

# Analytical Comparison of Optical Methods to Evaluate the Potential of the Photo Modelling Technique for Cultural Heritage

**Sofia Catalucci**  
sofia.catalucci@gmail.com

**Fabio Bianconi**  
**Marco Filippucci**  
**Gianluca Rossi**  
University of Perugia  
Perugia, 06125, Italy

## Abstract

A comparison of commercial 3D photo modelling software applications is presented. Starting from the simple acquisition of digital images, and based on the principles of photogrammetry, photo modelling represents a user-friendly and economical way to digitally preserve and three-dimensionally reproduce cultural heritage objects. The aim of this research is to evaluate the potential offered by the technique by reviewing a range of commercial and opensource software applications and making a comparison with reference data points obtained from a structured light 3D scanner. A marble artefact was selected from the collection of the Galleria Nazionale dell'Umbria di Perugia (Italy) as a test case for the analytical comparison of these two optical techniques.

**Keywords:** photo modelling, 3D modelling, cultural heritage, survey, measurement criteria

## Introduction: Photo Modelling

Due to the recent development of computer graphics technologies along with an increasingly competitive demand for hardware and software solutions, the optical acquisition of three-dimensional data represents an innovative tool compared to more traditional techniques. Based on the use of a simple digital camera, photo modelling (Buscemi et al. 2014; Filippucci 2010) is an optical technique based on the principles of photogrammetry, which is able to yield results comparable to those of commercial optical instruments, such as structured light 3D scanners.

This technique is accessible to a wide range of users because of the low-cost nature of the instruments involved. Digital cameras take the place of expensive machines, instruments, and devices, and opensource software and freeware are widely available along with commercial solutions.

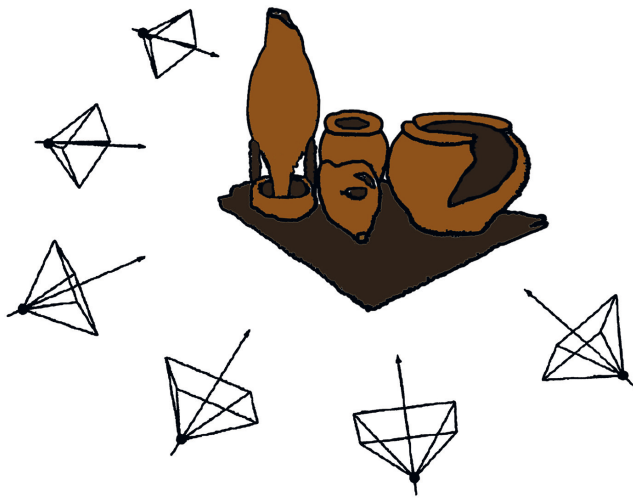
Photo modelling integrates survey, 3D modelling, and representation (De Luca 2011), giving the possibility to obtain highly detailed three-dimensional surveys in fields such as cultural heritage. As a conservation tool and developer of cultural information,

the use of this technique is helping to promote virtual tourism in museums and is employed for teaching purposes and for restoration (De Luca 2009).

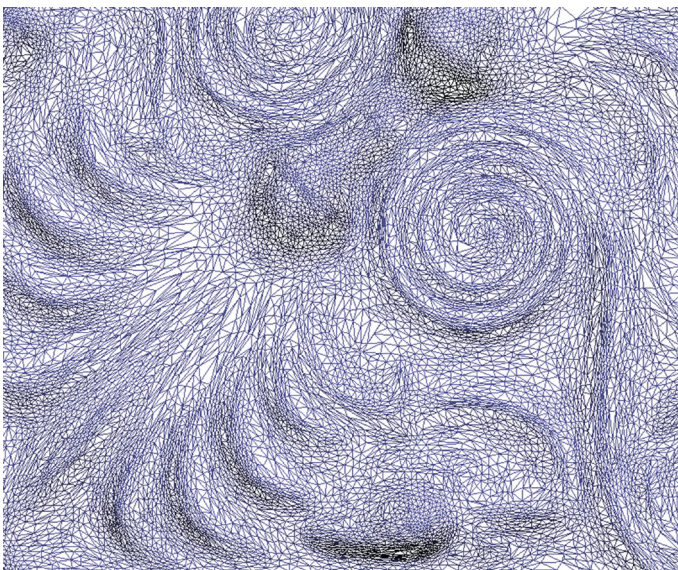
The reconstruction of 3D models starts from a preliminary analysis of the environmental conditions (i.e. environmental light) and the object to be measured. The first step involves the acquisition of several images with a common digital camera, with those images containing spatial information of the object to be measured. The result strictly depends on the acquisition plan and on the quality of the images. For this reason, the light of the surrounding scene must be as uniform and homogenous as possible. As well, the object must be accessible from different angles in its entirety (Figure 1).

The reconstruction steps are the following:

- a. image acquisition
- b. image processing
- c. point cloud reconstruction (sparse cloud and dense cloud)
- d. 3D model reconstruction (triangular mesh shown in Figure 2)
- e. editing, texturing and visualisation.



**Figure 1.** Image acquisition planning: ideally the pictures need to be taken moving around the vertical axis of the object at  $360^\circ$  for isolated objects and  $180^\circ$  for flat ones, with the camera oriented in the range of  $30^\circ / 45^\circ$ .



**Figure 2.** Triangular mesh reconstruction.

The Structure-from-Motion (SfM) algorithm (Szeliski 2010) is the main principle of the image processing step (b): the algorithm processes the images and automatically matches the common key points of a series of pictures, identifying a set of sparse correspondences and the positions of the cameras. After the extraction of significant points (common to three or more pictures), the algorithm obtains photographic parameters and matches the homologous points in multiple images, finding the spatial 3D coordinates of each point. A *sparse reconstruction*

algorithm obtains the real coordinates in  $x$ ,  $y$  and  $z$  for each key point, materialising them in a scattered point cloud (c), a cloud of low-density points. A *dense-matching* algorithm increases the number of points in the sparse cloud, giving as output a dense point cloud (Figure 3).

## Test Case and Experimental Set-Up

The experimental set-up is based on a comparison between a commercial structured light 3D scanner (Creaform GO!Scan50) and a DSLR camera (Canon PowerShot SX30 IS) for photo modelling reconstruction (Figure 4), combined with several point cloud processing software solutions. The Creaform Go!Scan50 is a structured light 3D scanner (LED white light) with a large field of view (scanning area,  $380 \times 380$  mm). The accuracy goes up to 0.100 mm and the resolution, 0.500 mm. As a test case, the selected artefact is an italic marble lion's head, "Doccione di fontana" of mid XIII century, from the collection of Galleria Nazionale dell'Umbria di Perugia, Italy (Figure 4).

## SfM Photogrammetry Software Solutions

As a preliminary evaluation of the potential of photo modelling, a range of 3D point cloud processing software applications are classified by data processing time, difficulty of usage, and cost, and are subdivided into 3D web-service, open-source software, and commercial solutions (Figure 5).




Agisoft PhotoScan and Photomodeler Scanner are advanced and detailed commercial software applications based on photogrammetry principles. Visual SfM toolkit, based on the SfM technique, gives outputs comparable to those of a 3D laser scanner. Arc3D is a freeware tool and allows users to upload images to an online web server and receive a full three-dimensional scene. Autodesk Remake (low cost) and Autodesk 123D Catch (freeware) enable






**Figure 3.** The sparse reconstruction algorithm transforms the x, y and z coordinates of common key-points in a scattered point cloud (left). The dense-matching algorithm increases the amount of data key-points giving as result a dense point cloud (right). Artefact selected in the collection of the Archaeological Museum of Amelia, Italy.



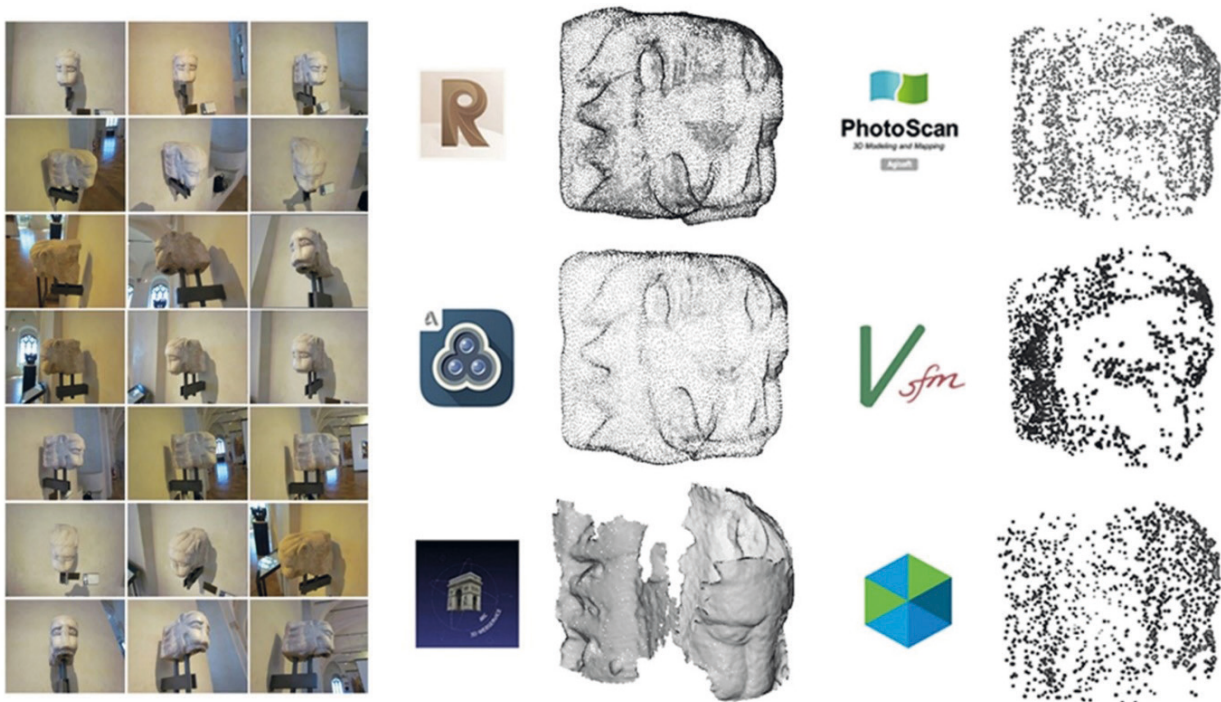
**Figure 4.** Structured light 3D scanner Creaform GO!Scan50 (left) and DSLR camera Canon PowerShot SX30 IS (centre). Test case: italic marble lion's head, "Doccione di fontana" (right), Galleria Nazionale dell'Umbria di Perugia, Italy.

	<b>Agisoft Photoscan</b>	
	Time data processing	average
	Difficulty	average
	Cost	160€ ca.
	<b>PhotoModeler Scanner</b>	
	Time data processing	slow
	Difficulty	difficult
	Cost	2240€ ca.
	<b>Visual SfM</b>	
	Time data processing	average
	Difficulty	average
	Cost	free

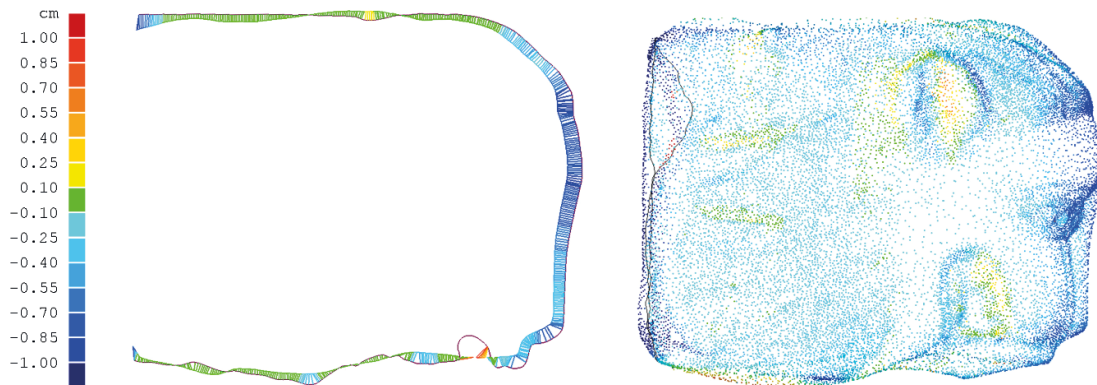
	<b>Arc3D</b>	
	Time data processing	fast
	Difficulty	very easy
	Costo	free
	<b>Autodesk ReMake</b>	
	Time data processing	average
	Difficulty	easy
	Cost	396,50€ / year
	<b>Autodesk 123D Catch</b>	
	Time data processing	fast
	Difficulty	very easy
	Cost	free

**Figure 5.** 3D point cloud processing software: Agisoft PhotoScan, Visual SfM, Arc 3D, Autodesk ReMake, Autodesk 123D Catch and Photomodeler Scanner.





**Figure 6.** Images acquisition and data processing: test point clouds processed and filtered with the selected software solutions.



**Figure 7.** Heat map of the comparison between reference polygonal model and test point cloud: cross section visualisation (left) and distributed colour map of the computed deviations (right).

the user to achieve rapid and automatically acceptable results with a good level of detail.

The 3D point cloud processing procedure begins with the navigation and filtering (i.e., cleaning, noise removal, outlier removal) of the data points acquired (Bianchini 2008). Once the point cloud is satisfactorily edited, it can be converted into a polygonal model (triangular mesh). The meshing starts from the input of data vertices, then edges and faces are generated. The result obtained is a set of vertex coordinates converted into a polygonal surface (Russo et al. 2011).

## Data Processing and Results

A “measure” is a range of values, acquired with the purpose of controlling a process, performing the calibration of an instrument or allowing the physical understanding of a partially known phenomenon (Rossi 2010). Referring to this assertion, the reliability of the photo modelling technique is tested by considering the graphic representations of 3D and 2D metric comparisons between the test point clouds (Figure 6) and the reference .stl polygonal model from the structured light scanner.

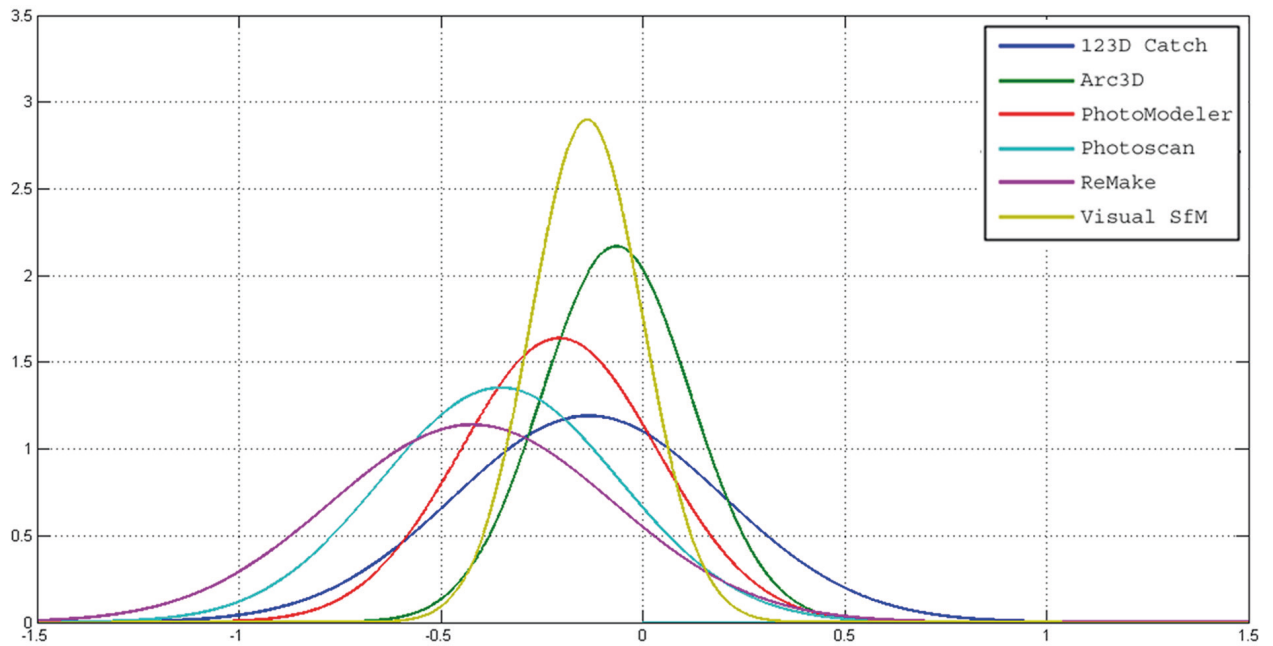


Figure 8. Probability density diagram.

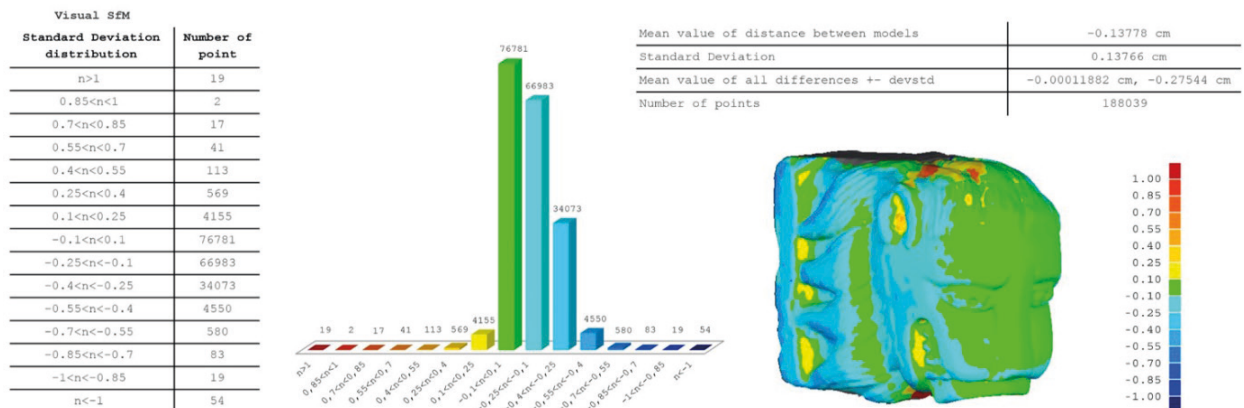


Figure 9. Comparison with reference model and results (Visual SfM): a considerable amount of surface presents deviations within the range of -0.25 and +0.1 cm.

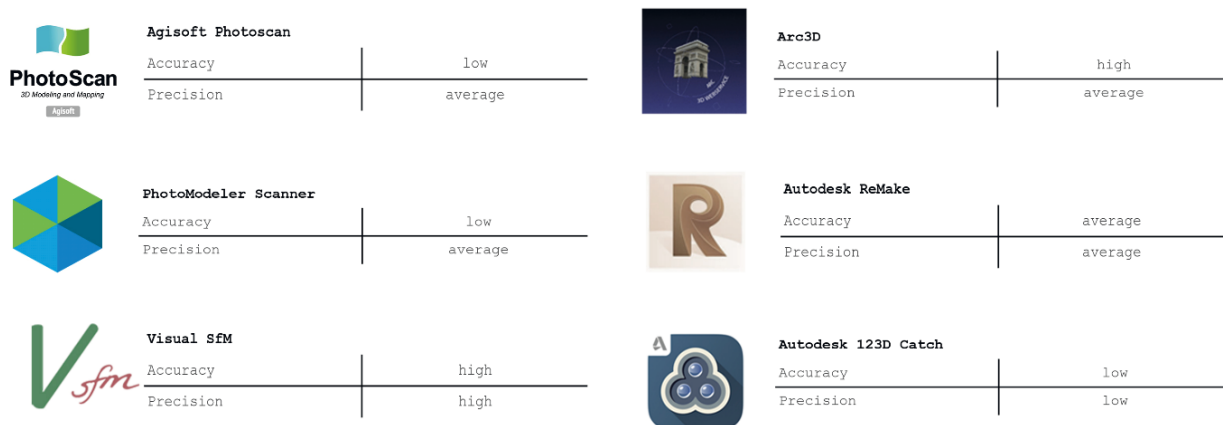


Figure 10. Results summary: accuracy and precision of the results obtained after the comparison between photo modelling technique and structured light 3D scanner.

The alignment for the comparison is made at first manually, identifying point pair correspondences between source and reference objects. After the manual pre-alignment, a Best-Fit Data to Reference model algorithm is used to match the source point cloud with the reference .stl within a maximum distance of 0.1 cm. After the alignment is completed, the analytical comparison is executed using a commercial metrology inspection tool. In order to assess which data points are considered as outliers, a range of 15 intervals of acceptability is set (between  $\pm 1.0$  cm deviations).

The heat map of the deviations is distributed on the point cloud, rendered with a customised colour map (Figure 7). From the comparisons obtained, it is possible to export a matrix in .csv format of the spatial coordinates (x, y, and z) of the data points (each point of the test cloud and its correspondent nearest neighbour on the reference surface) and the values of the mutual distances for each pair of data points. The results of the probability density distributions of the test point clouds processed with the selected software solutions are shown in Figure 8. The best results are given by the comparison between the reference .stl and the point cloud processed with Visual SfM toolkit (Figure 9).

## Conclusions

In this work the potential of the innovative and low-cost photo modelling technique was presented. The experimental tests show that the results achieved are comparable to the outputs given by commercial instruments, such as a structured light 3D scanner. Additionally, the use of freeware point cloud processing software solutions is a bonus given the affordability of this technique for any type of user. Based on the comparison of results, the Visual SfM toolkit represents a good compromise between accuracy and precision (Figure 10).

One of the important applications of this technique is the possibility to preserve the historical memory of Cultural Heritage objects, allowing for the reproduction of damaged artefacts, as well as the development of virtual catalogues of museum collections, with the aim to consider three-dimension-

al models as a reference for restorations. With the recent development 3D printing, photo modelling easily allows for the duplication printed versions of any artefact to temporarily or permanently replace objects damaged or degraded. In conclusion, photo modelling is an efficient technique, able to economically preserve historical and cultural heritage and guarantee restorative measurement authenticity.

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