Title:
An Exploratory Study on the Application of Reverse Engineering in the Field of Small Archaeological Artefacts

Authors:
Maura Mengoni, m.mengoni@univpm.it, Polytechnic University of Marche
Alma Leopardi, a.leopardi@pm.univpm.it, Polytechnic University of Marche

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Introduction:
In the recent decades, in the context of cultural heritage there was an explosion of innovation related to the application of 3D acquisition technologies, rapid prototyping and computer rendering and virtual prototyping techniques, to support the development and fruition of Digital documentation [6].

Some of the most important advances in Reverse Engineering techniques (e.g. evolution of the hardware and software tools, achievements in 3D reconstruction algorithms etc.) are reported in [3]. However, there is no methodology to identify which is the best technology in particular situation, where different needs and scales can be found (e.g. archaeology artifacts, sites, architecture and monuments, paintings and sculptures). This requires an interdisciplinary approach to specify the digital model parameters (resolution, accuracy, dimension) and the Reverse Engineering procedure based on conservation, rehabilitation and use of the artefact. This lack of a methodology is particularly noticeable when it comes to artifacts that, despite having small dimensions, present many particular details. In fact, according to the purpose or context of use of the digital model requires a high level of loyalty. This obviously impacts on the choice of adoptable technology, above all in reference to the level of accuracy that it allows to reach.

In this context, this paper proposed a structured methodology able to guide the choose of acquisition technology according to the model needs or parameters (e.g., accuracy and precision) and to the characteristics of the acquisition process (e.g., acquisition time, post-processing time, etc.). To validate the methodology, a case study is proposed in which two different acquisition technologies have been used, laser scanner triangulation and structure from motion SFM (based on photogrammetry), applied to a small artefact. This kind of artefacts, despite their dimensions, are rich of very small interesting details, that in some case, are very difficult to see with the naked eye. Consequently, when the scope and the use of 3D model require a very detailed rendering of these particulars, the model should be strictly faithful to the original object. To this end, the detail accuracy that is required for acquisition must be very high.

The paper is organized as follow: firstly, the pipeline of the proposed methodology to obtain the required digital model based on the best suited instrument and software is described in detail. Then, the test case is introduced and described. Results allow to highlight pros and cons of each considered technique in the consider context of application.

Main Idea:
The evaluation methodology is composed of six steps (Fig. 1) and integrates the achievements of previous research studies [4], [5]. It starts with the selection of the most suitable technologies for the scope, depending on the subject to be acquired and the type of results to be achieved. In fact, not all available scanning technologies are suitable for all cases and for this reason a preliminary benchmark is imperative; this is related also to analyse the subject artefact: material, size, topology, etc.

The second step includes the digitalization of the physical artefact with selected technologies (two or three) and the application of the procedure to obtain 3D models.

The third step regards the definition of a set of evaluation metrics used for comparison of the selected technologies performance and digitalization results. Set of evaluation metrics are as follows: acquisition and processing time, scans necessary to cover the object's surface, steps of the elaboration pipeline and related times. Other metrics could be accuracy of the models, units of measurement of 3D models and percentage of object's surface coverage.

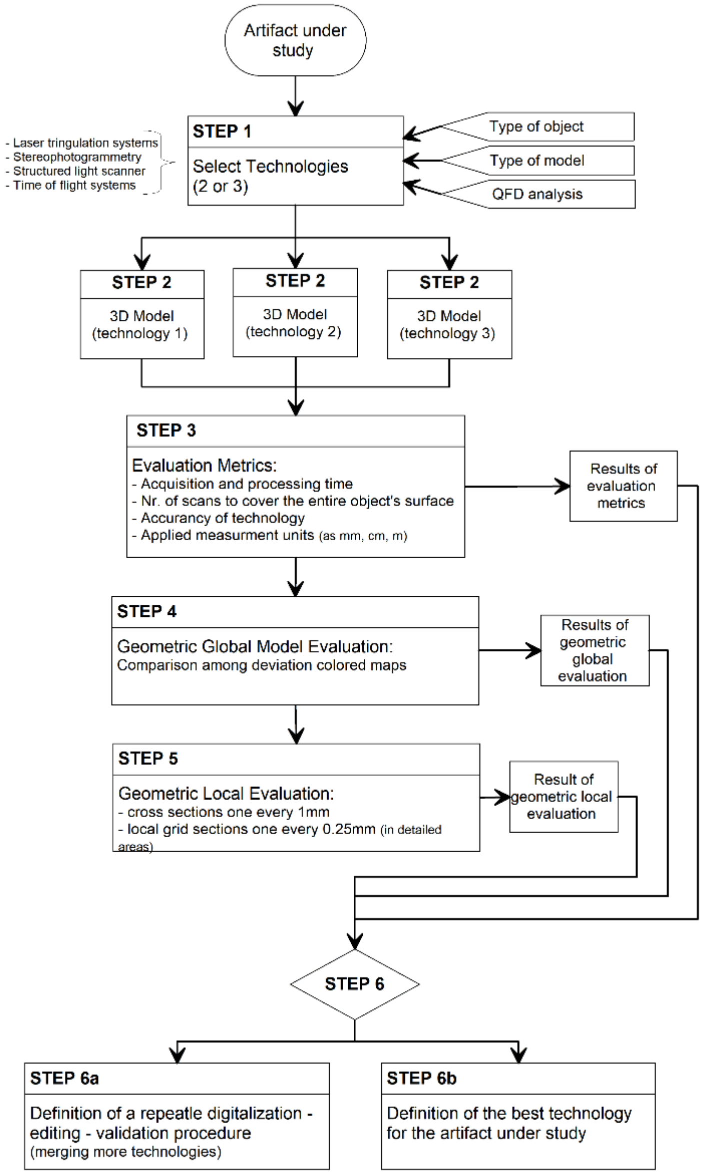

Fig. 1: Validation Methodology.

The fourth step foresees model alignment and geometric comparison; this step includes a general macroscopic comparison and an analysis of the obtained deviations. It is a critical point of the evaluated methodology. First of all, it started by imposing a tentative maximum deviation value of 1mm, to find the actual maximum deviation value. In a second phase of the fourth step, some reductions of maximum deviation value are checked to better understand the differences within analysed 3D models. The representation method is the colour map. In the small objects (as per this case of study) the deviation analysis focuses on areas where there are details, for which the maximum acceptable deviation should be significantly reduced. In this way, it is possible to detect model areas for which more detailed analysis should be done. By this methodology approach the results showed as coloured maps are very useful since more intuitive, however numerical values have not to be neglected.

The fifth step regards the evaluations of cross section focused in the areas of details. Cross sections are to be made every 1mm vertically and horizontally, so the intersect points of greatest interest are selected. In each cross section, the distance between each technology generated profiles are compared (always with the help of the coloured maps). In addition, the deviation values along the section can be extrapolated. Part of the fifth step, is the build-up of local grid sections in the areas of significant details. The grid is made up by vertical and horizontal cross sections every 0.25mm. At this point the deviation value can be extracted as before.

The sixth step is the definition of a repeatable digitalization, editing and validation procedure to be applied with both 3D scanning technologies and to assure the reliability of results or chose the best technology between the analyses ones.

The methodology has been validated for the study of “Venere di Frasassi”, that is one of the most important pieces exposed in the National Archaeological Museum of Marche (Ancona). The material of which is made this small statue (8,7 x 2,6 cm) is limestone, typical of the Frasassi clefts’ central part in the Apennines of Marche. This area is characterized by a lot of caves with stalactites, from which the statuette is supposed to have been obtained. Fig. 2 shows the some steps of the methodology application.

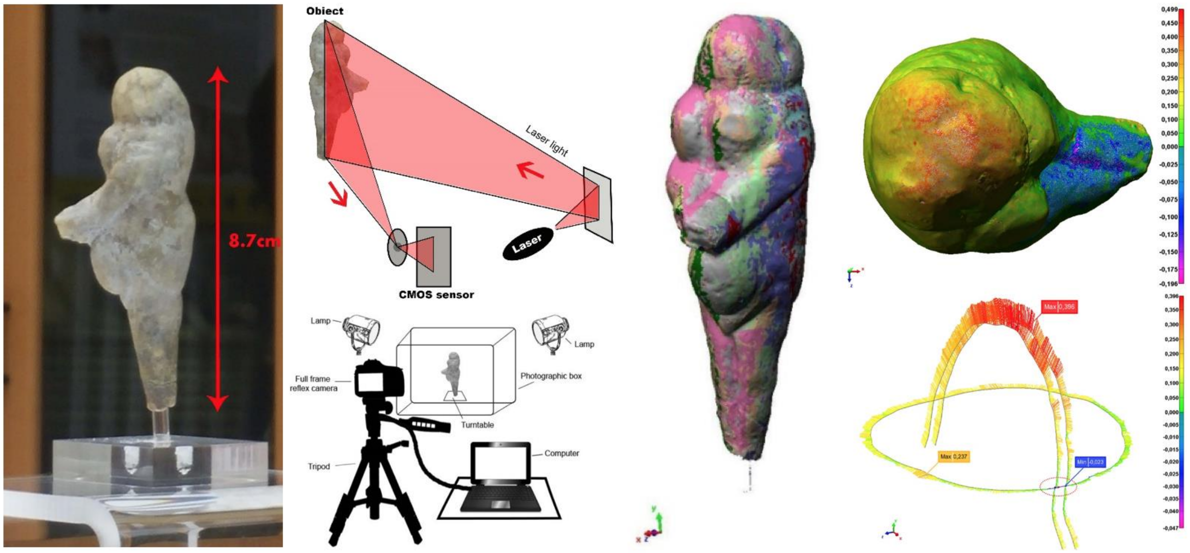

Fig. 2: From the physical sculpture to 3D reconstructed model comparison.

Tab. 1 reports the requirements for 3D digitizing technique selection. They are accuracy, precision, colour, scale and their importance weights based on the study needs. Quality Function Deployment (QFD) method is used to put in relation the requirements of the 3D model and the characteristics of the specific tools for acquisition and modelling. QFD is a customer-oriented approach to product innovation [4].

Tab. 2 shows the requirements of the 3D model for study conservation purposes.

Requirement	*3D model for public fruition*	*3D model for study/conservation*		
		Restoration	*Storage*	*Study*
Accuracy	3	9	9	9
Precision	3	9	3	9
Scale*	3	9	3	9
Colour	9	3	3	9
Cost (factor)**	9	0	3	3
Visual fidelity	9	3	3	3
Visual performance	9	3	3	3
Value: 0 not important; 3 important; 9 very important * Scale with respect to the real object ** Incidence of cost factor in the realization of the work				

Tab. 1: The Requirements

	Tool Specifications, acquisition, modeling / 3D model requirements for study/ conservation	Importance requirements	Importance requirements %	1 Accuracy (X e Y)	2 Precision (Z)	3 Resolution (Mpx)	4 Acquisition volume	5 Acquisition distance	6 Lighting	7 Acquisition time	8 Processing time	Total assigned value (row)	Technology: Laser scanner	Technology: Photogrammetry
1	Lightweight file	3	10.0	3	3	5	5					16	3	1
2	Real Scale	5	16.7	5	5	5		3				18	5	1
3	Fidelity	5	16.7	5	5	1						11	5	3
4	Colour	2	6.7			3			5			8	1	5
5	Cost	2	6.7				3			5	5	13	5	3
6	Detail level	5	16.7	5	5	5	3	3				21	5	3
7	Time of realization	3	10.0				5			5	5	15	5	5
8	Procedure 's consistency	5	16.7					3	3	5	5	16	5	4
	Total	30	100									118		

Tab. 2: QFD application in case of conservation

Conclusion:
This work shows an evaluation methodology to compare and define the most suitable technology with a determinate object. In this test case both technologies are valid for a little objects, because they show what is invisible to the naked eye. The results of the study point out the weakness of SFM in case

of need to have very accurate and real scaled model and non-expert personnel to carry out acquisitions.

However, the best solution is the integration of both technologies as SFM is good to achieve the artefact fac-simile to interact with visitors by novel human-computer interfaces while 3D scanner is a key technology for the velocity of acquisition and the high resolution of the point cloud.

This study and followed discoveries, show the increased need to scan the cultural heritage, both to preserve it and to enhance it with innovative applications. Future work will be focused on the collection of more digital artefacts and on the definition of a combined techniques to superimpose models different for accuracy, resolutions and provided information about colours and textures.

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