Antonia Moropoulou
Manolis Korres
Andreas Georgopoulos
Constantine Spyrakos
Charalambos Mouzakis (Eds.)

Communications in Computer and Information Science 962

Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage

First International Conference, TMM_CH 2018
Athens, Greece, October 10–13, 2018
Revised Selected Papers, Part II

Part 2

Springer

Communications in Computer and Information Science 962

Commenced Publication in 2007
Founding and Former Series Editors:
Phoebe Chen, Alfredo Cuzzocrea, Xiaoyong Du, Orhun Kara, Ting Liu, Dominik Ślęzak, and Xiaokang Yang

Editorial Board

More information about this series at http://www.springer.com/series/7899

Antonia Moropoulou · Manolis Korres
Andreas Georgopoulos · Constantine Spyrakos
Charalambos Mouzakis (Eds.)

Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage

First International Conference, TMM_CH 2018
Athens, Greece, October 10–13, 2018
Revised Selected Papers, Part II

Springer

Editors
Antonia Moropoulou
National Technical University of Athens
Athens, Greece

Manolis Korres
National Technical University of Athens
Athens, Greece

Andreas Georgopoulos
National Technical University of Athens
Athens, Greece

Constantine Spyrakos
National Technical University of Athens
Athens, Greece

Charalambos Mouzakis
National Technical University of Athens
Athens, Greece

ISSN 1865-0929 ISSN 1865-0937 (electronic)
Communications in Computer and Information Science
ISBN 978-3-030-12959-0 ISBN 978-3-030-12960-6 (eBook)
https://doi.org/10.1007/978-3-030-12960-6

Library of Congress Control Number: 2019930855

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Organization

General Chair

Antonia Moropoulou	National Technical University of Athens, Greece

Program Committee Chairs

Manolis Korres	National Technical University of Athens, Greece
Andreas Georgopoulos	National Technical University of Athens, Greece
Constantine Spyrakos	National Technical University of Athens, Greece
Charis Mouzakis	National Technical University of Athens, Greece

Steering Committee

Antonia Moropoulou	National Technical University of Athens, Greece
Manolis Korres	National Technical University of Athens, Greece
Andreas Georgopoulos	National Technical University of Athens, Greece
Constantine Spyrakos	National Technical University of Athens, Greece
Charis Mouzakis	National Technical University of Athens, Greece
Kountouri Elena	Directorate of Prehistoric and Classical Antiquities, Greece
Florentis Georgios	Ministry of Digital Policy, Telecommunications and Media of the Hellenic Republic, Greece
Keane Kathryn	National Geographic Society, USA
Hiebert Fredrik	National Geographic Society, USA
Burnham Bonnie	World Monuments Fund, USA
Avramides Yiannis	World Monuments Fund, USA
Korka Elena	International Council of Monuments and Sites (ICOMOS), France
Minaidis Lee	Organization of World Heritage Cities (OWHC), Canada
Potsiou Chryssy	International Federation of Surveyors (FIG), Denmark
Rodriguez-Maribona Isabel	European Construction Technology Platform (ECTP), Belgium
Forest Emmanuel	European Construction Technology Platform (ECTP), Belgium
Murphy Mike	European Society for Engineering Education (SEFI), Belgium
De Vries Pieter	European Society for Engineering Education (SEFI), Belgium

Caristan Yves	European Council of Academies of Applied Sciences, Technologies and Engineering Euro-Case, France
Prassianakis Ioannis	Academia NDT International, Italy
Massué Jean Pierre	Council of Europe, France
D'Ayala Pier Giovanni	International Scientific Council for Island Development (INSULA), France
Ronchi Alfredo	European Commission-MEDICI Framework, Belgium
Di Giulio Roberto	University of Ferrara, Italy
Ioannides Marinos	Cyprus University of Technology, Cyprus
Gravari-Barbas Maria	Paris 1 Panthéon-Sorbonne University, France
Efesiou Irene	National Technical University of Athens, Greece
Alexopoulou Aleka	Aristotle University of Thessaloniki, Greece
Tzitzikosta Aikaterini	Hellenic National Commission for UNESCO, Greece
Achniotis Stelios	Cyprus Scientific and Technical Chamber (ETEK), Cyprus
Baruch Yuval	Israel Antiquities Authority, Israel
Groysman Alec	Association of Engineers, Architects and Graduates in Technological Sciences, Israel
Nakasis Athanasios	Hellenic Section of ICOMOS, Greece
Lianos Nikolaos	Democritus University of Thrace, Greece
Avgerinou-Kolonias Sofia	National Technical University of Athens, Greece
Hadjinicolaou Teti	International Council of Museums Hellenic National Committee, Greece
Pissaridis Chrysanthos	ICOMOS, Cyprus
Mavroeidi Maria	International Committee for the Conservation of Industrial Heritage (TICCIH), Greece
Maistrou Eleni	National Technical University of Athens, Greece
Tournikiotis Panayotis	National Technical University of Athens, Greece
Corradi Marco	University of Perugia, Italy
Forde Michael	University of Edinburgh, UK
Aggelis Dimitris	Free University of Brussels, Belgium
Anagnostopoulos Christos	University of the Aegean, Greece
Asteris Panagiotis	School of Pedagogical and Technological Education (ASPETE), Greece
Athanasiou Stefanos	University of Bern, Switzerland
Balas Kostas	Technical University of Crete, Greece
Botsaris Pantelis	Democritus University of Thrace, Greece
Boutalis Ioannis	Democritus University of Thrace, Greece
Castigloni Carlo	Polytechnic University of Milan, Italy
Chetouani Aladine	University of Orleans, France
Chiotinis Nikitas	University of West Attica, Greece
Christaras Basile	Aristotle University of Thessaloniki, Greece
Coccossis Harry	University of Thessaly, Greece

D'Ayala Dina	University College London, UK
Dimakopoulos Vassilios	University of Ioannina, Greece
Distefano Salvatore	Kazan Federal University, Russia
Erdik Mustafa	Bogazici University, Turkey
Foudos Ioannis	University of Ioannina, Greece
Ioannou Ioannis	University of Cyprus, Cyprus
Kallithrakas-Kontos Nikolaos	Technical University of Crete, Greece
Katsifarakis Konstantinos	Aristotle University of Thessaloniki, Greece
Koufopavlou Odysseas	University of Patras, Greece
Koutsoukos Petros	University of Patras, Greece
Kyriazis Dimosthenis	University of Piraeus, Greece
Kyvellou Stella	Panteion University of Social and Political Sciences, Greece
Leissner Johanna	Fraunhofer Institute, Germany
Osman Ahmad	Saarland University of Applied Sciences, Germany
Mouhli Zoubeïr	Association de Sauvegarde de la Médina de Tunis, Tunisia
Loukas Athanasios	University of Thessaly, Greece
Mataras Dimitris	University of Patras, Greece
Mavrogenes John	Australian National University, Australia
Nobilakis Ilias	University of West Attica, Greece
Paipetis Alkiviadis	University of Ioannina, Greece
Papageorgiou Angelos	University of Ioannina, Greece
Pappas Spyros	European Commission, Belgium
Philokyprou Maria	University of Cyprus, Cyprus
Prepis Alkiviades	Democritus University of Thrace, Greece
Providakis Konstantinos	Technical University of Crete, Greece
Sali-Papasali Anastasia	Ionian University, Greece
Saridakis Yiannis	Technical University of Crete, Greece
Skianis Charalambos	University of the Aegean, Greece
Skriapas Konstantinos	Network PERRAIVIA, Greece
Sotiropoulou Anastasia	School of Pedagogical and Technological Education (ASPETE), Greece
Spathis Panagiotis	Aristotle University of Thessaloniki, Greece
Stavroulakis Georgios	Technical University of Crete, Greece
Tokmakidis Konstantinos	Aristotle University of Thessaloniki, Greece
Touliatos Panagiotis	Frederick University, Cyprus
Tsatsanifos Christos	International Society for Soil Mechanics and Geotechnical Engineering, UK
Tsilaga Evagelia-Marina	University of West Attica, Greece
Tucci Grazia	University of Florence, Italy
Xanthaki-Karamanou Georgia	University of the Peloponnese, Greece
Zacharias Nikos	University of the Peloponnese, Greece
Zendri Elisabetta	Ca'Foscari University of Venice, Italy

Scientific Committee

Antonia Moropoulou	National Technical University of Athens, Greece
Manolis Korres	National Technical University of Athens, Greece
Andreas Georgopoulos	National Technical University of Athens, Greece
Constantine Spyrakos	National Technical University of Athens, Greece
Charis Mouzakis	National Technical University of Athens, Greece
Abdal Razzaq Arabiyat	Jordan Tourism Board, Jordan
Abuamoud Ismaiel Naser	University of Jordan, Jordan
Achenza Maddalena	University of Calgary, Canada
Adamakis Kostas	University of Thessaly, Greece
Aesopos Yannis	University of Patras, Greece
Agapiou Athos	Cyprus University of Technology, Cyprus
Aggelakopoulou Eleni	Acropolis Restoration Service, Greece
Andrade Carmen	International Centre for Numerical Methods in Engineering, Spain
Argyropoulou Bessie	University of West Attica, Greece
Asteris Panagiotis	School of Pedagogical and Technological Education ASPETE, Greece
Athanasiou Stefanos	University of Bern, Switzerland
Avdelidis Nikolaos	University of Thessaly, Greece
Babayan Hector	National Academy of Sciences of Armenia, Armenia
Badalian Irena	Church of the Holy Sepulchre, Israel
Bakolas Stelios	National Technical University of Athens, Greece
Benelli Carla	Church of the Holy Sepulchre, Israel
Bettega Stefano Maria	Superior Institute of Artistic Industries (ISIA), Italy
Betti Michele	University of Florence, Italy
Biscontin Guido	Ca'Foscari University of Venice, Italy
Boniface Michael	University of Southampton, UK
Boyatzis Stamatis	University of West Attica, Greece
Bounia Alexandra	University of the Aegean, Greece
Bozanis Panayiotis	University of Thessaly, Greece
Caradimas Constantine	National Technical University of Athens, Greece
Cassar JoAnn	University of Malta, Malta
Cassar May	University College London, UK
Cavaleri Liborio	University of Palermo, Italy
Chamzas Christodoulos	Democritus University of Thrace, Greece
Chiotinis Nikitas	University of West Attica, Greece
Chlouveraki Stefania	University of West Attica, Greece
Correia Marianna	School Gallaecia of Portugal, Spain
Daflou Eleni	National Technical University of Athens, Greece
De Angelis Roberta	University of Malta, Malta
Delegou Aikaterini	National Technical University of Athens, Greece

Dellatore Stefano	Polytechnic University of Milan, Italy
Demotikali Dimitra	National Technical University of Athens, Greece
Dimitrakopoulos Fotios	National and Kapodistrian University of Athens, Greece
Don Gianantonio Urbani	Studium Biblicum Franciscanum in Jerusalem - Diocese of Vicenza, Israel
Doulamis Anastasios	National Technical University of Athens, Greece
Drdácký Miloš	Academy of Sciences of the Czech Republic, Czech Republic
Dritsos Stefanos	University of Patras, Greece
Economopoulou Eleni	Aristotle University of Thessaloniki, Greece
Economou Dimitrios	University of Thessaly, Greece
Exadaktylos George	Technical University of Crete, Greece
Facorellis Yorgos	University of West Attica, Greece
Farouk Mohamed	Bibliotheca Alexandrina, Egypt
Firat Diker Hasan	Fatih Sultan Mehmet Vakıf University, Turkey
Frosina Annamaria	Centre for Social and Economic Research in Southern Italy (CRESM), Italy
Fuhrmann Constanze	Fraunhofer Institute for Computer Graphics Research IGD, Germany
Ganiatsas Vasilios	National Technical University of Athens, Greece
Gavela Stamatia	School of Pedagogical and Technological Education (ASPETE), Greece
Ghadban Shadi Sami	Birzeit University, Birzeit, Palestine
Gharbi Mohamed	Institut Supérieur des Etudes Technologiques de Bizerte, Tunisia
Gómez-Ferrer Bayo Álvaro	Valencian Institute for Conservation and Restoration of Cultural Heritage, Spain
Hamdan Osama	Church of the Holy Sepulchre, Israel
Iadanza Ernesto	University of Florence, Italy
Ioannidis Charalambos	National Technical University of Athens, Greece
Izzo Francesca Caterina	Ca'Foscari University of Venice, Italy
Kaliampakos Dimitrios	National Technical University of Athens, Greece
Kapsalis Georgios	National University of Ioannina, Greece
Karaberi Alexia	National Technical University of Athens, Greece
Karellas Sotirios	National Technical University of Athens, Greece
Karoglou Maria	National Technical University of Athens, Greece
Katsioti-Beazi Margarita	National Technical University of Athens, Greece
Kavvadas Michael	National Technical University of Athens, Greece
Kioussi Anastasia	Fund of Archaeological Proceeds, Greece
Kollias Stefanos	National Technical University of Athens, Greece
Konstanti Agoritsa	National Technical University of Athens, Greece
Konstantinides Tony	Imperial College London, UK
Kontoyannis Christos	University of Patras, Greece
Kourkoulis Stavros	National Technical University of Athens, Greece

La Grassa Alessandro	Centre for Social and Economic Research in Southern Italy (CRESM), Italy
Lambropoulos Vasileios	University of West Attica, Greece
Lambrou Evangelia	National Technical University of Athens, Greece
Lampropoulos Kyriakos	National Technical University of Athens, Greece
Lee-Thorp Julia	Oxford University, UK
Liolios Asterios	Democritus University of Thrace, Greece
Liritzis Ioannis	University of the Aegean, Greece
Lobovikov-Katz Anna	Technion Israel Institute of Technology, Israel
Lourenço Paulo	University of Minho, Portugal
Lyridis Dimitrios	National Technical University of Athens, Greece
Maietti Federica	University of Ferrara, Italy
Mamaloukos Stavros	University of Patras, Greece
Maniatakis Charilaos	National Technical University of Athens, Greece
Maravelaki Pagona-Noni	Technical University of Crete, Greece
Marinos Pavlos	National Technical University of Athens, Greece
Marinou Georgia	National Technical University of Athens, Greece
Mataras Dimitris	University of Patras, Greece
Matikas Theodoros	University of Ioannina, Greece
Mavrogenes John	Australian National University, Australia
Milani Gabriele	Polytechnic University of Milan, Italy
Miltiadou Androniki	National Technical University of Athens, Greece
Mitropoulos Theodosios	Church of the Holy Sepulchre, Israel
Mohebkhah Amin	Malayer University, Iran
Neubauer Wolfgang	Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Austria
Nevin Saltik Emine	Middle East Technical University, Turkey
Oosterbeek Luiz	Polytechnic Institute of Tomar, Portugal
Ortiz Calderon Maria Pilar	Pablo de Olavide University, Spain
Osman Ahmad	Saarland University of Applied Sciences, Germany
Pagge Tzeni	University of Ioannina, Greece
Panagouli Olympia	University of Thessaly, Greece
Pantazis George	National Technical University of Athens, Greece
Papagianni Ioanna	Aristotle University of Thessaloniki, Greece
Papaioannou Georgios	Ionian University, Greece
Papi Emanuele	University of Siena, Italy
Pérez García Carmen	Valencian Institute for Conservation and Restoration of Cultural Heritage, Italy
Perraki Maria	National Technical University of Athens, Greece
Piaia Emanuele	University of Ferrara, Italy
Polydoras Stamatios	National Technical University of Athens, Greece
Psycharis Ioannis	National Technical University of Athens, Greece
Rajčić Vlatka	University of Zagreb, Croatia
Rydock James	Research Management Institute, Norway
Saisi Antonella Elide	Polytechnic University of Milan, Italy

Santos Pedro	Fraunhofer Institute for Computer Graphics Research IGD, Germany
Sapounakis Aristides	University of Thessaly, Greece
Sayas Ion	National Technical University of Athens, Greece
Schippers-Trifan Oana	DEMO Consultants, The Netherlands
Siffert Paul	European Materials Research Society, France
Smith Robert	Oxford University, UK
Stambolidis Nikos	University of Crete, Greece
Stavrakos Christos	University of Ioannina, Greece
Stefanidou Maria	Aristotle University of Thessaloniki, Greece
Stefanis Alexis	University of West Attica, Greece
Tavukcuoglu Ayse	Middle East Technical University, Turkey
Theoulakis Panagiotis	University of West Attica, Greece
Thomas Job	Cochin University of Science Technology, India
Triantafyllou Athanasios	University of Patras, Greece
Tsakanika Eleutheria	National Technical University of Athens, Greece
Tsatsanifos Christos	International Society for Soil Mechanics and Geotechnical Engineering, UK
Tsoukalas Lefteris	University of Thessaly, Greece
Turner Mike	Bezael Academy of Arts and Design Jerusalem, Israel
Tzannini Evgenia	National Technical University of Athens, Greece
Van Grieken René	University of Antwerp, Belgium
Van Hees Rob	Delft University of Technology, The Netherlands
Varum Humberto	University of Porto, Portugal
Varvarigou Theodora	National Technical University of Athens, Greece
Vesic Nenad	ICOMOS International Scientific Committee for Places of Religion and Ritual (PRERICO), Greece
Vintzilaiou Elissavet	National Technical University of Athens, Greece
Vlachopoulos Andreas	University of Ioannina, Greece
Vogiatzis Konstantinos	University of Thessaly, Greece
Vyzoviti Sophia	University of Thessaly, Greece
Ward-Perkins Bryan	Ertegun Graduate Scholarship Programme in Oxford, UK
Yannas Simos	Architectural Association School of Architecture, UK
Zacharias Nikos	University of Peloponnese, Greece
Zachariou-Rakanta Eleni	National Technical University of Athens, Greece
Žarnić Roko	University of Ljubljana, Slovenia
Zervakis Michael	Technical University of Crete, Greece
Zervos Spyros	University of West Attica, Greece
Zouain Georges	GAIA-heritage, Lebanon

Contents – Part II

Cross-Discipline Earthquake Protection and Structural Assessment of Monuments

Cultural Heritage and Pilgrimage Tourism

Reuse, Circular Economy and Social Participation as a Leverage for the Sustainable Preservation and Management of Historic Cities

Advanced and Non-Destructive Techniques for Diagnosis, Design and Monitoring

Advanced 3D Survey and Modelling for Enhancement and Conservation of Cultural Heritage: The INCEPTION Project

Roberto Di Giulio, Federica Maietti(✉), and Emanuele Piaia

Department of Architecture, University of Ferrara,
Via Ghiara 36, 44121 Ferrara, Italy
{dgr, federica.maietti, emanuele.piaia}@unife.it

Abstract. Digital documentation technologies combined with innovative analytical techniques and digital tools can be an effective strategy supporting multidisciplinary documentation and modelling aimed at conservation, enhancement and preservation of Cultural Heritage. New technologies and digital devices should play an important innovative role to understand, access, enhance and preserve Cultural Heritage.

In this framework, the ongoing project INCEPTION *Inclusive Cultural Heritage in Europe through 3D semantic modelling* – funded by the European Commission within the Programme Horizon 2020 – proposes a workflow aimed at the achievements of efficient 3D digitization methods, post-processing tools for an enriched semantic modelling, web-based solutions and applications to ensure a wide access to experts and non-experts. 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 users and different disciplines, both social and technical.

Moreover, INCEPTION deals with complex heritage architectures and sites; in order to manage this complexity, a common protocol for data capturing has been developed, considering the uniqueness of each heritage site, accuracy and reliability, additional data and semantic proprieties to be recorded for different heritage applications.

Keywords: Heritage digital documentation · Advanced data capturing · Semantic modelling · Inclusive accessibility · Enhancement · Conservation

1 Introduction

Cultural Heritage conservation is more and more linked to the opportunities of documentation, condition assessment, monitoring and predictive analysis by means of non-destructive procedures. Protection, conservation and sustainable maintenance of Cultural Heritage is one of the Europe's priority to preserve our common assets to future generation, to foster social cohesion, to reinforce a sense of belonging to a common European space and to support job creation and economic growth.

A. Moropoulou et al. (Eds.): TMM_CH 2018, CCIS 962, pp. 325–335, 2019.
https://doi.org/10.1007/978-3-030-12960-6_21

Heritage management is a strong interdisciplinary field 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 several challenges related to different fields of Cultural Heritage toward a European common identity, transnational dialogue and understanding.

Moreover, the increasingly widespread use of different diagnostic methodologies and three-dimensional survey devices opens new scenarios within the non-destructive assessment and characterization of structures and materials, toward an overall and holistic digital documentation of cultural heritage [1].

Fig. 1. INCEPTION "corporate" image. 3D digitization methods, post-processing tools for an enriched semantic modelling, web-based solutions and applications to ensure a wide access to experts and non-experts are the core of the project.

As stated during the Innovation & Cultural Heritage Conference, held on 20 March 2018 in Brussels [2], the future European research on cultural heritage needs a holistic and critical research agenda and an inclusive interdisciplinary approach. One of the key questions is how to best use the opportunities provided by digitalization in the valorization of cultural heritage. Several presentations, based on ongoing Horizon 2020 funded projects, showed the manifold advances of digitalization for conservation, presentation and consumption of heritage. "Digitalization can be an effective instrument of democratization of cultural heritage as it opens new forms of access, e.g. by allowing entrance to previously closed heritage places or museum collections, or by allowing memberships in heritage communities without physical presence in a locality. […] More research is needed concerning the use of digital heritage by the different social, cultural and professional groups, which takes into consideration the social

effects of virtual realities and the visibility of actorship in the processes related to cultural heritage practices" [3].

Advanced 3D documentation identifying different layers of data to be recorded for heritage knowledge, enhancement and conservation is one of the main outcomes of the European Project "INCEPTION - Inclusive Cultural Heritage in Europe through 3D semantic modelling" (Fig. 1), funded by the European Commission under the Programme Horizon 2020 and started in 2015. The project proposes the enhancement of efficiency in 3D data capturing procedures and devices, especially dealing with complex heritage "spaces": cultural heritage sites, historical architectures, archaeological sites characterized by non-conventional features, location and geometries [4] (Fig. 2).

Fig. 2. Integrated digital documentation of complex heritage buildings. The example of Palazzo del Podestà in Mantua (DIAPReM Centre).

The overall project workflow is developed starting from requirements, integrated data capturing and holistic heritage documentation, the semantic enrichment via 3D modelling in H-BIM environment, and the models deployment and valorization through the INCEPTION platform. Indeed, the main innovations under INCEPTION will be delivered through an open standard platform to collect, implement and share digital models. Platform interface and functionalities will allow users to download and upload models, work with H-BIM models with different level of details, enrich contents and information linked to geometric models in an interoperable way and explore a wide range of data and contents.

The project has the ambition to strongly support the development of a pan-European approach to data usage for decision making related to conservation and preventive interventions and for supporting site management and sustainable exploitation of assets by integrating new methods for condition assessment survey of Cultural Heritage based on predictive analysis (diagnostic, conservative, morphometric) and non-destructive procedures.

2 The INCEPTION Project Overall Vision

INCEPTION aims to develop new tools for the interoperability and the inclusive sharing of three-dimensional heritage models towards new forms of access and awareness of the European cultural heritage. In the middle of the fourth and last year of activity, the project is working on models deployment and widespread sharing, starting from a methodological and technical advancement in 3D data capturing and holistic digital documentation [5].

The project consists of five main actions:

- the definition of a common framework for catalogue methodology, by mapping the stakeholder' knowledge demands;
- the development of an advanced integrated 3D data capturing;
- the identification of the Cultural Heritage buildings semantic ontology and data structure for information catalogue and modelling in Heritage-BIM environment, based on Open BIM standard;
- the implementation of the INCEPTION Semantic Web Platform. Deployment and valorization of 3D heritage models, to enable the sharing and enrichment of the information and interpretation of the models by users.

2.1 Project Workflow

The overall project workflow is developed starting from requirements (according to specific users and needs, what kind of data and information can be collected and managed by a 3D model), the integrated data capturing and holistic heritage documentation. Semantic modelling for Cultural Heritage buildings in H-BIM environment and the development of the INCEPTION platform for deployment and valorization of enriched 3D models will allow accomplishing the main objectives of accessing, understanding and strengthening European Cultural Heritage [6].

According to the abovementioned workflow, the H-BIM modelling procedure starts with a depth analysis of user needs (considering both expert and non-expert users). The identification of the Cultural Heritage buildings semantic ontology and data structure for information catalogue will allow the integration of semantic attributes with hierarchically and mutually aggregated 3D digital geometric models for management of heritage information. The development of the INCEPTION platform is the key-targeted achievement of the overall project, in order to accomplish the main objectives of accessing, understanding and strengthening European cultural heritage by means of enriched 3D models. The main aim of the platform is to innovate 3D models "forever",

"for everybody", "from everywhere", by developing, collecting and sharing interoperable 3D semantic models (Fig. 3).

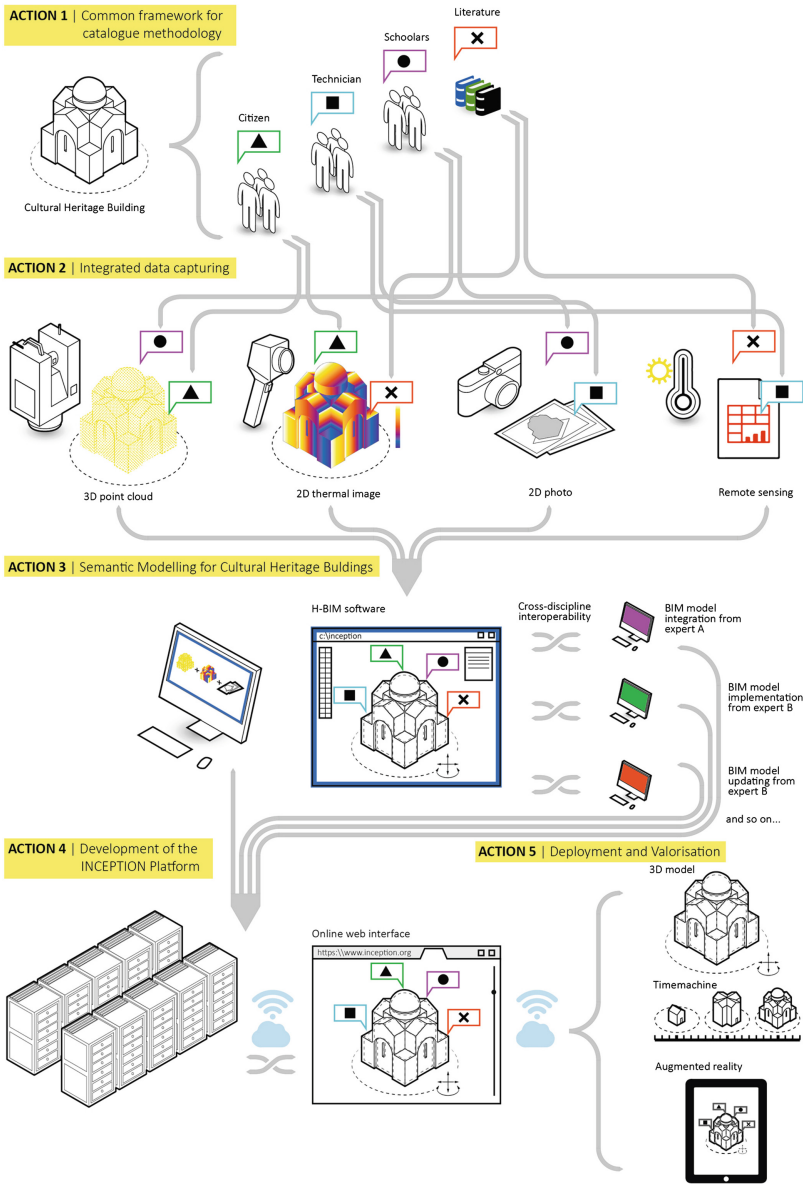

Fig. 3. Schema of the overall INCEPTION workflow, from the mapping of requirements and holistic documentation up to the semantic modelling and model sharing through the INCEPTION platform.

In the cloud-based platform, the main input is a BIM model of a Heritage building or site. All the BIM models are uploaded in the platform as IFC (Industry Foundation Class) standard files, in order to allow the access regardless of the software used to generate the BIM model. The IFC file is then processed by means of several server-side custom Windows services, extracting all the semantic information and generating Resource Description Framework (RDF) triples, according to the INCEPTION H-BIM ontology, serialized as Turtle (TTL) files. All these triples are stored in a semantic triple store, accessed via HTTP through a dedicated Apache Fuseki SPARQL server. The platform provides the user with the possibility of enriching the models with new semantic metadata, new data and attachments related to the whole CH site or to a specific geometrical element.

Therefore, semantic H-BIM models uploaded on the platform will allow users to interact with the models; thus, not only "to access" and "to understand" the models, but also to be stimulated "to give the users' perceptual responses to the models" through multi-layered information and documentation systems eligible for spatial and multi-criteria queries in a virtual 3D environment [7]. The end-users will be able to access information utilizing a standard browser, and they will be able to query the database using keywords and an easy search method.

This could be particularly relevant to foster the use of 3D models for diagnostic procedures and as a very efficient assessment and decision-making tool. Digital data can be used to manage dimensional analysis of the buildings or sites [8], typological analysis, technological analysis and material assessment to assess the current condition (typical materials and structures and their damage) and state of conservation, technical solutions for preservation and overall maintenance planning.

The INCEPTION platform offers the opportunity to manage contents such as single elements of a building to visualize different historic phases, stored data of previous interventions and links with external databases to increase the quality of reliable information. The possibility to share and make available documents linked to the geometric 3D model and the capacity to download 3D models with different scales of detail are very relevant tools supporting diagnostic procedures [9].

3 Integrated 3D Survey and Holistic Documentation

Methods and processes for data collection are continuously developing and today are characterized by an effective interdisciplinary. Skills on 3D laser scanner survey, diagnostic procedures and historical researches, as well as environmental condition assessment or management of metric and dimensional data support the vision of integrated digital documentation for cultural heritage assessment [10]. The INCEPTION's approach is focused on the 3D data capturing and modelling of heritage buildings and sites, through digital representation of the shape, appearance and conservation condition, in addition to a set of semantic information able to enrich research and deployment applications. The project is developing new research avenues in the field of heritage 3D data acquisition and modelling in order to guide the process of digitization of cultural heritage and innovation strategies to the three-dimensional modelling.

Advancement of 3D data capturing under INCEPTION starts from a primary concept: the 3D survey of complex heritage architectural spaces needs a common protocol for data capturing considering the uniqueness of each site, quality indicators, time-consumption, cost-effectiveness, data accuracy and reliability, additional data and semantic proprieties to be recorded for heritage applications, adaptability to different sites with different historical phases.

The architectural space becomes the foundations, the common core and the "connection" for the creation of a protocol for optimizing the 3D documentation of cultural heritage. The methodology set as a priority the unconventional features/ geometries, unique and complex within Heritage, avoiding the "segmentation" of data acquired and facilitating data access and use through an inclusive approach [11].

The integration of digital data and the possibilities of re-use digital resources is an important challenge for protection and conservation of the historic buildings as well as for an efficient management in the long term [12] (Fig. 4).

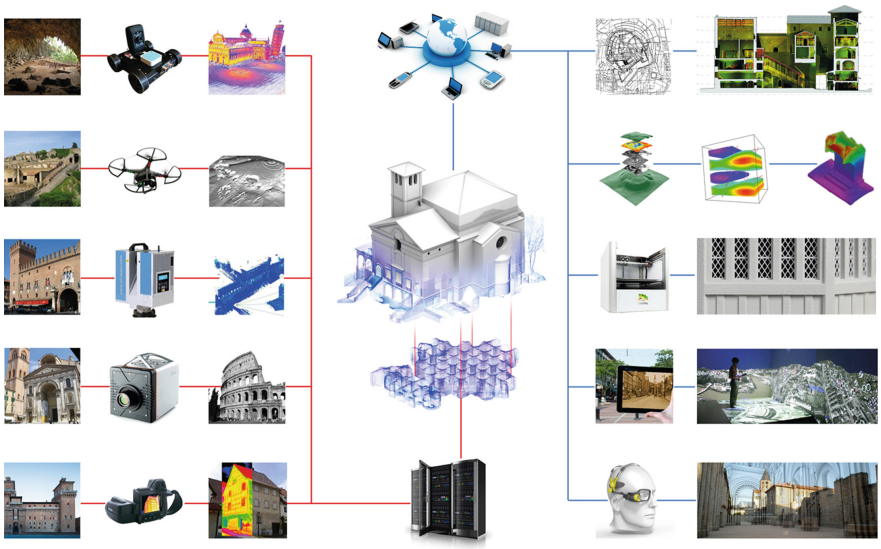

Fig. 4. From the left: integrated data capturing through the data acquisition protocol, advancement in 3D models processing in BIM environment and model sharing.

The data acquisition protocol has been developed within a more general methodological procedure of heritage documentation: integrated digital documentation under INCEPTION is carried out through a holistic approach. Through the 3D digitization of a monument, various aspects of recording concerning diagnostics (building material and decay patterns), construction and architectural documentation, new digital content management may be achieved. In this context, interdisciplinary approach means that the advantages and the output of every method applied to a monument, can lead to the

3D modelling approach, improving an inclusive understanding of European cultural identity and diversity [13].

3.1 The INCEPTION Data Acquisition Protocol

In order to face the main challenges related to 3D survey of complex architectures and to start solving the issue of the large amount of captured data and time-consuming processes in the production of 3D digital models, an Optimized Data Acquisition Protocol (DAP) has been set up. The purpose is to guide the processes of digitization of cultural heritage, respecting needs, requirements and specificities of cultural assets.

The DAP provides a workflow for a consistent development of survey procedures for tangible cultural heritage and define a common background for the use of H-BIM across multiple building types and for a wide range of technical users. Furthermore, this protocol will be useful for any agency, organization or other institution that may be interested in utilizing survey procedures aimed at 3D H-BIM semantic models creation and their implementation for the INCEPTION platform.

The DAP is intended to ensure uniformity in 3D digital survey for all the buildings that will be part of INCEPTION platform, considering a wide range of 3D data capturing instruments [14] because of multiple users and different techniques related to specific disciplines. 3D survey instruments and techniques continue to evolve, and this protocol will continue to be reviewed and updated to reflect advances in industry technology, methodology and trends; in every case, the protocol application will ensure data homogenization between surveys tailored to different requirements.

The survey workflow is split into eight main steps that define specific requirements and their related activity indicators: Scan Plan, Health and safety, Resolution Requirements, Registration mode, Control network, Quality control, Data control and verification, Data storage and archive. Each step of the workflow becomes a measuring system to verify the requirements of the survey, and the ability of finding the right answer define the level quality [15]. Every single step becomes an activity indicator that contributes to get a specific evaluation ranking. Four incremental evaluation categories have been defined (B, A, A+, A++).

"B" is the minimum evaluation category to be compliant with the INCEPTION Platform. It's intended to be used for very simple buildings or for the creation of low-detailed BIM model for digital reconstruction aimed at VR, AR and visualization purposes. In this case, the metric value of the model is less important than the morphological value.

"A" is the evaluation category suitable for documentation purposes where the metric and morphological values are equivalent in term of impact on the survey that needs to be preliminary scheduled and designed. The registration process of 3D captured data cannot be based only on morphological method but it should be improved by a topographic control network or GPS data.

"A+" is the most suitable for preservation purposes because only the surveys compliant with this category could be a useful tool for restoration projects that need extremely correct metric data. From these surveys, BIM models as well as 2D CAD drawings until 1:20 scale are available. The project phase gets more importance than previous categories in order to schedule and manage the survey campaign and choose

the right technical instruments to perform the data capturing. The management and the correction of metric errors are based on topographic techniques, in particular for what could concern the registration of different scan. The documentation phase will be developed organizing the information into Metadata and Paradata. Elements of quality control are integrated into the process.

"A++" is suitable for very complex buildings where the capturing process need to be documented and traced in order to get the maximum control on data or when monitoring process developed in a non-continuous time span take place. This category could be useful even if different teams of technicians work together, simultaneously or in sequence, with different capturing instruments and different accuracies. The A++ category allows analyzing how a survey has been performed in every single phase: moreover, this capability allows integrating a survey in different times.

4 Conclusions

"Heritage information – the activity and products of recording, documenting, and managing the information of cultural heritage places – should be not only an integral part of every conservation project but also an activity that continues long after the intervention is completed. It is the basis for the monitoring, management, and routine maintenance of a site and provides a way to transmit knowledge about heritage places to future generations" [16].

The possibility to achieve interoperable models able to enrich the interdisciplinary knowledge of European cultural identity is one of the main outcomes of INCEPTION. 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.

Collecting information to preventive conservation, monitoring and maintenance of European cultural historical heritage is undeniably connected with the use of methods, tools and techniques that in recent years have become technologically advanced and widespread. The technological evolution of survey systems represents an important innovation to manage three-dimensional databases [17]. The integration of other non-destructive procedures as thermal imaging, intensity value, integrated sensors, spectrophotometry, sonic surveys, etc. allows the collection and integration of other important digital data. These databases are geometric archives that can be used for research goals and for preservation, restoration and protection of cultural heritage.

Acknowledgments. The project is under development 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 centers 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 INCEPTION project has been applied under 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).

This research project has received funding from the European Union's H2020 Framework Programme for research and innovation under Grant agreement no. 665220.

References

1. Maietti, F., Piaia, E., Brunoro, S.: Diagnostic integrated procedures aimed at monitoring, enhancement and conservation of cultural heritage sites. In: MALTA International Conference–Europe and the Mediterranean–Towards a Sustainable Built Environment, SBE 2016, pp. 309–316. Gutenberg Press, Malta (2016)
2. The high-level Horizon 2020 conference "Innovation and Cultural Heritage" was organized by the European Commission Directorate General for Research and Innovation, in close cooperation with Directorates General for Education and Culture and for Communications Networks, Content and Technology
3. Innovation and Cultural Heritage: Conference Report. ISBN 978-92-79-81847-9, https://ec.europa.eu/info/sites/info/files/conferences/ki-02-18-531-en-n.pdf. Accessed 23 Aug 2018
4. Di Giulio, R., Maietti, F., Piaia, E.: 3D documentation and semantic aware representation of Cultural Heritage: the INCEPTION project. In: Proceedings of the 14th Eurographics Workshop on Graphics and Cultural Heritage, pp. 195–198. Eurographics Association (2016)
5. Ioannides, M., et al.: Towards monuments' holistic digital documentation: the Saint Neophytos Enkleistriotis case study. In: Ioannides, M., et al. (eds.) EuroMed 2016. LNCS, vol. 10058, pp. 442–473. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-48496-9_36
6. Maietti, F., Di Giulio, R., Balzani, M., Piaia, E., Medici, M., Ferrari, F.: Digital memory and integrated data capturing: innovations for an inclusive Cultural Heritage in Europe through 3D semantic modelling. In: Ioannides, M., Magnenat-Thalmann, N., Papagiannakis, G. (eds.) Mixed Reality and Gamification for Cultural Heritage, pp. 225–244. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-49607-8_8
7. Ioannides, M., et al.: Online 4D reconstruction using multi-images available under Open Access. ISPRS Ann. Photogram. Remote Sens. Sapt. Inf. Sci. **II-5 W1**, 169–174 (2013)
8. Kyriakaki, G., et al.: 4D reconstruction of tangible cultural heritage objects from web-retrieved images. Int. J. Heritage Digit. Era **3**(2), 431–451 (2014)
9. Yastikli, N.: Documentation of Cultural Heritage using digital photogrammetry and laser scanning. J. Cult. Heritage **8**(4), 423–427 (2007)
10. Doulamis, A., et al.: 5D modelling: an efficient approach for creating spatiotemporal predictive 3D maps of large-scale cultural resources. ISPRS Ann. Photogram. Remote Sens. Spat. Inf. Sci. **II-5/W3**, 61–68 (2015)
11. Di Giulio, R., Maietti, F., Piaia, E., Medici, M., Ferrari, F., Turillazzi, B.: Integrated data capturing requirements for 3D semantic modelling of cultural heritage: the INCEPTION protocol. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **XLII-2/W3**, 251–257 (2017)

12. Verykokou, S., Doulamis, A., Athanasiou, G., Ioannidis, C., Amditis, A.: Multi-scale 3D modelling of damaged cultural sites: use cases and image-based workflows. In: Ioannides, M., et al. (eds.) EuroMed 2016. LNCS, vol. 10058, pp. 50–62. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-48496-9_5
13. Maietti, F., Di Giulio, R., Piaia, E., Medici, M., Ferrari, F.: Enhancing Heritage fruition through 3D semantic modelling and digital tools: the INCEPTION project. In: IOP Conference Series: Materials Science and Engineering, vol. 364, p. 012089 (2018)
14. Stylianidis, E., Remondino, F. (eds.): 3D Recording, Documentation and Management of Cultural Heritage. Whittles Publishing, Dunbeath (2016)
15. Balzani, M., Maietti, F.: The architectural space in an inclusive protocol for the 3D integrated acquisition of Cultural Heritage for documentation, diagnosis, representation, enhancement and conservation. In: Bertocci, S., Bini, M. (eds.) The Reasons of Drawings. Thought, Shape and Model in the Complexity Management. Proceedings of the XXXVIII Convegno Internazionale dei Docenti della Rappresentazione - XIII Congresso Unione Italiana Disegno, pp. 1039–1044. Gangemi Editore, Roma (2016)
16. Letellier, R., Schmid, W., LeBlanc, F.: Recording, Documentation, and Information Management for the Conservation of Heritage Places. Guiding Principles. Getty Conservation Institute, J. Paul Getty Trust, Los Angeles (2007)
17. Maietti, F., Piaia, E., Turillazzi, B.: Digital documentation: sustainable strategies for Cultural Heritage assessment and inspection. In: MALTA International Conference–Europe and the Mediterranean–Towards a Sustainable Built Environment, SBE 2016, pp. 303–308. Gutenberg Press, Malta (2016)