Architectural Space in a Protocol for an Integrated 3D Survey aimed at the Documentation, Representation and Conservation of Cultural Heritage

Marcello Balzani, Federica Maietti

Abstract

Architectural space becomes the connective fabric for the creation of a protocol for optimizing 3D documentation of cultural heritage. The methodology set as a priority the unconventional features/geometries, unique and complex within heritage, avoiding the 'segmentation' of the acquired data and facilitating data access and use through an inclusive approach. The elaboration of the protocol for the advancement of data management processes is part of the INCEPTION project, Inclusive Cultural Heritage in Europe through 3D semantic modelling, *coordinated by the Department of Architecture of the University of Ferrara and funded by the European Commission within the Horizon 2020 program. The project is currently ongoing, and approaching the end of the second year of development. Future actions are related to the practical application of the holistic digital documentation procedure and of the optimized 3D data acquisition protocol of nine selected case studies in six European countries. The selected sites are representative of different types of cultural heritage assets, for the implementation of the methodology and necessary tools, based on criteria that cover different historical periods, a wide range of sizes and morphologies, different states of conservation, environmental conditions and various risk factors. Planned test-beds in significant heritage sites will allow validation of the documentation methodology, the necessary tools in terms of access and interaction with the3D digital model and the different outcomes based on an inclusive access by different users of semantic models.*

Keywords: protocol, representation, 3D integrated survey, cultural heritage, integrated documentation

Introduction

The increasing development of 3D laser scanner technologies allows the creation of high definition databases based on three-dimensional morphometric data. These 'digital archives' are an extremely valuable research tool in the field of cultural heritage: 'geometric memory' is essential for the knowledge, protection and conservation of architectural and historic heritage, although there are still some limits to the exploitation of 3D models obtained by laser scanner survey. The growing number of unexploited and 'uninterpreted' 3D models points out the need for innovative methods that could increment the informative value provided by new systems for surveying and representation as well as digital data management tools.
The development of 3D models characterized by complex geometries or particular conditions, such as occurs in the cultural heritage field, can still be time-consuming and expensive, and generate large amounts of not-easily-accessible data. The European project INCEPTION - Inclusive Cultural Heritage in Europe through 3D semantic modelling, funded by the European Commission within the Horizon 2020 program, proposes the enhancement of efficiency in 3D data capturing procedures and devices, especially as regards their suitability and aptitude for tangible cultural assets: heritage sites, historical architecture, archaeological sites, urban fabrics, characterized by unconventional features and geometries and always different, case by case.
The state of the art and interdisciplinary and international references consulted starting from the first research sta-

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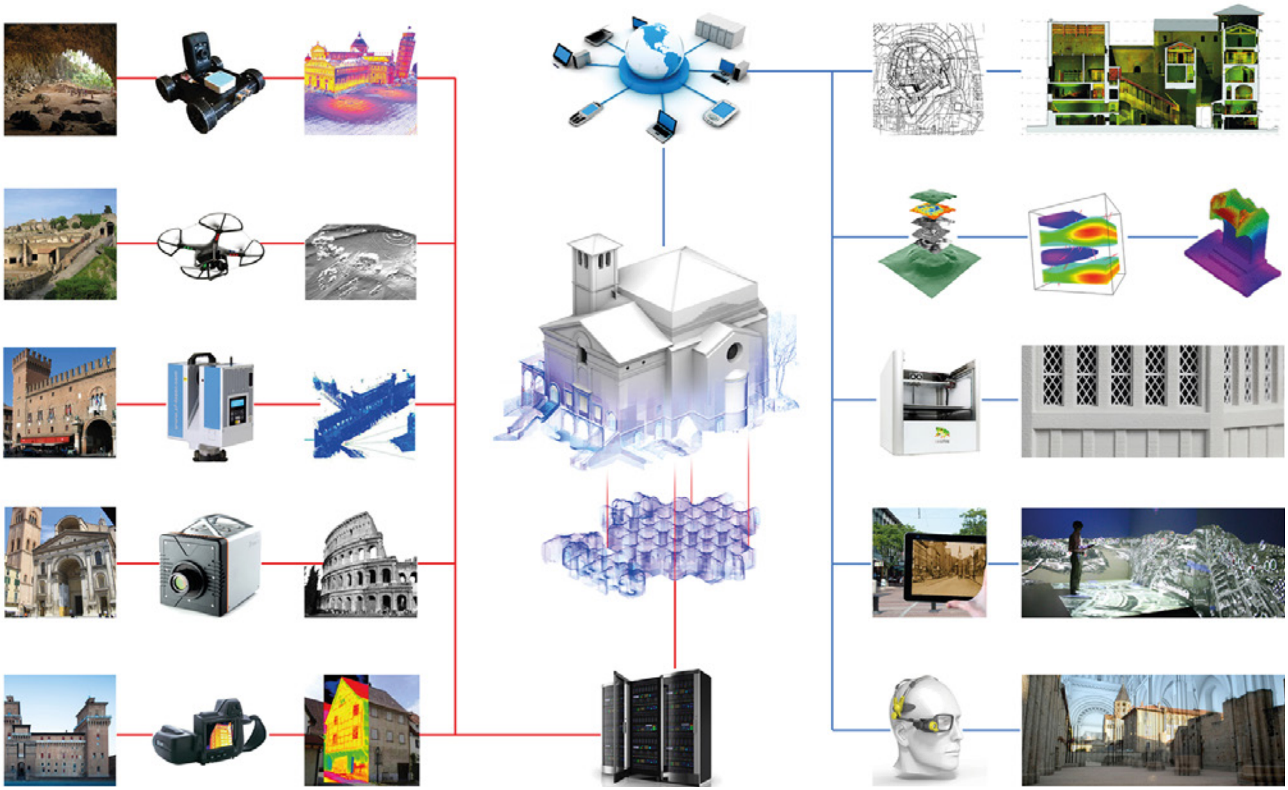
ges, together with a wide on-site experience of integrated 3D survey in various contexts, include the most recent contributions in the field of the survey of cultural heritage, representation, modelling and management of digital databases.
The main methodologies used address the problem of the complexity of current tools for the management of 3D models and the processing of results obtained by employing new technologies for representation beyond the 2D and 3D conventions. These outcomes are very often surprising, in terms of the model's navigational potential, but sometimes impoverished in the expressive 'vocabulary' of the representation of a proper reference model, which allows the investigation of the tangible material as well as the intangible values.
Architectural space geometry is an essential tool for managing spatial representation, useful for obtaining levels of knowledge and processes of documentation and conservation; survey and representation of heritage architectural spaces are an effective tool for exploring architectural morphologies from the two- to the three-dimensionality and vice versa.
An international comparison and interdisciplinary analysis of several indicators (within documentation, data acquisition and processing) aimed at the knowledge of cultural heritage through 3D modeling and database

Fig. 1. Diagram of the integrated documentation procedure developed within the INCEPTION project. The operational phases range from the acquisition of heritage data to the semantic query of three-dimensional models.



querying for data extraction are phases of the research that have already been completed, while the future steps will develop advanced 3D modeling to enhance the knowledge and understanding of cultural heritage.

Inclusive cultural heritage in Europe through 3D semantic modeling

The INCEPTION project funded by the European Commission, within the context of the *Work Programme Europe in a changing world – inclusive, innovative and reflective societies*, [1] started in June 2015. The project is developed by a consortium of fourteen partners from ten European countries led by the Department of Architecture of the University of Ferrara [2], coordinator of the project.
The research team [3] includes, in a broad manner, the different aspects of identity and diversity of cultural heritage, enhancing the documentation systems able to preserve its memory and identity, and putting into effect one of the main challenges that the European Commission has launched with the Horizon 2020 program: to contribute to a deeper awareness and understanding of the European cultural fabric as inspiration for addressing contemporary challenges, increasing the knowledge of heritage and its different European identities. To this purpose, new technologies and digitization processes play a key role since they allow new and enhanced interpretations of our common and collective cultural heritage.
The interdisciplinary consortium ranges in the different specific fields of interest of cultural heritage, from the documentation and diagnostic analyses of heritage, to the strategies for its protection, management and enhancement, to 3D acquisition technologies, to the development of hardware, software and digital platforms for the representation and dissemination of cultural heritage, through ICT processes, to the analysis of semantic information for a wider and more extensive use of digital models.

Fig. 2. Diagram summarizing the priorities addressed by the project on the basis of the requests of the Work Programme, the main areas and approach of collaborative research, the main goals, the users of the innovations and the means of validation and dissemination.

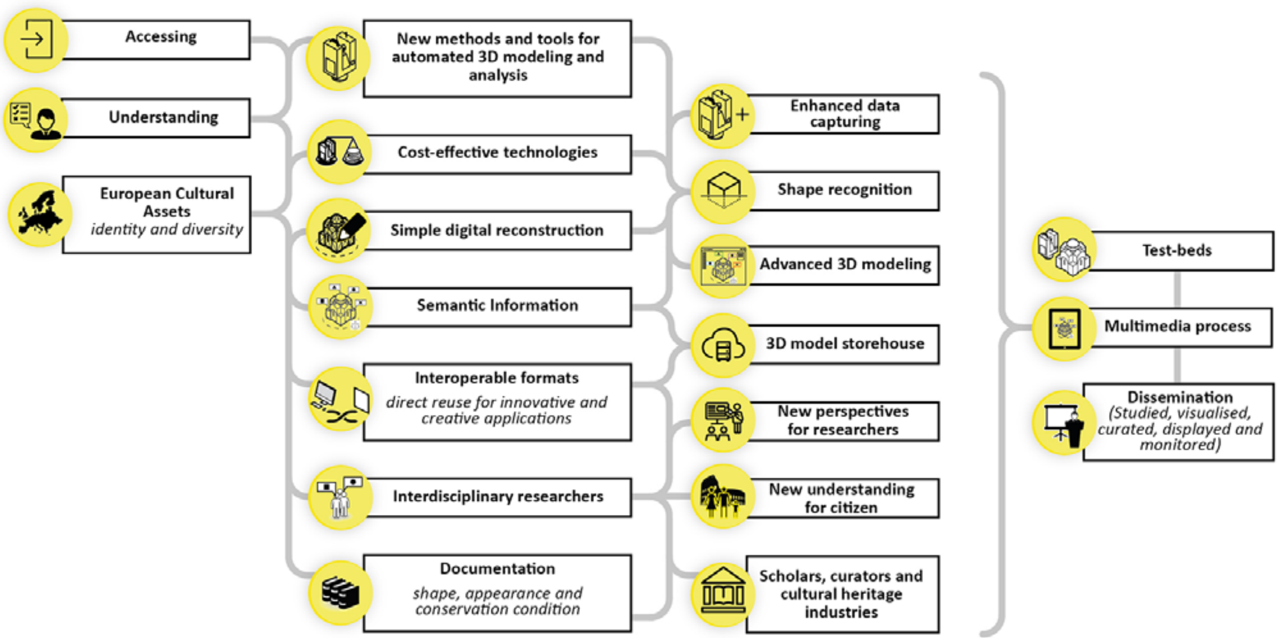
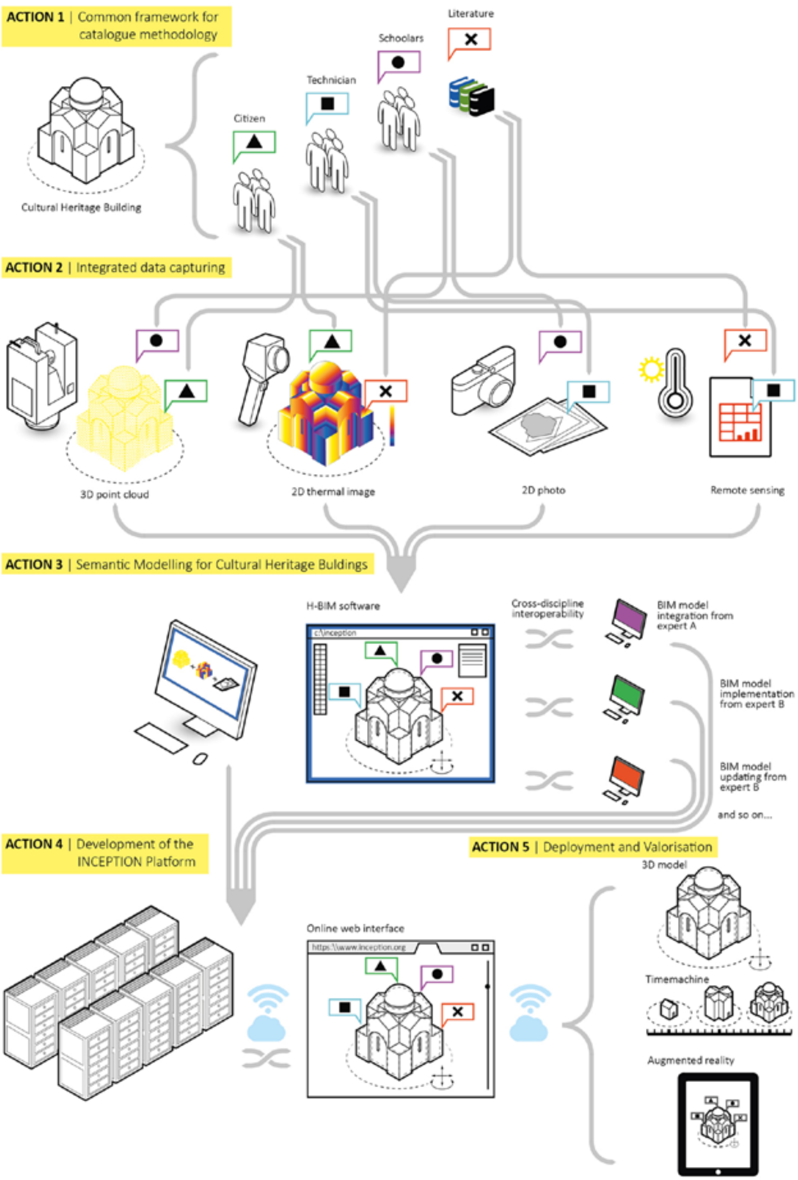


Fig. 3. The overall concept and methodology of the project: knowledge management, integrated data capturing, semantic modeling for cultural heritage architectural spaces, development of the platform, implementation and valorization.



The main objectives of the project can be summarized in the following points:
- to stimulate and augment innovation in 3D modeling of cultural heritage through an inclusive approach for dynamic 3D reconstruction of historical buildings and social environments;
- to create an inclusive understanding of European cultural identity and diversity by promoting and facilitating collaborations across disciplines, technologies and sectors;
- to develop cost-effective procedures for the 3D survey and representation of cultural heritage buildings and sites;
- to develop an open-standard semantic web platform for accessing, processing and sharing interoperable digital models resulting from integrated 3D survey and documentation following the protocols elaborated by the project.

In parallel to strategies aimed at defining a protocol able to guide the processes of digitization of cultural heritage, the project will develop nine case studies, nine pilot projects which, starting from the recognition of the specific needs and requirements of each building or cultural site, will enable the implementation of different systems of digital acquisition in order to develop three-dimensional modeling that will make the digital models usable by different categories of interdisciplinary users, populating the INCEPTION platform. These case studies will be the first test-beds for the application of the 3D acquisition protocol.

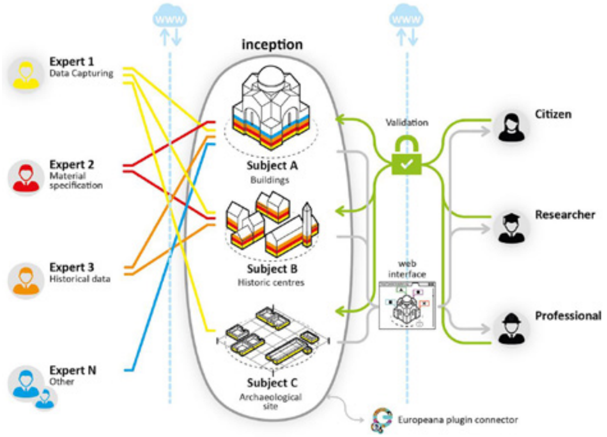


Fig. 4. The main aim of INCEPTION is to realize innovation in 3D modelling of cultural heritage through an inclusive approach. Methods and tools will result in 3D models that are easily accessible for all user groups and for multidisciplinary purposes.

The protocol for a 3D integrated survey

The overall concept and the methodology of the INCEPTION project include the definition of a shared and interdisciplinary approach to the documentation of cultural heritage, integrated survey, knowledge management, integrated data capturing, semantic modelling of historical buildings and sites, architectural spaces, development of the platform, and deployment and valorization strategies. Within the first two research areas addressed, strategies aiming at the optimization of a 3D data acquisition protocol [Di Giulio 2017] able to guide the processes of digitization of cultural heritage are among the central aims, at the base of all the next project steps. Digitization of cultural heritage requires respecting the needs and specificities of heritage sites, and innovation strategies to the three-dimensional modeling.

The optimized protocol and the definition of proposed 'added value' parameters for data capturing and management processes were developed, first of all, by critically reviewing the state-of-the-art on the data acquisition methodologies available today.

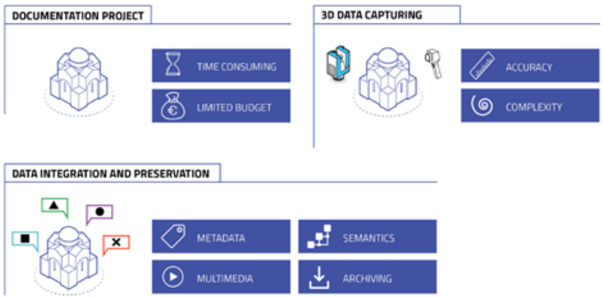
The innovation proposed by the INCEPTION project is related to the focus on the heritage spaces inherent to the digitization of the spatial context (at architectural and urban scale), one of the most important 'containers' of cultural expressions identified in the evolution of the concept of European cultural identity.

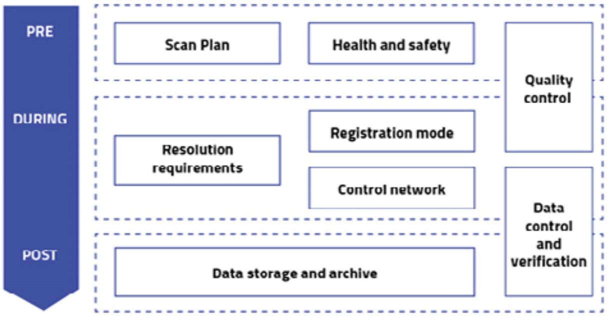
The project develops an integrated approach able to investigate the potential of spaces in order to create new cultural connections and awareness; architecture is an outstanding example of the multi-layered conceptual dimension of European heritage.

The 3D survey of historical architectural space requires a common protocol for data capturing and related enhancement of the potentialities, functionalities, and cost effectiveness of technologies and documentation instruments. The protocol considers the uniqueness of each site through quality indicators such as 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 combination of innovative methodologies and protocols, processes, methods and devices is aimed

Fig. 5. The major challenges in 3D documentation for the conservation of cultural heritage in relation to the principal workflow steps.

Fig. 6. Workflow and activity indicators.





at enhancing the understanding and the accessibility of European cultural heritage by means of 3D models bringing new knowledge, collaboration across disciplines, time and cost saving in the development and use of 3D digital models. The innovative procedures and applications enable remote communication and collaboration between professionals, experts, architects, etc. and increase the operational fields in cultural heritage.

The Data Acquisition Protocol provides a workflow for a consistent development of survey procedures for tangible cultural heritage and defines a common background for the use of H-BIM models across multiple building types and for a wide range of technical users [Pauwels et al. 2013]. Furthermore, this protocol will be useful for any agency, organization or other institution that may be interested in utilizing survey procedures aimed at the creation of 3D H-BIM semantic models and their implementation for the INCEPTION platform. This protocol will be tested and further improved according to the specific test-bed procedures scheduled in the INCEPTION research project.

The DAP is intended to ensure uniformity in 3D digital survey for all the buildings that will be part of the INCEPTION platform. This protocol considers a wide range of 3D data capturing instruments [Kadobayashi et al. 2004] because of multiple users and different techniques related to specific disciplines. Furthermore, 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, application of the protocol will ensure data homogenization between surveys tailored to different requirements [Yen et al. 2011].

The survey workflow was split into eight main steps that define specific requirements and their related activity indicators:

1. scan plan;
2. health and safety;
3. resolution requirements;
4. registration mode;
5. control network;
6. quality control;
7. data control and verification;
8. data storage and archive.

Each step of the workflow must be intended as a set of questions that the technician who is in charge of carrying out the survey should answer in order to pursue a correct data capturing. Those questions become a measuring system for verifying the requirements of the survey, and the ability of finding the right answer defines the level of quality. On this assumption, every single question becomes an activity indicator that contributes to the creation of a specific evaluation ranking. Not every activity indicator is always compulsory: if in the survey campaign only the minimum number of questions finds an answer, the capturing procedure will be classified in the lower ranking. Conversely, if each element is taken into account, the ranking will be the highest. In the case of directly measurable procedures, the specific activity indicator defines a range of accepted values. Instead, when alternative procedures are available, the protocol specifies their compliance with the evaluation categories. For this purpose, there are four incremental categories defined as following:

B: This is the minimum evaluation category for the survey to be compliant with the INCEPTION platform. It is intended to be used for very simple buildings or for the creation of low-detailed BIM models 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: This evaluation category is suitable for documentation purposes where the metric and morphological values are equivalent in terms of impact on the survey that needs to be preliminarily scheduled and designed. The registration process of 3D captured data cannot be based only on the morphological method, but should be improved by a topographic control network or GPS data.

A+: This evaluation category 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 up to a 1:20 scale are available. The project phase has more importance in respect to previous categories, for scheduling and managing the survey campaign choosing the right technical instruments to perform the data capturing. The management of data and the correction of errors in measurement are based on topographic techniques, in particular for what could concern the registration of different scans. The documentation phase will be developed organizing the information into metadata and paradata [Apollonio, Giovannini 2015]. Elements of quality control are integrated into the process.

A++: In addition to the specifications described in the previous categories, the A++ allows reconstruction of how the survey was done, in every single step, integrating a survey realized at different moments in time. This evaluation category is suitable for very complex buildings where the capturing process needs to be documented and traced in order to get the maximum control on data or when the monitoring process developed in a non-continuous time span takes place.

The A++ 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 the analysis of how a survey has been performed in every single phase: moreover, this capability allows integrating a survey realized at different times.

Fig. 7. Indicator aggregation for the identification of evaluation categories.

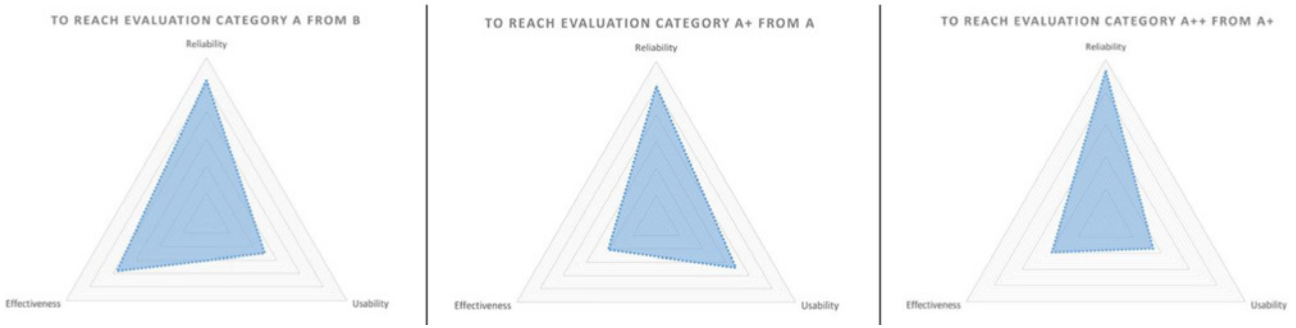
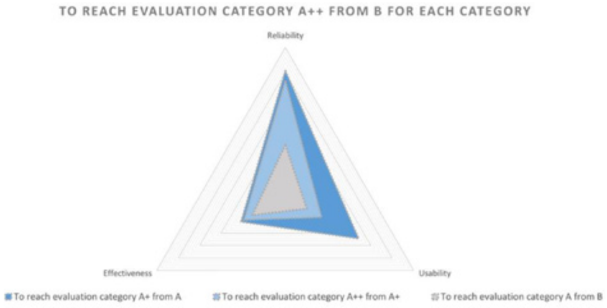


Fig. 8. Data aggregation for each protocol category.



Preliminary considerations on the development of the protocol

In order to understand the impact of the INCEPTION DAP, a specific evaluation grid has been arranged, starting from the usual three standard features of quality, time and cost. Each key feature for the evaluation of benefits and added values [Eppich, Chabbi 2007] is specifically addressed by examining the main aims of the INCEPTION project.
Since the evaluation process considers the point of view of the end users, who could be either technicians or not, the features have been developed as below:
- quality can be evaluated as the reliability of the survey;
- time can be evaluated as the usability of the survey;
- cost can be evaluated as the effectiveness of the survey.
Even if accuracy and precision are key factors for technicians performing the survey [Böhler et al., 2003], they are strictly connected with the purpose of the survey and for this reason using them for the evaluation of survey quality becomes impossible, in particular from the point of view of an end user. The quality of a survey could be better described as the capability to be compliant with standards and ensure a long term support [Bryan, Barber, Mills 2004].
For this reason, the key features of a reliable survey are:
- survey maintenance: the possibility to constantly update a survey database during its daily use for ordinary purposes, enriching it with new information or minor changes;
- survey integration: the possibility to perform major updates and upgrades of a survey, adding a new part of a building or a site, previously not included, or performing a more accurate survey of already-existing parts of the model;
- technological obsolescence: because data management hardware and software are evolving faster and faster, applying strategies to avoid technological obsolescence has become a key feature for ensuring the reliability of surveys over time.
The measurement of benefits in terms of time consumption could be performed taking into consideration the usability of the survey. The more usable a delivered survey is, the more time could be saved by the end users that will deal with it. One of the main aims of the procedure, indeed, is the ability of saving time in the processing phase. The Data Acquisition Protocol and the adoption of a standard shared by suppliers and end users can bring a strong added value in terms of easy usability.
For this reason, the key features of a usable survey are:
- common procedure: in order to ensure the full understanding of the output;
- collaboration tools: for possible data creation by different teams at different times.
The cost of a survey always depends on the final quality and time spent to perform it. For this reason, the measurement of the effectiveness could be a better parameter to consider for evaluating the added value.
For this reason, the key features of an effective survey are:
- on-field flexibility: the possibility to use different kinds of appropriate instruments in order to produce the right amount of qualitative data, avoiding those that are too expensive and therefore often underutilized;
- easy deployment: the ability to easily use the same delivered survey data for different kinds of deployment and direct application for multiple purposes;
- easy understanding: enabling the low-skilled non-technician end user to easily read and understand data provided by the survey.
In order to measure the benefits and added values of the INCEPTION DAP, typical survey and documentation processes in the field of cultural heritage have been categorized to perform a grouping of an infinite number of different single and specific cases. The main connections between survey categories and DAP evaluation categories have been identified, and the DAP has been split into three areas on the basis of requirements necessary for reaching a higher evolution category according to reliability, usability and effectiveness.

Conclusion

The integration of digital data and the possibilities for re-use of digital resources is an important challenge for the protection and conservation of historic buildings and contexts as well as for an efficient long-term management of 'geometric memory.' The need for a future reutilization of the quantitative, qualitative, descriptive data demands new applications to facilitate accessing information collected in three-dimensional databases without compromising the quality and the quantity of information captured in the survey. Furthermore, the vocation of INCEPTION for 'space' implies:
- understanding how space (defined by its geometric and morphometric characteristics) can be the connection with the temporal dimension; the space/time relation can be an understandable (and therefore inclusive) metaphor of memory (collective and European);
- understanding how space (architectural, urban and environmental) has its own dynamic characteristic that not only offers the possibility to navigate and to discover cultural heritage, but also identifies the option of choosing what to memorize in a certain time and why;
- understanding that only through space (and its complexity) is it possible to collect a high level of multi-function knowledge strongly linked to the multi-scale representation process.

The identification of the multi-function and multi-scale role of the model allows the exploitation of data, often not simple, but complex (obtained from, among others, the geometric analysis of the architectural and urban context) at different levels, over time and by different actors. Here is the value of the accessibility of the process, that until now has never been allowed to spatial scale nor realized through a mere visual navigation, often uninterpreted (an approach very far from the needs of knowledge, understanding and conservation). The integration of 3D data is consistent with the tendency of open linked data and big data for the visualization and sharing of the semantic web. INCEPTION, in this sense, would fit perfectly into the ongoing ICT research projects that identify appropriate technologies to support an ever more efficient web-based data sharing. The project will try to give a response to the use of data in relation to the various possible correlations in the cultural heritage sector (tourist development, accessibility, historical reconstructions, real-time identification of the state of conservation, etc.). Starting from the most recent innovations concerning 3D survey methodologies and digital documentation systems, the project, through its optimized protocol, aims to:
- close the gap between specialized technicians and non-technical users involved in heritage documentation;
- provide a guide to users and developers of survey technologies, sharing the planned characteristics in order to achieve the main goals in cultural heritage documentation and data capturing;
- define a common procedure for the retrieval of historical data from possible previous surveys; carry out an efficient cataloguing and digitization; augment the knowledge of geometric, surface and structural features; support the analysis of the state of conservation; provide the instruments for the maintenance of planned interventions in the short and the long term;
- identification of performance indicators to ensure the effective management of metric survey projects, focusing on the needs and requirements of heritage documentation.

The optimized protocol and the proposed 'added value parameters' of reliability, usability and effectiveness will be implemented, furthermore, as input for the configuration of applications for various users.

Notes

[1] 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 project has received funding from the European Union's Horizon 2020 program for research and innovation under Grant agreement No. 665220.

[2] The scientific coordinator of the project is Prof. Roberto Di Giulio, director of the Department of Architecture of the University of Ferrara. The coordination team includes the TekneHub Laboratory of the Technopole of Ferrara, belonging to the Construction Platform of the Emilia-Romagna High Technology Network, involved in the project with interdisciplinary competencies together with the coordination group of the Department of Architecture of the University of Ferrara.

[3] 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- and medium-sized enterprises includes: DEMO Consultants BV (The Netherlands), 3L Architects (Germany), Nemoris (Italy), RDF (Bulgaria), 13BIS Consulting (France), Z + F (Germany), Vision and Business Consultants .

Authores

Marcello Balzani, Centro DIAPReM, Department of Architecture, University of Ferrara, *bzm@unife.it*
Federica Maietti, Centro DIAPReM, Department of Architecture, University of Ferrara, *federica.maietti@unife.it*

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