ARCHITECTURE HERITAGE and DESIGN

Carmine Gambardella

XVI INTERNATIONAL FORUM

Le Vie dei Mercanti

WORLD HERITAGE and KNOWLEDGE

Representation | Restoration | Redesign | Resilience

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Collana fondata e diretta da Carmine Gambardella

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An inclusive approach to Digital Heritage for knowledge and conservation of European assets: the INCEPTION project

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Abstract
One of the main challenges to be faced at European level is to contribute to an understanding of cultural identity. In this direction, new technologies and digital cultural heritage should play an innovative role, enhancing heritage accessibility for as many people as possible by using ICT functionalities and applications. Nevertheless, we are witnessing to a more and more growing dichotomy between engaging user experiences and the enrichment of the scientific knowledge. Within this framework, the EU funded project "INCEPTION - Inclusive Cultural Heritage in Europe through 3D Semantic Modelling" is consistently aligned by accomplishing the main objectives of accessing, understanding and strengthening European cultural heritage by means of enriched 3D models where semantic attributes are linked to geometric models for management of heritage information.
The interdisciplinary and user-centred project aims at developing an innovative approach for creating interoperable 3D semantic models in H-BIM environment to be collected and shared on the INCEPTION Platform for visualization, management, deployment and valorisation of heritage buildings and sites. Advanced 3D documentation methodologies identifying different "layers" of data to be surveyed and managed, and semantic ontology and data structure for information catalogue allow accomplishing the main objectives of knowledge, protection, conservation, monitoring and safeguarding of assets, respecting values of the pre-existing.

Keywords: Conservation, Digital Heritage, 3D data capturing, 3D semantic modelling, Inclusiveness

1. Introduction
One of the main challenges to be faced at European level is to contribute to an understanding of Europe's culture and intellectual basis. In these efforts, new technologies and digital cultural heritage should play an important innovative role. New and innovative technologies are a great opportunity to understand access, enhance and preserve cultural heritage. Information and Communication Technologies (ICT) are constantly evolving and new digital media are increasingly used for accessing and understanding cultural heritage.
The enhancement of digital cultural heritage accessibility is the ability to access cultural contents and resources for as many people as possible by using ICT functionalities and applications (websites, databases, digital libraries, virtual applications, etc.) overcoming cultural, environmental and management barriers for an easy and spread fruition. Nowadays it is possible to integrate different information in order to access cultural assets in many different ways and for many different purposes, thanks to new languages of interactive media aimed at innovative ways of communication of cultural heritage.
Beyond the application of ICT for management, research, diagnosis, conservation and restoration procedures, education and enhancement, new technologies allow the communication and dissemination of cultural assets that become more and more accessible for new knowledge and experiences; through digital technologies broad categories of users have access to tangible and intangible cultural assets. The availability of databases collecting different information allows achieving the widest accessibility and interoperability at a multidisciplinary level.

New applications allow accessing sites and objects from the heritage site, or such as in labs, museums, classrooms, or even in personal homes or offices. Users have more and more interactive possibilities to access the knowledge about different sites and objects, to exchange the knowledge between each other, and to enrich the knowledge with their findings and complementary insights by means of interactive platforms and social media. The development of data capturing technologies and graphics features has maximized the enhancement of digital contents for virtual tour applications, serious games and many different immersive and interactive experiences that enable a sustainable access and enjoinment of heritage sites even by young generations.
As part of 3D integrated survey applied to Cultural Heritage, digital documentation is gradually emerging as effective informative support in addition to the shape, morphology and dimensional data [1]. The implementation of data collection processes and the development of semantically enriched 3D models is an effective way to enhance the dialogue between ICT technologies, different Cultural Heritage experts, users and different disciplines, both social and technical.
Innovative strategies in heritage documentation can be achieved through the implementation of effective data collection processes and the development of semantically enriched 3D models.
The increasing development of 3D laser scanner technologies allows creating high definition databases based on even more detailed three-dimensional morphometric data. These “digital archives” are an extremely valuable research tool in cultural heritage field: the “geometric memory” is essential for knowledge, protection and sustainable conservation of Cultural Heritage, although there are still some limits to the exploitation of 3D models obtained by laser scanner survey. The growing numbers of un-exploited and “un-interpreted” 3D models points out the remarkable need for innovative methods that could benefit from the informative value provided by new systems for surveying and representations as well as data management tools.
In this direction, advanced technologies and digital data are becoming increasingly significant in helping and supporting research, knowledge and activities related to conservation and enhancement of Cultural Heritage. The use of new technologies allows great advances not only for the surveying and representation of the built heritage during analysis phase but also for the management of the resulting data to be used for conservation and restoration procedures in a single process no longer divided into steps but unified into an overall digital model / database [2] for intermediate checks, testing, monitoring, maintenance, implementation, etc.
In this framework, this paper will present methodologies developed under the EU funded project “INCEPTION - Inclusive Cultural Heritage in Europe through 3D Semantic Modelling” focused on new avenues for accessing, understanding and strengthening European cultural heritage by means of enriched 3D models where semantic attributes can be effectively helpful in the protection, conservation and safeguarding of cultural heritage and landscape, respecting the values of the pre-existing.

2. Overall framework

The possibility to achieve interoperable models able to enrich the interdisciplinary knowledge of European cultural identity is one of the main outcomes of "INCEPTION - Inclusive Cultural Heritage in Europe through 3D Semantic Modelling", funded by European Commission within the Programme Horizon 2020 (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*).
INCEPTION project methodology is based on five main steps. The first one is focused on an effective, cross-disciplinary and collaborative work among partners, allowing to define the data collection process, stakeholders’ requirements and case studies setup. The second one is related to the setting up of an integrated and optimized 3D data capturing procedure, and the third step is aimed at the integration of semantic attributes to the 3D digital geometric models in order to manage effectively heritage information. The development of an interoperable Semantic Web H-BIM Platform is the fourth step, preliminary to the deployment and valorisation of 3D models, enabling a wide and easy access to the data by citizens, non-expert users and public at large [3].
Therefore, the overall project workflow is developed starting from requirements (what kind of data, information and visualization issues can be collected and managed by a 3D model according to specific users and needs), the integrated data capturing and holistic heritage documentation, the semantic enrichment via 3D modelling in H-BIM environment, and the models deployment and enhancement through the INCEPTION platform.
At the end of the third year of activity, the project is facing different challenging actions aimed at models’ deployment and widespread sharing, starting from a methodological and technical advancement in 3D data capturing and holistic digital documentation.
This paper will present the inclusive approach to digital heritage for knowledge and conservation of Cultural Heritage, developed under INCEPTION, starting from the meaning of integrated 3D survey within the wider framework of the “holistic digital documentation” (including all relevant data – in

addition to geometries and dimensions – according to the purpose of the data capturing), up to the approach to the semantic modelling, focusing on heritage buildings and sites. The 3D modelling in H-BIM environment and the development of the platform for deployment and valorisation of enriched 3D models will allow accomplishing the main objectives of accessing, understanding and strengthening European Cultural Heritage. According to the overall INCEPTION workflow, the H-BIM modelling procedure starts with documenting user needs, including experts and non-experts [4]. The identification of the Cultural Heritage buildings semantic ontology and data structure for information catalogue will allow the integration of semantic attributes with hierarchically and mutually aggregated 3D digital geometric models for management of heritage information.

3. Integrated 3D survey and holistic digital documentation

Integrated digital documentation under INCEPTION is carried out through a holistic approach: holistic documentation needs to cover assets of critical information regarding a monument's main attributes and characteristics, able to define it as a whole and to identify its significance and main needs.
The overall interdisciplinary approach is aimed to include documentation, analysis and management of all the different data, in order to meet visualization, protection and preservation issues, involving all the aspects of digital content management, representation and reproduction.
Through the 3D digitization of a monument, various aspects of recording concerning diagnostics (building material and decay patterns), construction durability and architectural documentation, new digital content management may be achieved.
Methods and processes for data collection are continuously developing and today are characterized by an effective interdisciplinary. Skills on 3D laser scanner survey, diagnostic procedures and historical research, as well as about environmental condition assessment or management of metric and dimensional data support the vision of integrated digital documentation for cultural heritage assessment [5]. The inclusive approach to digital documentation is focused on the 3D data capturing and modelling of heritage buildings and sites, through the digital representation of the shape, appearance and conservation condition, in addition to a set of semantic information able to enrich research and deployment applications [6].

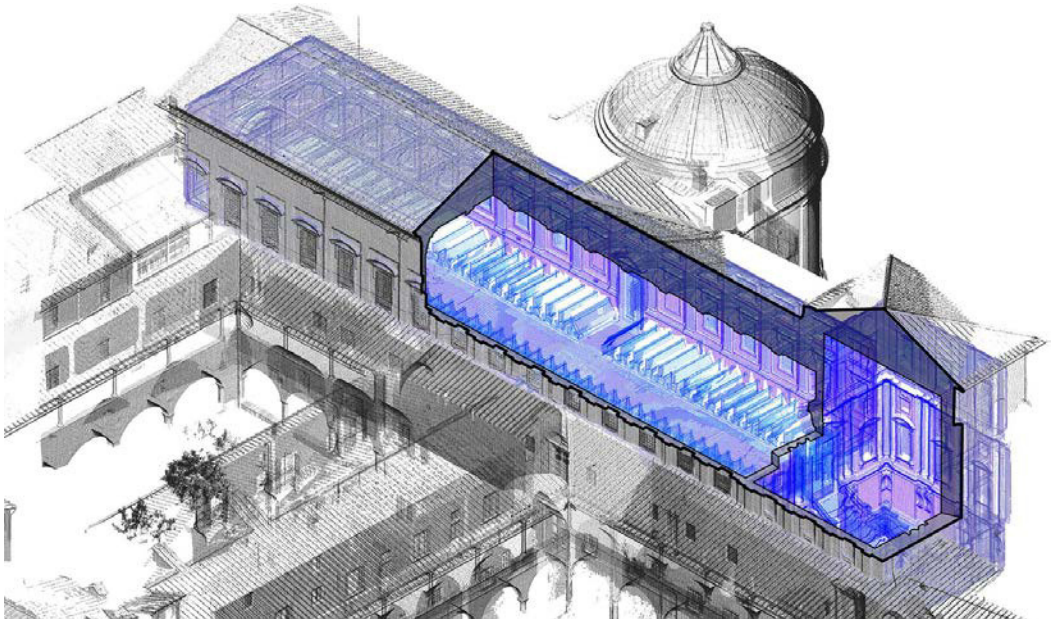

Fig. 1: Laurenziana Library, Florence, by Michelangelo, an example of complex architectural "geometry" to be detected.

3D laser scanner technologies allow creating high definition databases based on even more detailed three-dimensional morphometric data. These "digital archives" are an extremely valuable research tool in cultural heritage field: the so-called "geometric memory" is essential for knowledge, understanding, protection and sustainable conservation of Cultural Heritage. Starting from "geometric memory" it is possible to extract not only geometric features but also many different data for the enhancement of documentation and information for conservation, diagnostics, monitoring and restoration project, and for heritage promotion and exploitation.

This is the main direction toward INCEPTION is moving: setting up a methodology able to break through the barriers caused by segmentation in collecting documentation data by establishing a common framework through 3D documentation of Cultural Heritage buildings and sites.
From one side, applications under development allow accessing digital information both from the heritage sites (via mobile devices) and off-site (offices, research labs, museums, etc.) in order to improve access and knowledge possibilities, thanks to interactive experiences and improved digital contents. On the other hand, enriched 3D digital models available in an open-standard format can be easily accessible and reusable by researchers, scientists, experts, curators, and professionals in different cultural heritage fields, facilitating cross-disciplinary research, dissemination, education and business opportunities.

4. H-BIM modelling and semantic enrichment

Semantic 3D reconstruction of heritage buildings and sites supposes an interdisciplinary approach based on the collaboration of various experts from different disciplines towards the development of 3D models integrating semantic data. If 3D data can be captured following a more commonly shared procedure (set up, within INCEPTION, by the Data Acquisition Protocol), terminology and interpretation have a large diversity and variability when looking at semantics, due to different competencies, skills and languages.
Making data aggregable asks for a Semantic Web structure in order to give back to different users a new way to look at the information in a Cultural Heritage context. A semantic web structure means also that the relations, properties and composition of the “nodes” of the information give a new insight different from a list of the same concepts or a database structure. Since now, consistently structured data are missing in for Cultural Heritage architectures.
One of the main challenges in 3D modelling is related to an effective BIM approach for cultural heritage knowledge, semantic enrichment and model management. Starting from an improved procedure of 3D data capturing [7] and documentation, INCEPTION proposes an improvement in this methodology by recognizing that buildings are a set of elements named by an architectural style nomenclature and organized by spatial relationships. At the moment, a shared library for historical elements does not exist. Starting from the Heritage Building Information Modelling (H-BIM) approach the necessity of the libraries’ implementation is under development within INCEPTION by avoiding the oversimplification of the shapes. When used in models of Cultural Heritage, semantic BIM [8] will be able to connect different users (e.g. scholars, technicians, citizens, governments), supporting the need for interpretation of the Cultural Heritage model, in addition to the common BIM features of 3D visualization, technical specification and dataset [9].

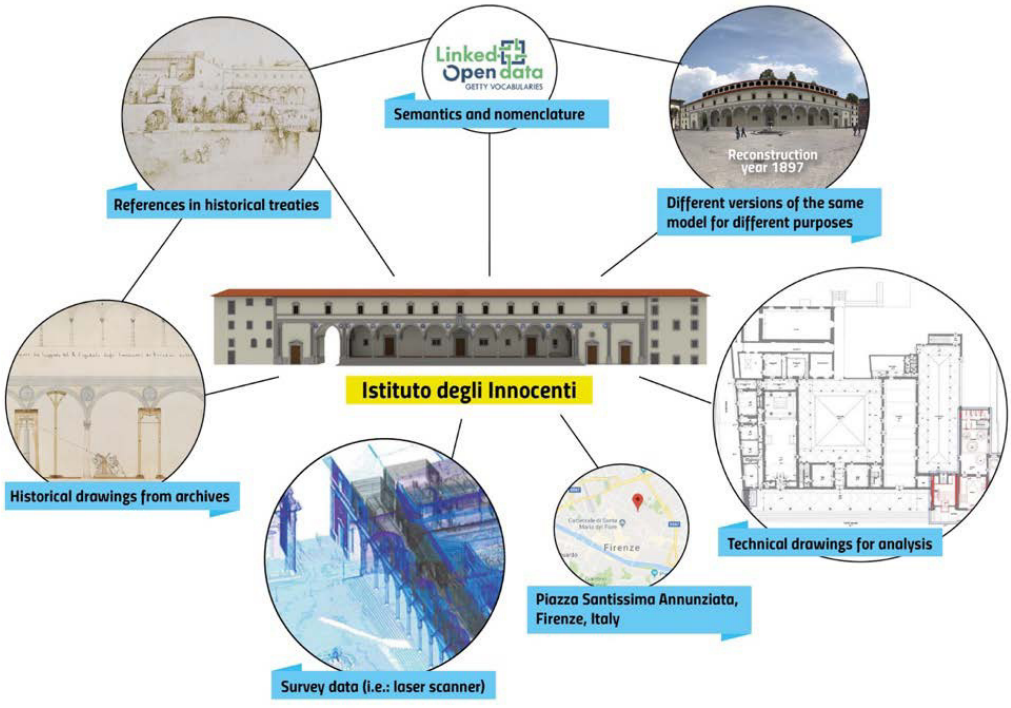

Fig. 2: Schema of the INCEPTION methodology, based on the example of Istituto degli Innocenti by Brunelleschi: from the holistic documentation and data capturing up to semantically enriched 3D models.

4.1 The Ontology setting up

The first step in creating semantic BIM for cultural heritage is defining the ontology: a formal representation of knowledge as a hierarchy of concepts within the cultural heritage domain, starting from a definition of concepts and their relationship. The linguistic definitions related to the ontology concepts can also be used as shared vocabulary to denote the types, properties and interrelationships of cultural heritage aspects [10].

The issue of naming architectural elements can be tackled in different ways and by consulting different sources. In the field of classical architecture, it is possible to check several books that deeply analyse and summarize which "rules" were basically adopted in classical buildings. When mainly based on classical orders, ancient architecture is easier to understand and name, even if the building practice often differs from the theory. For instance, just to list some of the most known theoretical books from the past, we can mention *De architectura* by Vitruvio; *De re aedificatoria* by Leon Battista Alberti; and *I quattro libri dell'architettura* by Andrea Palladio, some of the major treatises that influenced architectures all over the world for centuries. Nevertheless, local practices introduced several variations, as well there are a lot of different constructive techniques, shapes and decorations that were not standardized. Every building is the final result of different influences and combinations in order to solve practical problems, as well as further additions and changes over time.

For this reason, aiming at the standardization in heritage documentation, data handling and management, the INCEPTION project is developing common parameters, setting a nomenclature or "glossary of names" as a starting point to semantic enrichment and modelling in BIM environment [11]. The recognition of shapes, either manually or automatically performed, is possible only if single architectural elements (or their variations) are identified and univocally classified following a shared procedure.

Over the years, several architectural dictionaries have been produced. Thousands of architectural names have been collected and managed following a specific sorting. A traditional thematic dictionary, for example, collects names in alphabetical order, for a specific language, describing every single name and without the requirement of conceptually linking them together. On the other hand, an architectural treatise explained by graphics gives more consistency to the nomenclature, setting up a specific relation between elements.

This defines two different kinds of issues within INCEPTION: setting up of a common glossary of names for all Demonstration Cases under development by involving scholars and experts; organizing names following a structure that could ensure the linking between elements which could be re-used in the IT development phase.

4.2 The Nomenclature setting up

The need for the definition of an international "glossary'' for architectural heritage and by extension for Cultural Heritage has arisen. This need has originated from the fact that there are various methodologies regarding heritage documentation. As previously explained, various vocabularies and thesauri are used in the field of conservation, while the variety of "uniqueness" of each cultural artefact turns its categorization into a difficult effort. In addition, not only spatial information needs to be standardized, but also the related metadata. In order to face this issue and start setting a methodology to define a shared vocabulary, an extensive analysis of the State of the Art was performed. Herein in the field of Architecture and Heritage, the UNESCO Thesaurus as a general Vocabulary, the UK Archival Thesaurus as a general archive, the Centre National d'Archaeologie Urbaine for Archaeology and Heritage sites, the Pactols Thesaurus by Frantiq in the Archaeology field and the Getty Art & Architecture Thesaurus (AAT, but also TGN), are some of the Vocabularies checked.

The availability of so many different active sources providing valuable information that would be interesting to be reused, means both valuable but potentially competing information needs to be connected. Since this information is constantly in development, linking is preferable rather than copying a "static" version at a certain date. This is even truer for Heritage nomenclature.

Semantic Web technology and Linked Open Data principles make it possible to define an open H-BIM ontology without having the complexity of defining the complete schema as a copy of external sources. This State-of-the-Art technology is developed by members of the W3C organization and is at the moment a mature technology with mature supporting tools. INCEPTION makes use of the tools available supporting these standards.

The above-mentioned vocabularies and thesauri define a nomenclature for the Cultural Heritage domain. Before this valuable knowledge can be used as linked open data the following steps need to be defined: (i) translate the vocabularies / thesauri in a technology that supports linked open data; (ii) interlink the different vocabularies / thesauri and link them together; (iii) filter what is relevant for the H-BIM ontology within INCEPTION.

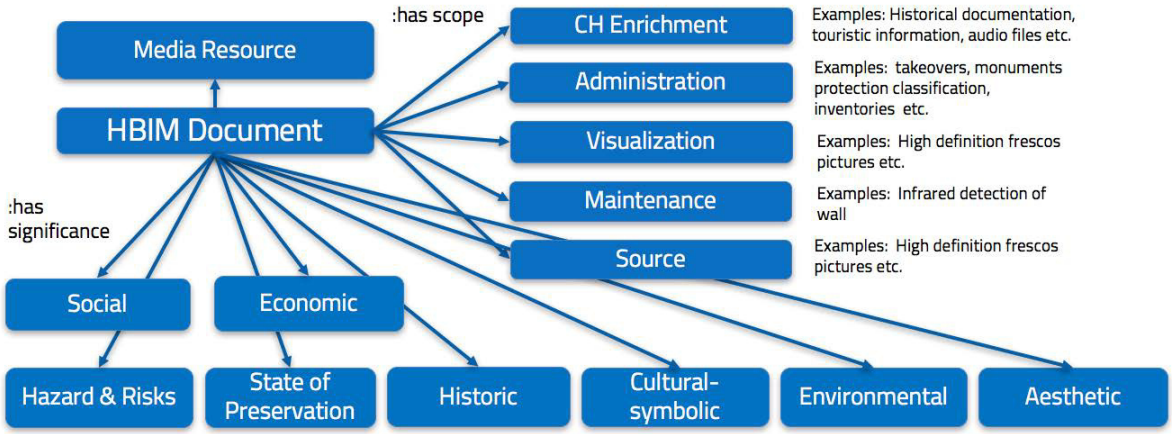

Fig. 3: H-BIM document ontology.

The starting point for semantic organization and glossary definitions for cultural heritage buildings is the integration of the glossary with ifcOWL (in order to start working on H-BIM modelling defining specific parts of the model), ifcOWL as Semantic Web serialization on schema level for IFC schemas will be followed where possible for BIM content stored/exchanged via IFC. Even if the analysis of available nomenclatures is continuously going on, by analysing national and international resources, for the Web service set up, the Getty Vocabularies were chosen as a starting point, including AAT - Art & Architecture Thesaurus, TGN - Getty Thesaurus of Geographic Names and ULAN - Union List of Artist Names.
The Getty vocabularies contain structured terminology for art, architecture, decorative arts, archival materials, visual surrogates, conservation, and bibliographic materials. Compliant with international IT standards, they provide authoritative information for cataloguers, researchers, and data providers. In the new linked, open environments, the vocabularies provide a powerful tool to be adopted within the INCEPTION project, even if a filtering activity is required in order to make them suitable. Furthermore, where an existing vocabulary will not correctly cover a specific definition, it will be integrated. Current work is creating an ontology as a valuable base for possible upgrading about what is expected/required in H-BIM.
The AAT, TGN and ULAN contain structured terminology for art and other material culture, archival materials, visual surrogates, and bibliographic materials. Compliant with international standards, they provide authoritative information for cataloguers and researchers, and can be used to enhance access to databases and websites. The Getty Vocabularies are produced by the Getty Vocabulary Program (GVP) and grow through contributions. The procedure under INCEPTION is aimed at extending the H-BIM ontology based on the classification available in Getty, integrating this with the 'BIM' classification generated from the IFC schemas.

5. Towards applications and digital tools for Heritage fruition

So far, the INCEPTION project has defined the approach and the methodology for semantic organization and data management toward H-BIM modelling, and the preliminary nomenclature for semantic enrichment of heritage 3D models. The organization of consolidated knowledge is performed following a specific workflow in order to get them suitable for their reuse into H-BIM semantic model, accordingly to digital documentation and capturing protocols that have been developed.
According to the INCEPTION workflow the H-BIM process starts documenting user needs, including and engaging not only experts but also non-experts. The demand has been leading us to "how" and "what" surveying information to be included in H-BIM. The surveying procedure produces a variety of different data, formats and outputs. It is essential to process that data without losing important information like metadata and paradata while editing and developing the digital elements of the H-BIM. A methodology of archiving digital data and linking them to the final product is one of the main outcomes. Before and during the creation of H-BIM, the nomenclature (vocabularies, thesaurus, etc.) is critical to maintain a common typology and to support interoperability.
Starting from the standardization for H-BIM modelling, the methodology for merging IFC models and semantic data has been defined. The development of a semantic 3D reconstructions, integrated with intangible information and social environment, structuring digital representation of buildings and sites will lead to the creation of models more accessible and implementable in a Heritage-BIM environment, based on Open BIM standard (IFC, IFD, etc.).

Fig. 4: Example of “on-site” application tested in the Italian Demonstration Case, the Istituto degli Innocenti in Florence.

Thanks to the use of data collected by Demonstration Cases, the identified methodological workflow and the technical tools and procedures will be further tested and stressed by end of the project. This will allow, from one side, to check the real validity of what has been developed until now and, on the other side, to upload several contents to the platform, bringing it into life and make it a significant dissemination tool.
Now, each INCEPTION demonstration case will produce data that will be hosted by the brand-new platform, allowing to test the validity of the platform itself (3D models and versioning, animations, images, etc.) and further developments (immersive environments, Virtual Reality, Augmented Reality, etc.).
The INCEPTION platform will be populated by using validated Demonstration Cases’ results and developing user-oriented applications to fulfil the user requirements, as well as to deliver exploitable innovation with a long-term impact. The deployment of 3D models with integral narratives will be tested on the heritage sites in on-site and off-site applications.

Fig. 5: Digital reconstructions of the façade of Istituto degli Innocenti in different eras through the use of a BIM model.

6. Conclusions

The integration between BIM environments and three-dimensional acquisition technologies is one of the challenges to be faced in order to guarantee an effective collaborative process in the heritage preservation field.

Starting from the implementation of the integrated 3D data capturing procedure for heritage applications and the identification of the Cultural Heritage buildings semantic ontology, the project is developing guidelines for 3D parametric and semantic modelling in a Heritage-BIM environment, based on Open BIM standard, improving a "BIM approach" for Cultural Heritage.

3D models generated through INCEPTION methods and tools will be accessible for many different users. Semantic enrichment will generate 3D models for multiple purposes depending on the needs and level of knowledge of the end-users. The semantic enrichment will link geometric information for 3D visualisation, historical information, and geotechnical data as well as structural information for material conservation, maintenance and refurbishment.

The current work is to create an ontology as a valuable base for possible up-grading about what is expected/required in H-BIM [12]. However, it is important to understand the difference between BIM standards and the Semantic Web technologies. Indeed, the ifcOWL is defined as a serialization of an IFC schema definition, in order to enable the use of contents semantically managed. For this reason, within INCEPTION, H-BIM is meant to be an ontology to support storage of semantic knowledge available for Cultural Heritage buildings and architectural complexes, as well as their related information [13]. The integration of Getty vocabularies and ifcOWL is a complex but feasible task, focusing on the actual queries, communications and current H-BIM work. Furthermore, within INCEPTION, we have the chance to test such integration, achieving positive results as well as beginning an implementation, thanks to the use of a "glossary of names" gathered by the Demonstration Cases analysis.

Once data are collected and aggregated thanks to the use of semantic technologies, the most valuable goal is strictly related to dissemination capabilities. Indeed, the richness of the INCEPTION project is represented by accessibility to a crowdsourced database of both scans and reconstructions, with different level of confidence by their source data.

Therefore, the INCEPTION platform will have to contain, visualize, manage, update, and exchange technical and divulgative information regarding historical heritage, through the use of 3D BIM models. Any form of digital or digitized content, stored or linked into a 3D H-BIM model, as well as semantically indexed by the use of the INCEPTION ontology, will allow the use of different navigation systems.

The need of a future re-use of such broad and descriptive source of measurement data demands new applications to facilitate information accessing collected in three-dimensional database without compromising the quality and amount of information captured in the survey.
Looking at the future development of the INCEPTION platform, the integration of qualitative and quantitative data, beginning from the data capturing phase, will allow the possibility to make qualitative query on quantitative data within a database of multiple CH buildings and, therefore, to better understand the cultural European complexity from its tangible heritage.
Databases allow users to understand how each survey-phase was carried out (scans, topographic support, images acquisition, etc.) and thus to obtain the maximum possible amount of morphological information; this procedure means to work with complex interfaces that are based on the programming languages of the software used to complete the survey itself.
Furthermore, tools for improved visualization and management of 3D models are becoming increasingly important in the preservation, protection, and collection of our cultural and natural environment; making easier the access to monuments, artefacts, building and culture, these technologies are actually enhancing the learning process, motivating and understanding of certain events and historical elements for the use of students and researchers [14].
Currently, efforts in developing the user interface are concentrated on providing direct or partially controlled access to the large three-dimensional scale models, also by means of immersive navigation. The creation of large digital spaces properly set up in terms of both form and dimensions, will make possible to navigate, enter, and extract its qualities and specifications (measurements, colours, materials, historical documentation, conservation records) in real time.
Current efforts are focused on creating immersive and easy-to-use 3D visualizations that can be accessed from a wide range of users. The field of experimentation underlying the integrated, interdisciplinary research effort shares many aspects (dimension and complexity of the data) with heritage surveys, and the results obtained so far give us reason to hope that these optimization processes can be exported.
New simplified navigation interfaces are also being developed for users with lower levels of expertise to facilitate access to and navigation of the three-dimensional models. New visualization and communication modes for the geometrical and measurement information have to be conceived and developed in step with the development and application of three-dimensional surveys.

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