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3D documentation and semantic aware representation of Cultural Heritage: the INCEPTION project

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Abstract

As part of 3D integrated survey applied to Cultural Heritage, digital documentation is gradually emerging as effective support of many different information in addition to the shape, morphology and dimensional data. The implementation of data collection processes and the development of semantically enriched 3D models is an effective way to enhance the dialogue between ICT technologies, different Cultural Heritage experts, users and different disciplines, both social and technical. The possibility to achieve interoperable models able to enrich the interdisciplinary knowledge of European cultural identity is one of the main outcome of the European Project "INCEPTION - Inclusive Cultural Heritage in Europe through 3D semantic modelling", funded by EC within the Programme Horizon 2020. The project ranges from the documentation and diagnostic strategies for heritage protection, management and enhancement, to the 3D acquisition technologies. The development of hardware, software and digital platforms is aimed at representation and dissemination of cultural heritage through ICT processes and BIM addresses to Cultural Heritage assets, up to the implementation of semantic information to a wider and more extensive use of 3D digital models.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information interfaces and presentation]: Artificial, augmented, and virtual realities—I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—

1. Introduction

One of the main challenge to be faced at European level is to contribute to an understanding of Europe's intellectual basis. In these efforts, new technologies and digital cultural heritage should play an important role. Innovative digital tools are a great opportunity to understand, access, enhance and preserve cultural assets. Information and Communication Technologies are constantly evolving and new digital media are increasingly used for accessing and understanding cultural heritage. The enhancement of digital cultural heritage accessibility is the ability to access cultural contents and resources for as many people as possible by using ICT functionalities and applications (web sites, data-bases, digital libraries, virtual applications, etc.) overcoming cultural, environmental and management barriers for an easy and spread fruition. Nowadays it is possible to integrate different information in order to access cultural assets in many different ways and for many different purposes, thanks to new languages of interactive media aimed at innovative ways of communication of cultural heritage.

Beyond the application of ICT for management, research, diagnosis, conservation and restoration procedures, education and enhancement, new technologies allow the communication and dissemination of cultural assets that become more and more accessible for new knowledges and experiences [DG16]; through digital technologies broad categories of users have access to European tangible and intangible cultural assets. The availability of databases collecting different information allow achieving the widest accessibility and interoperability at a multidisciplinary level.

New applications allow accessing sites and objects from the heritage site, or such as in labs, museums, classrooms, or even in personal homes or offices. Users have more and more interactive possibilities to access the knowledge about different sites and objects, to exchange the knowledge between each other, and to enrich the knowledge with their findings and complementary insights by means of interactive platforms and social media. The development of data capturing technologies and graphic features has maximized the enhancement of digital contents for virtual tour applications, serious games and many different immersive and interactive experiences that enable a sustainable access and enjoinment of heritage sites even by young generations. As part of 3D integrated survey applied to Cultural Heritage, digital documentation is gradually emerging as effective support of many different information in addition to the shape, morphology and dimensional data. The increasing development of 3D laser scanner technologies allows creating high definition databases based on even more detailed three-dimensional morphometric data. These "digital archives" are an extremely valuable research tool in cultural heritage field: the "geo-

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metric memory" is essential for knowledge, protection and sustainable conservation of Cultural Heritage, although there are still some limits to the exploitation of 3D models obtained by laser scanner survey. The growing numbers of un-exploited and "un-interpreted" 3D models points out the remarkable need for innovative methods that could benefit from the informative value provided by new systems for surveying and representations as well as data management tools.

Advanced 3D documentation methodologies identifying different layers of data to be recorded for heritage applications is one of the main outcome of the European Project "INCEPTION - Inclusive Cultural Heritage in Europe through 3D semantic modelling", funded by EC within the Programme Horizon 2020. The project proposes the enhancement of efficiency in 3D data capturing procedures and devices, especially as regards their suitability and aptitude for tangible cultural assets: cultural heritage sites, historical architectures, archaeological sites characterized by non-conventional features, location and geometries.

1.1. The INCEPTION project

Starting from innovative methodologies for the 3D survey and modelling of Heritage buildings and sites, the INCEPTION project aims to develop new tools for the interoperability and the inclusive sharing of three-dimensional models towards new forms of access and awareness of the European cultural heritage. The project, started in June 2015, is developed by a Consortium of fourteen partners from ten European countries led by the Department of Architecture of the University of Ferrara. 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 centres Consorzio Futuro 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 puts into effect one of the main challenges that the European Commission has launched by the program Horizon 2020 and in particular in the Societal Challenge 6 - Work Programme 2014-2015: to contribute to a deeper awareness and understanding of European cultural heritage as inspiration for addressing contemporary challenges, increasing the knowledge of heritage and its different identities. To this purpose, new technologies and digitization processes play a key role since they allow new and enhanced interpretations of our collective cultural heritage, while contributing to sustainable economic growth.

Simultaneously to strategies aiming at the optimization of a 3D data acquisition protocol able to guide the processes of digitization of cultural heritage, the project will develop nine case studies. Pilot projects started with the recognition of the specific needs and requirements of each building or site, developing specific three-dimensional modelling operations that will make the digital models used by different categories of inter-disciplinary users, populating the INCEPTION platform. The INCEPTION project aims at an effective knowledge and dissemination of European cultural heritage through a Stakeholder Panel. This Panel is an assembly of European institutions, which will provide a meaningful discussion with experts in the field of Cultural Heritage not only scientifically but also directing research toward those strategies needed by "end users" and institutions to increase knowledge, enhancement and dissemination through digital models in order to promote the inclusiveness and accessibility of European cultural heritage. The institutions involved in the project "demonstration cases" will cooperate in the development of important applications, tools and methodological processes of great value and interest. The strategies of dissemination of digital models will involve both in situ applications for visitors, tourists, scholars and researchers, and remote applications that enable the widest possible access and knowledge of cultural heritage.

2. INCEPTION research avenues

INCEPTION aims to release innovation in 3D modelling of cultural heritage through an inclusive approach for time-dynamic 3D reconstruction of buildings, sites and social environments. The overall inclusive approach comprises an effective enrichment of the European identity through understanding of how cultural heritage continuously evolves over long periods of time. This innovation is beyond the state-of-the-art of rather static 3D reconstruction. 3D models generated through INCEPTION methodologies and tools will be accessible for all types of user. Semantic enrichment will result in "intelligent" 3D models for multiple purposes depending on the needs and the level of knowledge of the end-users (e.g. 3D semantic models contain geometric information for 3D visualisation, historical information for narration, information for material conservation, etc.).

The project follows three main objectives. The first one is creating an inclusive understanding of European cultural identity and diversity by stimulating and facilitating collaborations across disciplines, technologies and sectors. This objective is addressed by enabling 3D digital reconstructions in an open-standard format for Heritage Building Information Modelling (H-BIM). Such models will be easily accessible and reusable by researchers, scientists, experts and creative practitioners working in cultural heritage industries in order to promote collaboration across sectors and facilitate cross-disciplinary researches, dissemination, education and business opportunities. Semantic integration of rich narratives with Virtual and Augmented Reality (VR and AR) will create accurate perception and deep understanding for specialists and common users. The accessibility and analytical quality of the models is supported by Semantic Web Platform with Semantic Query function to retrieve rich data, as well as to interface between hardware and software for VR and AR. User apps for mobile devices will be develop to access and enrich the H-BIM. These apps are designed for specialists as well as common users to access the socio-economic significance for diffusion, dissemination, knowledge and enhancement of Cultural Heritage. Demonstration will be done involving the members of Stakeholder Panel.

The development of cost-effective procedures and enhancements for on-site 3D survey and reconstruction of cultural heritage buildings and sites is the second objective. Enhancement of the efficiency of 3D data capturing procedure and devices is addressed to

the suitability and aptitude for the physical cultural resources and assets. Condition assessment are considered as well.

An open-standard Semantic Web platform for accessing, processing and sharing interoperable digital models resulting from 3D survey and data capturing will be developed. This objective will be achieved through a standard for managing 3D point clouds data at multiple scales, linked with Geo-spatial Information Systems. Related actions are: defining an open standard format and semantic ontology to generate high-quality, reliable and interoperable models of H-BIM [LDS15]; developing and testing APIs (Application Programming Interfaces) to allow both definition, implementation and interoperability of various software and data models without compromising quality and functionality; implementing multilevel databases of 3D semantic models oriented towards various use cases such as understanding, enhancement, promotion, management and enjoyment of cultural heritage and supporting conservation and restoration works.

"Space" and "Time" are two basic dimensions throughout the INCEPTION project. The overall approach to the survey and modelling of heritage spaces and geometric dimensions is the opportunity to explore and improve the multi-layered conceptual dimension of European heritage. At the same time, one of the main challenges of the project is to develop a set of features allowing the creation, visualization and analysis of 3D H-BIM models over time, with emphasis on how the modelled heritage evolves in association with its build and social environments. The so-called INCEPTION "Time-machine" will be developed as open-standard Semantic Web Platform. The implementation of the dynamic structure of the INCEPTION Platform through models and reconstructions/simulations related to specific historical periods, allows to "move across time and space" enabling features like time machines.

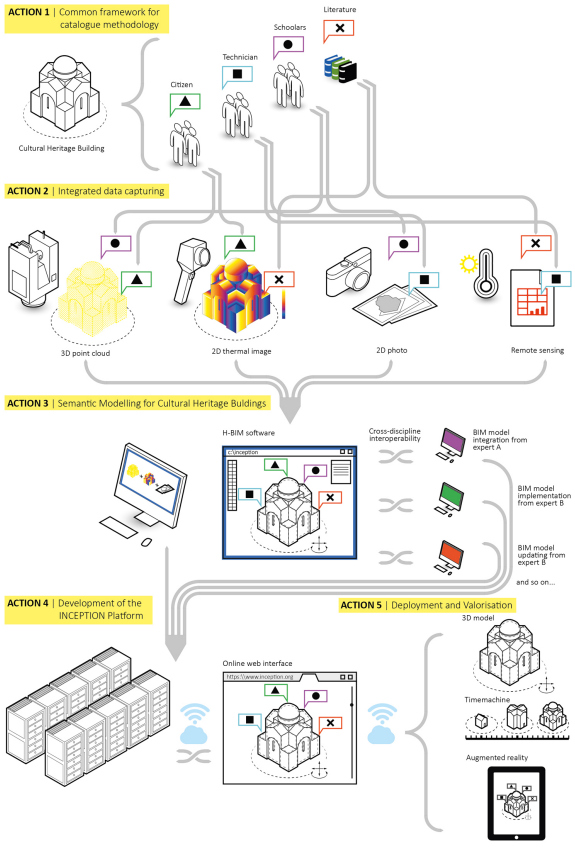

Figure 1: *Scheme of the overall project concept and approach divided into five main Actions.*

3. Project concept and approach

Scientific and technological approach followed within the project is focused on technological development and validation mechanism, ranging from Technology Readiness Level 4 to 7 (improvement and validation of technical protocols, selected hardware and software, test models in relevant environments, etc.). Within this scientific and technological framework, the main progresses beyond the state of the art are related to: braking through the segmentation in collecting data, assessment and optimization of 3D data acquisition protocol and tools, hardware advancement, tailored algorithms for managing captured data, conversion of point-cloud data to H-BIM, platform to achieve the widest accessibility to 3D models, improvement in the achievement of information integrated in 3D models.

The overall concept and project methodology of INCEPTION is based on five main Actions. Action 1 is related to the development of a common framework for catalogue methodology, basically by mapping the stakeholders' knowledge demands and targeted implementations by scholars, technicians, citizens and governments through the identification of key requirements that contribute to meet Europe's societal objectives related to Cultural Heritage [IMTF*14]. The implementation of an effective, cross-disciplinary and collaborative work methodology allowed to define the data collection process, case studies setup, selection and utilization of system and instruments, implementation of semantically enriched models and exploitation in education and business.

Action 2 is related to the integrated 3D data capturing. The INCEPTION optimized data acquisition protocol is a set of guidelines to be followed during the planning and performing of a 3D laser scanner survey of Cultural Heritage, and it is referred to an architectural, archaeological, urban and site scale. It is also referred to data management (scan registration, data verification) data storage and archive. It is both a methodological procedure and an optimized workflow specification. Further steps of this action are related to the enhancement of functionalities, capabilities and cost-effectiveness of data capturing technologies and documentation instruments.

Action 3 is focused on the identification of the Cultural Heritage buildings semantic ontology and data structure for information catalogue. Integration of sematic attributes with hierarchically and mutually aggregated 3D digital geometric models is indispensable for management of heritage information. The aims of this stages are:

- the creation of a shared semantic field for Cultural Heritage to be integrated in a wiki-like 3D parametric modelling approach;
- the implementation of guidelines for 3D parametric and semantic

modelling in an Heritage-BIM environment, based on Open BIM standard (IFC, IFD, etc.);
- the development of semantic 3D reconstructions of the heritage sites, integrated with intangible information and social environment, structuring digital representation of sites and artefacts to create models more accessible and implementable.

Action 4 is the development of the INCEPTION Semantic Web Platform. The interoperable Semantic Web H-BIM Platform will allow achieving the widest accessibility and interoperability, the use of three-dimensional models by researchers from different disciplines and non-expert users, minimizing the difficulties of interaction with these kind of data, now accessible only by experts through the use of dozens of different software. The implementation of the dynamic structure of the platform through models and reconstructions/simulations related to specific historical periods will prove users with a dashboard for accessing survey data, i.e. cloud of points, and building 3D historical simulations. The collection of semantic data associated to the models will enable the information enrichment by users, sharing knowledge and allow new interpretation and understanding of European cultural assets. An historical database repository will be created in relation to EUROPEANA's main scopes and objectives, to save and share 3D models with the associated semantic information, documents and all the other possible contributions delivered by external users (i.e. Professors, Experts, Students, End-Users). The database will store the geographic coordinates to display these models into a specific historical map managed with a historical geographic information system (HGIS). Moreover, an historical model search engine will be implemented. This web application will allow to search with specific keywords contained in the semantic information [DM12].

Action 5, Deployment and Valorisation, will start by developing a wiki-like feature to enable the sharing and enrichment of the information and interpretation of the models by users; the 3D models will be delivered in different Apps for numerous of purposes. The "browsing and query interface" will be defined allowing contributions by researchers and experts that actually do not deal with 3D data, and enabling a wide and easy access to the data by citizens, non-expert users and public at large [Val16]. Demonstration activities will start at the beginning of the third year pursuing three main goals: to gather practical input from the stakeholders; to setup a relevant environment (realistic or near-to-operational) for testing and validation of the research outcomes; and to disseminate the preliminary results through real examples with direct involvement of the stakeholders. Every user will be able to upload 3D models (following the specific Inception standard), semantic data, documents (i.e. pictures, maps, literature), leave comments or other material necessary to improve the scientific knowledge. It will be authorised only authenticated users with a verified email address. The user applications and model deployment with integral narratives will be done remotely, simultaneously or in different moments, from the heritage site, such as in labs, museums, classrooms, or even in personal homes or offices. This will provide the users (i.e. visitors/tourists, scholars/researchers) with an interactive possibility to access the knowledge about the sites and objects, to exchange the knowledge between each other, and to enrich the knowledge with their findings and complementary (or contradicting) insights.

4. Results and future developments

The need of a future re-use of such broad and descriptive source of measurement data demands new applications to facilitate information accessing collected in three-dimensional database without compromising the quality and amount of information captured in the survey. Databases allow users to understand how each survey-phase was carried out (scans, topographic support, images acquisition, etc.) and thus to obtain the maximum possible amount of morphological information; this procedure means to work with complex interfaces that are based on the programming languages of the software used to complete the survey itself. Currently, efforts in developing the user interface are concentrated on H-BIM environment and semantic enrichment and in providing direct or partially controlled access to the large three-dimensional scale models, also by means of immersive navigation. The creation of large digital spaces properly set up in terms of both form and dimensions, will make possible to navigate, enter, and extract its qualities and specifications (measurements, colours, materials, historical documentation, conservation records). However, the user's needs and desire for knowledge might be somewhat stymied by such complicated interfaces that could be hard to understand. Current efforts are focused on creating immersive and easy-to-use 3D visualizations that can be accessed from a wide range of user. The field of experimentation underlying the integrated, interdisciplinary research effort shares many aspects (dimension and complexity of the data) with heritage surveys, and the results obtained so far give us reason to hope that these optimization processes can be exported. New simplified navigation interfaces are also being developed [MS16] for users with lower levels of expertise to facilitate access to and navigation of the three-dimensional models. It is thus clear that new visualization and communication modes for the geometrical and measurement information have to be conceived and developed in step with the development and application of three-dimensional surveys.

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