# Digital models of architectural models: from the acquisition to the dissemination

Massimiliano Lo Turco

Elisabetta Caterina Giovannini and Noemi Mafrici

edited by

# Digital & Documentation

## Digital strategies for Cultural Heritage

Volume 2

PaviaUniversityPress

Digital & Documentation. Digital Strategies for Cultural Heritage / Massimiliano Lo Turco, Elisabetta Caterina Giovannini and Noemi Mafrici (edited by) - Pavia: Pavia University Press, 2020. - 205 p. : ill. ; 21 cm.

(Prospettive multiple: studi di ingegneria, architettura e arte ; 2)

ISBN 978-88-6952-123-2 (brossura)

ISBN 978-88-6952-124-9 (Open Access)

The present publication is part of the series "Prospettive multiple: studi di ingegneria, architettura e arte", which has an international referee panel. "Digital & Documentation: Digital Strategies fo Cultural Heritage" is a scientific text evaluated and approved by the Editorial Scientific Committee of Edizioni Pavia University Press of University of Pavia.



The photo credits in the "Event Photo Gallery" are by Elisabetta Caterina Giovannini and Francesca Picchio.


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Graphic project
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Printed by
DigitalAndCopy S.A.S., Segrate (MI)

ISBN 978-88-6952-123-2 (brossura)

On cover: Graphic photocollage by Elisabetta C. Giovannini

The volume consists of a collection of contributions from the seminar "Digital & Documentation: Digital Strategies fo Cultural Heritage", realised at the Politecnico di Torino on June 14th, 2019. The event, organized by the "BIM Acquisition as Cultural Key TO Transfer Heritage of ancient Egypt For many Uses To many Users REplayed" - B.A.C.K. TO T.H.E. F.U.T.U.RE. Project - team of DAD - Department of Architecture and Design of Politecnico di Torino, promotes the themes of digital modeling and virtual environments applied to the documentation of architectural scenarios and the implementation of museum complexes through communication programs of immersive fruition.
The event has provide the contribution of external experts and lecturers in the field of digital documentation for Cultural Heritage. The scientific responsible for the organization of the event is Prof. Massimiliano Lo Turco, Politecnico di Torino.

This publication is made with the contribution of DAD, Department of Architecture and Design of Politecnico di Torino, through the "BIM Acquisition as Cultural Key TO Transfer Heritage of ancient Egypt For many Uses To many Users REplayed" - B.A.C.K. TO T.H.E. F.U.T.U.RE. Project, in collaboration with Fondazione Museo delle Antichità Egizie di Torino. The project is one the winner of the call "Metti in rete la tua idea di Ricerca" partially financed by Compagnia di San Paolo.

POLITECNICO DI TORINO
Dipartimento di Architettura e Design

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The event "Digital & Documentation - Vol. 2" has seen the participation of professors, researchers, scholars and private institutions

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The event is promoted by Unione Italiana del Disegno (U.I.D.)

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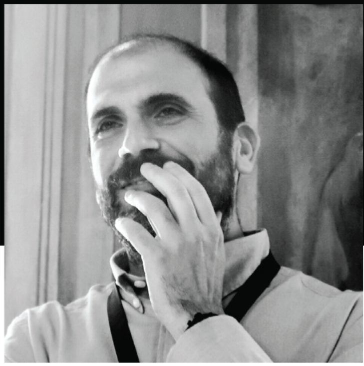

Architect, PhD in Architectural Representation (SSD ICAR / 17). He carries out research activities on the digitization of museum environments at DAD (Politecnico di Torino). He teaches at the Camerino University in the 3D Modeling Lab in the Master's Degree Course in Computational Design of the SAAD (Ascoli Piceno); he carries out further training activities in the representation courses of the Politecnico di Milano and IUAV in Venice. Coordinator and teacher of workshops focused on Digital Fabrication processes. The research activity is aimed at the study of responsive surfaces and new methods of "remote survey". Lecturer at the AANT Academy of Arts and New Technologies (Rome) in the course of Digital Modeling and Rapid Prototyping. Co-founder of the ArFacade studio (www.arfacade.com) specialized in design and development of architectural envelopes.

# 03 DIGITAL MODELS OF ARCHITECTURAL MODELS : FROM THE ACQUISITION TO THE DISSEMINATION

Alessandra Spreafico, Giacomo Patrucco, Michele Calvano

*Abstract*

Antiquities and works of art preserved in museum collections represent an invaluable evidence of our history. A proper three-dimensional metric survey and digitisation of these assets (which are intrinsically fragile and for this reason need a continue and careful documentation) allow to increase significantly their resilience and they offer a valid contribution for the management of these objects belonging to movable heritage.
This work takes place during a research experience carried out in the framework of B.A.C.K. TO T.H.E. F.U.T.U.RE. (BIM Acquisitions as Cultural Key TO Transfer Heritage of ancient Egypt For many Uses to many Users REplayed) during which a collection that consists of fourteen wooden models belonging to Museo Egizio of Torino has been digitised using both image-based and range-based modeling techniques. In addition to geometric and radiometric data, provided by textured model, information of various nature related to the considered asset has been integrated. The main aim of the research, starting from the digital 3D models, is the creation of three-dimensional databases (with alphanumeric and multimedia informations about historical, artistic and management aspects), useful for several purposes: 3D visualisation, communication, dissemination and data management. In this paper 3D metric acquisition strategies have been evaluated and the followed methodology as regards data enrichment have been illustrated.

I reperti e le opere d'arte conservati nei musei rappresentano una testimonianza insostituibile della nostra storia. Un adeguato rilievo metrico 3D e la digitalizzazione di questi beni (che sono intrinsecamente fragili e per questo motivo necessitano una continua e attenta documentazione) consentono di aumentare in maniera significativa la resilienza e offrire un valido contributo alla gestione dei beni appartenenti al patrimonio mobile.
Questo lavoro è stato svolto durante un'esperienza di ricerca condotta nell'ambito del progetto B.A.C.K. TO T.H.E. F.U.T.U.RE. (BIM Acquisitions as Cultural Key TO Transfer Heritage of ancient Egypt For many Uses to many Users REplayed) durante la quale una collezione composta da quattordici modelli di legno appartenente al Museo Egizio di Torino è stata digitalizzata con tecniche di modellazione image-based e range-based. Oltre ai dati geometrici e radiometrici, forniti dal modello texturizzato, sono state integrate informazioni storiche e gestionali relative ai beni considerati. L'obiettivo principale di questa ricerca, a partire dai modelli digitali 3D così ottenuti, è la creazione di database tridimensionali (contenenti informazioni alfanumeriche e multimediali a proposito di aspetti storici, artistici e gestionali), utili per molteplici scopi: visualizzazione 3D, comunicazione, diffusione e gestione dei dati. In questo articolo sono state valutate le diverse strategie di acquisizione metrica 3D ed è stata illustrata la metodologia seguita per quanto riguarda il data enrichment.

Objects preserved in museum collections have always been a valuable evidence of our history and our heritage. The need to document these priceless assets is undeniable and it requires a careful consideration about the techniques and the methods for the entire digitisation process[1]: from the physical object, through the digital model and its data enrichment to the divulgation step. These digital models are extremely versatile as regards not only research purposes: as 3D documentation to increase the resilience of these valuable and fragile assets, as basis for various analyses by experts operating in the framework of movable Cultural Heritage valorisation[2], but also as tool for online dissemination[3]. This experience takes place in the framework of B.A.C.K. TO T.H.E. F.U.T.U.RE. research project[4] and proposes a procedure for the digitization and data enrichment of museum collections; the path has been made up of a series of case studies: 14 'travel models of Egyptian architecture'. A collection that originally included thirteen temples and an obelisk now belonging to the Egyptian Museum in Turin. The survey and information enrichment are well-known operations on an architectural scale, but not for small objects, which is why the path taken by the research group was a starting point for investigation in different fields. Procedures and tools suitable for describing the shape have been identified; at the same time, historical and artistic information has been collected for subsequent information enrichment. The data collection phase was followed by the merging of shape and information, work carried out with the operation of final dissemination in mind; a series of models linked to databases useful for the digital documentation of the objects detected.

## Geomatics methods and instruments for museum collection

In the last few years, increasingly users operating in the fieldworks of 3D modelling have investigated the strategies for movable heritage digitisation in order to define the most efficient acquisition methods considering not only the geometric information, but also data about the radiometry and the consistency of the considered assets[5].
In this regard, the role of the Geomatics has been decisive. Since the development of new sensors, range-based techniques, image-based techniques and, connected to that the improvement of photogrammetric computer vision technologies and image-matching algorithms, the Geomatics has provided effective tools as regards movable heritage 3D metric acquisition and the realisation of very detailed 3D models[6]. Generally, for the digitalisation of these kinds of objects (such as those acquired during this research), different methodologies are usually adopted, the image- and the range-based approaches and the structured light system exploiting the triangulation principle[7]. The present case study considered different scanner instruments and digital images processed using Structure-from-Motion (SfM) algorithms following metric criteria.

## Acquisition and Modeling of the wooden maquettes

During the research activities illustrated in this paper, the acquisitions of the 26 pieces (smallest one 23x23x65 cm3, biggest one 42x106x41 cm3) (Figure 1) composing the 14 maquettes of the Nubian monuments (2016), have been carried out in six surveys between February 2018 and April 2019 and testing the suitability of the following sensors (Figure 2):
Laser-based and structured light-based active sensors:
(1) Terrestrial laser scanning system Faro Focus 3D
(2) Hand-held structured light scanner Faro Freestyle
(3) Hand-held structured light scanner Stonex F6 SR (Short Range)
Image-based passive sensors:
(4) High-resolution full frame digital camera Canon EOS 5DSR equipped with a Zeiss 50 mm macro lens.

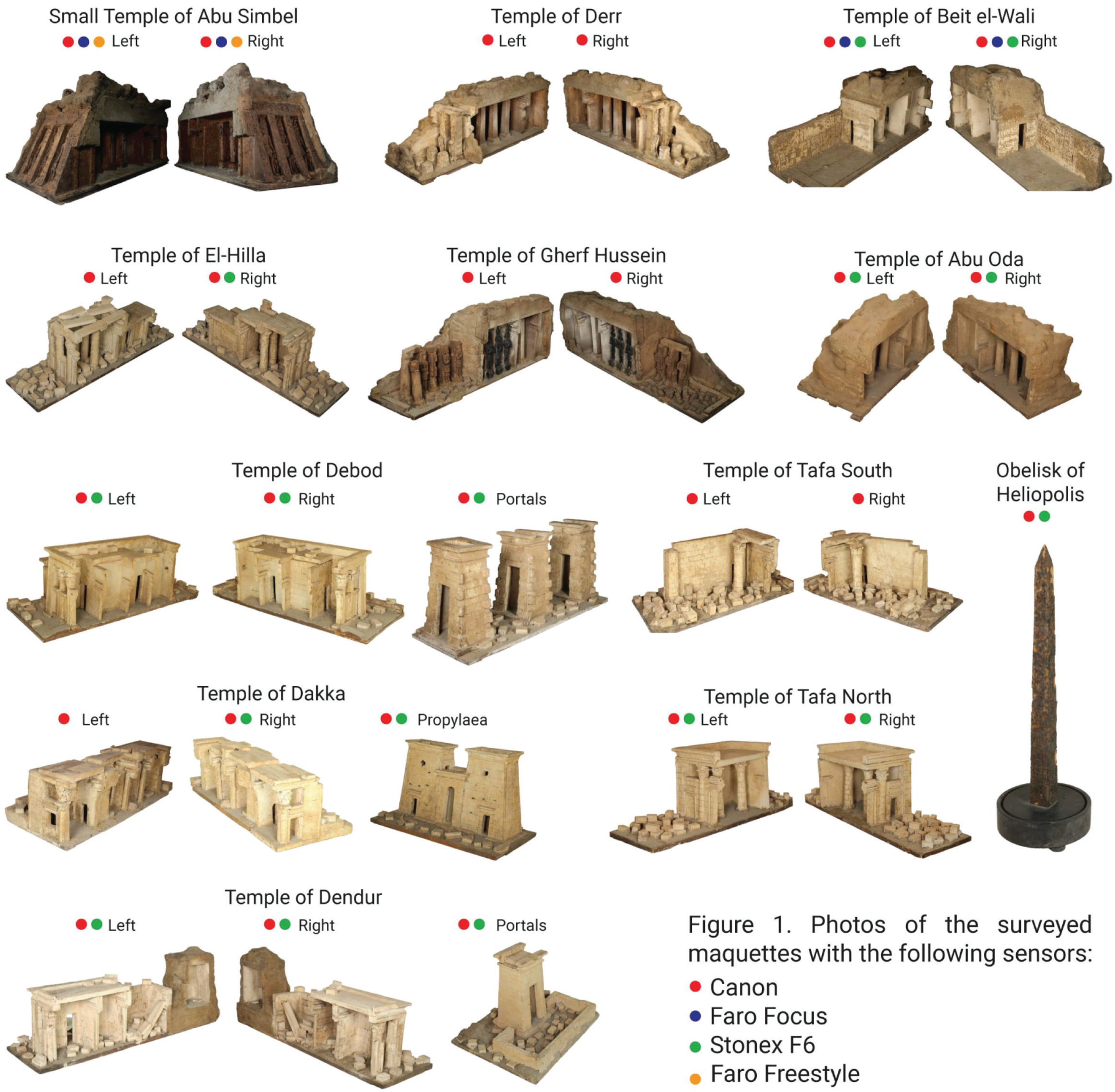


Figure 1. Photos of the surveyed maquettes with the following sensors:

- Canon
- Faro Focus
- Stonex F6
- Faro Freestyle


Fig. 2 - From right to left: (1) Faro Focus 3D 330, (2) Faro Freestyle, (3) Stonex F6 SR, (4) Canon EOS 5DSR with Zeiss Milvus 50 mm f/2M lens

The geometric accuracy is evaluated thanks to metric bars positioned in the acquisition stage.
As regards the processing phase, according to the type of acquired data and to their level of completeness, different approaches have been considered: image based, range based and integrated solution merging different datasets. The latter has been already presented in Lo Turco et al 2018.
Basically, the point cloud obtained by the data processing of the acquired datasets, both for range and image based sensors, represents the starting point as regards the metric survey and the 3D modelling; from the proper interpretation of the point cloud - or the union of different point clouds - a Triangulated Irregular Network (TIN) of each maquette has been generated following five steps (Figure 3):
1. Editing of the point clouds (e. g. removal of outliers, filter for noise reduction, etc.).
2. Manual segmentation of the point clouds in order to identify the regular surfaces (e. g. the walls of the temples) which can be approximated to a flat geometry with small discrepancies (less than 2 mm). For each segment a discrepancy analysis has been performed in order to evaluate the acceptability of the simplification.
3. Interpolation of the flat surfaces through least square interpolation and topological reconstruction. During this phase a simplified mesh has been triangulated from each of the flat surfaces.
4. Creation of the final mesh, obtained from the union between the flat surfaces and the reality based high-resolution TIN generated from the acquired point clouds.
5. Texturization of the 3D model, exploiting the same coordinate system of the same model for different datasets.
The aim of these workflow is to obtain an optimized 3d model for data enrichment and digital visualisation, therefore weight, geometrical and radiometric completeness of the model are key factors.

## Best strategies for reality-based modelling

For the purposes of this research, beside the metric accuracy of the obtained models, three other principal aspects have been considered: rapidity, level of detail and model texture; in particular, the presence of a texture allows to provide valuable information about consistency of the materials that compose the maquettes.
The sensors more suitable for this type of digitisation have proved to be Canon EOS 5DSR (as regards the image-based approach) and Stonex Smart F6 (as regards active

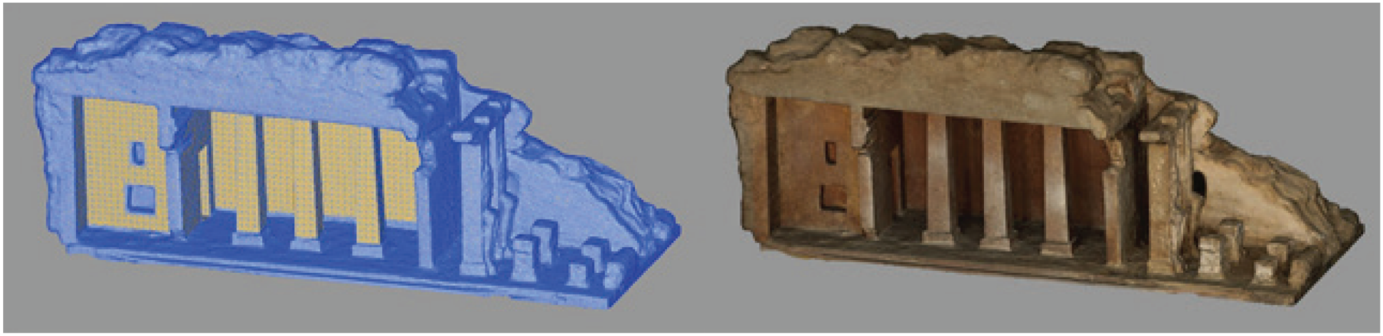

Fig. 3 - Example of final 3D model (with and without texture

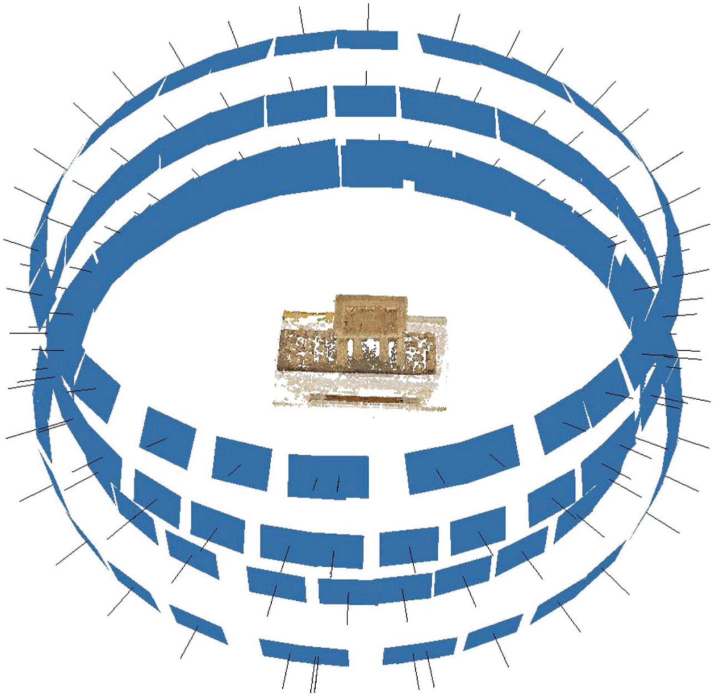

Fig.4 - Strategy of acquisition through circles with four different assets (left): in blue images alignment and in the middle the SfM based tie-points extraction. Positioning of the maquette and photogrammetric set (right)

sensors), in terms of level of metric accuracy, reached level of detail, quality of the texture and time-spending from acquisition phase to the creation of the final model.

The photogrammetric strategy has been proved as extremely competitive, not only as regards the texture, the level of detail and the millimetre-level accuracy, but also as concerns the rapidity of the acquisition. In fact, a rotating platform enabled to rotate the wooden maquettes in order to record multiple images from different points of view; this strategy optimized the focus control of the image and the movements of the photographic tripod, with a considerable reduction of the acquisition time (for each model about 100-150 images have been acquired in about 20-30 minutes). The acquisition of the images has been planned with four different camera assets in order to cover most of the surfaces of the maquette, even those hardest to reach because of complex morphology of these objects such as the parts covered by the colonnade or other obstruction (Figure 4). Nonetheless, the fixed point of view of the camera with the same background and changing position of the model negatively affect the relative orientation during the photogrammetric elaboration based on SfM algorithm. In order to overcome these problems, during the data processing phase masks (Figure 5) have been applied to the acquired images in order to perform the tie points extraction only in the areas of the images representing the acquired object.

As regard the Stonex F6 SR, rapidity and free movement typical of handheld solution are competitive factors, but ability to work without markers, colour recording, real time visualisation and short-range working distance increase its affordability in case of movable cultural heritage. In fact, the F6 SR is a structured light system able to capture 640000 points per second within a range of 25-50 cm with declared sub-millimetric accuracy. In the tested field, the coloured point cloud of a single maquette has been acquired in about 5-15 minutes, speeding up both the acquisition and processing phases. In fact, an integrated RGB camera permits to associate the material colour of the object to the point cloud captured with a triangulation infrared light-based principle (Figure 6). Nonetheless its metric accuracy and colour reproduction of the texture are still under analysis because influenced by operator behaviour, object material and lighting conditions.

## Design and implementation of a prototype procedure for information modelling

One of the aims of the research is the online publication of the surveyed models; this operation is possible using

Fig. 5 - Masking of the images: (left) image as acquired, (right) image with mask on the background

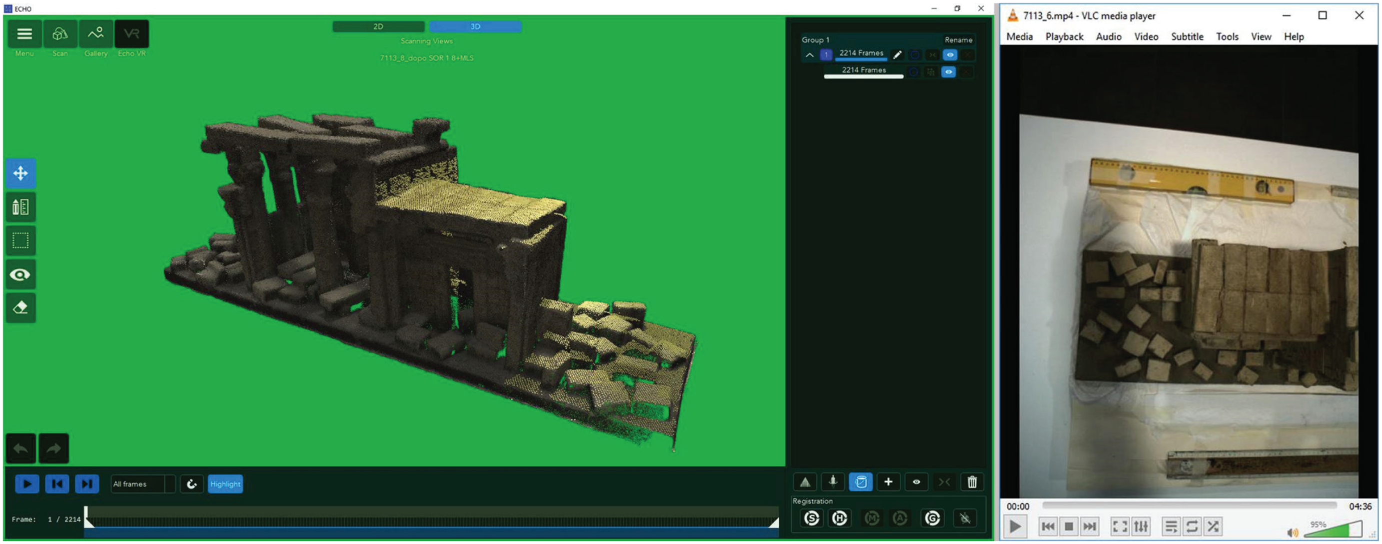


Fig. 6 - Right maquette of the temple of El-Hilla acquired by Stonex F6: Point cloud (left) visualised in the Echo software where the portion highlighted in yellow correspond to the frame captured at the same time with the RGB camera (right)

applications for the interactive navigation of high-resolution digital models. In addition to the visualisation, there is the aspect of dissemination of historical and managerial information. The model can be viewed and dynamically selected in some parts within a standard Web page; hotspots guarantee access to alphanumeric and multimedia information derived from historical, artistic and management surveys.
We start from the numerical model (mesh) that generally represents the object by means of a single polyhedral surface that morphologically, does not clearly express the parts that make up the acquired objects, except through the information coming from the texture projected on the model.
It was therefore decided to introduce an annotative phase to define parts of shapes (semantic recognition) and functions that make up the entire model. The models examined are small-scale reproductions of architecture, so the recognition of architectural parts is important for the understanding of the architecture maquette.
Data modeling for dissemination involves operations for the implementation of historical and artistic information relating to the entire maquette or some of its parts, an operation that in our research took place in a CAD environment and on two-dimensional images. The annotations foreseen are of different types:
a) general annotations - involve the entire model and provide a general description of the object (year of construction, author, historical and artistic context, etc.);
b) circumscribed notes - recognize parts of the object by providing functional information of the model, sculptural elements, etc.;
c) dot annotations - useful when shading and texture delimit parts of the model visually, so punctual reference can easily be associated with an area of the model.
The enriched model is then displayed and queried in a web

environment. The interoperability between CAD and Web environment is solved by means of a visual programming language (Grasshopper), an open tool for research that can be easily implemented even by non-informaticians.

We can mention in the annotative procedure for the Collection Information Modeling (CIM) different phases that are distinguished by the actions carried out and the relationship with space[8]. The workflow can be summarized in the following points:

1. creating images from the model;
2. notes on images;
3. remapping 2D annotations in 3D;
4. implementation of the 3DHOP html code for the reiterative parts.

## Generating images from the model

The annotative phase, being addressed to experts in different fields of knowledge, takes place in a simplified digital environment (on the XY system of the CAD environment), easily editable, so on two-dimensional images of the model. The images used are the result of the 3D model's projection on the faces of its bounding box (fig. 8). For complex models, characterized by internal spaces, the automated procedure is able to produce section images (Figure 9).

## Annotations on images

The images are then reopened in 2D space by a drawing software with which to trace points and areas of different complexity that can be represented with common digital drawing tools, but equipped with tools for enriching data of simple geometries. In figure 10, the annotation operation is illustrated on a front view of the minor temple of Abu Simbel on which to identify an information hierarchy in relation to the methods of annotation. When the image is selected, an annotation window opens in which you can provide information on the characteristics of the model: attribution, historical period of construction, materials, the object's journey through time, etc. For the semantic annotation, a closed polyline is introduced, even if irregular, in order to frame the portions of the image to which the data reported in the appropriate windows refer (Figure 10). The annotation strings can also be compiled with links to multimedia content and images.

## Remapping 2D annotations onto 3D model

The annotation phase is aimed at the compilation of an application (3DHOP) for the navigation of informed 3D

Fig. 8 - Beit el Wali, digital relief of the model (dimensions of the two halves 51 x 68 x 29 cm). Construction of the images by projection on the bounding box

Fig. 9 - Elevation and cross-section of the surveyed model

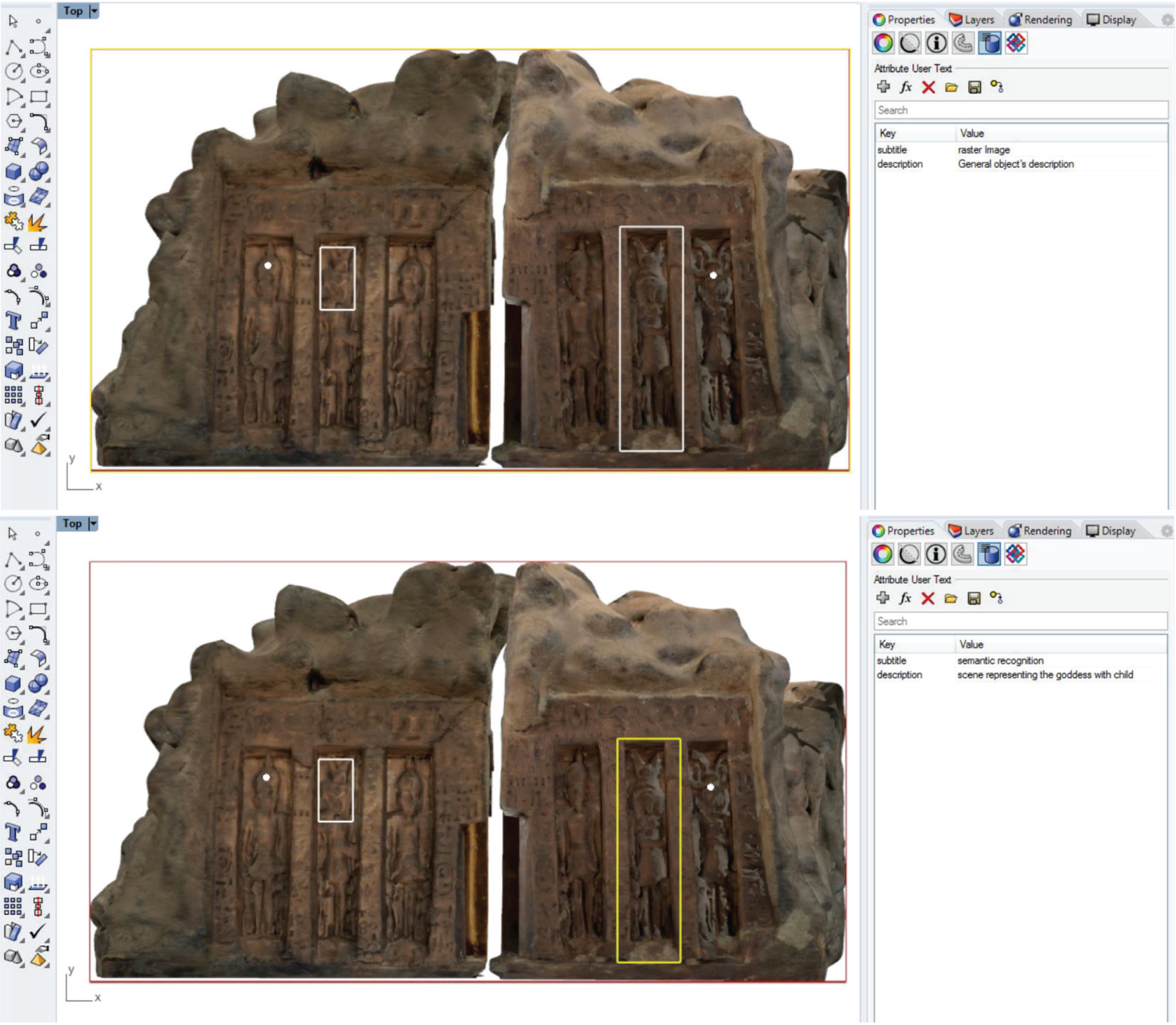


Fig. 10 - Annotation of geometry is done by following a hierarchy

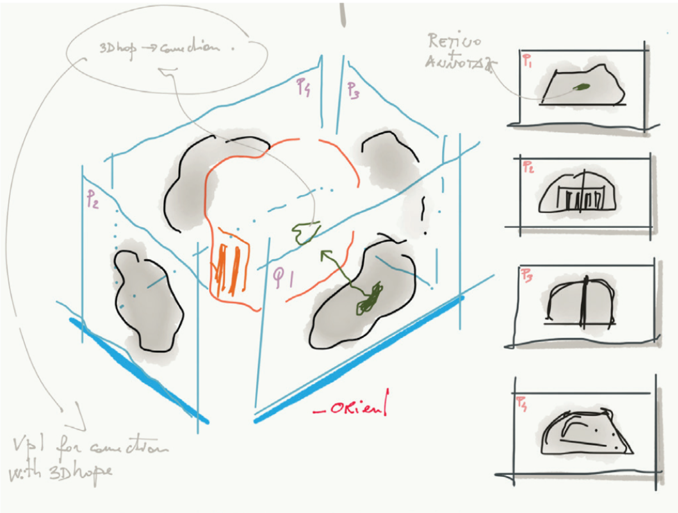

Fig. 11 - Remapping of the geometries and information from the 2D image to the acquired 3D model

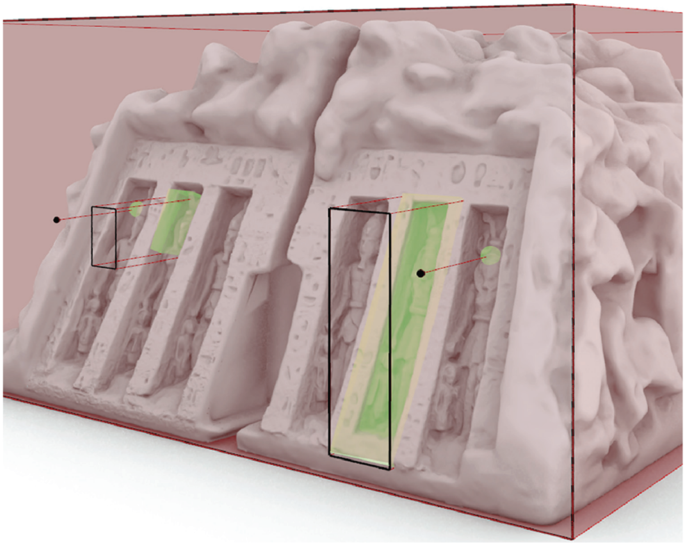

Fig. 12 - Remapped geometry from the picture, then projected on 3D model

models in a web space, the application combines the morphological data and the historical and artistic data of the examined models. Therefore, the attributes previously associated with flat images of the chosen subject, must be reported on interactive punctual or volumetric geometries capable of providing the information collected. The mapping phase foresees an implementation of the annotations made in 2D without dispersing the data collected in the previous phase, information that will be activated when the user selects the interactive elements created (hotspots) in the web portal. Remapping of the geometries and information from the 2D image to the acquired 3D model is done using typical NURBS operations[9] and Descriptive Geometry[10] (Figure 11)

The synthetic algorithm of the whole process foresees the orthogonal projection of the acquired object on the faces of the boundary parallelepiped that circumscribes the detected model; then the faces of the parallelepiped are oriented on the horizontal plane and saved separately. The image is textured on nurbs surfaces that are equipped with an internal two-dimensional reference system with two variables: u, v. Each annotative element can therefore be related to the two-dimensional system in the plane that will be transferred directly on the faces of the parallelepiped and then projected perpendicularly to the faces on the scanned 3D model. Each annotative element, during the transformation from the plane to the space, carries with it the original ID reference that connects it to the information database (Figure 12); this happens for the areal and punctual annotations.

## Parametric tools for implementing 3DHOP HTML code

Code for the graphic construction of the web portal consists of one part for the implementation of the portal layout and another part for the implementation of information on annotative objects.

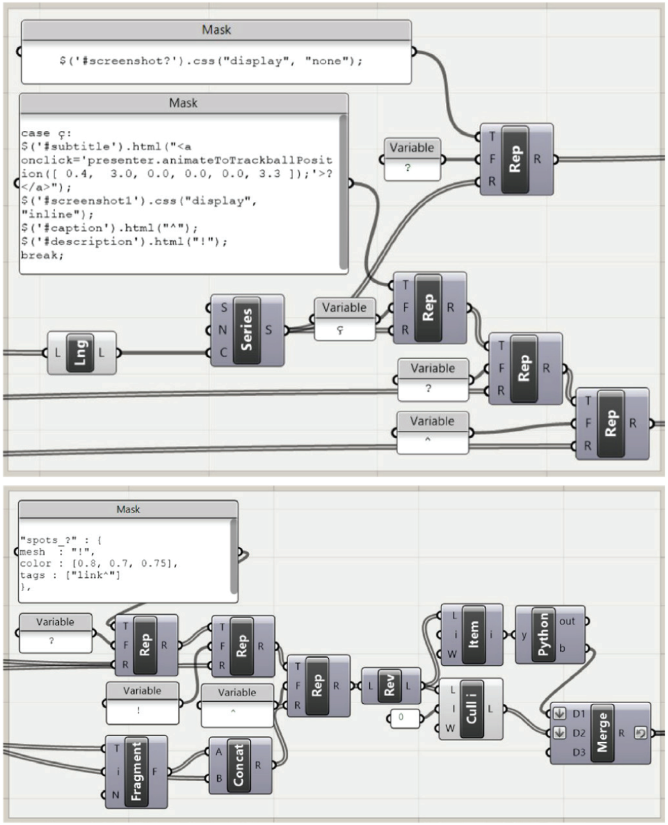


Fig. 13 - Textual mask structured according to the html syntax to create the consequentiality of the code parts

This last part can be defined as “parametric” because it is influenced by the number of annotations made on the images. As the number of annotations increases, the length of the code that manages the 3D objects of the portal varies, linking them to the notes described by the expert. For this reason, the basic code for the construction of the portal can be grouped in the following parts:

1. the part dedicated to the organization of the user interface layout;
2. the part describing the attributes and behaviours of the models in the scene.

The portions of code belonging to the second point, once mapped in relation to the basic syntax, can be replicated in relation to the number of annotative objects previously collected and associated in the CAD environment.

Through the use of the VPL language, a textual mask structured according to the HTML syntax has been created. The mask is composed of code fragments to be repeated in relation to the number of annotative geometries introduced. Special characters are placed inside the code as placeholders to identify the variables in which to place progressive elements to create the sequentiality of the parts of the code (Figure 13).

At this time the code is proposed as an open VPL diagram that allows the usual changes and updates during the research phase; once validated the procedure on several case studies, the code will be grouped into individual components in order to become an add-on for the VPL, which will be used for future operations of interrelation between CAD space and web portal. The result of the automation of the annotative enrichment phase, allows the almost complete compilation of the part of the code delegated to describe the attributes and behaviours of the models in the scene, generated by the 2D annotations.

Conclusions

The described procedure proposes innovative actions for the communication and dissemination of culture through digital products. The innovative aspects are mainly aimed at the application of informed modelling procedures for small-scale, non-architectural objects generally contained in museums. The possibility of digitizing the container and the content triggers a dialogue that has repercussions on the management and design of spaces and museum installations. The acquisition and the numerical representation of the shape has a sure consequence on the conception of installations that exploit technologies of Augmented Reality (AR) and Virtual Reality (VR)[11].

Adding information to the shape allows us to interact with the invisible values of the works. The invisible values we are talking about are generated over time and derive mainly from the historical and artistic vicissitudes of the digitised artefact. Values are not only a legacy of the past, but also the present proposes new indicators from social networks or the media in general; invisible properties become as important as the formal values of the work. The weighted relationship between these values introduces an attractive index to be used in the exhibition design of museum spaces[12]. In addition to communication and the design of cultural contents, the proposed procedure allows to renew the management aspects of the works. Among the data connected to the model there are also those for the museum's operators, which can be accessed from the object sheets[13]. These contain the logistical information but also the parameters that guarantee the well-being of the work within the exhibition spaces. The presence in the digital environment of data relating to the contents (Collection Information Modeling) and the container (Building Information Modeling) allows the creation of evaluation algorithms to support the setting up of temporary exhibitions.

## Notes

[1] Cf. Patrucco et al. 2018; Kersten et al. 2018.

[2] Cf. Guidi et al. 2017; Di Pietra et al. 2017; Adami et al. 2015.

[3] Cf. Rechichi and Fiorillo 2019.

[4] Cf. Lo Turco et al. 2018a.

[5] Cf. Rechichi and Fiorillo 2019.

[6] Cf. Patrucco et al. 2018.

[7] Cf. Kersten et al. 2018; Guidi et al. 2018; Gajski et al. 2016.

[8] Cf. Lo Turco, Calvano, Giovannini 2019.

[9] Cf. Di Marco 2017.

[10] Cf. Migliari 2008.

[11] Cf. Luigini, Panciroli 2018.

[12] Cf. Lo Turco, Calvano 2018.

[13] Cf. Manoli 2015.

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