the innovative key factor that allows to input high-density metric-morphological data as an essential support for the setting up of three-dimensional databases able to establish over time a useful archive of "geometric memory" of architecture applicable not only for research but also for conservative purposes and to support restoration projects, monitoring procedures and enhancement of heritage sites.

The high definition metric survey performed by 3D laser scanners produces 3D morphometric models described by sets of millions of coordinates; during the extraction and representation phases, it is possible to perform a multi-scale approach to the metric-descriptive investigation, relating the whole to its details and making the interrogation process reversible. The integration among the 3D laser scannerand the total station (topographic survey) is used to generate a geometric network able to resolve the set of problems relating the creation of the 3D model and the setting up of a coordinate system that allows to relate to each other all or just some parts of the building or complex.

2.2. *State of conservation analysis and diagnostic survey*

The data acquired by means of these integrated procedures (3D laser scanner based on time-of-flight technology, topographic survey, high-definition photographic survey, diagnostic analysis, etc.) are stored in a digital data base aimed at the periodical monitoring of surveyed areas and surfaces and progressive checking of the interventions of restoration. Digital archives allow making it easier to monitor deterioration processes and to plan restoration interventions.

The described procedure can be extremely powerful in monitoring the architectural items and setting up interactive metric databases able to provide at any time information about the surveyed objects. The results obtained until now have shown that it is possible to organize data bases of a great variety and nevertheless complementary to one another, so as to allow a global view of the conservative problem.

One of the main out-come resulting from this integrated procedure is the definition of guide-lines for the interventions on structures and surfaces and the actions for conservation of physical integrity of historical buildings, complexes, city centres and urban landscape or surfaces. This procedure is very useful to develop procedures and operative tools in order to identify, analyse and monitor cultural heritage state of conservation. Some considerations can be outlined in

order to point out a possible procedure to exploit the ICT technologies and 3D survey methodologies for enhancement and conservation of cultural assets:

- interdisciplinary competences are needed to preserve the authenticity of the cultural heritage according to the fundamental principles of minimum intervention, compatibility, interpretability and reversibility;
- promotion of maintenance like common strategy in conservation to avoid strong interventions, maintenance of natural assets to enhance the local landscape and use of local materials;
- development of non-destructive techniques and monitoring technologies;
- knowledge of decay mechanisms acting on original materials and structures and identification of critical areas for deeper investigation;
- use of high and innovative technology for no-contact surveying and documentation;
- understanding of accuracy and limits of the technologies, also related to different materials toward a multidisciplinary approach to diagnosis;
- elaboration of databases containing typical damages, testing problems, methods for assessment, diagnosis and monitoring, case studies, structural models, publications, research projects, websites, etc.
- creation of a data base to collect "best practice" interventions, innovative successful technologies, integrated conservative systems, technological transfer, high performance material and technologies and their interaction.

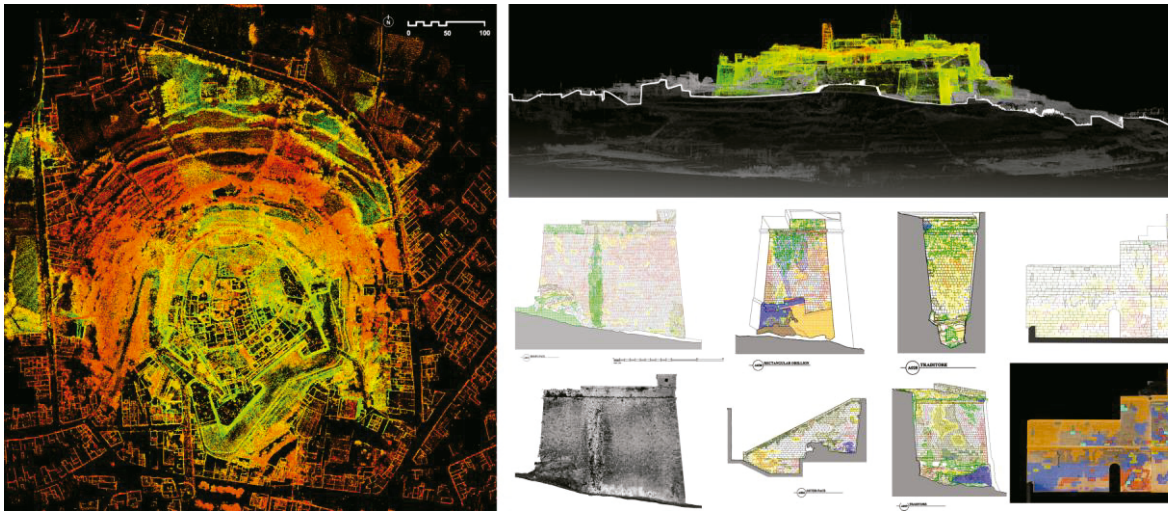

Fig 2. The survey of the Citadel of Gozo, Malta, is an example of high-definition documentation aimed at the restoration project. The primary objective was the 3D detailed acquisition of outer an inner surfaces of the walls, and a complete mapping of the state of conservation of the structures and surfaces.In addition to the purposes of knowledge, documentation and enhancement, the project started from the need to obtain a model for the extraction of accurate two-dimensional representations, a technical and scientific basis aimed at the restoration project (DIAPReM Centre, Department of Architecture, University of Ferrara, and CFR).

3. THE REFLECTIVITY INDEX FOR SURFACES CHARACTERISATION

As part of the integrated methodology of survey of cultural heritage, and in particular in survey methods aimed at conservative interventions on historical surfaces, procedures with the use of 3D laser scanner for the extraction of information for diagnostic evaluation on historical architectural surfaces have been experimented.

By means of time-of-flight technology, in addition to the metric coordinates, it is also possible to acquire the reflectance data of the surface (or reflectivity index), a value that represents the intensity with which the laser emitted from the scanner returns to the instrument

itself, and depends on the angle of incidence, the state of conservation and the nature of the analysed material.

The point cloud, the 3D model in which each point is spatially defined by the coordinates x, y, and z, can be displayed in "false colour" mode: the different colours that the software connects to the different parts of the model are related to the reflectance data. The conditions in which the survey is developed (location, light, humidity, etc.) are discriminating for a rigorous evaluation of the reflectance data for diagnostic purposes.

The knowledge of these data enables the collection of information through homogeneous areas on the basis of the angle of incidence and the kind of surface material; the intensity variation from point to point can be used to derive information about materials and the degradation of the investigated surface. Unlike the geometric characteristics, the surface qualities are not uniquely determined and must be carefully interpreted by comparison with other direct surveys. On the basis of this procedure it is possible to extract thematic drawings in which to display the surface areas that manifest different reactions in the reflection of the laser beam.

The accurate use of integrated diagnostic procedures can be an effective tool in the study and analysis of historic architectural surfaces aimed at conservation, monitoring and restoration. Such integrated procedures could be very effective to define guide-lines useful at the future conservative interventions for the preservation of historical centres. By integrating historical documentation, 3D survey, macroscopic analyses and colorimetric characterization, it is possible to collect and merge historical, metric and conservative data.

4. DIAGNOSTIC PROCEDURES FOR HERITAGE CONDITION ASSESSMENT

In the literature and following the analysis of many cases (state of art and on the field), it appears that is very difficult to define a common methodology for the preservation and enhancement of the cultural heritage [10]. A number of criteria borrowed from the study of the context and the market opportunities are what ensure a good result in economic terms and as regards the safeguarding of the building and the site as a whole. In-depth knowledge of the building is necessary, by an assessment of its state of structural conservation and material decay. Only after the diagnostic phase the planner can decide how to proceed and to choose between different techniques.

3D survey methodologies can be used to for the enhancement and conservation of cultural assets, by promoting programmed maintenance strategies and/or to enhance possible re-use strategies without damaging the authenticity of the cultural heritage according to the fundamental principles of minimum intervention.

The main aim of a sustainable approach on cultural heritage is to assess whether the maintenance/restoration/enhancement projects are carefully evaluated to respect the characteristics of the building, otherwise the building itself will no longer respond properly to environmental stress. Orientation and use of natural materials and natural factors such as lighting, energy and ventilation are the environmental elements which characterize historical buildings and which must be taken in consideration when assessing a restoration procedure. According to these criteria, sustainability is not related to an energy class, but to an historical, cultural, cost-efficient planning of the interventions.

In this context, 3D diagnostic procedures represent a very efficient and precise decision-making tool. Digital data-acquisition and storage can be used to manage:

- dimensional analysis of the buildings or sites;
- typological analysis of a typical site, to explain or rule out possibilities for expansion, in keeping with the original type;
- technological analysis to assess the current condition, to a “map of the decay” containing typical materials and structures and their damage;
- technical solutions for preservation or partial replacement (depending on the case in hand and requirements) in an overall maintenance planning.

Technical data is an essential tool in the creation of maintenance and renovation projects. The creation of a database for checking and surveying the “state of health” of a building or a site

can be considered as an integral part of the planned strategies for maintenance and the procedures for restoring them, supported by an estimate of the costs of performing. The possibility of planning the level of intervention strongly depends on the assessment of a sustainable monitoring, conservation and regeneration processes that can be summarized in the following steps:

- advanced surveys: non-destructive diagnostic tests onmaterials and forms of degradation, on structures and structural – safety monitoring;
- evaluation of the reversibility of the intervention;
- compatibility of the intended use (in the case of restoration);
- chemical-physical compatibility of the restoration materials (mortars, plasters, etc.);
- structural compatibility compared to the existing structure;
- collection and storage of recyclable materials;
- management of waste from interventions (partial demolition and reconstructions included);
- maintenance of the technical and of existing surface finish;
- environmental optimization of products;
- materials extracted, processed and produced in limited distance (km 0).

Data captured for the definition of an assessment and programmed maintenance or refurbishment method have to be interfaced with the analysis of the regulatory, economic and historic context and also the evaluation of the quality of the market demand and of the local requirements, so as to allow for the quick interpretation of usage and economical potential, and the definition of the peculiar parameters of the quality of the building.

5. INCEPTION PROJECT: APPLICATIONS FOR MONITORING, ENHANCEMENT AND CONSERVATION OF CULTURAL HERITAGE

The European Project "INCEPTION - Inclusive Cultural Heritage in Europe through 3D semantic modelling", funded by EC within the Programme Horizon 2020[1], is focused on innovation in 3D modelling of cultural heritage through an inclusive approach for time-dynamic 3D reconstruction of built and social environments.

The project aims to create an inclusive understanding of European cultural identity and diversity by stimulating and facilitating collaborations across disciplines, technologies and sectors; to develop cost-effective procedures and enhancements for on-site 3D survey and reconstruction of cultural heritage artefacts, buildings, sites and social environments; and to develop an open-standard Semantic Web platform for accessing, processing and sharing interoperable digital models resulting from 3D survey and data capturing.

Among the main purposes related to the 3D semantic modelling and wide accessibility of semantically enriched digital models by different users, a specific section of the research is related to enhance the efficiency of three-dimensional data capturing procedures and devices, especially their suitability and aptitude to survey artefacts with non-conventional characteristics, location and geometries. This goal comes under the optimization of a 3D data acquisition protocol, an integrated methodology for Cultural Heritage acquisition in order to close the gap between specialist technicians and non-technical users involved in heritage documentation;

[1]The project, started in June 2015, will be developed by a consortium of fourteen partners from ten European countries led by the Department of Architecture of the University of Ferrara (scientific coordinator Prof. Roberto Di Giulio) which makes use of the facilities and researchers of the Laboratory TekneHub, Ferrara Technopole, belonging to the Construction Platform of the Emilia-Romagna High Technology Network. Academic partners of the Consortium, in addition to the Department of Architecture of the University of Ferrara, include the University of Ljubljana (Slovenia), the National Technical University of Athens (Greece), the Cyprus University of Technology (Cyprus), the University of Zagreb (Croatia), the research centersConsorzioFuturo in Ricerca (Italy) and Cartif (Spain). The clustering of small medium enterprises includes: DEMO Consultants BV (The Netherlands), 3L Architects (Germany), Nemoris (Italy), RDF (Bulgaria), 13BIS Consulting (France), Z + F (Germany), Vision and Business Consultants (Greece). The project has been applied for the Work Programme Europe in a changing world – inclusive, innovative and reflective Societies (Call - Reflective Societies: Cultural Heritage and European Identities, Reflective-7-2014, Advanced 3D modelling for accessing and understanding European cultural assets).

provide a guide to the user and the supplier of metric survey data, explaining expected features in order to achieve the main goals in cultural heritage documentation and data capturing; define a of common procedure for historical data retrieval and possible previous survey; cataloguing and digitization; knowledge of geometric, surface and structural features; analysis of the state of conservation; maintenance of programmatic interventions in the short and long term; outline a list of performance indicators to ensure the effective management of metric survey projects, focusing on the needs and requirements of non-technical users of heritage documentation.

About that, the project will develop new methods for condition assessment survey of cultural heritage based on predictive analysis (diagnostic, conservative, morphometric), non-destructive procedures (thermal imaging, level of reflectivity, integrated sensors, spectrophotometry, sonic surveys, etc.) and will be supported by economically sustainable technologies and devices.

Moreover, INCEPTION solves procedures for registering and handling the index of reflectivity. Defining a novel, practical method for obtaining 3D digital models that clearly show material deterioration is one the main requirement by cultural heritage owners or managing organizations to facilitate detection and decision making on the corrective and preventive measures to be adopted.

An applied research approach will be developed in INCEPTION, based on a combination of state-of-the-art 3D data acquisition, with a tailored computational algorithm for managing the reflectivity index provided by laser scanning devices. A BIM compatible unique digital model, including geometrical, colour and reflectivity information of complex shaped objects, could be readily obtained, thereby favouring not only the cataloguing, but also revealing the probable degradation causes.

Time, expenditure and areas to be cleared up are expected to be clearly defined by the proposed method, which will be implemented through a practical tool for handling 3D point clouds, giving support to current and further automatic procedures.

6. CONCLUSION

Approaching cultural heritage for planning maintenance or restoration purposes requires an in-depth knowledge and clear instructions in order to avoid damaging or compromising the historical identity.

Management policies on cultural heritage must respect the historical and artistic value of the building and should be sustainable and economically efficient. This can be made possible by promoting integrated procedures to identify, analyse and monitor cultural heritage state of conservation to promote out possible communal procedures for the enhancement and conservation of cultural assets.

Non-destructive ICT technologies and 3D survey methodologies allows a wide range of opportunities for the interventions on structures and surfaces and the actions for conservation of physical integrity of historical buildings, complexes, city centres and urban landscape or surfaces.

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