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Comparison between two non-contact techniques for art digitalization

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Abstract. Many measurements techniques have been proposed for the "digitalization of objects": structured light 3D scanner, laser scanner, high resolution camera, depth cam, thermal-cam, ... Since the adoption of the European Agenda for Culture in 2007, heritage has been a priority for the Council's work plans for culture, and cooperation at European level has advanced through the Open Method of Coordination. Political interest at EU level has steadily grown cultural and heritage stakeholders recently highlighted in the Declaration on a New Narrative for Europe: "Europe as a political body needs to recognize the value of Cultural Heritage". Photomodelling is an innovative and extremely economical technique related to the conservation of Cultural Heritage, which leads to the creation of three-dimensional models starting from simple photographs. The aim of the research is to understand the full potential offered by this new technique and dedicated software, analysing the reliability of each instrument, with particular attention to freeware ones. An analytical comparison between photomodelling and structured light 3D scanner guarantees a first measure of the reliability of instruments, tested in the survey of several Umbrian heritage artefacts. The comparison between tests and reference models is explained using different algorithms and criteria, spatial, volumetric and superficial.

1. Photomodelling and Cultural Heritage

The innovative technique of photomodelling is a modern frontier of the survey, based on the extraction of information from digital images, which can be considered as experimental [1]. Photomoeelling is lexical neologism, combination of the words photography and three-dimensional modelling. Through the common camera, the operator is able to extract spatial information of the elements present in a scene, acquiring multiple frames. This technique introduces a new working environment, which enables the restitution of buildings, objects, archaeological finds, based on the integration between



survey, 3D modelling and representation [2]. The incessant improvement and economic progress of tools mean that these new techniques are accessible to an incredible range of users. The digital camera replaces expensive devices such as laser scanners or 3D structured light scanning systems and open source software and freeware ones come up beside the commercial products.

During the last years, these techniques are having great success in the field of conservation and enhancement of cultural heritage, proving to be one of the major breakouts of passive detection. In fact, photomodelling is the result of the digital revolution that influenced all the artefacts of our culture, from images to tools for interpretation and design, and it can be considered as a development of photogrammetry. In fact, one of the most interesting aspects in the field of Cultural Heritage is the possibility to perform three-dimensional surveys, which allows the virtual reconstruction of the objects in a scenario with high level of details. This procedure is recognized not only as a conservation tool, to promote the virtual tourism in museums, and as a teaching resource, but also for purposes of recovery, restoration and enhancement of Cultural and Environmental Heritage. The survey and the representation acquire an essential role in the protection of assets. Digital contents contribute to the development and accessibility of cultural information and three-dimensional representation becomes effective support, in order to document the status of the goods concerned [3].

1.1. Structure from Motion, algorithms and the photographic survey

Photomodelling is based on the methodology of the Structure from Motion [4], the calculation process that allows the geometry reconstruction of an object through the automatic collimation of points from a series of digital images. After the extraction of significant points, named features, well recognizable in three or more frames, the SfM obtains photographic parameters and crosses the homologous points on multiple images, finding the spatial coordinates of each point (figure 1). At first, the dedicated software aligns the various images in three-dimensional space, generating a 3D point cloud. The following step is the reconstruction of a triangular mesh, processed and textured, with a high number of polygons and a clear geometry of the models. The editing step is always necessary, like various elaborations of smoothing, decimation of the faces, closure of gaps, in order to make suitable the generated model [5].

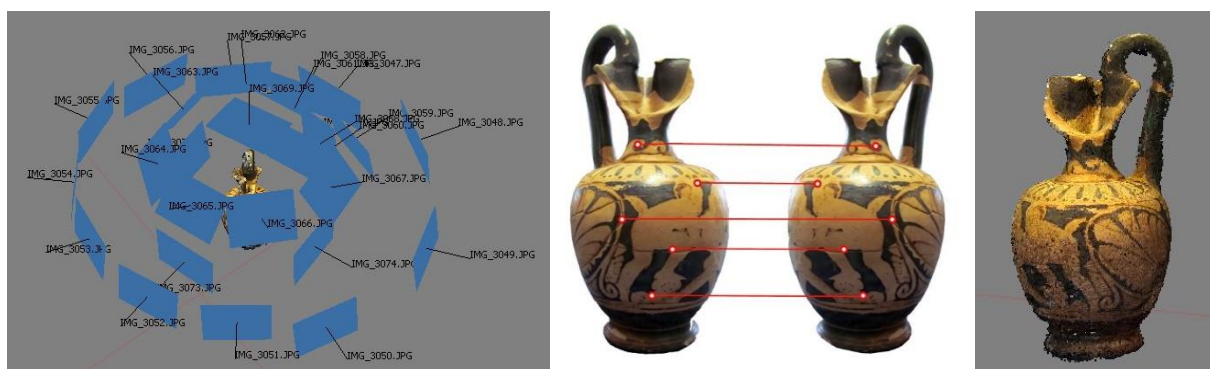


Figure 1. Matching: identification of homologous points (features) between each image.

Photomodelling is different from photogrammetry thanks to the introduction of image or multi-image matching algorithms, which allow the complete three-dimensional reconstruction procedure in automatic [6]. The comparison between the pairs of frames is carried out by decomposing the photographs in a grid of small squares and founding chromatic analogies between them. The calibration of the camera is automatic, as the reconstruction position of each picture in the space; for each key point the real coordinates x,y,z are obtained, materialized in three dimensions in a scattered point cloud, a cloud of low-density points (sparse reconstruction). In the next step the sparse cloud is increased in a dense point cloud (dense reconstruction) thanks to the SfM dense-matching algorithms, developed in photogrammetry: the data relating to the position x,y,z of each key point are used to

recognize and extract the coordinates of all the surrounding elements (figure 2). The procedure of SfM, coupled to the algorithms of dense image-matching, allows the reconstruction of the 3D geometry of a scene (Structure), identifying a set of sparse correspondences, and the positions of cameras (Motion).

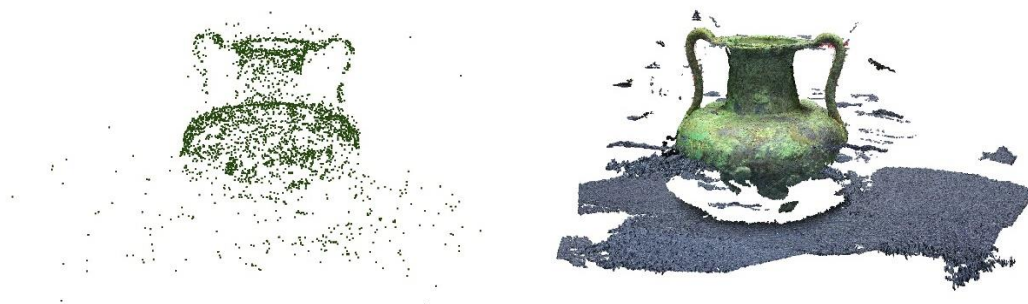


Figure 2. Sparse reconstruction and dense reconstruction of a bronze artefact of Archaeological Museum of Amelia (TR), Italy.

Photography, the best representation of reality, acquires an innovative role: pixels represent spatial coordinates x,y,z of sparse and dense point clouds, the first shapes of a model. Each step of photomodelling strictly depends on the photographic strategy and on the quality of images. These criteria influence the results obtained following the alignment of frames, manually or automatically. It is really important that users have to evaluate parameters like the sharpness, the brightness and the contrast of the photos, particularly to obtain good results during the orientation of cameras. The lighting of the scene has to be as uniform as possible: overshadowed parts or strongly illuminated ones could cause issues during the reading of information in the images. For these reason it is also important to remove the flash. Users have to analyse the colour characteristics of the scene: objects with particular chromatic variations are better than aseptic scenes. The object must be accessible to the photographic survey entirely, from different angles as much as possible. The ideal plan for photographic survey is to take pictures, going around the vertical axis of the object at 360° for isolated one and 180° for flat plate one, at a constant distance from it and with the camera oriented between $30^\circ / 45^\circ$ downwards. The number of picture is not fixed, although it is important that the same images are not repeated too many times. In order to avoid the repetition of the same information, the photographic survey should be scheduled at the beginning. The number of images depends on the dimensions of the object to survey, which must be photographed in its entirety as much as possible (figure 3).

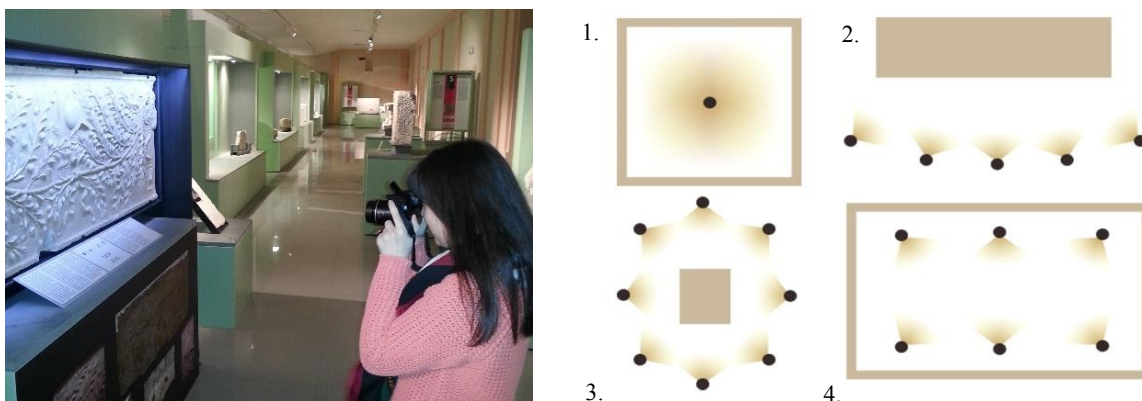


Figure 3. Photographic survey in the Archaeological Museum of Amelia (TR), Italy. Close environment, one point of view, multiple pictures like a 360° panorama (1.); a flat plate object, 180°

pictures in front of the object, multiple point of view (2.); isolated object, 360° pictures around the object, multiple point of view (3.); close environment, multiple point of view and multiple pictures (4.).

The 3D reconstruction steps starting from the analysis of the environment and the object to detect, until the reconstruction and the visualisation of the complete 3D model:

- preliminary study and photographic survey;
- preliminary image processing;
- two stages of point cloud restitution (sparse and dense);
- 3D model definition (mesh/triangular weave);
- editing, texturing and visualisation.

The 3D modelling procedure is always the same: the first operation is the manipulation of the point cloud, created from a set of photographs. Once created the point cloud, models can be imported into a mesh processing and editing software editing. The creation of three-dimensional model is called “triangulation”: starting from the input data vertices, edges and faces are generated. The result obtained is a set of coordinates, which is converted into a polygonal surface [7] [8].

MeshLab [9] and Geomagic Studio [10] are examples of applications in which it is possible to perform manual editing of data, merge, scale, align different surfaces, creating a three-dimensional surface with the aid of different algorithms. The first is an open-source software that provides a simple to use set of tools for editing, cleaning, repair, control, representation and conversion of meshes; the second is a commercial software, with editing and advanced surfacing commands, partially automatic. During the research, Poisson Reconstruction [11] and Ball Pivoting [12] [13] algorithms on MeshLab reproduced the 3D models, at the end scaled on Geomagic Studio with different approaches in relation to the functions available.

2. Dedicated software and instruments

This research involved the analysis of the varied overview of software instruments available today with the aim to understand the potential of these tools. Software were evaluated by their time data processing, difficulty of use, accuracy and precision of results. The applications proposed are also divided into 3D web-service, open-source software and commercial software (figure 4).







	Autodesk ReMake	Time data processing	average		Autodesk 123D Catch	Time data processing	fast	
		Difficulty	easy				Difficulty	very easy
		Cost	396,50€ / year				Cost	free
	Visual SfM	Time data processing	average		Arc3D	Time data processing	fast	
		Difficulty	average				Difficulty	very easy
		Cost	free				Costo	free
	Agisoft Photoscan	Time data processing	average		PhotoModeler Scanner	Time data processing	slow	
		Difficulty	average				Difficulty	difficult
		Cost	160€ ca.				Cost	2240€ ca.

Figure 4. Dedicated software, different from time data processing, difficulty of use and costs.

Agisoft PhotoScan [14], a commercial software, is the most efficient solution for completeness of results; the instrument has provided results during the experiments with the largest number of points. At the same time and with greater accuracy and precision Visual SfM software [15] is the best solution in the reproduction of point clouds, in case of good surrounding conditions. This freeware tool is based on the Structure from Motion technique and it is able to reconstruct elements similar to Laser Scanner products, following a semi-automated workflow, starting from the alignment of frames until the matching between the homologous points. Arc3D [16] is a freeware tool, which allows users to upload images to an online web-server and to obtain a full three-dimensional scene. Arc3D, as Visual SfM, depends on the surrounding conditions of light and space of the scenario. Autodesk Remake [17] and Autodesk 123D Catch [18] are applications, the first low-cost and the second freeware, to get quickly and automatically a borderline result with an average level of details, to print or to be loaded and displayed on an online platform. Photomodeler Scanner [19] software, a commercial tool based on the principles of photogrammetry, permits to follow every step of 3D reconstruction, from the orientation of pictures, until the restitution of a textured mesh.

The purpose of the research is to know and test different types of software and identify among these the best solution, able to return as much as possible complete outcomes.

3. The reliability of instruments

In order to provide scientific results, this research has considered an analytical comparison between photomodelling and structured light 3D scanner Creaform GO!Scan50 [20], tested in the survey of “Doccione di fontana”, Galleria Nazionale dell’Umbria in Perugia, Italy. Two different criteria, a spatial one and a surface one, explained the comparison between a reference mesh (the one created with structured light 3D scanner) and testing ones, extrapolating data relating to the distribution of deviations between triangular elements that compose models. Other experimentations have been proposed considering the surveys of several museum artefacts from the collection of the Archaeological Museum of Amelia (TR), Italy. In this case, three objects have been chosen and the test clouds have been compared with the ones recreated on Agisoft Photoscan, which provided results with the highest number of points.

The work was divided into three steps (figure 5):

- acquisition and processing of images relating to dataset samples;
- elaboration and editing of 3D models;
- alignment and comparison of tests with reference models.

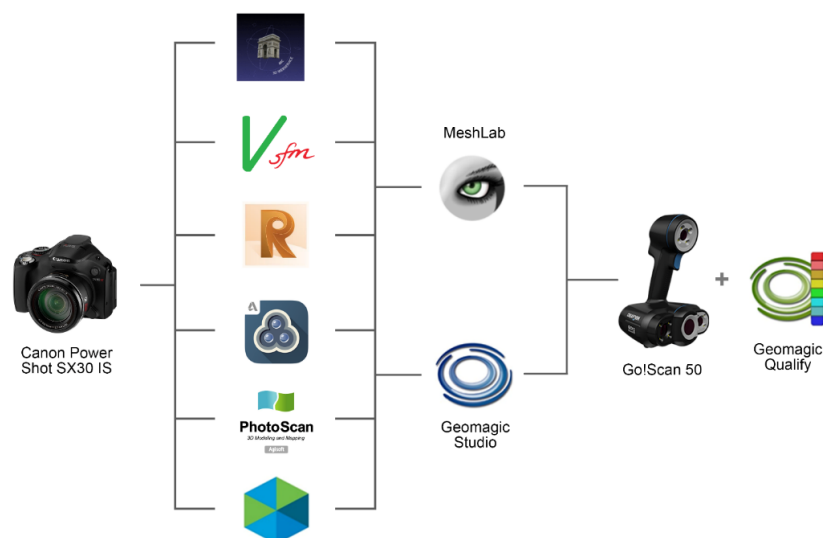


Figure 5. The workflow: from the photographic survey to the comparison between models.

3.1. Measurement, criteria and comparisons

A "measure" is a range of values, acquired with the purpose of controlling a process, perform the calibration of an instrument or allow the physical understanding of a partially known phenomenon [21].

Referring to this assertion, the research considered different methods of analysis (figure 6), a superficial one, a spatial one and a volumetric one:

- comparison of point clouds by a map that identifies the distance of each 3D data point;
- comparison of 2D profiles;
- comparison through a volumetric algorithm.

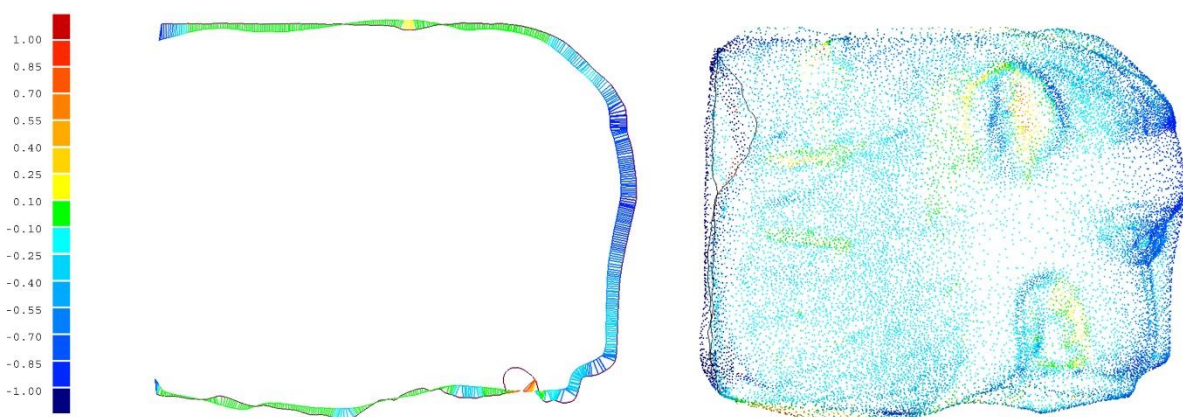


Figure 6. Comparison criteria between reference and test models: comparison between sections and between point clouds.

The tests have been carried out by means of analysis algorithms, which provide variances and deviations between geometric entities in the space, using the software Geomagic Qualify [22]. The analysis was executed by setting a spectrum of 15 intervals of values between -1.0 and +1.0 cm deviation, the range of acceptability; the range between -0.1 and +0.1 cm is the optimum correspondences between the test and reference points. The software applies the colour map of deviations of each coordinate of the point cloud, distributed and projected on the faces of the 3D model. Observing the maps generated, it is possible to notice sometimes areas coloured in grey or missing parts of the models, which the software cannot compare.

The comparison involved the creation of 2D and 3D maps of the deviations, from which it was possible to derive a matrix in .CSV format of the spatial coordinates x,y,z of models points, test and reference ones and the values of the mutual distances for each pair of points. By importing the matrix into MATLAB it was possible to process data in the histograms of frequency, the absolute values of deviations and the curves of the probability density.

3.1.1. Comparison between instruments: case study of "Doccione di fontana", Galleria Nazionale dell'Umbria in Perugia, Italy

Object of the survey is a lion's head in italics marble, dating back to the middle of XIII century.

The reference model was realised using a 3D structured light scanner Go!Scan50 of the Engineering Department in the Università degli Studi di Perugia. This measuring instrument allows through the use of a structured light and the shooting with multiple cameras to capture surface portions of any object. These surface portions are then joined by a dedicated software, which allows to rebuild the three-dimensional object in its entirety, both in its shape, its surface and its microstructure. This

instrument can measure with details in the order of tenth of a millimeter on objects of dimensions in a range of 10 cm and a few meters.

The test models were realised using six photomodelling software, starting from the same number of images, captured during the photographic survey in the Galleria Nazionale dell'Umbria (figure 7).

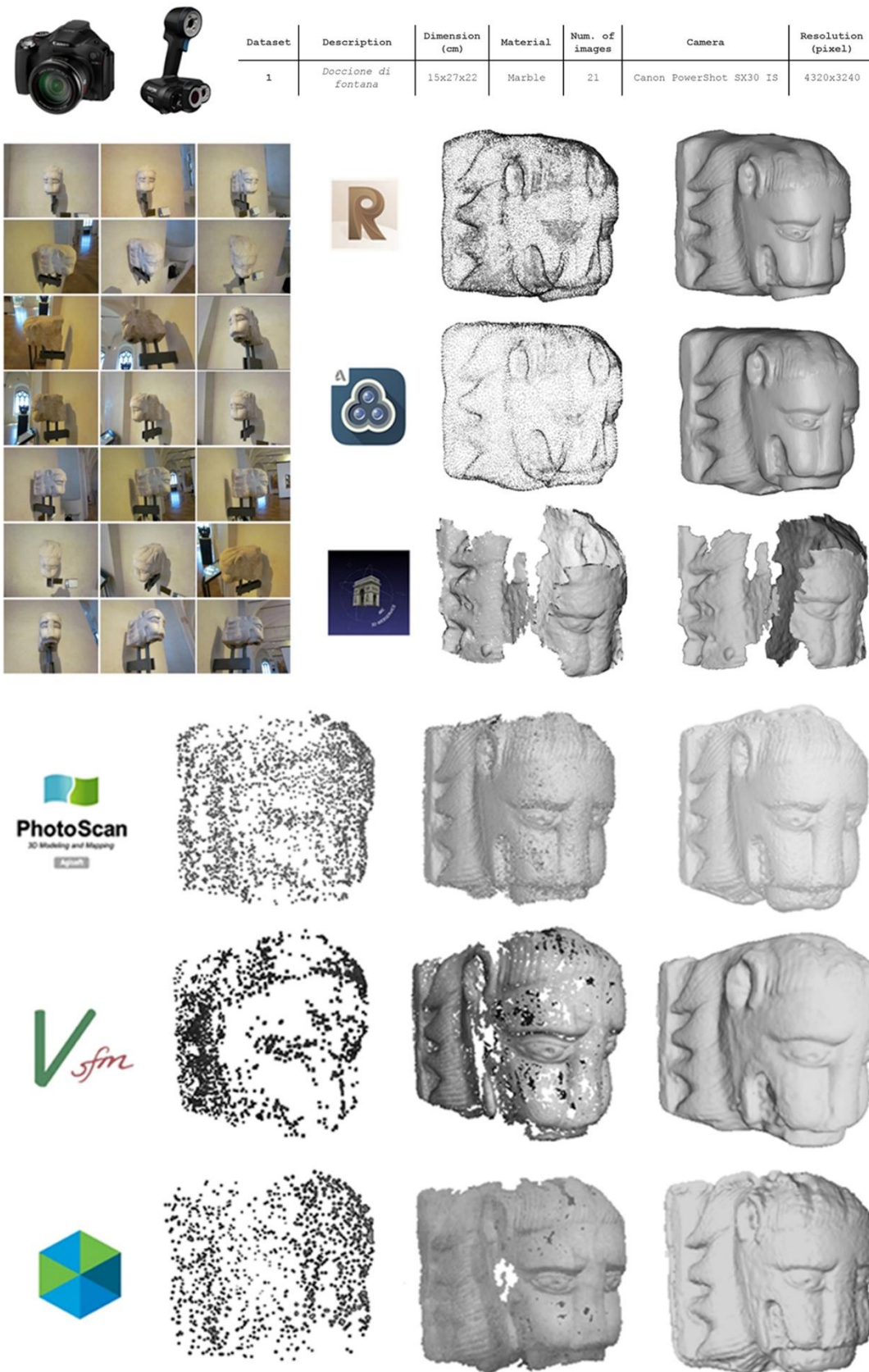


Figure 7. Test models: same number of images, same object, different software.

Considering the graphic representations of 3D and 2D metrics comparisons between test models generated with photomodelling technique and the reference model realized with the structured light GO!Scan50 system, the distribution of the deviations is not uniform.

The colour map projected on the model created with Arc3D shows significant gaps: it appears incomplete and fragmented. An important result is obtained by comparison with the model developed by Visual SfM. Almost the entire front surfaces present deviations within the range of -0.1 and +0.1 cm. The 3D map that presents major deviations is obtained by comparison with Autodesk ReMake. In fact, looking at the map, it is immediately evident that the distances for most of the surface and in correspondence with the front faces are in the range between -1 cm and -0.55 cm. The average value of the deviation between the test and the reference models is the maximum of the results (figure 8,9,10).

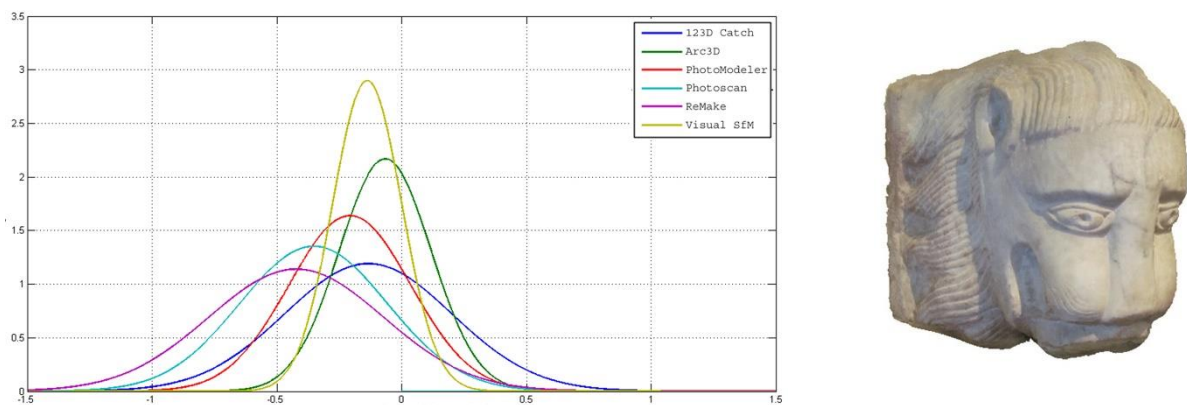


Figure 8. Probability density diagram (left); 3D textured model realized by Agisoft Photoscan (right).

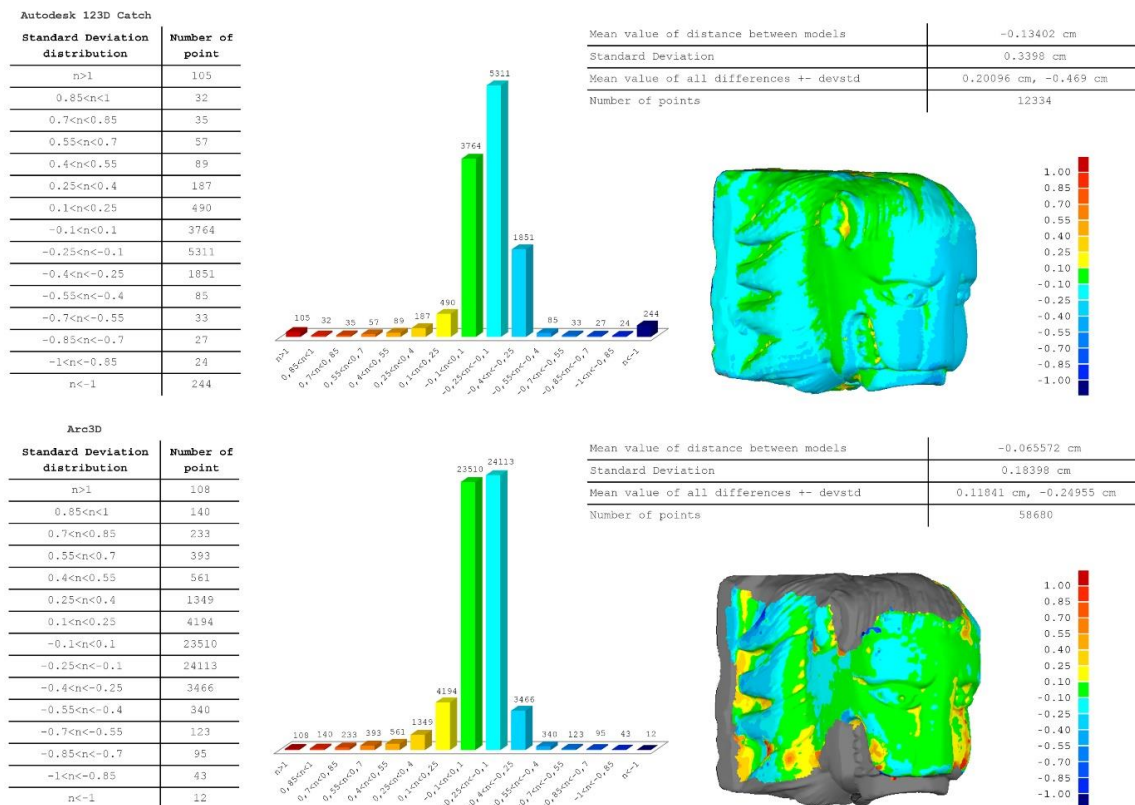
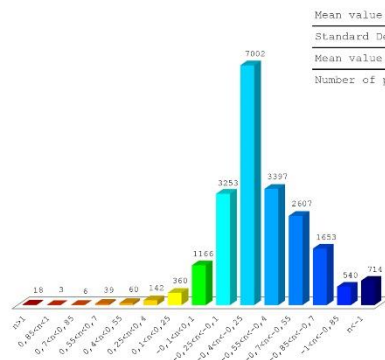
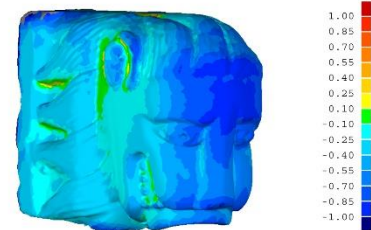


Figure 9. Maps of deviation distribution on surface of modes (Autodesk 123D Catch; Arc3D).

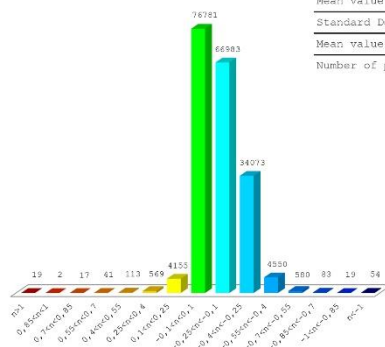
Autodesk ReMake	
Standard Deviation distribution	Number of point
n>1	18
0.85<n<1	3
0.7<n<0.85	6
0.55<n<0.7	39
0.4<n<0.55	60
0.25<n<0.4	142
0.1<n<0.25	360
-0.1<n<0.1	1166
-0.25<n<-0.1	3253
-0.4<n<-0.25	7002
-0.55<n<-0.4	3397
-0.7<n<-0.55	2607
-0.85<n<-0.7	1653
-1<n<-0.85	540
n<-1	714



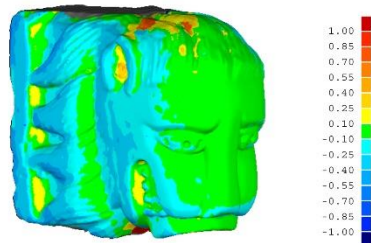
Mean value of distance between models	-0.4229 cm
Standard Deviation	0.35018 cm
Mean value of all differences +- devstd	-0.072719 cm, -0.77309 cm
Number of points	20960



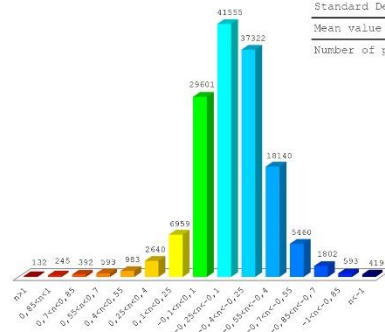
Visual SfM	
Standard Deviation distribution	Number of point
n>1	19
0.85<n<1	2
0.7<n<0.85	17
0.55<n<0.7	41
0.4<n<0.55	113
0.25<n<0.4	569
0.1<n<0.25	4155
-0.1<n<0.1	76781
-0.25<n<-0.1	66983
-0.4<n<-0.25	34073
-0.55<n<-0.4	4550
-0.7<n<-0.55	580
-0.85<n<-0.7	83
-1<n<-0.85	19
n<-1	54



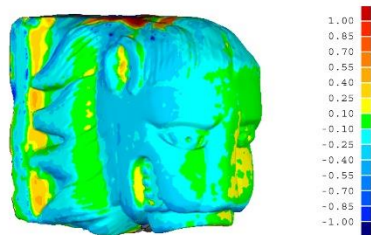
Mean value of distance between models	-0.13778 cm
Standard Deviation	0.13766 cm
Mean value of all differences +- devstd	-0.00011882 cm, -0.27544 cm
Number of points	188039



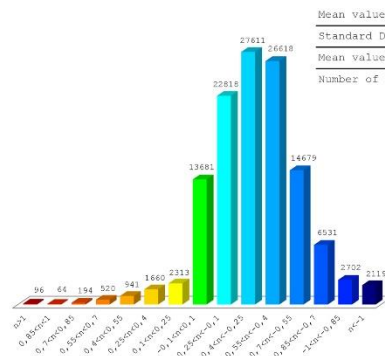
Photomodeler Scanner	
Standard Deviation distribution	Number of point
n>1	132
0.85<n<1	245
0.7<n<0.85	392
0.55<n<0.7	593
0.4<n<0.55	983
0.25<n<0.4	2640
0.1<n<0.25	6959
-0.1<n<0.1	29601
-0.25<n<-0.1	41555
-0.4<n<-0.25	37322
-0.55<n<-0.4	18140
-0.7<n<-0.55	5460
-0.85<n<-0.7	1802
-1<n<-0.85	593
n<-1	419



Mean value of distance between models	-0.20708 cm
Standard Deviation	0.24349 cm
Mean value of all differences +- devstd	0.036412 cm, -0.45057 cm
Number of points	146836



Agisoft Photoscan	
Standard Deviation distribution	Number of point
n>1	96
0.85<n<1	64
0.7<n<0.85	194
0.55<n<0.7	520
0.4<n<0.55	941
0.25<n<0.4	1660
0.1<n<0.25	2313
-0.1<n<0.1	13681
-0.25<n<-0.1	22818
-0.4<n<-0.25	27611
-0.55<n<-0.4	26618
-0.7<n<-0.55	14679
-0.85<n<-0.7	6531
-1<n<-0.85	2702
n<-1	2119



Mean value of distance between models	-0.35253 cm
Standard Deviation	0.29478 cm
Mean value of all differences +- devstd	-0.057747 cm, -0.64731 cm
Number of points	122548

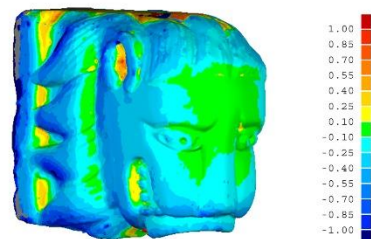


Figure 10. Maps of deviation distribution on surface of modes (Autodesk ReMake; Visual SfM; Photomodeler Scanner; Agisoft Photoscan).

3.1.2. Volumetric comparison algorithm

To further support the experimentation, the same obtained 3D models of the “Doccione di fontana” have been imported into the multi-paradigm numerical computing environment MATLAB. Through the elaboration of chromatic maps (figure 11), which identify the volumetric error distribution and the distance between barycentre of the meshes composing the models, it has been possible to compare the reference and tests three-dimensional surfaces through an algorithm. This algorithm is based on a function named ICP (Iterative Closest Point), which identifies the distance between vertices of each triangles that compose mesh test and the surface of triangles that compose reference mesh (figure 12). For each comparison, the algorithm has elaborated box plot statistical diagrams (figure 13) and volumetric error distribution graphs (figure 14).

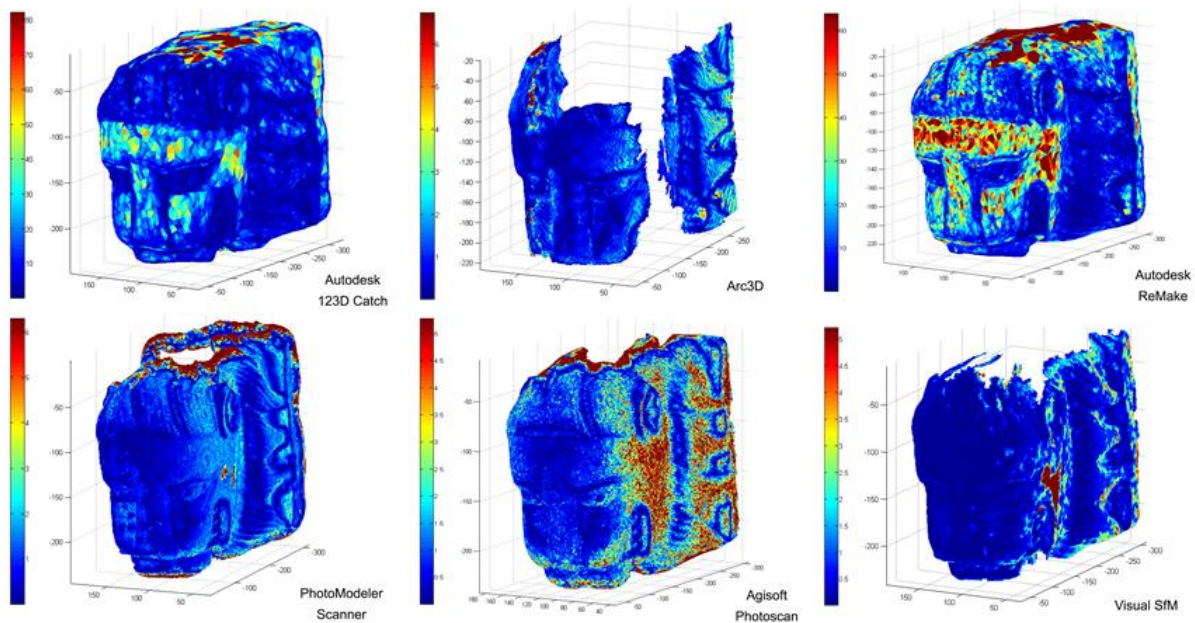


Figure 11. Maps of the volumetric error distribution on surface of modes (MATLAB).

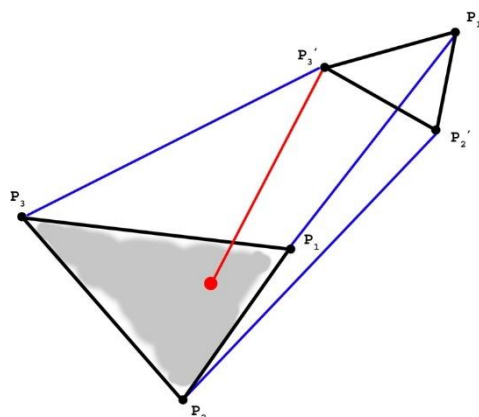


Figure 12. Triangular mesh distance (mm): ICP function (Iterative Closest Point)

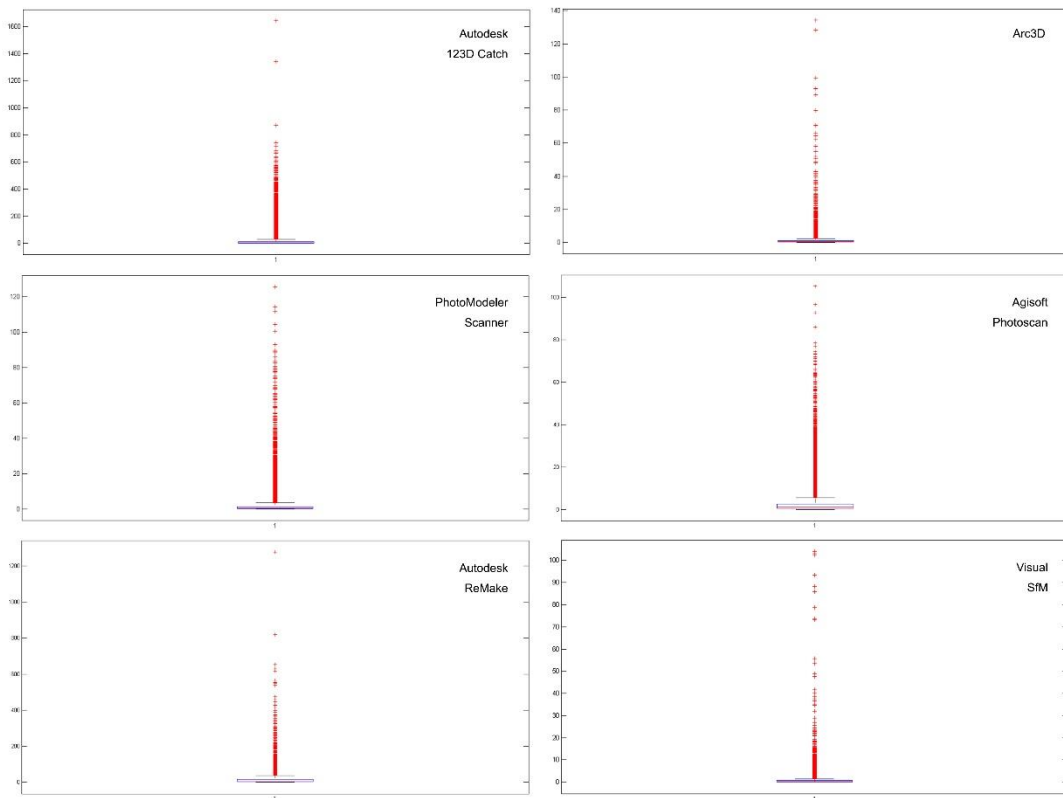


Figure 13. Box plot statistical diagrams (MATLAB).

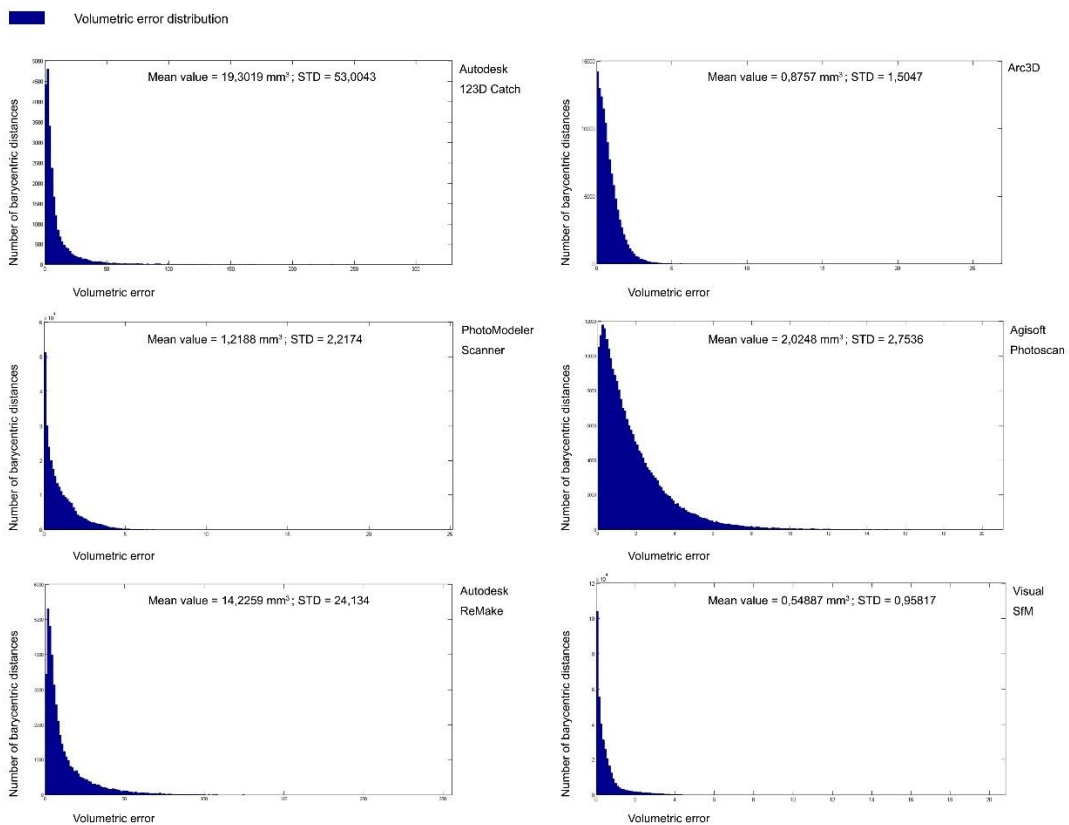


Figure 14. Volumetric error distribution graphs (MATLAB).

3.1.3. Comparison between software: case study of Archaeological Museum of Amelia (TR), Italy

Object of comparison have been three artefacts of the Archaeological Museum of Amelia, selected from more than thirty ones, of which was carried out the survey and 3D modelling, with the aim of recreate a real museum multimedia catalogue. The three artefacts are different in material, size and photographic survey. It was used a Canon PowerShot SX30 IS digital camera.

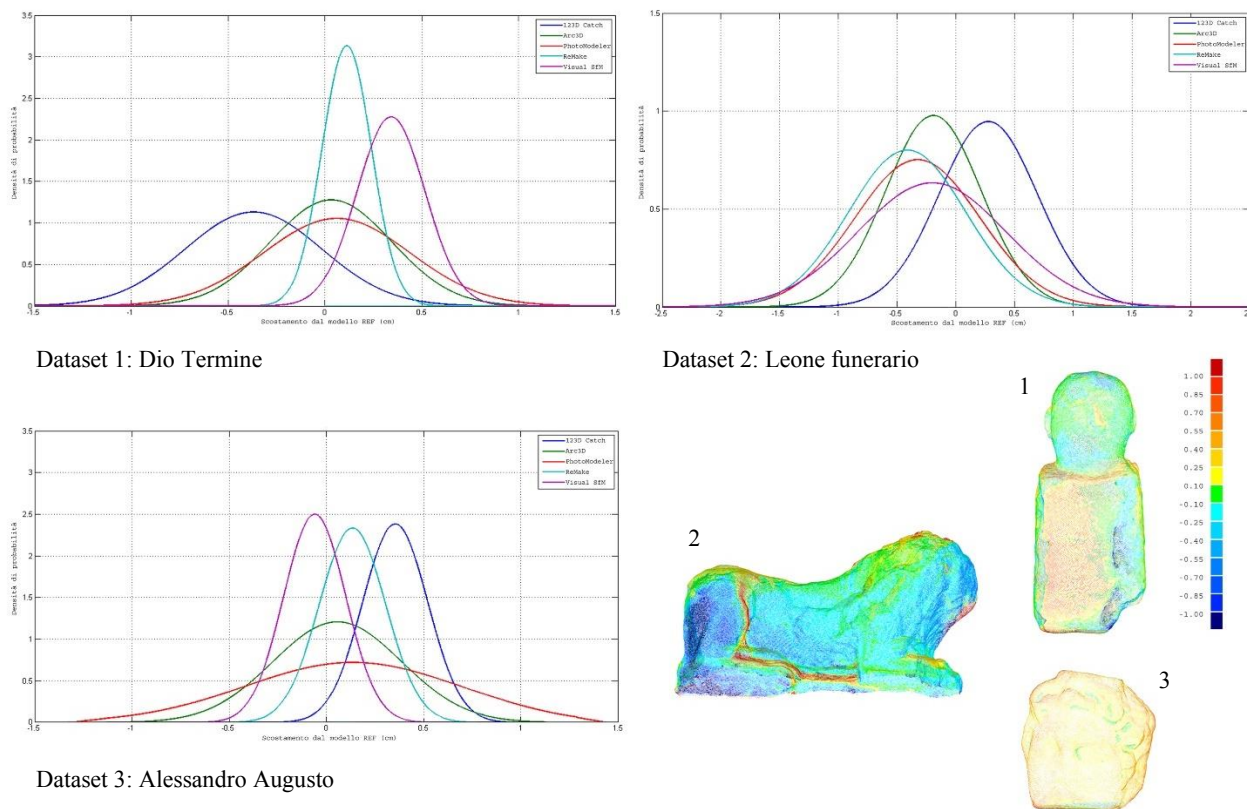


Figure 15. Probability density diagram of each dataset.

From the comparison between geometric models of the first dataset “Dio Termine”, it is possible to verify the goodness of the model from Autodesk ReMake, which presents, among all results, the value of the lower Standard Deviation. Compared to tools like Arc3D and PhotoModeler Scanner, which have average values close to zero, Autodesk ReMake, with less uncertainty, ensures a better match with the reference model. The model distinguished by the inaccuracy is the one realized with Autodesk 123D Catch, which is scarcely accurate and precise, largely underestimating the measure and presenting a high dispersion (figure 15,16).

As for the analysis conducted on the third model "Alessandro Augusto", the results are quite consistent with the previous test. The most obvious difference is the greater precision and accuracy of the model generated by Visual SfM and the greater precision of the model developed with Autodesk 123D Catch, which remains in any case poorly accurate. The results obtained by adopting the Arc3D tools, Autodesk ReMake and Photomodeler Scanner is similar to the first case. In this case, it is interesting to notice the results from some software, for example Photomodeler Scanner, which has recreated only a part of the acquired surface, with very accurate results although imprecise (figure 15,16,17).

Very significant case is the second dataset "Leone funerario": comparisons results are closer than the previous tests. This is probably due to the considerable size of the sculpture. The results of all tests are very similar, but the best is the model generated by the 3D web-service Arc3D (figure 15,16,17).

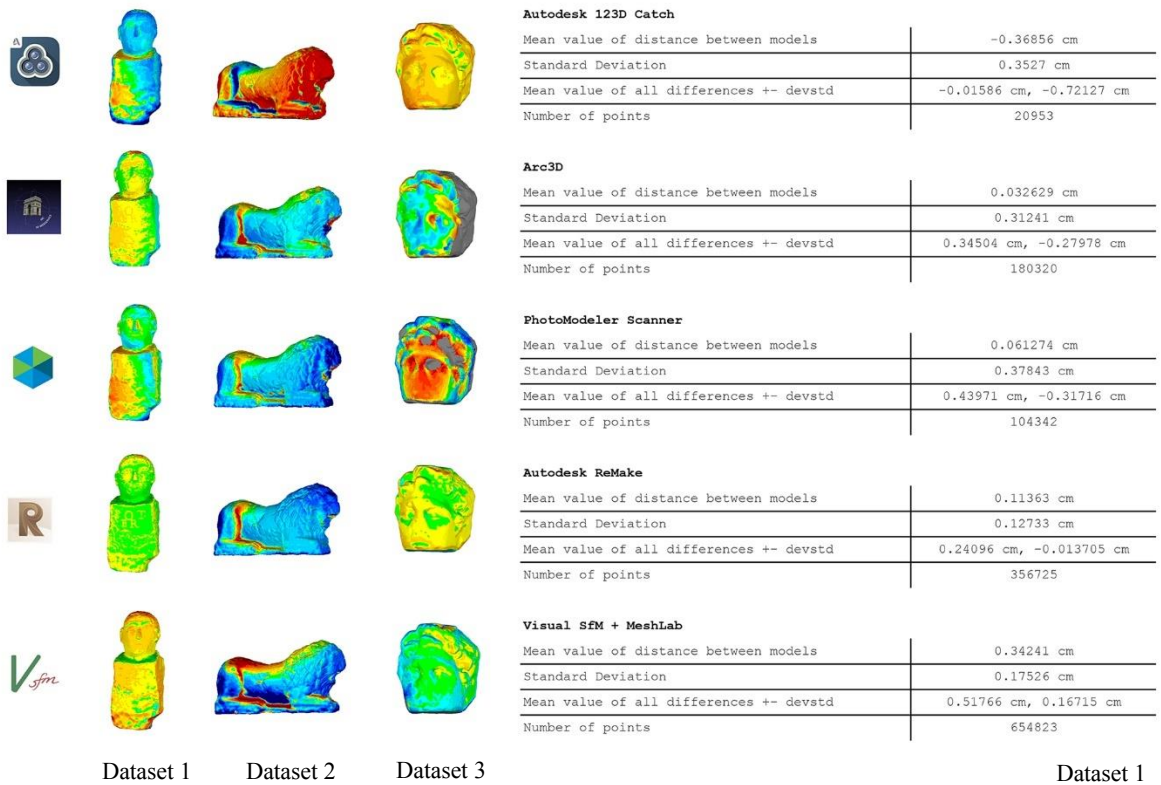


Figure 16. Maps of deviation distribution on surface of modes and data of Dataset 1.

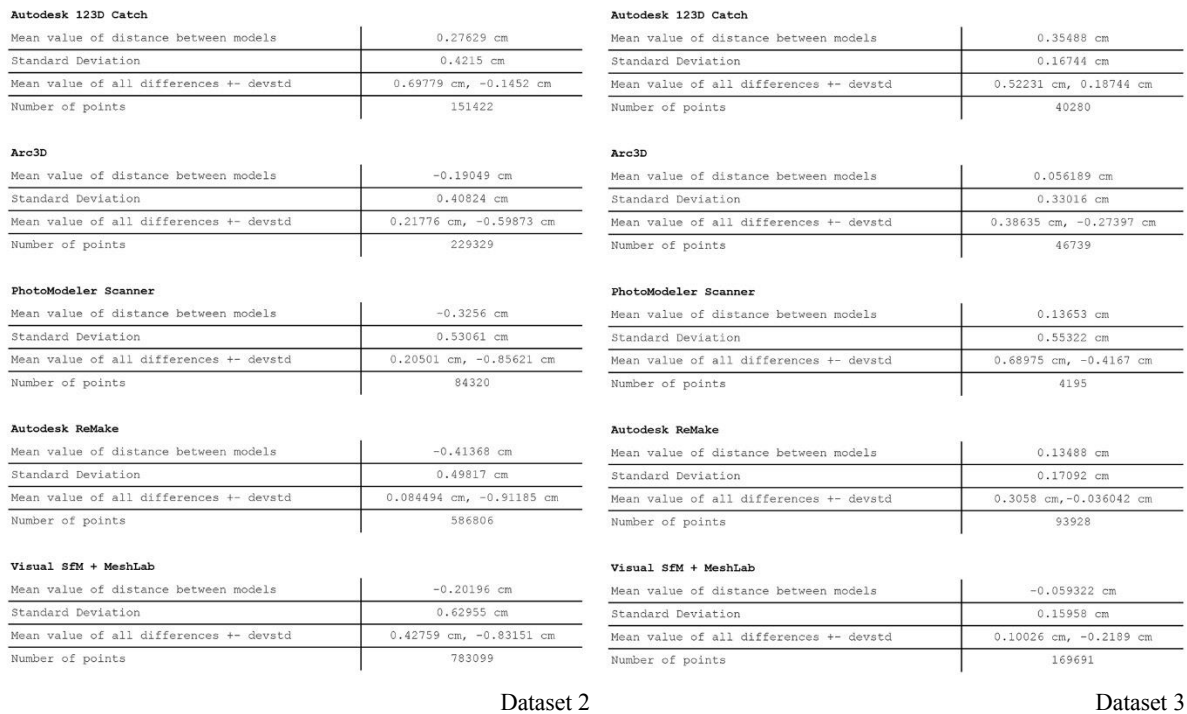


Figure 17. Data of Dataset 2 and Dataset 3.

3.2. Obtained results

In the totality of the tests, the results of the comparisons highlight the lack of a complete software, suitable to solve every need, while preserving precision and accuracy of the models created (figure 18). The best software is a compromise solution within accuracy and precision: Visual SfM is the one with a good balance between these parameters, with the generation of fairly complete and dense point cloud. Arc3D is a valuable software, referring to the accuracy of the results, but it processes inaccurate models and incomplete point clouds, tied to the conditions of the photographic survey.

Considering the comparison between a reference cloud created with Agisoft PhotoScan and test ones processed through other software, it is clear that, referring for example to the model of Arc3D web-service and toolkit Visual SfM, despite the excellent results obtained in the measurement comparisons, models manifest in almost the totality of the evidence the most significant gaps.

The analysis conducted shows not only the essentiality to undertake an effective campaign of photographic survey, but also the changing of performances, depending on the choice of the acquisition tool and the quality and accuracy of processing software.

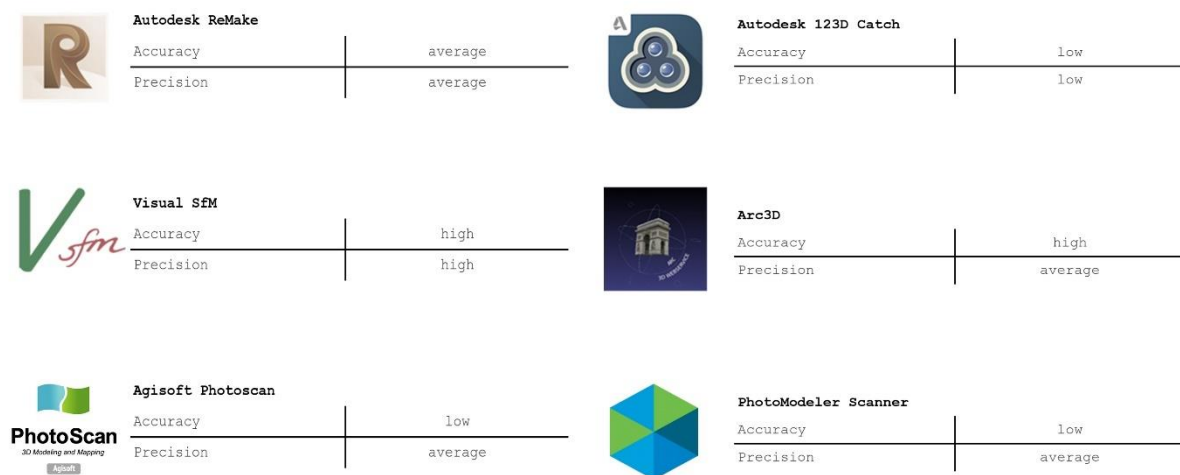


Figure 18. Accuracy and precision of each software.

4. Conclusions

The research was marked by an experimental approach: starting from the comparison with the structured light instrument Go!Scan50, it was possible to define criteria for assessing the reliability of instruments, using spatial, volumetric and surface analysis, comparing the reference meshes from which values can be extracted such as distribution of the deviations. After the interpretation of the obtained data, it was possible to collect a variety of information regarding the levels of uncertainty of the results, achieved by means of the comparison between instruments and software.

The research shows the limits and the advantages of photomodelling, which appears primarily as a technique able to integrate the operations of detection with excellent results. Compared with other techniques, as the laser scanning and structured light 3D scanning, if the surrounding conditions guarantee a correct process of application, photomodelling will become a valid economic alternative and an important integration tool.

The experience has shown that, regardless of the tools used, a specific software, which can meet the requirements of precision and accuracy of 3D models, doesn't exist. The web-service Arc3D and Visual SfM represent good compromises between these parameters. Both software are freeware, further evidencing the economic efficiency of this new technique.

The broad scope of application considers photomodelling as an efficient technique in case of multimedia reconstructions for digitization and developments related to the virtuality of Cultural and Environmental Heritage, an instrument for any need of restoration after earthquakes and natural

disasters. The intent is to make available innovative methods and tools to preserve unaltered the historical memory: it will be possible to reconstruct the objects possibly damaged, by using in advance the technique of photomodelling. At the end of the research, photomodelling is revealed as a suited technique, able to preserve the historical and cultural heritage and guarantee the authenticity of restorative measurements.

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