

Impact of Industry 4.0 on Architecture and Cultural Heritage

Cecilia Maria Bolognesi
Politecnico of Milano, Italy

Cettina Santagati
Università di Catania, Italy

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Chapter 9

Documentation, Processing, and Representation of Architectural Heritage Through 3D Semantic Modelling: The INCEPTION Project


Federica Maietti

 <https://orcid.org/0000-0002-8076-0020>
*Department of Architecture, University of
Ferrara, Italy*

Roberto Di Giulio

*Department of Architecture, University of
Ferrara, Italy*


Marco Medici

 <https://orcid.org/0000-0002-9643-4721>
*Department of Architecture, University of
Ferrara, Italy*

Federico Ferrari

*Department of Architecture, University of
Ferrara, Italy*

Anna Elisabetta Ziri

 <https://orcid.org/0000-0001-8909-4557>
Nemoris Srl, Italy

Beatrice Turillazzi

Consorzio Futuro in Ricerca, Italy

Peter Bonsma

RDF Ltd., Bulgaria

ABSTRACT

Documentation, data processing, and representation of Architectural Heritage through digital models are one of the main challenges in the field of conservation, preservation, management, and inclusive use and understanding of European heritage assets. In this framework, the impact of Industry 4.0 is more and more crucial, since new technologies, devices, and digital environment are strongly influencing the ways in which heritage contents are explored, used, managed, and shared, also in citizens' everyday life. In this direction, the INCEPTION project – founded by the European Commission within the Horizon 2020 programme – develops key-targeted innovations in efficient 3D digitization methods, post-processing modelling tools, semantic web-based solutions, and applications to ensure a wide and aware access to digital Cultural Heritage. This chapter presents main actions achieved by INCEPTION.

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Documentation, Processing, and Representation of Architectural Heritage**INTRODUCTION**

“The digital revolution is leading to new and innovative forms of artistic creation while making culture and heritage more accessible and opening up new ways of enjoying cultural content. Making our cultural heritage widely available in the digital era is vital. It is great news that many Member States will now work closer together to fully leverage the cultural opportunities brought by digital technologies”. This is the opening statement to the Digital Day 2019, held in Brussels, by Vice-President for the Digital Single Market Andrus Ansip, Mariya Gabriel, European Commissioner for Digital Economy and Society, and Commissioner for Education, Culture, Youth and Sport, Tibor Navracsics. This short declaration summarizes some of the main challenges related to the so-called “4th industrial revolution” and its impact in the field of Cultural Heritage. Accessible heritage, new ways of enjoying cultural contents, digital technologies, are some of the key words leading from the potential of 3D digital modeling and representation to new ways of visualization, application and data processing towards understanding, enhancement and conservation, up to restoration of Cultural Heritage.

In this perspective, efficient 3D digitization methods, post-processing tools for an enriched semantic modeling, web-based solutions and applications to ensure wide access of heritage contents to experts and non-experts are the key results of the INCEPTION project. INCEPTION - Inclusive Cultural Heritage in Europe through 3D semantic modeling, has been funded by the European Commission under the Horizon 2020 Work Programme *Europe in a changing world – inclusive, innovative and reflective Societies* (Call Reflective-7-2014, Advanced 3D modeling for accessing and understanding European cultural assets).

The project development has been split in five different actions (Figure 1) in order to cover the main challenges and requirements in terms of changing role of digital models in the field of Cultural Heritage, semantic enrichment, interoperable formats, collaborations across disciplines and use and reuse of digital sources.

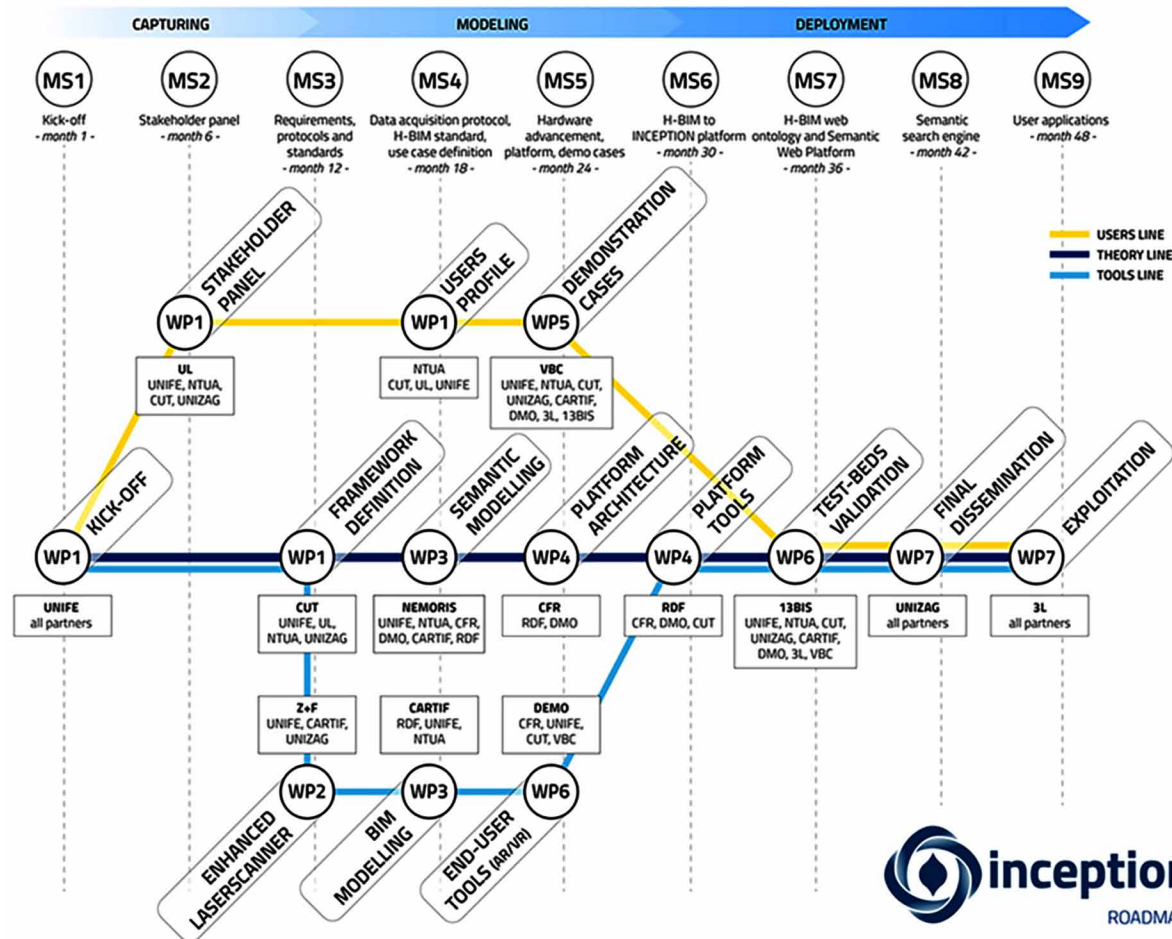
The first one develops a common framework for integrating different expertise, in order to pursue holistic and critical research and an inclusive interdisciplinary approach, making possible the real integrated data capturing of the second action. Once data are collected, the semantic modeling allows to aggregate data in an effective way. Thanks to the adoption of BIM (Building Information Modeling) standards, in the fourth action, it is possible to develop a platform to collect, archive and share semantically enriched models. In the end, in the fifth action, the deployment of such data is performed through user-oriented application, starting from the interoperability with existing ones (Di Giulio, Maietti, & Piaia, 2016).

INCEPTION has moved from the consideration that, 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, although there are still some limits to the exploitation of 3D models obtained by laser scanner survey (Maietti et. al., 2017). 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.

In addition to the explanation of the INCEPTION project, innovative strategies in heritage documentation through the implementation of effective data collection processes and the development of semantically enriched 3D models will be presented.

Documentation, Processing, and Representation of Architectural Heritage

Figure 1. The roadmap of the overall project architecture



The Chapter describes the main outcomes of the project, starting from the analysis and review of the State of the Art in the field of digital applications for Cultural Heritage, up to the methodological path followed. The objectives of this essay are mainly related to the presentation of the added value of the holistic documentation as the starting point to any digitization, considering that the main issue is very often related to the large amount of data compared with the lack of information about heritage.

The Chapter is divided into six main sections:

- the paragraph related to the “Background” describes the overall vision of the INCEPTION project;
- “Holistic documentation of architectural heritage” explains the main context of application of the main outcomes of INCEPTION and the procedure of optimization of the documentation procedure through the Data Acquisition Protocol;
- The section related to BIM and H-BIM data management explains also the INCEPTION platform architecture;
- Semantic processes and ontologies within INCEPTION are faced explaining the H-BIM ontology developed under the project;

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- The section “Data modeling and aggregation” explains the methodology and outcomes from the overall process in aggregating information to the parametric model for semantic search and enrichment through the INCEPTION platform;
- An overview of the main tools and applications linked to the platform for an inclusive use of 3D models by different users is presented.

BACKGROUND

“Combining innovation with heritage points to the fact that cultural heritage has an inspiring and creative role in present European societies and communities. Research and innovation are needed to better protect cultural heritage from natural or man-made destruction. [...] Innovation in the context of cultural heritage has manifold meanings. It means technological, social, policy, entrepreneurial, economic or methodological innovation”. This is one of the opening statement of the Conference Report released after the high-level Horizon 2020 conference “Innovation and Cultural Heritage” held in Brussels on 20 March 2018. *“Cultural heritage is a limitless source of innovation where traditions meet with cutting-edge technologies,”* stated Commissioner Carlos Moedas in charge of Research, Science and Innovation (Innovation & Cultural Heritage, 2018).

One of the key questions presented at the conference was how to best use the opportunities provided by digitalization in the valorization of Cultural Heritage. Digitalization can be an effective instrument of democratization of cultural heritage as it opens new forms of access, and new and innovative technologies are a great opportunity to understand, access, enhance and preserve 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. Thanks to the “Digital Revolution”, nowadays it is possible to digitally integrate different information in order to access cultural assets in many different ways and for many different purposes.

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 knowledge and experiences; through digital technologies broad categories of users have access to European tangible and intangible cultural assets.

This is the framework and overall background of INCEPTION. The four-years project started in June 2015 and has been completed in May 2019.

The analysis of the State of the Art from which INCEPTION started to structure a methodological proposal for integrated documentation and inclusive use of 3D models, revealed the existence of several projects and initiatives focused on the digitization of heritage (Rechichi, Mandelli, Achille, & Fassi, 2016), many of which however addressed on movable heritage, and not on a building scale. Moreover, since one of the main outcomes from INCEPTION is the development of a semantic-based BIM platform for Cultural Heritage buildings and sites, the features included in the platform have been compared to several web-based platforms (Fassi, Achille, Mandelli, Rechichi, & Parri, 2015; Tommasi, Fiorillo,

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Jiménez Fernández-Palacios, & Achille, 2019) that provide 3D models downloading and exchange. Platforms specifically focused on Cultural Heritage are often related to a specific project of documentation / enhancement (Rizvic, Okanovic, & Sadzak, 2015), or are set to provide interactive visualization of 3D models (Potenziani et. al., 2015; Potenziani, 2016).

INCEPTION advancement beyond the State of the Art faced three main fields:

- **Capturing:** There is a wide range of devices and technologies for 3D data capturing, and more and more accurate and fast devices, but bigger data means time-consuming processes and very often, there is a lack of technological integration between different kinds of devices. INCEPTION proposes a common protocol for 3D data capturing and device enhancement for a more efficient processing.
- **3D Processing:** Nowadays there are performant software for data management and display of point cloud data and BIM with advanced solid modeling tools, but a standard for Cultural Heritage buildings is missing, as well as management for captured data interoperability. INCEPTION works in the direction of tools for managing point cloud in BIM environment and sets up a semantic ontology definition for Cultural Heritage buildings in order to share cross-disciplines data.
- **Model Sharing:** There is a lot of 3D data on Cultural Heritage buildings all over the Europe, and a wide range of technologies and user-oriented apps, but a platform to share digital models of Heritage buildings is missing. INCEPTION develops a web platform for accessing and understanding digital Cultural Heritage buildings, the possibility of collecting and explore time upgradable 3D models and user-oriented apps.

In this framework, INCEPTION proposes a workflow aimed at the achievements of efficient 3D digitization methods, post-processing modeling tools, semantic web-based solutions (Apollonio et. al., 2018) and application to ensure a wide access to experts and non-experts.

HOLISTIC DOCUMENTATION OF ARCHITECTURAL HERITAGE

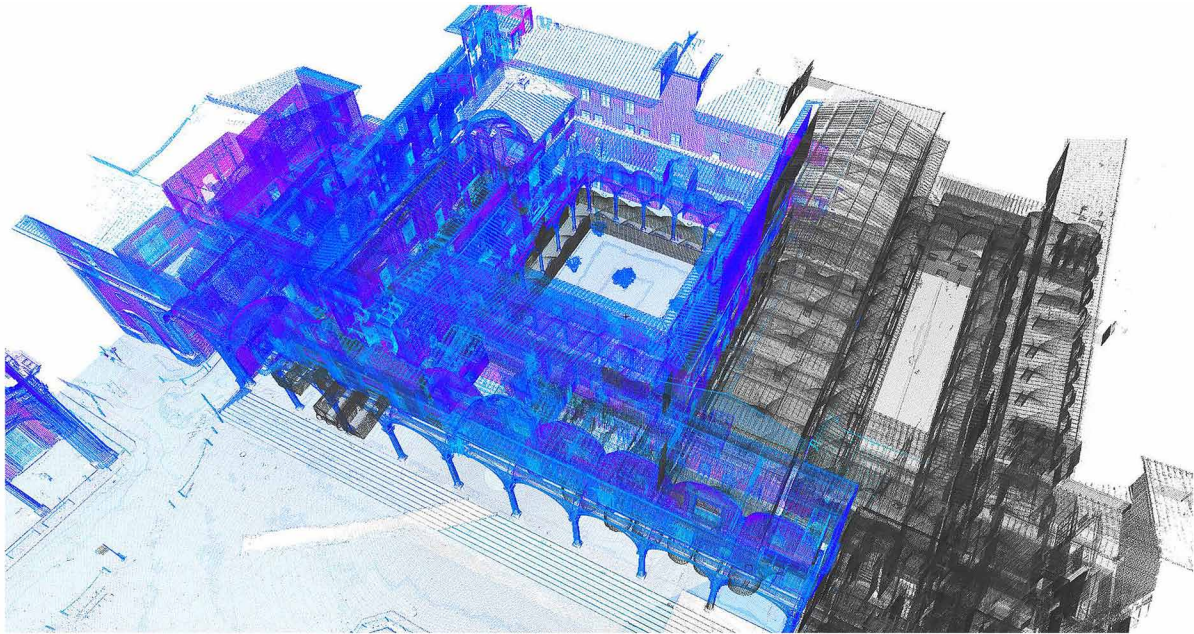
3D Survey of Architectural Heritage

The main topic launched within the Societal Challenge Work Programme was to contribute to a deeper awareness and understanding of European cultural heritage thanks to the use of 3D models. Following this aim, and after the assessment of gaps in the digital documentation field listed in the previous paragraph, the actions related to data capturing under INCEPTION were addressed facing issues such as the time-consuming and expensive generation of high quality 3D models, the file formats, very often not interoperable, and the data accessibility in a broad way.

Moreover, the documentation methodology set up under INCEPTION is focused on complex heritage architectures and sites (Figure 2). The proposed integrated approach investigates the potential of spaces in order to create new cultural connections and awareness; the architecture is a key example of the multi-layered conceptual dimension of European heritage.

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Figure 2. The 3D data capturing of the Italian Demonstration Case, the Istituto degli Innocenti in Florence, is an outstanding example of complex heritage building



In order to test and apply the overall INCEPTION process, nine Demonstration Cases were selected from six European partner countries:

- National Archive - Museum of Hydra in Greece;
- Technical Museum Nikola Tesla in Zagreb, Croatia;
- The Church of the Assumption of the Blessed Virgin Mary, in Mirlovic Zagora, Croatia;
- Istituto degli Innocenti in Florence, Italy;
- The Saint Nicholas Chapel, also known as the church of Obergum in Groningen, The Netherlands;
- Villa Klonaridi in Athens, Greece;
- Church Panayia Phorviotissa in Cyprus;
- Castillo de Torrelobatón, Valladolid, Spain;
- Akropolis of Erimokastro, Rhodes, Greece.

All these buildings and sites were selected in order to have a wide range of different contexts to test the INCEPTION methodologies; all these sites are different for typology, dimension, state of conservation and requirements by Stakeholders (enhancement, touristic valorization, assessment, documentation, conservation, etc.).

A common protocol for 3D data capturing and documentation was set up, considering also enhancement of functionalities, capabilities and cost-effectiveness of technologies and documentation instruments (Bianchini, Ippolito, & Bartolomei, 2015; Zlota et al., 2014).

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The protocol considers 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 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 (Stylianidis & Remondino, 2016).

The identification of the multi-function and multi-scale role of the model allows the exploitation of uneasy and complex resources (obtained by the collection of geometric shape and not just of the architectural and urban context) at different levels, over time and by different actors. Here it is the value of accessibility/affordability of the process that until now has been barely allowed to spatial scale but through a mere visual navigation often un-interpreted, an approach very far from the knowledge, understanding and conservative needs (Fröhlich, Mettenleiter, Held, Bliersch, & Kurz, 2015). The combination of innovative methodologies and protocols, processes, methods and devices allows enhancing the understanding of European Cultural Heritage by means of 3D models bringing new knowledge, collaboration across disciplines, time and cost saving in develop and use of 3D digital models (Brusaporci, 2015; Ioannides et al., 2016).

Concept and Methodology

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 protocol led the digitization and documentation of the nine selected Demonstration Cases, dealing with some issues such as complexity of heritage sites and accuracy of 3D models, integration of metadata and semantics into the 3D model, integration with additional information such as images, structural analysis data, materials, preservation records, etc., archiving of 3D digital records using wide accepted standards.

The assessment and optimization of 3D data acquisition tools allow the improving of methodological and technological advancement for 3D data acquisition and development of procedural standards. The output is a methodological report for documenting Cultural Heritage by means of 3D data capturing.

Within INCEPTION, the data acquisition protocol has been developed within a more general methodological procedure of heritage documentation. Since every cultural asset is unique and requires survey, analysis and investigations “case by case”, according to many different characteristics and to the main purposes of survey and documentation procedures, the protocol is set as flexible guidelines. This approach considers different kind of instruments and devices, different accuracies and levels of detail, etc., in addition to site specifications and the uniqueness of Cultural Heritage (Balzani & Maietti, 2017).

The DAP can 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 (Koussi, Karoglou, Labropoulos, Bakolas, & Moropoulou, 2012) and an optimized workflow specification.

The main aims of the INCEPTION DAP are:

- To set up an optimized procedure, based on principles of simplicity and efficiency, for surveying heritage buildings and sites by using different 3D data capturing instruments;

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- To provide a workflow for a consistent development of survey procedures for tangible cultural heritage and a set of instructions and guidelines for collecting, presenting and storing data;
- To provide a tool able to guide a 3D data capturing procedure able to generate 3D models accessible for a wide range of users;
- To enhance the accuracy and efficiency of 3D data capturing by documentation and instruments integration;
- To support a cost effective and time saving procedure;
- To serve as the basis for the enhancement of functionalities of data capturing technologies and documentation instruments;
- To close the gaps between technical fieldwork and modeling in 3D data capturing.

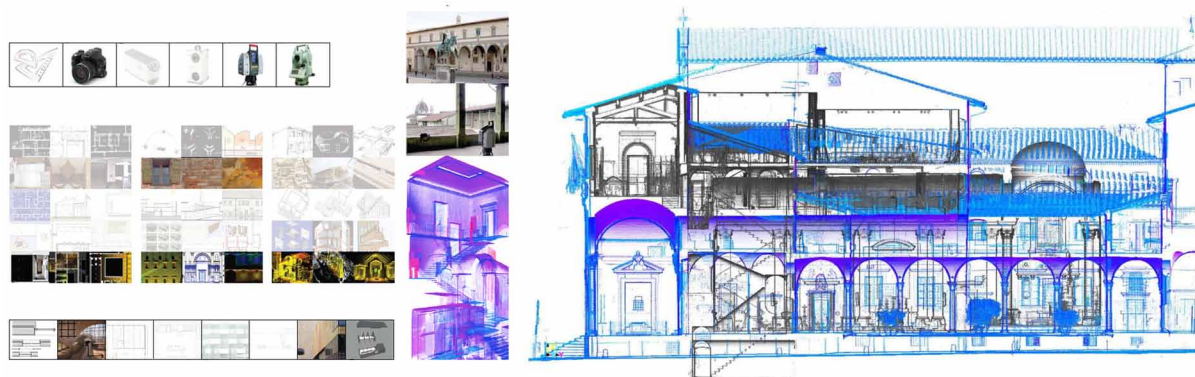
Data Acquisition Protocol

The DAP (Figure 3) is intended to ensure uniformity in 3D digital survey for all the buildings that will be part of INCEPTION platform. This protocol considers a wide range of 3D data capturing instruments (Kadobayashi, Kochi, Otani, & Furukawa, 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, the protocol application will ensure data homogenization between surveys tailored to different requirements.

The survey workflow was 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

Figure 3. The Data Acquisition Protocol applied to the Istituto degli Innocenti in Florence



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- Quality control
- Data control and verification
- Data storage and archive

Each step of the workflow is a set of “checks”, a sort of measuring system to verify the requirements of the survey. Every single check is an activity indicator that contributes to reach a specific “evaluation ranking”. Not every activity indicator is always compulsory: if in the survey campaign only the minimum number of question find 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 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 evaluation categories. For this purpose, there are four incremental categories defined as following:

B: This 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: This evaluation category is 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 can't be based only on morphological method but it 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 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 (Apollonio & Giovannini, 2015). Elements of quality control are integrated into the process.

A++: This evaluation category 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. 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 analyzing how a survey has been performed in every single phase: moreover, this capability allows to integrate a survey different times.

In the following tables (Tables 1a and 1b) the DAP is graphically summarized in order to understand how reach a specific evaluation category. All its requirements are also split into specific activity indicators that has been fully described in the project documentation. Nevertheless, an activity indicator could work in three different ways:

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Table 1a. Activity indicators and their metrics for each phase foreseen by the Data Acquisition Protocol

B	A	A+	A++	Scan Plan
				General site plan
				Acquisition plan
				Inspection of the survey site
				Simulation of the digital levelling of the building
				Registration mode and overlapping scans
				Weather condition recording
				Selection of instruments
				Equipment calibration
				Health and safety
				Safety conditions and equipment
				Resolution requirements
				Level of detail: density and accuracy
				Data voids
				Field of view
				Geolocation
				Registration mode
				Automatic + pre alignment
				Morphologic
				Morphologic + control network
				Automatic with Inertial Platform + compass + barometer
				Inertial Platform + control network
				Automatic with integrated GPS
				Automatic with integrated GPS + Inertial platform + compass + barometer
				Automatic with integrated GPS + compass + barometer
				Targets
				Targets + control network

- **Presence:** The activity indicator could be compulsory for a specific evaluation category or not. It's the most used type of indicator;
- **Value Range:** When a measurable value range is available for every evaluation category;
- **Alternative Procedures:** The choice of an alternative procedure defines the compatibility with an evaluation category. It's used for alternative registration methods.

The Data Acquisition Protocol 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 (Pauwels, Bod, Di Mascio, & De Meyer, 2013).

Documentation, Processing, and Representation of Architectural Heritage*Table 1b. Activity indicators and their metrics for each phase foreseen by the Data Acquisition Protocol*

B	A	A+	A++	Control network
				Control Networks project
				Evaluation on the positioning of topographical geodetic marks
				Control networks interrelations: topographic, GPS and 3D survey
				Control networks validation for angle of incidence
				Quality control
				Survey documentation
				Documentation forms for each 3D scan station
				Documentation forms for each control network station
				Documentation forms for each geodetic mark or benchmark
				Homogenization of reflectance data by different instruments
				Influence of the incidence angle on the reflectivity index
				Illustrative diagrams outlining the position of scan stations and control points
				Additional image data
				Texture image data
				Additional Image Panoramic data
				Data control and verification
				Panoramic view as on-field checking
				Control Network analysis and verification
				3D model registration analysis and instruments reports
				Summary outlining all known data voids
				Redundancy hardware
				Data storage and archive
				Point Cloud data format
				Other Data format
				Metadata and Paradata
				Data Backup, Data archiving and Recovery Procedures
				Original data preservation

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 (Fassi, Fregonese, Adami, & Rechichi, 2017).

BIM/H-BIM DATA MANAGEMENT AND PLATFORM ARCHITECTURE

The step following the documentation and data collecting is related to semantic modeling in order to aggregate data in an effective way, thanks to the adoption of BIM.

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The BIM applied to Heritage is the key component making the link between the State of the Art of the BIM world and the State of the Art of the Cultural Heritage world. This is strongly related to the development of the INCEPTION platform, the key-targeted achievement of the overall project. The INCEPTION platform implements semantics about specific contents on individual 3D models and allows access to metadata or paradigms. In the cloud-based architecture, the main input is a BIM model of a cultural heritage site. The models can refer to several categories, such as museums, archaeological sites, historical sites and heritage buildings.

A layered and interoperable ontology has been developed to gather and store new heritage information into the BIM model matching correct architectural elements to each structural or decorative part of the building (Iadanza et. al., 2019). Then the Heritage-BIM (H-BIM) ontology has been extended to create a connection between external documentation and the whole 3D model or individual elements specified in the H-BIM graph. The H-BIM ontology has been developed to remap the architectural features from ifcOWL (an open standard for BIM modeling in a semantic web language) and to integrate them with the architectural elements specific of the cultural heritage domain, starting from 3D models developed as INCEPTION demonstration cases.

BIM State of the Art

Given BIM is defined as Building Information Management and Building Information Model, this can be covered for a large part with a widely accepted strong open standard within the Building & Construction sector, i.e. IFC (Industry Foundation Classes or ISO 16739:2013) (Djuedja, Karray, Foguem, Magniont, Abanda, 2019). That such an open standard exists and is accepted so widely is not a coincidence.

The Building & Construction industry is highly fragmented in many ways. The majority of the companies applying the real work in this sector are Short-Medium Enterprises (SME's), and virtually any project is unique with a unique set of partners and with unique design and context (Olawumi & Chan, 2019). In addition, organizational wise there is not a single company or small set of companies dominating the sector in contrary to other sectors like the automotive or aerospace. On the software side for this sector, we find a similar situation, although some large software vendors dominating in some part of the sector also here a significant fragmentation of tooling can be found. In this situation, exchange of knowledge via an open standard is essential (Logothetis, Karachaliou, Valari, & Stylianidis, 2018).

Although IFC is covering a significant part of BIM it is not covering everything and has its own limitations. The organization behind IFC is aware of this and, next to keep improving and extending IFC itself, it also covering important identified gaps. The bSDD (Building SMART Data Dictionary) is covering the issue of limited classification power of IFC, and the support for up-to-date serializations like ifcOWL and less strongly ifcXML are trying to solve the central single model approach limitations.

Within INCEPTION, the work of BuildingSMART is reused including the efforts on improving known limitations. As INCEPTION is fully based on current Semantic Web technology (i.e. the core of IFC is dating back to STEP EXPRESS technology from 1985) within INCEPTION it was possible to tackle several of the known issues with simply using existing functionality from Semantic Web technology. Geometrical information is separated from non-geometrical knowledge while keeping the interlinking data available and conversion towards H-BIM and GEOM ontologies allow nearly loss-less conversion of any available IFC schema variant and any available IFC file including current schemas like IFC4 ADD2, IFC4x1 and IFC4x2 including the alignment extension for GIS related content.

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The INCEPTION platform is based on current Semantic Web technology (De Boer et. al., 2012), by many seen as academically correct solutions to complex issues however useless in practice given the technologies well known scalability issues and academic tooling dependencies (Parisi, Turco, & Giovannini, 2019). This seems to be especially relevant as geometry in general, even strongly for semantically poor geometry definitions based on point cloud scans, quickly explode in data size, and therefore triggering scalability issues.

The scalability issues however are prevented by cleverly structuring and organizing the relevant content being able to optionally exclude for example geometrical content from SPARQL engines and other sensitive components concerning scalability. SPARQL is the standard language to query ontologies; it is a Semantic Web technology and it has been made standard by the Data Access Working Group, a working group of the W3C consortium (SPARQL query language). This allows the INCEPTION platform to be fully Semantic Web based but persist performance even if the amount of data grows rapidly.

The platform itself is running on and created from commercial solutions, running on an Amazon server, using Fuseki-2 data store with SPARQL functionality using Windows based servers. The conversion tools are created in a combination of C# and C++ and can be compiled for both Windows and Linux, following the language and solution choices of the commercial market in contrary to the more JAVA oriented academic world.

With this, the INCEPTION platform offers a mature, scalable solution integrating the best State of the Art solutions of two worlds, this all with the help of current technology.

The INCEPTION platform in its essence is the H-BIM ontology that is extendable and adjustable. Each project is initialized using the open standard IFC export of a BIM model. This export is available on all major CAD / BIM solutions; however, the quality of the export strongly depends on what the modeler created within the solution.

Once the IFC model initiated the H-BIM ontology in the INCEPTION platform the user is able to adjust, enrich and update all knowledge available. The H-BIM ontology and the initial BIM model help the user in structuring and organizing available content.

The INCEPTION platform offers out-of-the-box great functionality for enriching, organizing and querying the content of projects. This front-end itself is 100% working on the available SPARQL endpoints available on the server. Technically, there is no limitation developing a similar or even better user-interaction yourself using the exact same techniques.

SEMANTIC PROCESSING AND ONTOLOGIES

Since one of the keywords and scope of the INCEPTION Project is “interoperability”, the choice to use the Semantic Web technologies (Ronzino, Hermon, & Niccolucci, 2012) as a machine-readable layer for 3D models was successful for the possibility to relate, layer and connect different knowledge bases on the platform.

The Semantic Web standards, led by the W3C consortium (W3C, 2018), allow providing formal representations of knowledge called ontologies, a format that represents multiple level relationship objects. Integrating a specific H-BIM ontology with a 3D model led to multiple benefits.

Using an ontology layer as an interface for interactions provided to:

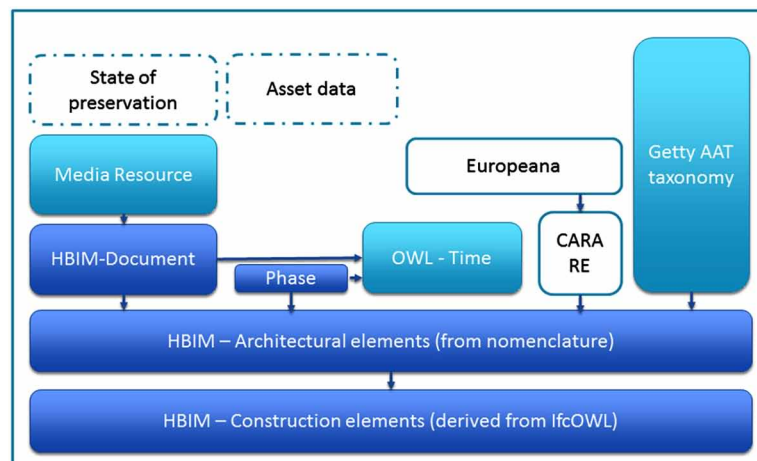
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1. Correctly define the architectural features, both structural and decorative, of the 3D model, focusing on Cultural Heritage domain.
2. Link them with external related vocabularies and ontologies, being the W3C standards a common language in research and heritage data sharing.
3. Easily link documents useful to deepen the knowledge related to any part of the building, independently from their file format, with a very fine granularity.
4. Filter information by User profile and Scope in order to allow personalized user-friendly navigation for tourists, professionals, cultural heritage experts and administrators.
5. Develop a standard API to query data and properties to connect and share the knowledge embedded in the 3D model hosted on the INCEPTION platform, allowing third parts to develop tools based on available, self-explaining data.
6. Add layers of knowledge, bridging other specific ontologies suitable for projects specialized on specific scopes. For example, if a project is focused on maintenance, adding a specific material and state of conservation ontology can be helpful to define correctly essential properties. This kind of information could be not relevant in a model with only touristic purposes so that in this case it can be skipped.
7. Reuse information shared from other machine-readable sites, like Getty AAT (The Getty Art & Architecture Thesaurus), Wikipedia, Europeana etc. promoting the INCEPTION Platform as a way to merge 3D representation and the Linked Open Data world.

The first ontology layer (Figure 5), called H-BIM, developed within the set of the INCEPTION standards framework, is derived from the IfcOWL ontology (buildingSMART), an open standard for BIM modeling written in a semantic web language, OWL (Time Ontology, 2017).

For performance and functional reasons, only a subset of IfcOWL suitable for the INCEPTION Platform scope was chosen for the H-BIM ontology and integrated with further definitions of the Cultural Heritage Architectural domain.

Figure 5. The ontology model with the layering of data and information in Heritage domain



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To obtain the building project ontology, the 3D model, achieved with commercial tools, can be exported in the IFC format that can then be converted to H-BIM through the software available on the INCEPTION Platform.

Usually changing domain arises new challenges, and importing the Heritage models through IFC format was suddenly evident that standard BIM structure did not entirely answer to the complex nomenclature required for historical sites and buildings. The original ontology classification derived from IfcOWL needed to be expanded with new features definitions to bridge the gaps of the current BIM definitions and have a classification suitable for Heritage buildings.

The feature definitions list was thus enriched with architectural elements names gathered from the INCEPTION demonstration case set, with a top-down approach to build a glossary that acquires user data and integrate them with well-known architectural vocabularies like the Getty AAT.

Correct naming is the first step to evolve from a geometrical representation of the reality to a semantic and conceptual one, levelling up the knowledge displayed in this new kind of digital representation of the relevant data of the building.

The INCEPTION H-BIM Ontology

In the H-BIM ontology we find a dedicated ontology part representing IFC, however in a more current shape based on the work that was already in progress by standardization body BuildingSMART. This part represents the BIM part of the H-BIM ontology.

In the H-BIM ontology, we further find several of the existing State of the Art classifications and data structures for Cultural Heritage, in general with none, or with minimal conversions given the already current nature of data structures in these found open standards (López, Lerones, Llamas, Gómez-García-Bermejo, & Zalama, 2018; Logothetis, Delinasiou, & Stylianidis, 2015). This part represents the “H” part in the H-BIM ontology, or the connection with the Cultural Heritage field. Both worlds of BIM and Heritage are interconnected by adding a layer of mappings as typically applied with Semantic Web technology.

The H-BIM is indeed further extended by mapping ontologies; these ontologies represent the mapping for classifications from the Cultural Heritage domain with the BIM domain. In practice this means that the H-BIM itself is represented in a set of distributed ontologies, however interconnected and for practical reasons stored in the Fuseki-2 data store via Turtle serialized ontologies. This is however the practical solution allowing the knowledge of H-BIM to be used in the INCEPTION platform. The real H-BIM ontology is the combined existing knowledge from the open standard IFC and BuildingSMART extensions together with the State of the Art data structures and classifications as already available for the Cultural Heritage domain (Felicetti, d’Andrea, & Niccolucci, 2012) combined with the knowledge our experts within INCEPTION added to integrate both worlds.

Therefore, we can define the INCEPTION H-BIM ontology as a set of classifications for building components compatible with the Cultural Heritage needs that can be enriched with definitions, synonyms, information and documentation.

The scope of this H-BIM ontology is in fact to fill the gap between geometry and the representation of the knowledge in all its different aspects, tangible or intangible, achieving a holistic approach in the description of the digital double of the real building.

Once the H-BIM ontology sets the main schema definitions, the data of the single project are converted, assigning to any of them a specific class concept and a Uniform Resource Identifier (URI), to explicit

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the relationship between elements and link the external enrichment properly, both at a definition and at a single object level. Therefore, every project produces an OWL language ontology, composed of a shared set of building element definitions and the specific individual digital components of the building.

The project components are 1) all the elements described in the 3D model, 2) their relationship with the other elements and 3) the specific properties that are imported in the ontology layer. That information is acquired uploading the file in the INCEPTION Platform and extracting all the relevant properties.

This operation also adds the correct hierarchical specification of components based on the general architectural definitions that are shared by all the different model's descriptions without losing the backward compatibility.

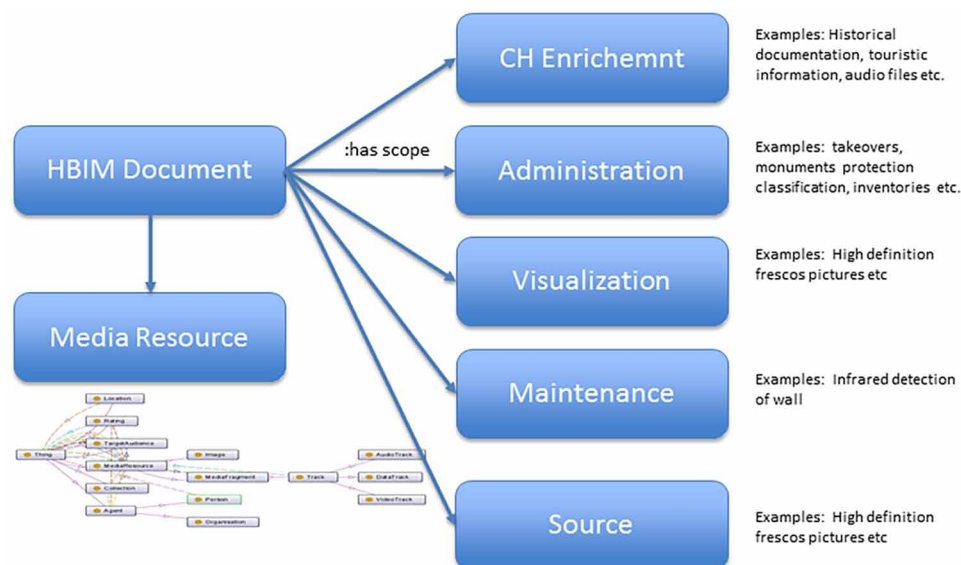
Having a single architectural element represented in the ontology as an individual, allows a very deep granularity, giving the opportunity to enrich any single component with complex information. All the components are hierarchically related to other building parts if the relationship is transitive: for example, if they are parts of the same room or construction subset, and this graph structure is important to navigate the enriched content seamlessly at different levels.

The ontology layer built from the model can now be related with external machine-readable vocabularies, for example, the already mentioned Getty AAT vocabulary, to translate the architectural elements in various languages or to assign an official definition to any of them.

For the INCEPTION user, it is now easy to explore the properties and documentation simply navigating the model, giving a sort of "3D structure" to the original flat set of external data (text, properties, images, external files).

To achieve this scope, another integrated ontology, called HBIMDocument, was developed (Figure 6). The two main scopes of this ontology are to 1) add metadata to visualize and filter the relevant documents and to 2) identify each document to link it to the specific part of the model, or even to some model defined category (like all the model columns). Data are available only when necessary, and the

Figure 6. Schema explaining the HBIMDocument ontology developed under INCEPTION



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localized information is a real interactive enrichment due to the side-to-side visualization of the element and its related data.

In Heritage domain, the documentation related to the whole model or part of it varies hugely: usually it is previous to the 3D model as a source of the reconstruction. Sometimes it is easy to integrate formal knowledge extracted from existing ontologies or structured databases, but often the information should be interpreted analyzing already existing external files or digitized objects.

To navigate those objects INCEPTION has built a set of properties both used to define the intrinsic file properties and the way the user could explore them.

Cultural Heritage buildings and sites importance also depend on their significance due also to the social and historical events that involved the asset through time (Hermon & Niccolucci, 2017). The significance and scope factor was thus added to the ontology, as a useful tool that can be used according to the interactive user profile and behavior to show only the documents they are interested in or allowed to access.

The files available in the INCEPTION demonstration cases as external enrichment were mostly media files like images, videos, audio, and text. In those exploitable interchangeable formats, it is possible also to represent intangible features linked to the assets in the form of audio, traditional tales, local witnesses. Furthermore, common file formats can be immediately shareable through an internet browser or other software tools.

The ontology is implemented in RDF/OWL, the standard language of Semantic Web, also used to implement the INCEPTION H-BIM ontology, and partially derived from W3C Media Resources ontology (Ontology for Media Resources). The scope of this ontology is to target the media resources formats commonly used on the World Wide Web.

One of the main problems to address in H-BIM development was indeed the amount of external documentation related to the different utilization of the digital model of an asset: maintenance, interventions, administrative or historical issues (Figure 7). Metadata and ontologies are useful also to filter only the relevant documentation related to the user objectives, to be effective and not to overwhelm him.

All this documentation is available not only for the interactive user but also, through a REST API, for third-party development or mobile integration. The third party can ask the raw data, the relationship between components and query through different models, using a semantic search engine or a SPARQL endpoint.

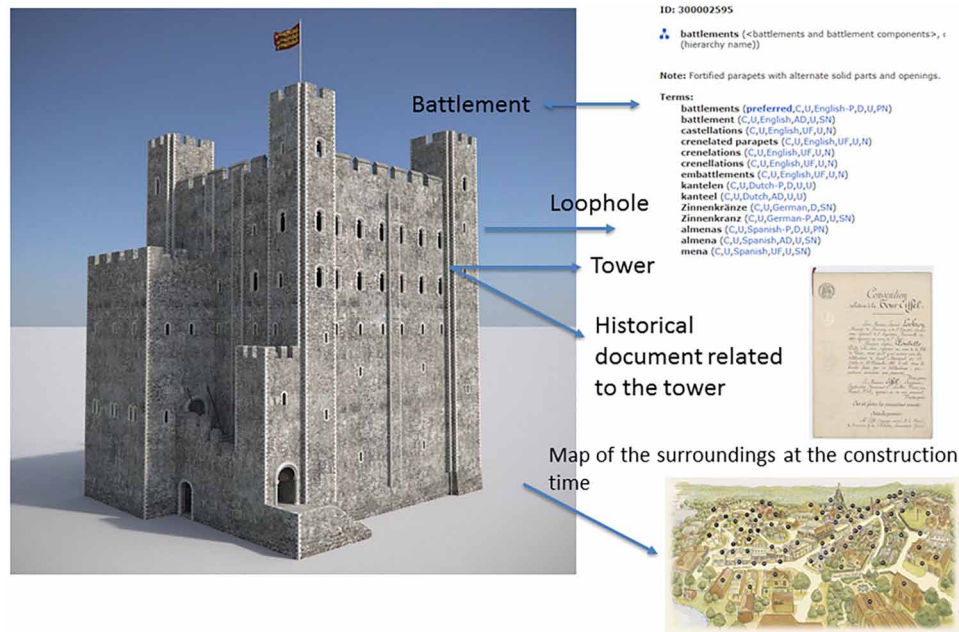
Third parties can retrieve data and enrichments organized by position, time, scope, file format etc., depending on their needs, like simulating a visit to the building in an Augmented or Virtual Reality environment. When the model changes, any new data is then immediately available and updated; extending in this way the external app implies using the INCEPTION platform as an organized data repository.

Through the SPARQL endpoint, the INCEPTION platform can also join the Linked Open Data domain, sharing the information of Cultural Heritage 3D models to the world of interchangeable data.

Of course, not any model nor any data will be shared with the public, but allowing the possibility to promote the building or site model, history and general-purpose data through intelligent agents allow the reuse of digital Heritage assets on the Web, making the architectural heritage more exploitable and enjoyable for anyone.

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Figure 7. Example of H-BIM ontology enrichment. Several sources are related to the model



DATA MODELING AND AGGREGATION

Three-dimensional data captured in the form of point cloud and the massive variety of significances that are represented by a building, need to be aggregated in a way that could allow scholars and professionals to explore and reuse them. Indeed, data acquisition on Architectural Heritage doesn't only mean to capture the geometrical shape even if it could be seen as the aggregator. Looking for a suitable standard able to collect 3D shapes and information, the INCEPTION project focuses on the BIM approach, since BIM is a standard already adopted by the construction sector with significant results. In the attempt to achieve a process that could be replicable, the workflow has been critically investigated in order to identify any unsolved issues and give an answer to them. For this reason, the INCEPTION approach offers either methodological solutions and ICT tools to facilitate and speed up the adoption of BIM technologies in the Cultural Heritage sector.

If we start from the basic definition of BIM, as previously mentioned, we can already identify the two different data components that we are looking for. On one side we do have a building model, made of discrete elements as they compose a real building, while on the other we have pieces of information where we can store the intangible values represented by a building itself.

Going more in-depth asks us to answer the following questions:

1. How to create an object-based BIM model out of a point cloud model?
2. How to aggregate information around a BIM object that could be valuable for documenting CH significances?

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When considering to create a BIM model, we are used to referring to the LOD - Level of Development - definition. However, since it usually increases as the project proceeds, in the case of existing buildings we can't apply it without critical considerations. Indeed, the building is not actually developing, but we are just creating new data capturing reality.

The schema below (Figure 8) represents the usual equivalence between the LOD and the elements that are composing it for new buildings. And it works really good for them: each building stage requires a specific amount of geometrical details and information. They could not increase coherently but they always increase in terms of quantity, quality, and reliability.

In order to apply such equivalence to Heritage buildings, we tried to figure out in advance what geometries and information are dependent on. We identified in the so-called "final scope" the element that leads the data modeling and aggregation. The same final scope defined while adopting the DAP in the data collection phase. Indeed, only on this could be based the choice of the most appropriate level of geometrical details of the model and the information, or even better the knowledge, to be attached to it. In order to give an example, a Virtual Reality application needs for a more accurate geometrical detail rather than an Augmented Reality application, where probably we will not see only the historical enrichment popping up from the reality. The lower part of the schema explodes further in details this approach, trying to figure out a consistent answer to the previous question.

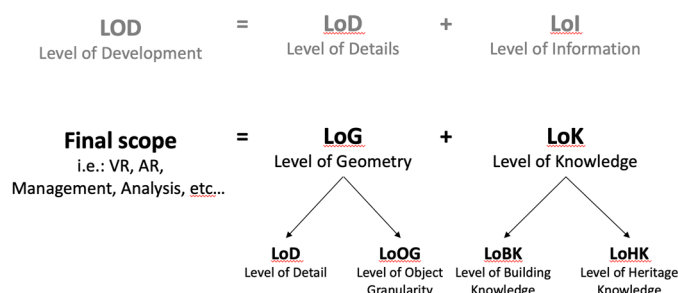
From Point Cloud to BIM: A Methodological Approach

When we have a point cloud of a building, we usually have a bunch of data still un-interpreted and unsegmented. Nowadays, the increasing capabilities of the BIM software (Apollonio, Gaiani, & Sun, 2017) allows us to bring into this environment a huge amount of data but the modeling procedure is still time consuming.

Of course, it can be speeded up with shape recognition algorithms but the only way to decrease dramatically the time needed for this effort is to define a correct methodological approach, in order to better understand what we need to model, and so be more effective and avoid wasting time in modeling unnecessary details.

Indeed, understanding where a building element ends and the next one begins can be even more difficult on a point cloud than in the reality. For instance, on a façade, we could easily identify what is a wall and what is a window, and then decompose the window into several elements like glass, frame,

Figure 8. How to apply the LOD relation to INCEPTION H-BIM models



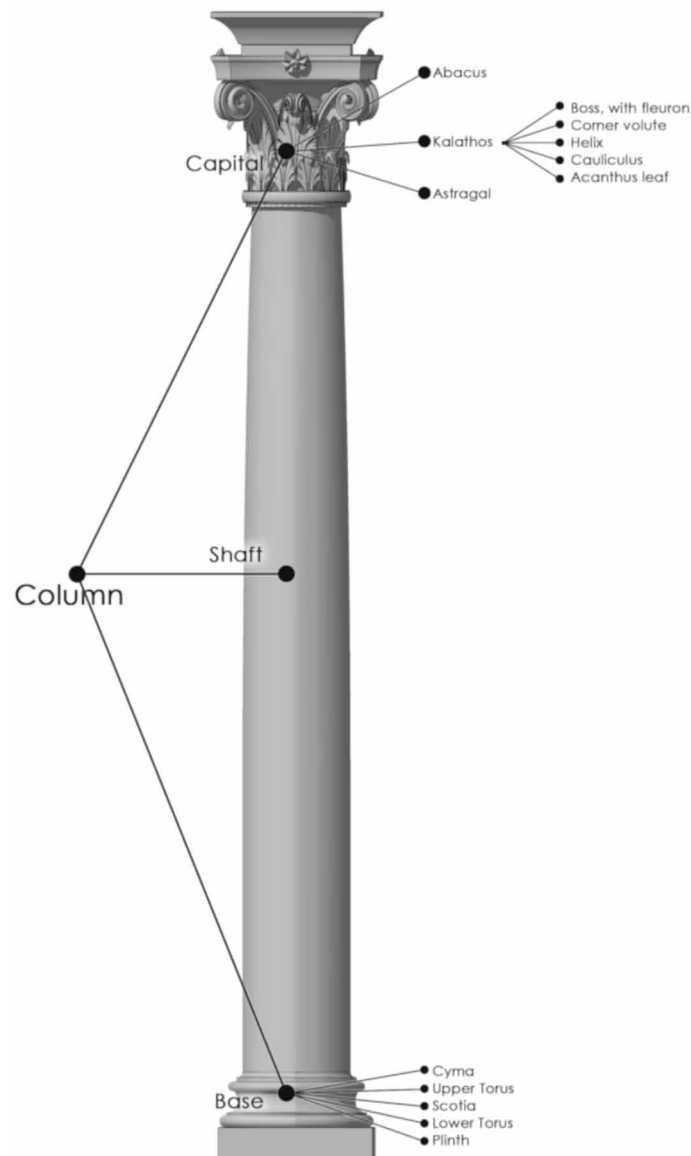
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vertical or horizontal elements of the frame, and so on and so forth. And this hierarchical relation works well for new and old buildings (Bianchini, Inglese, & Ippolito, 2016).

However, let's take a different example: a column for instance (Figure 9). An element called column is already included into the IFC standard, the standard format used for BIM. But what is missing are the classification of the elements in which a column can be decomposed as well as the correct nomenclature of each pieces according with historical source. Would it be still useful a 3D model without that knowledge attached (De Luca, Véron & Florenzano, 2007)?

This brings us to further subdivide the Level of Geometry in two different aspects:

Figure 9. Hierarchical nomenclature of a historical column



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- A level of detail, or geometrical detail, that describes objects with a certain degree of geometrical accuracy;
- A level of object granularity, that helps us to divide a bigger geometry into proper pieces.

The first aspect, the level of detail, is dependent on the final scope due to the final appearance that a 3D models need to have (i.e.: Virtual Reality application) or rather the coherency of the quantity take-off (i.e.: maintenance). While the level of object granularity is still dependent on the final scope but with a more strictly link with the knowledge that we want to attach at it (Figure 10). Having for instance a photographic documentation of the restoration of a capital, we would have the capital modeled as a single object in order to attach those files to that specific element and not at the entire column.

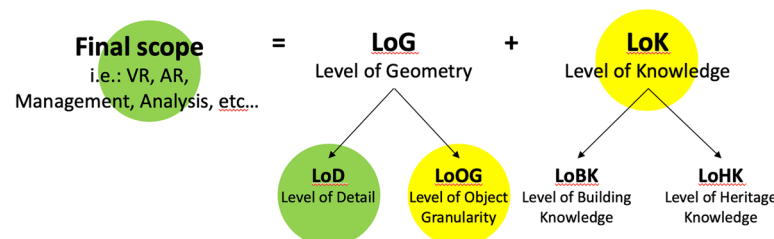
From BIM to H-BIM: Towards an ICT Solution to Data Aggregation and Model Enrichment

Switching from a traditional BIM model to H-BIM is a matter of knowledge and how to aggregate it to a 3D model (Dore & Murphy, 2015). The data modeling approach previously presented already includes some elements that are yet to be solved in a practical way. In fact, even if different software environments allow at attaching information to an element, most of them get lost adopting the already mentioned IFC standard file. In order to simplify this consideration, we could state that information proper of building components can be stored in the IFC file (i.e.: materials, quantities, if load-bearing, etc.), while the knowledge related to the significance of that element can't (i.e.: picture of wall paintings, links to historical sources, etc.).

In order to solve this gap and ensure a reliable and reusable way to aggregate data for model enrichment, we developed the INCEPTION platform not only as a data repository but as an actual working tool to extend the capabilities of existing standards (Figure 11). Thanks to technical solution previously described, during the uploading phase of a BIM model on the INCEPTION platform, an HTML interface makes use of semantic web technologies in order to assign to every modeled geometry an URI – Unique Reference Identifier. By means of this URI, data and files can be attached to each single element accordingly.

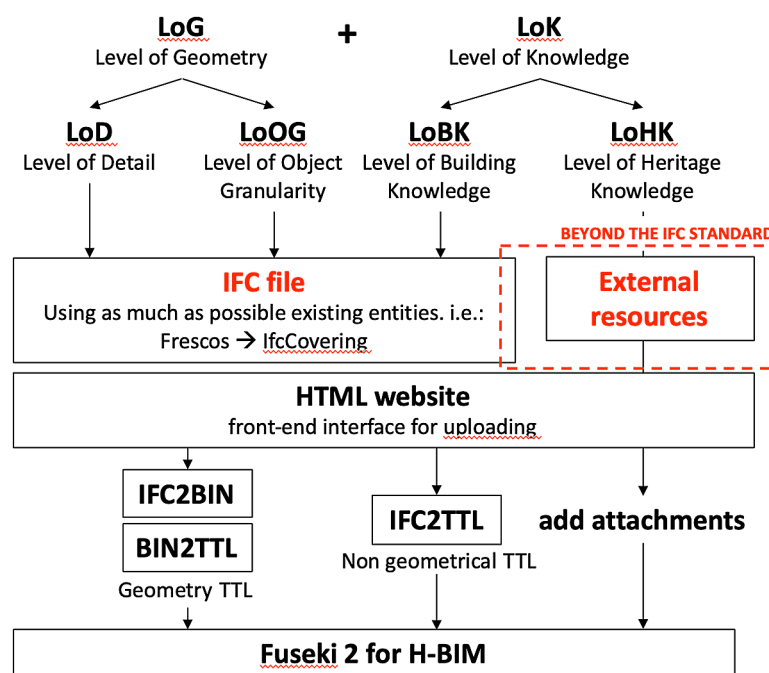
Integrating the platform usage in the process of aggregating data, allowed to further extend the use of the IFC standard in the modeling phase. When new IFC property sets are included into the IFC file, these are automatically handled by the platform and interpreted by the translator to Semantic Triples. Furthermore, when those property sets are created for a specific purpose supported by INCEPTION, included data can be even further elaborated.

Figure 10. Data dependencies on correlating 3D shapes and information



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Figure 11. Towards the INCEPTION H-BIM: how data are aggregated using the platform



For instance, the screenshot below (Figure 12) highlights a façade element called *tondo*. Of course, this is not part of the IFC standard nomenclature but, as it can be noticed, more properties than the standard ones are included. Among those, an exact definition of the element and the author (from Getty vocabularies) that will automatically lead to an external resource on the platform and time information, that can be used to automatically generate a Time Machine function.

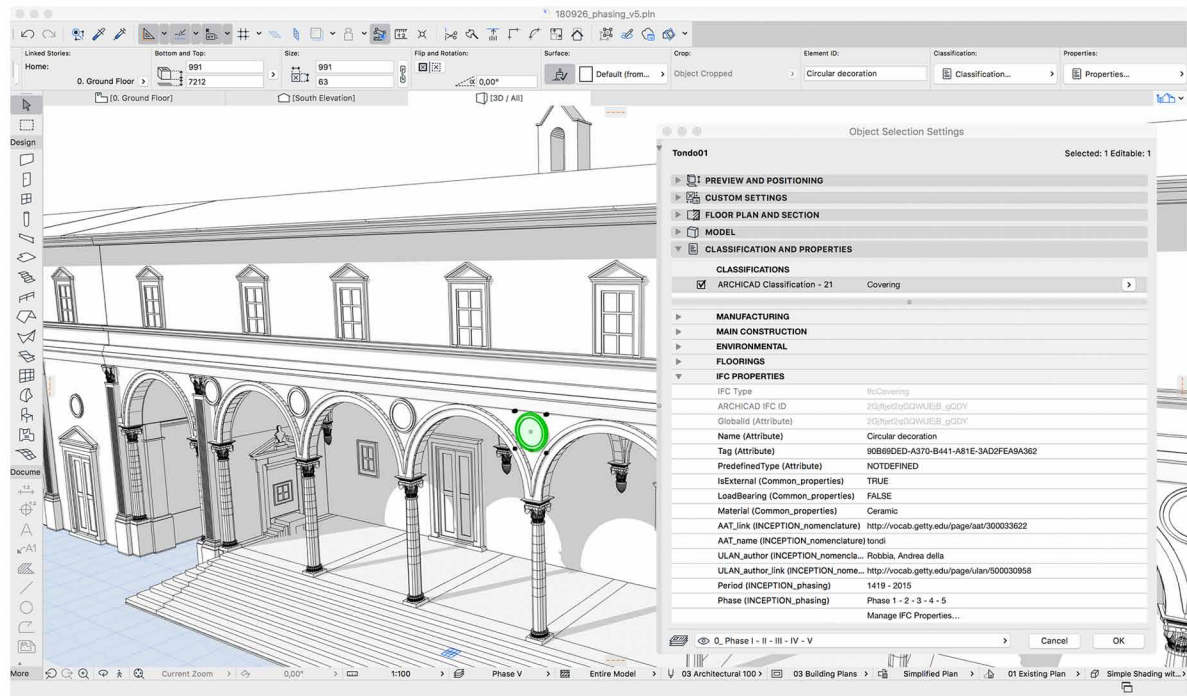
THE INCEPTION PLATFORM AND RELATED TOOLS

In developing the INCEPTION platform, the “circular workflows” are of particular relevance for the use of 3D models and related data semantically aggregated (Vlachidis et. al., 2018) for the development of connected external applications. One of the choices concerned the possibility of loading other types of three-dimensional models, such as the DAE format in addition to the BIM models of architectural complexes. This choice is due to several factors:

- Difficulty of some BIM Authoring products in exporting any applied textures (as in the case of frescoes) in IFC format;
- Possibility of loading and connecting to the main BIM model of the architectural complex other 3D models of related architectural details in different scales (capitals, decorations) or sculptural works contained within;

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Figure 12. Extending the IFC standard: new IFC property sets will be retrieved and used by the platform



- Being able to reuse different types of non-BIM three-dimensional models previously created for other purposes, integrating them into the platform and reconnecting them to the semantic structure;
- Increase the sharing of 3D models through the use of the platform (Apollonio, Gaiani, & Bertacchi, 2019).

This great flexibility allows the availability of a structurally organized database on the platform, effectively useful and usable for the creation of specific contents and applications.

Some specific tools being developed allow enjoyment of these contents in an easy way to guarantee to the different users greater ease in the visualization and in the understanding of the architectural heritage and in the choice of the contents. In fact, the different types of three-dimensional models of the architectural complex (IFC, DAE, etc.) are analyzed by the platform to be connected and related to each other. It is possible to dynamically switch from one model to another while maintaining the same point of view, using a “transparent” rotation and navigation tool. Similarly, it is also possible to make “transparent” selections of the geometry (Figure 13) from one model to another. It is possible to select a frescoed surface in the DAE model and obtain all the information connected to that specific geometry, going to the BIM model. The only limit is related to the geometric differences between the different DAE or IFC format files. Geometric differences that can be reduced within a tolerance of 8%.

In addition to the possibility of exploiting the different contents (3D models, ontologies, textual information, images, videos, etc.) in “static” mode by downloading and “embedding” information for external applications, it is possible to exploit the INCEPTION API to receive information directly from the platform on the external application in “dynamic” mode through a “socket” of communication.

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Figure 14. Examples of three time phases in the evolution of the complex of the “Spedale degli Innocenti” in Florence, realized in an immersive way using specific VR tools



The software used to create the immersive visual experience are those of raster or vector graphics through real-time rendering (Figure 15). Advantages and disadvantages are related to the hardware/software that can be used to create immersive content to be explored by different users. The wearable devices used for immersive VR are mainly head-mounted displays (HDM) or simply headsets.

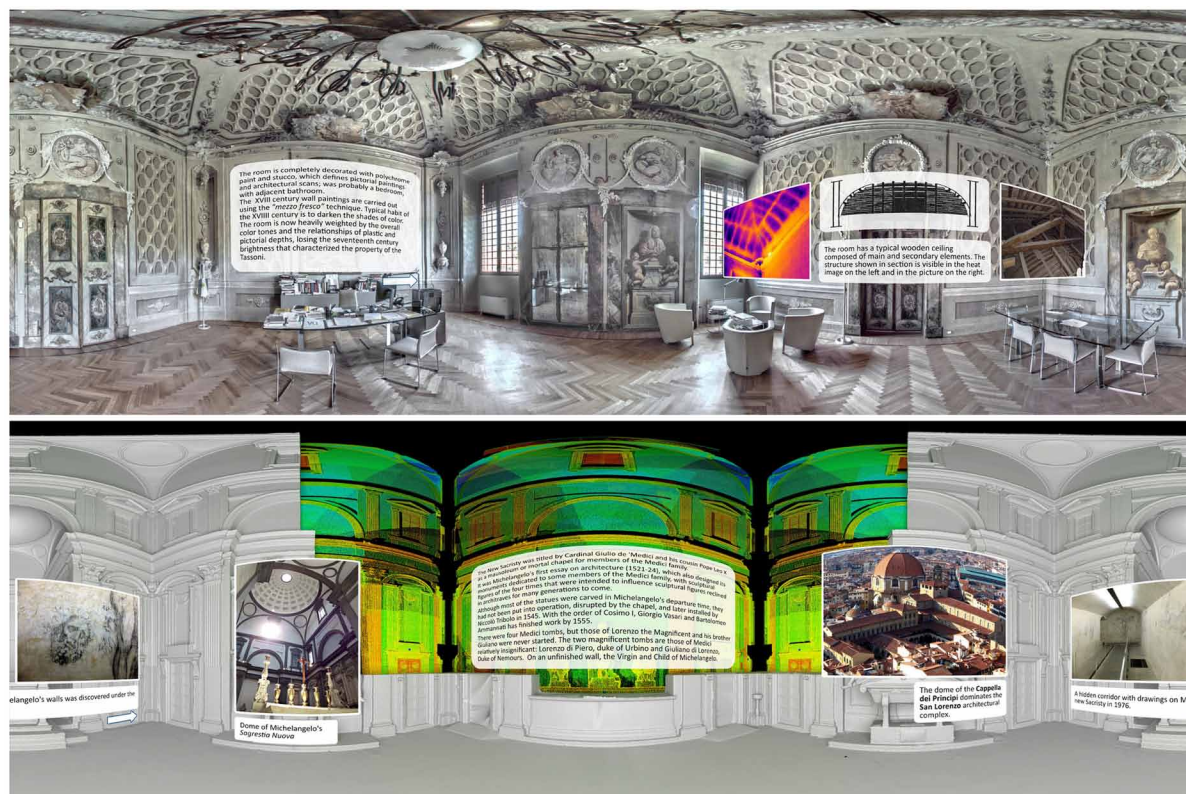
The HDMs can be divided into two macro-categories:

- Portable HDM or “All In One”, systems embedding the computing hardware directly inside the HDM (integrated hardware or simply via a smartphone inserted inside) as Oculus GO or Samsung VrGear ;
- Fixed HDM, systems physically connected to an external graphic computational unit that performs real-time rendering of contents, such as OculusRift, HTC VIVE or PS VR.

Fixed HDMs contain high-resolution displays (up to 4k) that are connected via cable (like a common monitor) to a graphics workstation. The movement is given by the gyroscopes inside the HDM or by external motion sensors. Navigation, graphic quality and interaction can be extremely high. On the other hand it is necessary to develop the Virtual Reality application in a specific environment through Graphic Engines such as UNITY ©, UNREAL Engine®, Sumerian ©, TwinMotion ©. Within the performed tests, an application was developed by using this last software starting from the data uploaded

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Figure 15. Experimentations of AR / VR. Analysis of data related to different types of users



on the INCEPTION platform in “static” mode, downloading the multi-temporal model of the Istituto degli Innocenti in Florence.

The portable HDMs launched within the Google Cardboard project are based on the use of smart-phones (which already contains all the necessary hardware, such as multicore CPUs, dedicated GPUs, high-resolution displays, compass, gyroscope) to enjoy 360° graphics. This has led to the development of HDM devices totally “All In One”. Portable HDMs are often lighter, more comfortable and easier to use, making them more suitable for a greater number of users, such as the elderly or pre-schoolers. On the other hand, the reduced computational power (compared to graphic workstations) requires the development of immersive solutions more oriented towards the use of raster graphics than 3D vector graphics.

For this reason, 360° images and videos with historical development phases were generated from the Virtual Reality scene previously created for the Istituto degli Innocenti in Florence. The images and the 360° video thus generated and uploaded to the platform can be enjoyed both in a “static” and in a “dynamic” way from the INCEPTION platform. In order to check this technology on different users, several tests related to different Demonstration Cases and architectural contexts were carried out. Some tests have been performed on a large audience during the European Commission’s Open Doors Day in 2017 (Figure 16).

Viewing and web browsing of 3D or 360° content via HDM (fixed or portable) with a simplified shader will be possible directly inside the INCEPTION platform thanks to the updating of the integrated viewers and the use of the WebVR compatible browser.

Documentation, Processing, and Representation of Architectural Heritage*Figure 16. Testing HDM devices and contents developed using AR / VR technologies at the European Commission's Open Doors Day in 2017*

It is possible to define Augmented Reality (AR) as a set of technologies that allow the fruition of multimedia / informative / visual content overlaid to the reality. The AR experience can take place through common mobile devices (smartphones, tablets, notebooks) or through specific headsets (mainly intended for business and professional uses).

The problems faced in order to use data and 3D models stored within the INCEPTION platform in the “static” and “dynamic” ways were also essential for the integration of the platform with Augmented Reality applications. As for Virtual Reality, for the construction of high-level applications, specific or targeted on sectorialized interaction or for use with specific devices, it is necessary to use specific external software resources that do not allow any “dynamic” interaction with the ICEPTION platform that can supply the material in “static” mode by downloading the contents and any uploads.

Through a specific connection socket, a predefined standard scene is generated, ready to use by AR applications (Figure 17), directly exploiting technologies based on QR code or image detection as an access point to 3D content on-site.

FUTURE RESEARCH DIRECTIONS

The recent Declaration “Cooperation on advancing digitization of cultural heritage” signed by Member States during the Digital Day 2019, confirmed the commitment by the European Council, the European Parliament and the European Commission in fostering digital technologies to record, document and preserve Europe’s cultural heritage and their accessibility to European citizens.

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Figure 17. Development of AR applications at the Tesla Museum in Zagreb. Image Detection techniques are being used as an access point



Moreover, the Declaration states “*The Union needs to collaborate to advance 3D digitisation of our cultural heritage. European research institutes and start-ups have developed world-leading expertise and are pioneering technologies in these fields, and can contribute to advancing the digital transformation of the cultural heritage institutions. The Union also needs to ensure that its digitised cultural content and related applications are available, where appropriate, on European platforms, in line with our values*”.

According to this aims, future efforts and pursue progresses have been listed under three main pillars:

1. A pan-European initiative for 3D digitization of cultural heritage artefacts, monuments and sites;
2. Re-use of digitized cultural resources to foster citizen engagement, innovative use and spill-overs in other sectors;
3. Enhancing cross-sector, cross-border cooperation and capacity building in the sector of digitized cultural heritage.

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INCEPTION' developments, outcomes and future follow-ups will move in the direction stated by this declaration. Future researches will include data recording and digitization in order to meet the need of documentation and preservation due to the increasing threats to cultural heritage due to natural disasters, pollution, mass tourism, deterioration over time, terrorism and vandalism, increasing at the same time the accessibility of heritage sites at risk to European citizens. High quality 3D models, interoperable formats and open access to digital cultural heritage assets are essential to an effective use of digital contents, increasing digital engagement and fostering sectors such as tourism, education, creative industries.

At the conclusion of the project, in May 2019, further actions in the field of heritage digitization through the application of the Protocol and platform population are going to be implemented. These actions will meet requirements stated by the above-mentioned "Declaration" regarding common standard, methodologies and guidelines to model data; framework conditions for open repositories for storing, managing and re-using interoperable 3D models; and best practices on developing expertise and skills for 3D digitization.

Future development will also include the use of data collected on the platform for on-site and off-site applications. Big data, artificial intelligence, natural language processing, augmented-virtual-mixed reality and 5G to enable innovative use of digitized cultural resources, knowledge extraction and more engaging experience of heritage content are future research avenues that can benefit from what has already been developed.

Moreover, the next Multiannual Financial Framework 2021-2027 will offer opportunities through Digital Europe, Creative Europe and Horizon Europe programmes to further build and strengthen digital capacities of cultural heritage organizations as well as cross-sectorial collaborations, notably on digital skills and emerging technologies.

CONCLUSION

INCEPTION focuses on developing new methods and tools for 3D surveying, modeling and analysis of European cultural assets starting from the State of the Art and proposing advancements of hardware and software tools, as well as new approaches and methodologies for Cultural Heritage 3D data inclusive access and exploitation by means of the Platform.

Holistic documentation and the protocol for the integrated data capturing have been developed starting from a common framework for catalogue methodology. The need of data interpretation, in addition to documentation, guided the overall process of the cross-disciplinary work methodology. In this direction, mapping of stakeholders' knowledge demands and targeted implementations by scholars, technicians, professionals, citizens, governments, institutions, etc. was essential for the identification of key requirements in digital documentation and use of 3D models for different purposes. This dialogue with stakeholders has continued throughout the development of the project, and will continue for the next applications and for populating the platform.

The actions related to parametric modeling applied to Heritage has been particularly challenging, and future developments are expected. As discussed in the specific sections of this chapter, during the uploading phase of a BIM model on the INCEPTION platform, an HTML interface makes use of semantic web technologies in order to assign to every modeled geometry an identifier, so data and files can be attached to each single element accordingly.

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Thanks to the approach and the methodology for semantic organization and data management toward H-BIM modeling, the INCEPTION platform for deployment and valorization of enriched 3D models allows achieving the main purposes of retrieving, knowledge and enhancement of European Cultural Heritage.

According to the INCEPTION workflow, the H-BIM process starts documenting user needs and performing a surveying procedure that includes information to be included in H-BIM. The INCEPTION methodology foresees the inclusion of essential information such as metadata and paradata in the processing of digital elements within the H-BIM environment. The methodology of archiving digital data and linking them to the final product is one of the main outcomes.

In this way, 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.

Digital models and aggregated data collected on the platform allow models deployment via Virtual and Augmented Reality applications for different uses, as well as connection among the platform and targeted tools such as the Cultural Heritage Asset Management Tool developed to perform condition assessment.

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KEY TERMS AND DEFINITIONS

Data Acquisition Protocol: Flexible and upgradable guidelines providing a workflow for a consistent development of survey procedures for tangible cultural heritage tailored to different requirements.

Demonstration Cases: set of heritage asset, which serves as case studies in order to illustrate the applicability of the use cases in a variety of real scenarios, and the overall project methodology.

Evaluation Categories: Incremental categories developed within the Data Acquisition Protocol to be compliant with according to specific purposes of the heritage survey and documentation.

Documentation, Processing, and Representation of Architectural Heritage

Heritage Workflow: set of actions through which it is possible to access and retrieve specific information on the INCEPTION platform, that make possible defining the required user tools, for which technical solutions can be designed and implemented. There are typical Workflows according to specific needs (restoration, site management, virtual reconstruction, etc.).

Holistic Documentation: Overall retrieving of critical information regarding a heritage's main attributes and characteristics, able to define it as a whole and to identify its significance and main needs. It includes morphometric survey, historical documentation, features, state of conservations, etc.

INCEPTION Platform: Semantic-based BIM platform for Cultural Heritage sites grounded on semantic web technologies. The platform makes extensive use of WebGL and RESTful APIs, in order to enrich heritage 3D models by using Semantic Web standards.

Inclusive Approach: INCEPTION is based on a methodology that stimulates and facilitates collaborations across disciplines, technologies and sectors, making the platform a space for interchange of information and for the dialogue among different users.

Semantic Approach: integration and connection of semantic attributes hierarchically and mutually aggregated to 3D geometric models to manage heritage information.

Time-Machine: Functionality within the INCEPTION platform that allows using of time-scale for dynamic 3D digital reconstruction with emphasis on how the modelled cultural heritage evolves over time.

Use Case: A list of actions or steps, typically defining the interactions between a user and a system, to achieve a goal. Use cases in Cultural Heritage represent the actions defined within the framework of conservation, enhancement, protection, understanding, etc. of cultural heritage assets.