The digitisation of museum collections for research, management and enhancement of tangible and intangible heritage

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***Abstract*—This research project aims to define a new methodology that employs Building Information Modelling (BIM) tools, normally used in the Architecture, Engineering, and Construction (AEC) sector, in an unconventional manner, to create 3D databases for small objects: those belonging to museum collections inaccessible to the public. The project will develop a methodology to virtually reproduce 3D objects through the integration of geometric and alphanumeric information. The new procedure will exploit some different levels of knowledge concerning objects in a museum: research, data management, setting up of virtual communication platforms, applying it to some objects that are a part of the collection of the Egyptian museum in Turin.**

Keywords*—*Modelling and Simulation, Metric Survey, Museums, Data Management, BIM

I. INTRODUCTION[1]

A huge patrimony of artefacts is stored in the depots of museums and has no real possibility to be exposed as active part of the museums' collection; at the same time, a great effort is necessary to manage the right conservation of such "hidden" heritage. Digital technologies could allow a way to share the knowledge of such hidden artefacts and, at the same time could provide tools for the management of such an important and often fragile patrimony.

In this regard, the research project, still in progress, B.A.C.K. TO T.H.E. F.U.T.U.R.E. (*BIM Acquisition as a Cultural Key TO Transfer Heritage of ancient Egypt For many Uses To many Users Replayed*) attempts to offer a solution, albeit partially, to these requirements. The research project aims to define a new methodology in which the BIM is intended as a process involving the generation and management of digital representations of a 3D object where the conventional tools can be employed for unconventional purposes to realize the 3D databases of mobile heritage, such as those belonging to large museum collections. This can be useful both for scientific research and for the setting up of virtual dissemination platforms both for the lifecycle management of the object.

II. STATE OF THE ART

The relationship between digital technologies, visual models, and cultural heritage involves an increasingly wide area of research, which is oriented towards the renewal of archives and museums for the preservation and promotion of culture also determined by the requirements of a new audience, which is increasingly "digital". As manifested in the studies conducted under the Mu.Sa European project, funded in 2017, the state of the art is highly uneven and fragmented then a new approach that can promote the effective integration of heritage and digital technologies is desirable.

About the use of BIM in cultural heritage, it is necessary to remember that the scientific community believes that Heritage (H) BIM applications can also be critically investigated in terms of geometric accuracy, infographic representation, and most importantly, data enrichment [1]. About the use of BIM in the context of cultural heritage with reference to small objects, no prior experience exists [2] due to some structural problems, mainly, the total absence of object libraries pertaining to archaeological elements, but also the rigidity involved in the 3D modelling of unconventional forms. The digitisation of collections, whether 2D or 3D, represents the first step for

[1] The project is a part of the pilot initiative "Create a network around your research idea", funded by Politecnico di Torino and Compagnia di San Paolo, and is carried on in collaboration with Museo Egizio of Turin.

establishing a project perspective aimed at the digitisation of museum heritage. In recent years, some research has been conducted on the digital survey and modelling of models and maquettes preserved in museums as well as the enrichment of data concerning these models [3] [4]. The research projects related to these themes are considerably broader in their scope: the European project MINERVA (2002/2005) was already aimed at improving the accessibility and usability of cultural heritage on the Internet. Subsequently, the MICHAEL and MICHAELplus (2004–2008) projects created a network of national databases that allow access to Cultural Heritage.

In 2008, with the birth of Europeana, the idea of a European digital library was affirmed, guidelines and standards have been produced such as European Data Model (EDM) documentation. Additionally, other projects have worked towards the digitisation and 3D documentation of historical artefacts (3D-COFORM). CARARE (2010–2013) and 3D Icons (2012–2015) [5] were designed to support various cultural institutions interested in providing digital cultural content. In the current Horizon2020 programme the call Reflective 6 and Reflective 7 testify the need for research and development in this direction. Also the last calls (2018–2020) address the management of digital resources and advanced digitisation, also aimed at the narration of objects, then projected towards the communication of cultural heritage.

Several approaches have been tested to enable interaction between 3D environments and users. Platforms have been developed for document sharing and management, methods and techniques for multi-level annotation, metadata, paradata and controlled vocabularies for the declaration of interpretative instance. A variety of commercial and academic strategies for the annotation of virtual environments have been proposed or are currently in use [6]. The International Committee for Documentation (CIDOC) developed a Conceptual Reference Model (CRM) to solve an engineering problem of knowledge integration across museum databases [7] faced by the International Council of Museums (ICOM): this was the reference ontology chosen for the ARIADNE project where the goal was the implementation of interoperability across archaeological data at the European level [8].

The communication aspect and the dissemination of initiatives aimed at the digitisation of museums and museum heritage has led to the development of other projects such as V-MUST (2011–2015), GRAVITATE and INCEPTION. These projects are also sustained by European coordination actions. An example is Virtual Multimodal Museum (Vi-MM) that support the main organisations working in the virtual museums to promote the development of high-quality policies on decision-making processes.

III. Research activity

BIM requires the generation and management of digital representations of physical and functional features of places and components. The creation of 3D databases for small objects requires precision and accuracy of each component to preserve and share knowledge about them, which concerns different levels of knowledge related to objects in a museum: scientific research, data management, virtual platforms for dissemination. As the currently available metric survey techniques for recording the geometry of small objects can successfully realise detailed point clouds with a submillimetric resolution, special attention will be given during the conversion of these data into a compatible geometric information modelling structure, oriented towards a parametrisation approach while preserving high metric quality.

The project will involve the application of the proposed methodology to some small objects belonging to the collection of the Museo Egizio in Turin. The achieved digital models will be used to demonstrate the way in which museums can utilise them for different purposes: to monitor their collections (3D repository linked to a database) and offer the users (visitors) the possibility of exploring objects stored in their depots and storerooms that cannot be put on display due to a lack of space.

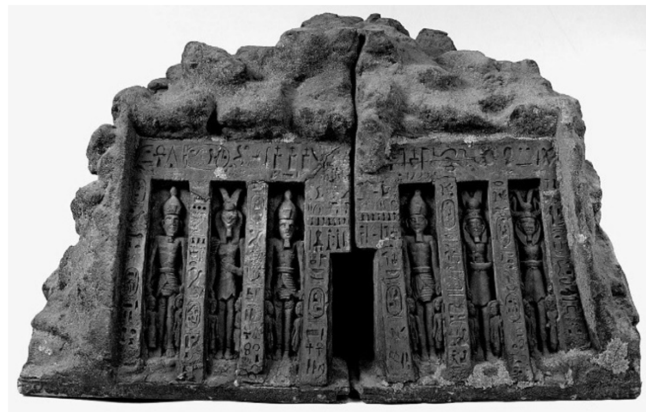

Fig. 1 Wooden model attributed to Jean-Jacques Rifaud, conserved in the Egyptian museum of Turin (Image from *[10]*).

IV. Case Study Description

Museo Egizio houses 11 physical models (maquettes) that are the reproduction of Nubian temples from the geographical region between Abu Simbel and the Aswan dam. The models, dating back to the early 1800s, are generally composed of two halves (Fig. 1) that, if opened, allow us to observe the interior; the authorship of the models is attributed to French sculptor Jean-Jacques Rifaud (1786–1852) due to observed similarities with some of his drawings from the time [9]. Most of these maquettes are conserved in specific storerooms inaccessible to the public.

The first wooden model that would be worked on is the representation of the minor temple of Abu Simbel (Nefertari's temple); it is composed of assembled wooden elements covered with a mixture of sand and wax. Its dimensions are approximately 80 x 60 x 35 cm [10].

V. Methodology

The proposed workflow is as follows:

1. Metric survey of the maquette;
2. Elaboration of the collected data to obtain a reality-based virtual 3D model;
3. Data enrichment and data management;
4. Communication and content sharing.

A. Metric Survey

Point cloud acquisition techniques represent the best solution today for providing primary data necessary for the development of a complete 3D survey of objects falling under the category of movable cultural heritage [11] [12] [13].

Point clouds do not represent a real 3D model due to the absence of topology between the points. Therefore, a subsequent segmentation is necessary to define the geometric breaklines, which facilitate the final step of modelling. In case of irregular surfaces, automatic modelling represents one of the possible ways to create a complete 3D model. When the regions defined by the breaklines are considered as simple geometric surfaces, their definition would allow the elimination of the points and consequently a reduction of the required memory space.

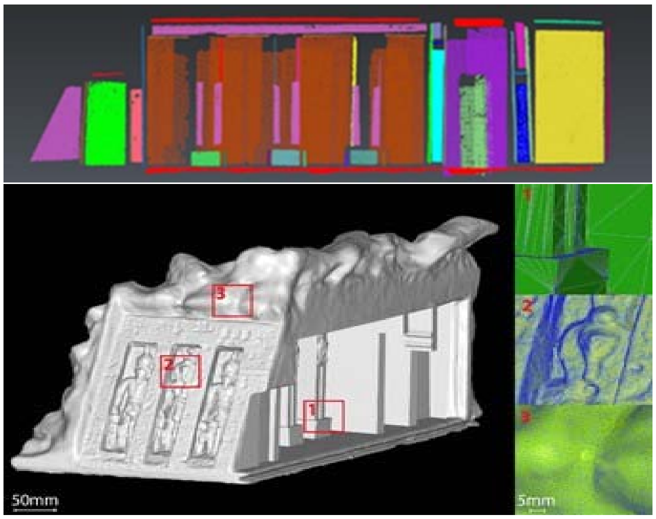

Fig. 2 a) On top, segmentation of the point clouds to describe the flat surface of a sub-model; b) below, complete 3D reconstruction of a sub-model formed by merging the three generated meshes

The case study is formed by two separate parts that constitute the Nefertari temple's model. Each sub-model is delimited by different kind of surfaces: the outer surface of the temple, inner surfaces, and irregular rock surface, which simulate the original position of the temple. By considering the goal of the project a metric accuracy of 2 mm is accepted. Therefore, it is possible to consider survey techniques that are usually excluded when higher accuracies are required. For each sub-model, three different techniques have been applied:

- terrestrial laser scanning (TLS) acquisition with a time-of-flight scanner (Faro Focus3D X 330);
- hand-held laser scanner (Faro Freestyle3D);
- photogrammetric survey with a DSLR camera (Canon EOS 5DS R) mounting a Canon lens (focal length 24 mm with manual focus).

In order to cover the maximum number of surfaces in the sub-models, 15 scans with TLS for the right part and 14 scans for the left one were acquired. This high number of scans is required due to the morphological complexity of the geometries. With the Faro Freestyle3D, it was possible to acquire a complete point cloud of both halves of the model with a unique acquisition for each of them. This technique certainly formed the fastest sensor among those used (each acquisition lasted for approximately 15 minutes), but, at the same time, the one that gave the lowest resolution. As far as the photogrammetric survey is concerned, 67 high-resolution images (50 megapixel each on 24x36 mm^2 sensor size) were captured for the right part and 62 for the left one, in accordance to the photogrammetric acquisition principles to facilitate the automatic matching of homologous points [14].

B. 3D Modelling

The realisation of a reality-based 3D model, to serve as the geometric base for data implementation, requires a well-conceived process of elaboration of the acquired point clouds, especially regarding the recognition of geometric features. The adopted procedure follows the below defined scheme:

- cloud-to-cloud registration of the scans with the Faro SCENE platform;
- processing of the photogrammetric blocks and automatic matching with the open source software MicMac;
- cleaning and filtering of point clouds obtained from all the acquisitions with the 3DReshaper platform;
- adjusting the resulting point clouds in a unique coordinate system and checking the accuracy with the 3DReshaper platform.

This final step gives residuals less than 2 mm for the registration of the three different scans in a unique coordinate system. The three point clouds differ in terms of density, resolution, and holes (shadow areas). The final dataset represents the result of the balanced union of the three datasets.

The analysis of the morphological complexity of the model led to its subdivision into parts represented by three different kinds of surfaces. Internal and external surfaces of the temple represent the flat parts (type 1) and sculptures (type 2); the external part is an irregular surface that simulates the rock mass (type 3). The list of the procedures adopted to identify the different areas is listed below:

- Type 1: Interpolation of regular surfaces from the LiDAR point cloud with the 3DReshaper; the maximum deviations between the segmented point clouds (Fig. 2a) and regular surfaces adopted are less than 2 mm and the mean value is nearly null. By exporting these surfaces into the Rhinoceros platform, the topological reconstruction is possible;
- Type 2: Creation of a Triangulated Irregular Network (TIN) model of the photogrammetric dataset by using 3DReshaper;
- Type 3: Creation of a TIN model of LiDAR dataset by using 3DReshaper.

The three surfaces can be then joined into a single 3D model that can be used for subsequent operations of data enrichment (Fig. 2b).

C. Data Enrichment

The definition of the informative attributes, whose semantic structuring and extreme heterogeneity could lead to the definition of some levels of informations, expressly conceived for the museum's heritage. To provide the highest level of interoperability, the CIDOC-CRM is selected as the reference ontology for the semantic structuring. Furthermore, the CIDOC-CRM ontology has been already proved to be compatible with the currently developed Italian national standards for the encoding of archaeological information, adopted and maintained by the Central Institute for Catalogue and Documentation (ICCD) [15].

1) Data Types

- historical-artistic data of the digitized object
- historical-artistic data concerning the wooden model
- management and lifecycle data of the object as a part of museum's collection

2) VPL Procedure

The informative stratification is created using the Grasshopper visual programming language (VPL). Hotspots are modelled inside the CAD space with primitive geometries appropriately enriched using the tools available in the drawing software utilized for the experience (Rhinoceros 6). Two enrichment operations are subsequently carried out: a) the enrichment of the detected model (local enrichment); b) the enrichment of the primitive geometries added (specialized enrichment). The first activities are conducted by linking the surveyed model to a spreadsheet on which information from the various disciplines is collected and then linked to the model using VPL add-ons that allow importing data from spreadsheets (Excel in the proposed case). Then the detected model is enriched by the collected data and opportunely translated into the web language. The use of stratified data, which can describe the diversified contents of the model, must be manipulated to be correctly structured using CIDOC-CRM as a formal ontology.

3) Sharing

In the prototype procedure displayed, the sharing of form and information takes place through the networking of the enriched model. The model can be viewed dynamically and selected for parts that compose it (right and left part of the surveyed model).

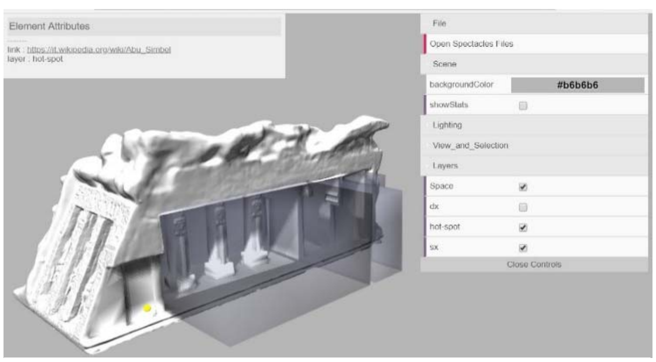

Fig. 12 Navigable model within a web portal. By selecting an object, it is possible to read the data linked with the VPL procedure.

VI. Conclusions

The described experience forms the first step towards the creation of interconnected databases using BIM methodology, which we define Collection Information Modelling (CIM) for museums digitised collections, and it looks at some instances that the Scientific Community is questioning in accordance with the above regulatory requirements (DM 113/2018).

In addition, the complete digitisation of shapes and information regarding collections, even those that are not exposed due to the availability of limited space, allows the scheduling and prefiguration of exhibition of goods without distinguishing between exposed and unexposed collections that if accessible online for reading (referencing) and writing, allows maintenance and immediate control of the status of the works, facilitating professionals' back office work. Finally, the digitisation of shapes and contents encourages communication and cultural sharing also using remote fruition with museum websites and social networks, defining communication strategies aimed at social inclusion and the diversification of cultural activities by expanding the possible catchment area of potential visitors.

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