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M-BIM: A NEW TOOL FOR THE GALLERIA DELL'ACCADEMIA DI FIRENZE

M-BIM: UNA NUEVA HERRAMIENTA PARA LA GALLERIA DELL'ACCADEMIA DI FIRENZE (FLORENCIA)

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Highlights:

- A holistic information management system for museums (M-BIM) is proposed, including both information on the building and the collections.
- International and Italian guidelines, and best practices on museums management are compared.
- The Galleria dell'Accademia di Firenze is used as a case study for testing the application of M-BIM on a heritage building.

Abstract:

The paper deals with an ongoing research activity for developing a Building Information Model (BIM) for the facility and collections management of museums. The BIM success lies not only in its application for the design and construction of buildings but also because it helps the information management of a building throughout its life cycle. Compared to other activities, in museums management, the container/content relationship is essential for the preventive conservation of artworks, according to national and international guidelines. Then, an effective BIM-based museum information system linked to external databases (called M-BIM) should include also the art collections for managing information regarding both the building and artworks by 3D objects handling. This facilitates the management of the procedures prescribed by international best practices (as the facility and conservation reports set up for the loan of artworks) or by Italian regulations (as to check the compliance of a museum with the minimum standards or to archive renovations and temporary exhibitions). The proposed methodology has been tested on the Galleria dell'Accademia di Firenze (Florence, Italy), situated in a complex heritage building. Starting from data acquired during a laser scanner survey carried out in 2011, a HBIM of the whole building has been created. Then, the sculptures and paintings of a consistent part of the museum have been modelled with different approaches and inserted as BIM objects. Artworks instances include 3D geometry and physical data (dimensions, materials, weight, etc.), other data are obtained from links to already existing external catalogues. A database conceptual model has been formalised, according to INSPIRE Consolidated Unified Modelling Language (UML) of the INSPIRE Directive, with the aim to maintain the independence of the BIM approach but improving data connection with other databases and sources.

Keywords: collection management system; virtual museums; HBIM; digitisation; data re-use, data transparency; 4D & 6D BIM

Resumen:

El artículo trata una investigación en curso que aborda el desarrollo del modelado de información de la construcción (BIM) para la gestión de instalaciones y colecciones de museos. El éxito del BIM no reside sólo en su aplicación en el diseño y la construcción de edificios, sino también en que ayuda en la gestión de la información de una construcción durante todo su ciclo de vida. En comparación con otras actividades, en la gestión de los museos, la relación contenedor/contenido es esencial en la conservación preventiva de las obras de arte, de acuerdo con las directrices nacionales e internacionales. Entonces, un sistema eficaz de información museística mediante BIM y que se enlace con bases de datos externas (denominado M-BIM) debería incluir las colecciones de arte para la gestión de la información relativa tanto al edificio como a las obras de arte mediante la manipulación de objetos en 3D. Esto facilita la gestión de los procedimientos prescritos por las mejores prácticas internacionales (como los informes de instalación y conservación establecidos para el préstamo de obras de arte) o por la normativa italiana (como el control de la conformidad de un museo con los estándares mínimos o almacenar renovaciones y exposiciones temporales). La metodología propuesta se ha probado en la Galleria dell'Accademia di Firenze (Italia), situada en un edificio patrimonial de gran complejidad. Se ha creado un HBIM de todo el edificio a partir de los datos capturados en 2011 en un levantamiento con escáner láser. Después, las esculturas y pinturas de una parte consistente del museo se han modelado con diferentes enfoques e insertado como objetos BIM. Los ejemplos de obras de arte incluyen geometría 3D y datos físicos (dimensiones, materiales, peso, etc.), otros datos se obtienen a partir de enlaces a catálogos externos ya existentes. Se ha formalizado

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un modelo conceptual de bases de datos, según el el lenguaje unificado de modelado (UML) Consolidado INSPIRE de la Directiva INSPIRE, con el objetivo de mantener la independencia del procedimiento BIM, pero mejorando la conexión de los datos con otras bases de datos y fuentes.

Palabras clave: sistemas de gestión de las collecciones museales; museos virtuales; HBIM, digitalización; reutilización de los datos; transparencia de los datos; 4D y 6D BIM

1. Introduction and goals

The management of a museum is a complex activity influenced by different dimensions, the scientific side, related to the care and study of the collections, the demand side, which must consider the users' needs and profiles, and the resources side, which can be divided into the human, economic and built resources. The entire museum system can be thought as a result of the relationship between these three macro-areas, whose interconnections determine all the requirements for management, maintenance and security. The collection care requests that all relevant information is "properly recorded in as good and safe a condition as practicable", including a "full identification and description of each item, its associations, provenance, condition, treatment and present location. Such data should be kept in a secure environment and be supported by retrieval systems providing access to the information by the museum personnel and other legitimate users" (ICOM, 2017).

In view of "the duty to acquire, preserve and promote their collections as a contribution to safeguarding the natural, cultural and scientific heritage" and the requirements of preventive conservation, museums should ensure a suitable environment about access, health and safety, protection against disasters, security requirements, insurance and indemnity.

The interaction between the objects that make up the collections, intended in their physical consistency, and the buildings in which they are located is therefore of the utmost importance. Currently, digital systems are available for the museum's data management (collections management systems, or CMS), and for building construction and management in general (building information modelling, or BIM) (Mehrbod, Staub-French, Mahyar, & Tory, 2019; Tucci et al., 2019).

As well known, museums can cover very different aspects of knowledge. The International Council of Museums (ICOM) definition says "A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment" (ICOM, 2017). This definition is fully adopted by the Italian law D.M. 23.12.2014 which also adds "…promoting knowledge among the public and the scientific community".

The research is based on a concrete case study concerning the Galleria dell'Accademia di Firenze and contains references to Italian law, but the proposed methodology can be applied to the management of art galleries, understood as buildings permanently intended to house collections and temporary exhibitions mainly of painting and sculpture. Many topics can, however, be adapted to all museums that contain tangible heritage items.

This paper describes a holistic information management system for museums (M-BIM) including both information on the building and the collections as a tool for managing this complex activity. Basically, the data of the collections will be included as BIM objects (composed of a simplified 3D model and the information coming from other existing databases) in the museum BIM.

The versatility of BIM and the possibility to collect information on exhibition and work areas, collections, microclimate, visitor flows and many other significant aspects could optimise the museum activities, improve safety, security, management, economic and environmental sustainability (Fig. 1).

The case study involved the creation of a BIM model of the entire building, while the information system for the works of art was tested including all the sculptures and paintings that are in the three main exhibition halls at ground floor (*Tribuna del David*, *Galleria dei Prigioni* and *Sala del Colosso*).

Figure 1: A scheme of the use of M-BIM as a link between the macro-areas of the museum system.

2. Museums and collections information systems: a state of the art

2.1. BIM for museums

BIM is now one of the most widely used information systems in the AEC (architecture-engineering-construction) world (Dore & Murphy, 2015; Dore & Murphy, 2017; Joblot, Paviot, Deneux, & Lamouri, 2017; López, Lerones, Llamas, Gómez-García-Bermejo, & Zalama, 2018).

Although this entails greater economic and organisational investment in the early stages of design, improved communication between operators leads to shorter construction times and costs.

BIM models can also be converted into different exchange formats to improve the information sharing and the interoperability between different operators (owners, designers and consultants from different disciplines, builders, managers, etc.) to manage in a coordinated way all the information relating to a building and its components, associated with their 3D representation. Among exchange formats, IFC (Industry Foundation Classes) data model facilitates interoperability between different BIM and other database software, gbXML (Green Building XML) is dedicated to sharing information with engineering analysis tools. DWG and DXF formats are used for data exchange with CAD software.

For these benefits, the implementation of the BIM system is now mandatory for new buildings in many countries and is therefore also applied to the design of new museum buildings. Coach Museum in Lisbon, Portugal (architects Paulo Mendes da Rocha and Ricardo Bak Gordon, engineering AFA consult) was inaugurated in 2015.

In this example, BIM has been used for work coordination, in particular with regard to clash detection between structure and plants, but there are no references to its use in relation to Facility Management (FM) or collections (Meireles, Salavessa, & Gonçalves, 2019; Rangel, Amorim Faria, & Poças Martins, 2019)

The advantage of the BIM system has effects throughout its life cycle. Building life cycle refers to all those aspects that involve maintenance and decommissioning, renewal and updating interventions (Antonopoulou & Bryan, 2017; Arayici et al., 2017). Considering that a building lasts much longer than the design and construction phases, the potential of BIM has yet to be fully exploited also for the management of the following time phases (4D BIM) and for FM (6D BIM) (Montaser & Moselhi, 2015; Nicała & Wodyńskib, 2016; Pishdad-Bozorgi, Gao, Eastman, & Self, 2018; Altun & Akcamete, 2019).

Most museums, not only in Italy and Europe, are in historical buildings or simply built before the adoption of the BIM system. Therefore, considering the application of BIM to museums, it is also necessary to review the issues related to the BIM of existing buildings (as-found BIM) or historical buildings (H-BIM). In these cases, unlike new constructions, material and constructive consistency must be largely reconstructed only by their exterior characteristics, resulting in many uncertainties. The survey of existing or heritage buildings for developing BIM models is generally performed with geomatics techniques of 3D acquisition (laser scanning or photogrammetry) for completely digital data management. The digitization phase is however expensive and time-consuming and therefore is generally undertaken only in view of major building renovations (Volk, Stengel, & Schultmann, 2014).

Most investigations on BIM for existing buildings is focused on 3D modelling of historical architecture with BIM software, while fewer researches are oriented to diagnostics, monitoring, energy retrofitting, structural reinforcement, FM, etc. (Bruno, De Fino, & Fatiguso, 2017; Rota, Corgnati, Paolo, & Di Corato, 2015; Banfi et al., 2019).

A few studies only have considered the use of BIM for the integrated management of the museum building and collections. Bhowmik (2015) imagined the integration in a BIM of 3D community's digital artefacts for creating a shared and collaborative museum digital ecosystem.

Recent articles (Lo Turco & Calvano, 2019; Lo Turco, Calvano, & Giovannini, 2019) deals with the creation of semantically enriched 3D models (called Collection Information Models - CIM) mentioning the opportunity to operate on the relationship between museum (container) and objects (content) within the BIM environment.

In the H-BIM modelling of Palazzo Ferretti in Ancona, which houses the Archaeological Museum of the Marches (Moreira, Quattrini, Maggiolo, & Mammoli, 2018), BIM objects consisting of simplified volumes (cylinders) have been inserted to represent the archaeological finds linked to an external database containing the information (texts, images, 3D models).

A peculiar application is presented by (Atkinson, Campbell-Bell, & Lobb, 2019) concerning the information modelling of the ship HMS Victory stored in the National Museum of the Royal Navy in Portsmouth, UK. The ongoing 3D modelling of each component, associated with the physical and historical information is aimed at supporting the conservation plan and the management of the ship, which could be assimilated to the typology of the "house museum". In this case, the impossibility of using off-the-shelf BIM tools led to the choice of using McNeel Rhinoceros as a modelling tool and Microsoft Access as a database management software, with attention to saving data in open and non-proprietary formats in view of the future development of BIM technology.

The digitization of museum objects is instead a well-known topic, especially for the creation of models for the web or virtual museums, displaying digital representations of museum collections associated with all kind of information. Digital content is often the result of an ad hoc modelling project. Although the proposed system of museum BIM concerns the digitization of the physical characteristics of the containers and contents, the models created for the virtual museums can be reused for the creation of a museum BIM. Among the tools used for this purpose, (Parrinello & Dell'Amico, 2019) uses a BIM authoring tool (Autodesk Revit) to model in parametric form the single parts of finds of an ethnographic museum to classify objects belonging to the same category.

A case study concerning the Historical Archive-Hydra Museum, (Hydra, GR), as part of the INCEPTION project, has involved both the digitization of the building for creating an H-BIM model and the collections for visualization with AR/VR tools, but not the combined use of the two parts (Karadimas et al., 2018)

2.2. Collections management systems

Many museums have centuries-old history and tradition and have been run for a long time according to criteria established in the past. The focus on long-term preservation poses different and often conflicting needs between traditional practices and current digital management challenges. Issues arise from the lack of shared standards and from local regulations leading to poor systems interoperability (Ekosaari & Pekkola, 2019).

ICOM defined basic principles and best practices for museum governance. Referring to them, there are several commercial and open source programs for the management of museum collections (collections management systems, Chapman, 2015). Many of them are compatible with the procedures specified by the SPECTRUM standard (set by the English organisation Collection Trust, see Gosling & McKenna, 2017) and also adopted by institutions in other countries.

SPECTRUM 5.0 specifies 21 collections management procedures. In addition to inventory and cataloguing –which in turn can follow other standards, such as the ones defined by ICOM's International Committee for Documentation, CIDOC CRM (see Doerr, 2003; Van Ruymbeke, Hallot, Nys, & Billen, 2018) or the Italian Istituto Centrale per il Catalogo e la Documentazione, ICCD (see Mancinelli, 2018)–, the procedures cover the following aspects as location and movement control, loans in and out, condition checking and technical assessment, collections care and conservation, emergency planning for collections, damage and loss, just to mention the most strictly material aspects of a museum object.

The data included in collections management systems can also be used for other purposes, for example for the dissemination of contents to visitors with multimedia systems, even with virtual or augmented reality (VR/AR systems, see Kosmopoulos & Styliaras, 2018).

3. The Italian museums in an international context

The idea of developing a museum information management system including both the building and the collections (a Museum BIM or M-BIM) is based on many considerations. The Italian norm "Guidelines for the assessment and mitigation of seismic risk of cultural heritage" (MIBAC, 2008) indicates for heritage buildings a "limit state of damage to artistic heritage" (SLA) concerning the damage to decorative parts that can be significant even without any major structural damage (Tucci, Conti, & Fiorini, 2018). In a museum, mostly when it is situated in a historical building, the destiny of the content is closely linked to container and it should be protected against disasters as stated by ICOM (2017). In addition, the management activities of the museum, both related with the building maintenance or the study, care, and promotion of the artworks, are connected to their location and physical attributes and must be cared according to the principle of preventive conservation (Putt & Slade, 2004; Schalm et al., 2019).

In Europe, especially in the Anglo-Saxon countries and in the rest of the world, unlike Italy, museums have long enjoyed legal, managerial and administrative autonomy. This has led to the drafting of statutes and founding acts, charters of principles, mission statements, management documents and guidelines for the main activities of management of the museum; but above all, they induce museums to implement quality checks followed by regulatory compliances with certification protocols for sustainability, preventive conservation and conservation parameters and quality indicators are discussed (Pangallozzi, 2019).

In Italy, the first steps to improve the management and enhancement of museums are the D.Lgs. 112/98 and then the D.M. 10/05/2001. (Guidelines on technical-scientific criteria and operating standards of museums).

The latter, inspired by the ICOM Code of Ethics, which introduced and disseminated the principle of minimum standards for ensuring the existence and proper working of a museum, transfers the management of some museums to local authorities, indicates technical and scientific criteria and minimum standards to be observed and gives autonomy to local authorities to develop own accreditation procedures for the achievement of quality standards (Acidini, 2001).

In summary, the guidelines:

- Have shown how the lack of legal autonomy had a negative impact on management and economic aspects, have not encouraged the drafting of statutes and charters of principles and has not developed a process of self-assessment on the quality of the existing or to be pursued requirements, for directing their mission toward the visitors and not only in a keeper/preserver role.
- For the first time, introduced the word "standard" in an Italian bill, intended both as a parameter for verifying the essential conditions of the transfer itself (safety, prevention, use, etc.), and as a method for the research and technical development of quality indicators.
- Have transformed technical and scientific criteria and standards into guidelines for proper conservation, management and enjoyment not only for museums but for the entire Italian artistic heritage.
- Have interpreted the standards in a flexible way and with a multidisciplinary approach, according to different kind of museums. It also marked the need for one (or more) new museum definitions.
- Have identified eight functional areas for the definition of standards (I legal status, II financial structure, III structures, IV personnel, V security, VI collection management, VII relations with the public, VIII relations with the territory), each one including a premise, a technical standard and other supporting documents and specifications.
- Aimed to bridge the cultural gap between the Italian and international situation in the management of cultural heritage.
- Have distinguished between mandatory and voluntary norms, to be followed for regulating specific fields when they are fully or partially activated only.

In 2014, a special autonomy has been established for a limited number of museums and the technical and scientific autonomy for the others gathered in a Regional museum hub.

From 2015 to 2017, a ministerial study commission was set up to assess which type of integrated museum system could be implemented in Italy, referring to other foreign experiences, in particular in the United Kingdom and France (MiBACT, 2017).

In 2018, with the D.M. 21-02-18 n.113 adopted the minimum uniform levels of quality "Adoption of the minimum uniform quality levels for public museums and cultural places and activation of the National Museum

System". The National Museum System is born, a network of museums and other cultural places connected to improve the system of enjoyment, accessibility and sustainable management of cultural heritage.

The aim of aligning the Italian situation to an international context is reflected in considering that the technical annexe to the D.M. 21-02-18 n.113 is officially translated into 5 languages.

Museums and places of culture that are not state-owned, public or private, can also access the System on a voluntary basis and by means of an accreditation system defined in the same decree.

Compared to the previous system, uniform quality levels have been identified for accreditation to the National Museum System, which constitutes a check on the compliance of museums with the minimum standards.

The standard is divided into three areas: (I) organization, (II) collections, and (III) communication and relations with the Regional government, and divided into subsections.

Minimum standards and objectives for improvement are indicated for each section. Although almost all areas are related to the physical consistency of the building and collections, the following are directly related to the requirements of the building:

- the comfort of exhibition spaces;
- access for people with disabilities;
- safety (indicating compliance with regulations on structural engineering, mechanical, electrical and plumbing (MEP), sanitation, accessibility and so on),

and of the collections:

- periodic monitoring of the state of conservation of the collections;
- formalised procedures for the management and control of handling operations;
- new acquisitions;
- registration, documentation and cataloguing of the collections
- permanent exhibitions;
- temporary exhibitions;
- R&D programmes and activities;
- organisation of deposits.

Although there is above-mentioned software for the digital management of collections, the norm does not prescribe their use.

International best practices on the artworks loan, require to set up conservation reports on the condition of the artworks (Green & Mustaligh, 2009) and facility reports describing the building where they will be exhibited (AAM-RC, 1998; UKRG, 2015). The latter contains all useful data to assess the physical, environmental, management, security and safety characteristics of a museum and the risks to which a loaned work may be exposed.

Inspired by this, Filippi and Rota (2009) propose the compilation of a Confidential Facility Report (adopted by the legislation of the Piedmont region (D.G.R. 29/05/2012 n. 24-3914), a check tool used by museum managers for analysing the museum facilities, layout, installations, exhibitions, conservation of the collections, management, safety and security, maintenance and for collecting all useful data for obtaining the accreditation or for managing loans.

Although there are tools for exchanging data between institutions, both at the national and international level, there are no requirements that clearly indicate the content of facility reports and there is no provision for the use of digital data. However, by scrolling through some of these (AAM-RC, 1998; UKRG, 2015) many of the information reported are spatial (quantitative and qualitative: location of the building, surfaces, characterization of the walls, characterization of the plants, etc.) and could be efficiently obtained or managed with BIM tools. Moreover, the tools used so far represent the museum in a static way, while the museums are characterized by a constantly changing space, just think of temporary exhibitions and exhibitions that can change an environment even for a few days or tourist flows changing on a seasonal basis.

4. The Galleria dell'Accademia di Firenze case study

The Galleria dell'Accademia di Firenze (Florence, Italy) date back to the 17^{th} century, when Grand Duke Pietro Leopoldo gathered the Academy of Fine Arts in the premises of two ancient institutions, the *Ospedale di San Matteo* and the *San Nicola di Cafaggio* convent. A major transformation took place in 1783 when the architect De Fabris designed the *Tribuna* for relocating Michelangelo's David, formerly situated in *Piazza della Signoria*.

The museum is in a consistent part of a city block shared with the *Accademia di Belle Arti*, the *Conservatorio Musicale Cherubini* and *Opificio delle Pietre Dure* which are the most prominent institutions in Florence for the artistic education and restoration.

Because of refurbishments occurred without any unitary project over the centuries, the spatial organisation of the activities is very intricated (Fig. 2) and it is difficult, at first sight, to understand the distribution of the Galleria (Mignani, 2017).

Like most other Italian and European museums, historic buildings designed for other reasons hold invaluable works of art without considering the pressure of mass tourism and the risks (first and foremost the seismic one) to which the museum and the collections are subjected. Also, for this reason, this important museum, with over 1500000 visitors every year, suffers from a chronic lack of space: there is no space for a cafeteria or a coatroom and the administration is in little rooms. The deposit is in a part of the first floor separated by a glass frame from the exposition areas, so it is difficult to find an alternative location of the works of art even during minor building maintenance works.

Again, visitors visit the museum almost exclusively to see the Michelangelo's David, overlooking the other six other sculptures by (or attributed to) Michelangelo and other important collections, as the world's richest set of gold background paintings, the ancient musical instruments and many others.

For all these reasons, the administrations of the museum and the other neighbouring institutions are studying a

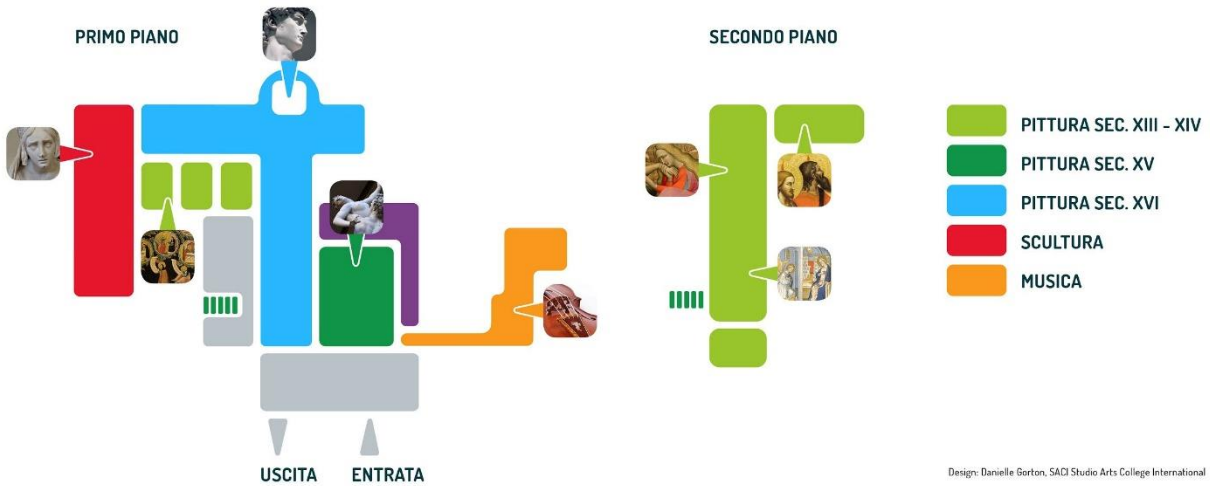


Figure 2: Distribution scheme of the exposition rooms of the Galleria dell'Accademia. The case study involved the artworks in the *Sala del Colosso* (dark green) and in the *Galleria dei Prigioni* and *Tribuna del David* (blue) [Image by Design Danielle Gordon, Studio Arts College International (SACI), from http://www.galleriaaccademiafirenze.beniculturali.it/galleria/]

new distribution of the spaces and an accurate knowledge of the buildings is required, as like design and simulation tools.

4.1. The 2011 survey

The current research on the creation of an information management system for the Galleria dell'Accademia di Firenze, including both information on the building and the collections has largely reused a previous study started in 2010 regarding the evaluation of the seismic risk.

In 2011 an accurate integrated survey was carried out, described in Tucci, Bonora, Conti, & Fiorini (2017). A topographic network with 113 vertices has been created for the survey referencing and control. Over 400 laser scans were then carried out to completely survey the building and all the parts of the adjacent premises structurally connected with the museum, for a total of over 15000 m^2. Initially, 2D CAD drawings only were drawn from the point model, for a total of 7 plans and 15 sections, according to the seismic risk assessment procedures and to obtain a complex architectural survey. The 2011 survey was the main source of information from which the same working group created the BIM model as described below. The model of the building has been obtained mainly from CAD drawings, while the position of the works of art has been directly identified in the point clouds.

4.2. The *Ratto delle Sabine* Project

A separate project concerned the model of the *Ratto delle Sabine* by Jean de Boulogne that was surveyed with a laser scanner at higher resolution in 2011 before its restoration (Tucci, Conti, & Fiorini, 2015). This 3D model is, therefore, more complete than the one obtained from the overall scans of the room in which it is located and was then inserted into the BIM to test the possibility of updating the geometry of the models.

4.3. Mobile mapping updates

In 2018, a new survey was carried out for testing the mobile mapping system Trimble Indoor Mapping Solution (TIMMS) which uses the simultaneous localization and mapping (SLAM) technology (Campi, Di Luggo, Monaco, Siconolfi, & Palomba, 2018). In just a few hours of work, all the main exhibition spaces were acquired. The new data have been validated against the 2011 survey. The survey also documented the occurred transformations, consisting of some new installations and in the relocation of some works. In this research, the 2018 survey data were used for testing how to document the different time phases of museum's installations in an information system.

4.4. The BIM

The new research started with the aim of creating a BIM for the implementation of a finite elements (FE) model and therefore it was first oriented to the modelling of the structural components. Autodesk Revit 2018 software has been used following different approaches. In most cases, the available 2D CAD drawings have been used for a CAD-to-BIM workflow. Sometimes this approach has been considered time-consuming for the previous 2D vectorisation and the survey may be inaccurate or updated. In this case, however, the survey has been considered reliable as it was carried out only a few years before by the same research group.

If some parts were not visible in 2D drawings, they have been modelled using the point cloud as reference. In other cases, objects modelled in other software have been used for creating so-called "In-place elements" to show deformed structural elements. Many approaches were used for modelling the vaults: parametric models tailored on dimensions of the individual instances have been used for serial elements, while single vaults were modelled with in-place elements according to the profiles and paths that are drawn in the 2D survey or extracted from scans.

Currently, the model used could be considered an initial step in the implementation of a fully operational BIM and essentially contains the geometric and semantic information on the load-bearing structures, to be integrated with data on the finishes and characterisation of the materials (Fig. 3).

After all, BIM always allows to enrich models with additional data and to add other information by creating links to external databases. Also, what level of detail (LoD) or level of development is the most appropriate for the various applications is still a controversial issue (Brumana et al., 2018). Often, however, the geometric and semantic information of a model must be purposely processed to be used in specific applications, for example for structural or energy analysis, or for creating an M-BIM as is here presented (Díaz Vilariño et al., 2017).

Figure 3: Cross section of the Building Information Model.

5. Collections modelling for BIM

The digital model of the Academy Gallery building has been populated by digital BIM of the works of art on display. Given the high number of works in the museum, it was decided to limit the test to the main exhibition areas, developing a workflow for sculptures, paintings and installations that could be extended and adapted in the future to other categories of objects displayed in the Gallery or in other museums.

The 3D models can be obtained in different ways:

A. With ad hoc acquisition projects.
B. Reusing models previously produced, e.g. for virtual museums.
C. Obtaining data from the point models acquired during the survey projects of the building (Bitelli et al., 2017).

In A and B cases there will be complete and already processed models with a suitable resolution but not referenced. These solutions, involving a greater investment, are appropriate if the aim is keeping high-resolution models for other purposes: scientific, dissemination, cataloguing and so on.

On the other hand, if the models are used solely for management activities, case C is more economical because, during the geomatics survey of the museum to create the HBIM, the geometry and location of the works and the installations are simultaneously acquired.

In the case of data re-use, models may have lower resolution and some gaps. However, as indicated below, they could later be replaced with better models, documenting the replacement in the metadata (Custodi, 2019).

Models' usability is another determining point, the relationships between the amount of information implemented, the scalability of the geometric resolution and the overall size of the files, vary according to the purpose of the survey but always in order to work in the virtual environment in the smoothest way.

The modelling workflow follows the following layout:

1. Data analysis and selection.
2. Point cloud segmentation from the background.
3. Artwork segmentation from the bearing and/or decorative elements (base, frame, etc.).
4. Point clouds decimation of all the parts.
5. Mesh creation and editing.
6. Extraction of profiles for parametric objects, like some simple stands and frames.
7. Retopology.
8. Extraction of dimensions and volumes, to be associated with materials to compute weight.
9. Importing section profiles into Revit for parametric models.
10. Import into Revit of mesh for creating more complex objects.
11. Creating BIM objects in the Revit Family Editor.
12. Objects parametrisation (attributes, metadata and paradata).

If there were more than one acquisitions of the same work, the highest quality one was used.

Most of the models were made using the 2011 campaign data for only a few models, as in the case of one of the statues of the *Prigioni* where the back part was not being acquired, the 2018 campaign data were used.

If the meshes had small gaps and/or topological errors, the models were corrected and integrated. In the case of large holes, the model has been closed with flat surfaces. The metadata contains all the information on the model realization.

Several programs have been used: MeshLab 2016 (ISTI CNR) for segmentation, decimation and meshing, Geomagic Studio 2014 (3D Systems) for mesh editing and eventual further decimation, ZBrush 2018 (Pixologic) for retopology, Rhinoceros 5 (McNeel) for the realization of the cross-section profiles and meshes conversion in DWG format to be imported in Revit 2018 (Autodesk) where, finally, all the Families have been made (Fig. 4).

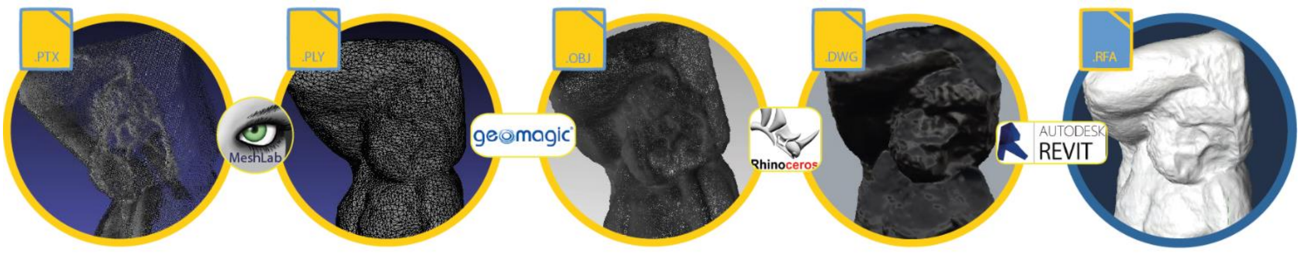


Figure 4: Artwork BIM objects workflow, files and file formats.

Data handling required to use low-poly models, with a preference for information content even with database connections and external files. However, where available (as in the case of the *Ratto delle Sabine*), high-poly models have also been archived for other applications of structural verification, AR/VR, etc. (Fig. 5).

Figure 5: M-BIM view of the *Tribuna del David*.

Different criteria were followed for paintings and sculptures, modelling all the works of the *Tribuna* and of the *Sala del Colosso* (about 80 paintings and 10 sculptural works).

The sculptures were processed as completely closed meshes using a low-resolution model for importing in Revit.

The paintings are on a wooden board of variable size, usually with gilded wood frames. The frames can have a simple profile or a more complex shape or decoration and this has resulted in two types of modelling. In the case of complex objects, models created by importing into the Revit Family Editor a mesh of the sole frame or of the entire board (if it has a complex shape), adding the geometry of the wooden panel created within the Editor were used. For more simple objects, models were used with the frame made from the profiles obtained from the mesh; in this case, all the elements were created in the Editor. Finally, with the Decal tool, the image has been applied on the surface of the board created in Revit.

5.1. Semantic meaning application to models

The qualifying element of a BIM is the richness of the information associated with the geometric representation. On this basis professionals from different disciplines can manipulate geometric entities and perform analyses, queries, obtain reports, schedules, etc.

In the compilation of a database it is important to avoid data duplication, so it is considered more appropriate that BIM includes only essential information, while other data already present in external databases (ICCD catalogue, Conservation Report, etc. provided by the Galleria dell'Accademia di Firenze) or in collections management software (if used) can be externally linked (Fig. 6).

The properties and information of the models should not only describe the features of the object but also include the properties of the 3D model itself in terms of metadata and paradata. This implementation is required to achieve the "scientific transparency" described by the Seville Principles (principle n. 7)[1] in order to verify the validity of a 3D model.

Object data:

- Catalogue and/or inventory number.
- ID code.
- Name and author.
- Low-res photo.
- Type of object (painting, statue, coin, furnishings, etc.).
- Geolocation of the work (in the museum or in case of a loan).
- Components (e.g. frame, canvas, painted board, base, etc.).
- Metric and overall data (length, width, depth, volume, weight, etc.).
- Components material and physical data (materials, density, coatings, etc.).
- Conservation (presence of "Climaframe", support systems, etc.).
- Parameters of environmental compatibility.
- Classification of the object according to the AEC industry standards (title OmniClass, number OmniClass etc.).

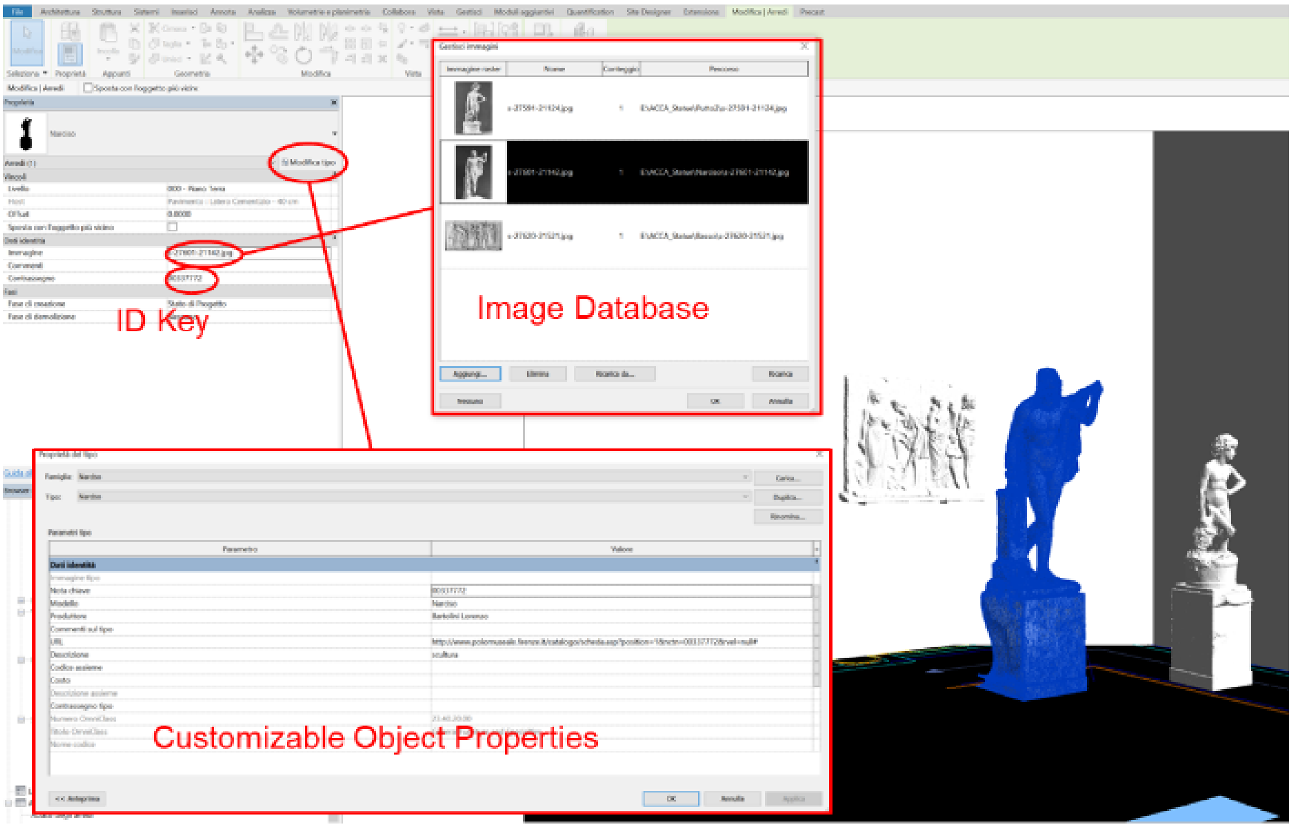
3D model metadata and paradata:

- Acquisition date (source data).
- Acquisition mode (technique/device).
- Acquisition resolution (preset and final sampling on the object e.g. point cloud).
- Author of the acquisitions (operator, institution, etc.).
- Surface model creation date.
- Modelling workflow.
- Operator.
- Object ID (survey code, file name, etc.).
- Type of the model (mesh or parametric).
- Final resolution (faces, tolerance).
- Model owner (client, operator, etc.).
- Last revision.
- Notes (issues, specifications).

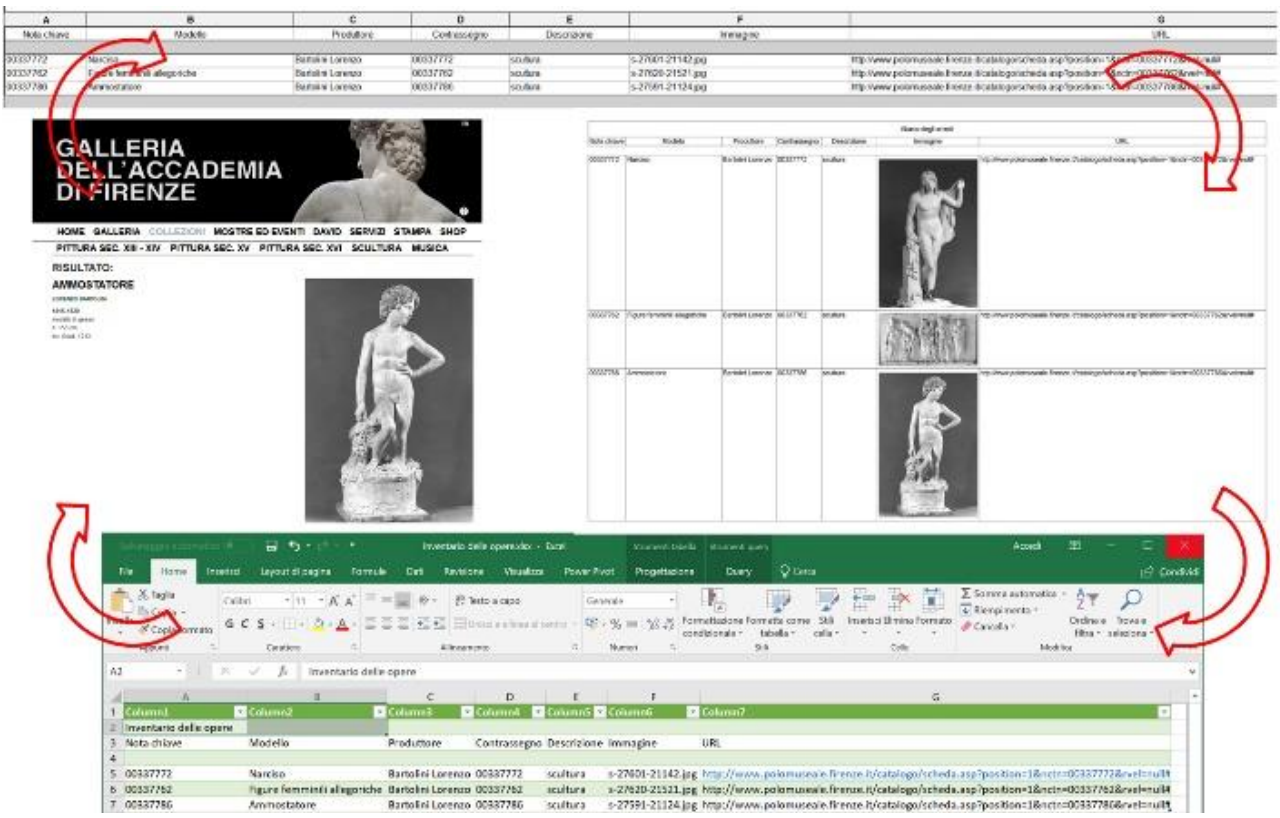
5.2. Exhibitions and renovations archive

With surveys that document the consistency of the museum at different periods and the digital models of the works of art, it is possible to reconstruct the position of each object or furnishing in the building at a certain time, as provided for in the minimum standards for permanent collections from DM 113/2018, or also for documenting temporary exhibitions. In this way, it is possible

[1] http://www.sevilleprinciples.com/



(a)



(b)

Figure 6: Artworks BIM objects: a) properties management; b) Data exchange between BIM schedules/quantities, external software and web catalogues.

Figure 7: M-BIM view of the *Sala del Colosso* with paintings and the *Ratto delle Sabine* statue.

Figure 8: Comparison between different installations: a) Paintings disposition in 2011; b) Paintings disposition in 2018; c) Superposition between the two phases: removed paintings have red frames, new paintings have white frames.

to create a digital archive of the evolution of the museum (building, systems, installations, collections) over time.

BIM allows multiple phases management by attributing time-related information to each BIM object. 4D BIM is generally used for construction scheduling, for renovation projects or for documenting the evolution of historical buildings. For the present test, only two phases (corresponding to 2011 and 2018 surveys) have been considered, but time phases can be customised to define views in which to visualize only objects present in a given time, also allowing comparisons between different phases to assess the different position of single objects over time. This also affects object schedules, as schedules corresponding to a specific time can be displayed and information on the location of objects in a given room can be obtained.

In summary, using phases with model views, families and objects is possible:

- to archive the exhibitions over time (Fig. 7);
- to make a database of the changes of each work;
- to compare the transformations occurred in the rooms;
- to list the objects in every room at a certain date.

The works carried out in the *Sala del Colosso*, *Galleria dei Prigioni* and *Tribuna* rooms show the changes undergone by the exhibition in 2011 and 2018. The two phases were compared both in a visual way and with schedules (Fig. 8).

In this case, it was observed:

- the relocation of works of art due to refurbishment, restoration, storage, lending, etc.;
- the changes in the furnishings of each room;
- single works changes (e.g. frames replacement or removal).

6. The artwork database conceptual model

All the information (Fig. 9) related to artworks of the case study such as report conditions, the cycle of the lifetime, catalogues, metadata, including the information related with the building, have been modelled as instance objects into a general conceptual database, in order to connect processes, workflows, repositories, relationships among different physical archives.

In fact, even if the BIM approach allows to describe building objects together with all the information to be associated, the database conceptual model aims to:

- define, such as abstract classes, objects of interest independently from geometries, conditions, geolocation that could change over time, space, properties and parameters of conservations;
- define relationships between contents and contained objects;
- define a connection toward standard external catalogues or dictionaries;
- define a core repository that could connect other information on the web in an interoperable way.

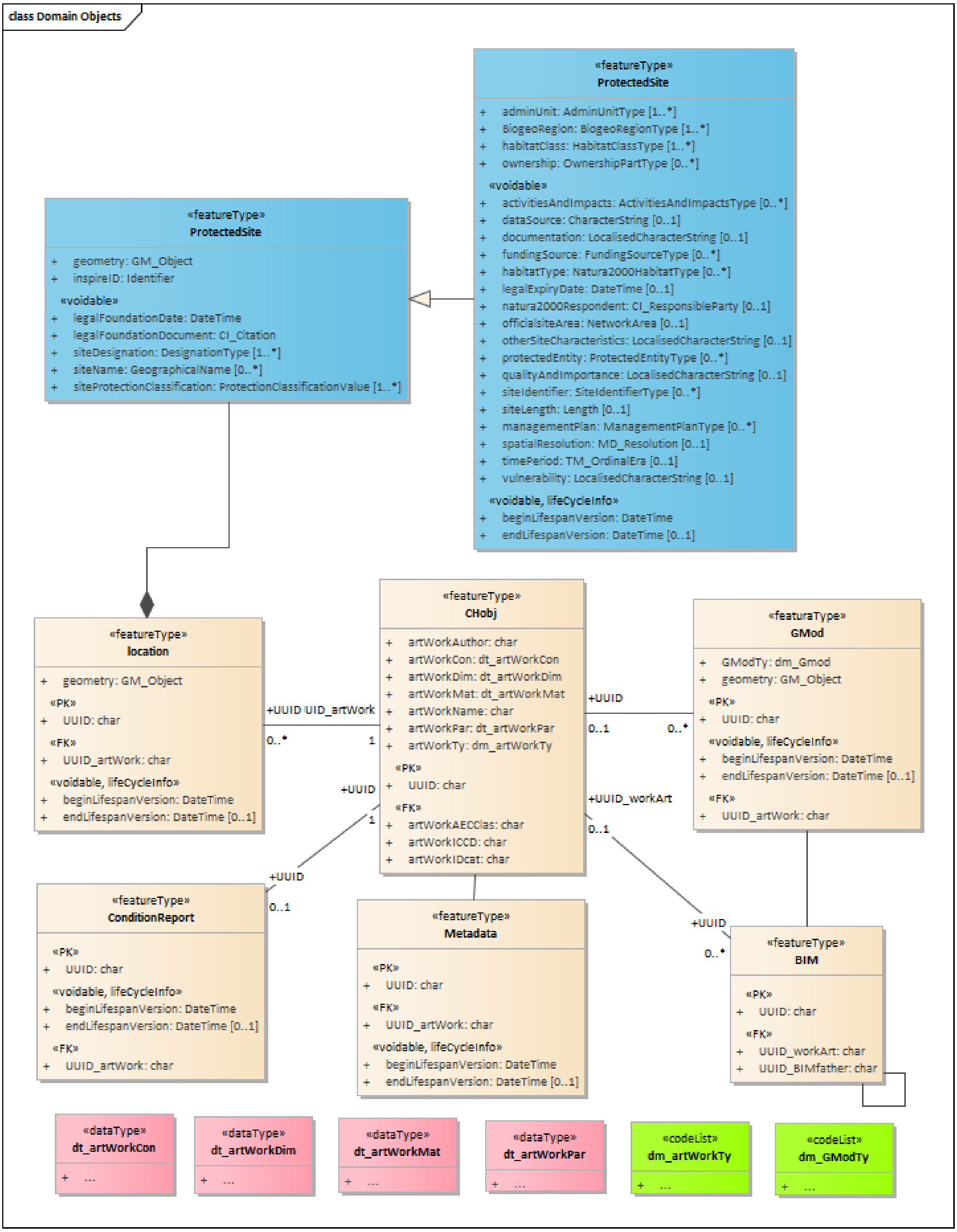


Figure 9: Database conceptual model: class appearance key: blue (from INSPIRE); light pink: main artwork DB; pink: data type; green: code list.

Figure 10: M-BIM view of the *Galleria dei Prigioni* with Michelangelo's David in the *Tribuna*.

For these reasons, a specific requirement analysis has been carried out and, consequently, an application schema of the conceptual data model has been formalised. To describe the universe of discourse the UML (Unified Modelling Language) has been used for formalisation, according to INSPIRE Consolidated UML model of the INSPIRE Directive. In fact, the case study of the Galleria dell'Accademia di Firenze has been modelled as a use case of the INSPIRE "Protected Site" data specifications[2].

Data modelling has been addressed to maintain the independence of the BIM approach, but at the same time adding more information in order to:

- avoid the replication of data by different sources;
- allow the connection with open data catalogues (i.e. ICCS RDF catalogue[3]);
- allow the connection between different BIMs related to the same artwork or located in the same building;
- manage the temporary location of an artwork over time;
- associate different kinds of models including different geometrical aspects or LoD, to a specific artwork thanks to the link to geometries of the International Organization for Standardization (ISO) Spatial Schema[4];
- associate to each artwork geolocation in comparison with INSPIRE principle and themes (i.e. Protected sites);
- define an independent platform data model to be implemented according to interoperable standards and open data approach.

7. Conclusions and future work

The paper discussed the opportunity of creating a BIM-based museum information system linked to external databases to manage information regarding both museum and collections by handling 3D objects (Fig. 10). The system, which in this case study has been applied to an art gallery, could be adapted to other types of museums, but it is still questionable whether any museum collection can be managed as a BIM object.

Other issues deal with the current museum's management systems, many data are not yet digitized, or stakeholders archive them in different ways. So, it would be necessary to follow the standard and common recording rules in advance, according to local and international standards and best practices.

Since the works of art are all different and often geometrically complex, the BIM is quite heavy. Currently, the system has been tested only for some rooms, but it may not be manageable for large museums. There may be various solutions, such as using other BIM authoring tools or using more symbolic 3D representations of works. In future, with newer BIM tools, visualization could be facilitated by dividing the model into linked parts.

[2] https://inspire.ec.europa.eu/Themes/117/2892
[3] http://www.catalogo.beniculturali.it/opendata/?q=node&query=&page=1
[4] ISO/TC211 19107, 2003

In the same way, it is necessary to optimize the management of the phases: the installations are frequently updated, and software created to manage less frequent phases of building transformations could hardly handle them.

About the database management, currently, there is not a physical structure that implements all contents, nor an interface application that make easy to access to all information without data administrator skills. For the moment, only a conceptual model has been tested, considering different software. As future development, at the database point of view, we are going to implement a unique interface that querying different models or aspects of information, answering in an easy way queries of thematic experts, using standard protocols of web services and with interoperable datasets.

Another issue concerns the training of personnel, accustomed to traditional management systems and lacking experience with 3D and BIM systems. A more intuitive solution could be for curators to manipulate 3D objects within AR/VR systems. This requires overcoming the current issues in visualizing BIM in XR systems, optimized for visualizing lighter models produced with other workflows (Fig. 11).

H-BIM indicates a new pproach for managing conservation through the use of building information modelling, but it should be considered that this experience has been developed for a specific case study and is subject to existing technical restrictions. BIM requests a long-time view and if data are properly collected, in the future technical constraints may change, offering more efficient ways to handle the unique value of museums and built heritage.

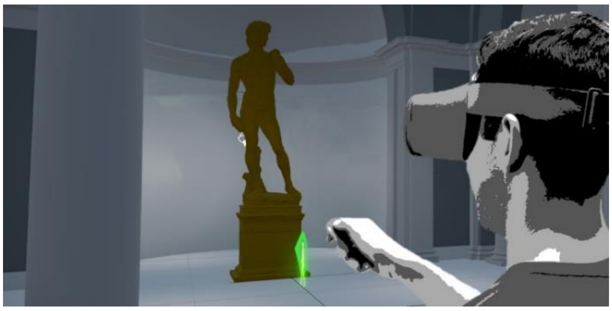


Figure 11: Test of visualisation of the BIM model in VR.

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