LOW COST SOLUTIONS FOR DENSE POINT CLOUDS OF SMALL OBJECTS: PHOTOMODELER SCANNER VS. DAVID LASERSCANNER

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ABSTRACT:

The study of archaeological artifacts requires a great care for the object. Current technologies allow the study of the object scanned in three dimensions. Hence, the digitization of objects has almost become compulsory for simplicity of study and analysis. For each scale of objects, dedicated hardware equipments exist oftentimes at important costs. Among others, scanning arms, handheld scanners, triangulation scanners, terrestrial laser scanners offer a wide variety of possibilities to produce 3D data. However, the question of cost is central in the field of archaeological research. That is probably why the technology is not widely spread in the community. Besides, the question of knowhow is also an important issue. Despite the appearances, a 3D digitization project is not so easy to carry out. Hence a low cost solution susceptible of being operated with reasonable effort could contribute to popularize 3D acquisition tools. In our study, we focus particularly on two solutions: David Laserscanner and PhotoModeler Scanner. Both systems come from two different techniques: laser scanning and photogrammetry. They can both produce dense clouds of points of small objects. Our comparison is completed according to several criteria. The most important criterion is undoubtedly accuracy; it is therefore significant to quantify the ability to produce a reliable point cloud. To compare the point clouds obtained with both systems, we use a point cloud provided by an arm scanner whose accuracy is less than 1/10th of a millimeter. As a second important criterion the maximum spatial resolution reachable for a specified hardware configuration is obtained by the optimization of the acquisition parameters. Acquisition is often repetitive and on site. Ergonomics of systems is also important to evaluate. The interface can be divided into two parts: hardware and software. It is the combination of the two phases of acquisition and processing which will take into account of the general ergonomics of the systems.

1. INTRODUCTION

3D modeling has been a subject of intensive research for a long time. Mature solutions exist and improvements of their performances have been appearing constantly. In the field of cultural heritage and among others, in archaeology (Forte & Pietroni, 2009; Guidi et al., 2004; Papagiannakis et al., 2005), these technologies have been used successfully for many years. Applications in documentation, representation, preservation and reconstruction should convince if necessary the huge possibilities of 3D digitizing. However, though many impressive results may be found in the literature, 3D modeling remains a sophisticated task which requires specific skills as well as adapted equipment (Al-kheder et al., 2009). Hence, though popular and well known, the technology has not spread overall and many archaeologists, though interested, may be discouraged to get introduced in this world. Thus, the need for affordable solutions still exists.

In this paper, two low-cost solutions are presented: dense point cloud photogrammetry (through the PhotoModeler Scanner©, EOS Systems©, PMS) and the DavidScanner Laser, DSL. Instead of presenting the theoretical aspects of both methods, which is of little concern for practitioner, a case study is carried out through the very beginning till the final digital model. The stress is put on the ergonomics of the method and the minimum skills are presented so as to convince the reader that, provided he is willing to invest a little time, he will be able to obtain results with a very good precision.

The performances of the two methods are hence presented in terms of accuracy. The paper ends with a comparison (advantages / drawbacks) of the two methods to serve as a guide for whoever may be interested in trying 3D modeling.

2. SCANNER AND PHOTO TECHNOLOGIES

2.1. David laserscanner

DSL belongs to the so-called triangulation-based laser range finders. A complete description of the system may be found in (Winkelbach et al., 2006). The principle is as follows: The laser ray is expanded to a plane by a cylindrical lens. The image of the intersection of this plane with a known background allows determining the laser plane's equation. Then, the image of the intersection of the laser plane and the surface to digitize allow determining the xyz co-ordinates of a set of points.

By displacing the laser plane, one scans the entire object and obtains a 3D description of the object. As the intersection of the laser plane and the object to digitize is obtained through a video camera (webcam, for instance) in a real time process, the laser plane may be operated by hand. Hence, there is no need for complex actuators and that makes the method particularly cheap. One needs essentially a video camera (a high resolution webcam is well suited), a commercial hand-held laser line and the DSL software. Though it is not the purpose of this paper to describe how the system is operated (which is completely done by the software itself), it is important anyway to insist on some points to make it possible for beginners or non-specialists to evaluate whether they feel capable of managing the whole thing.

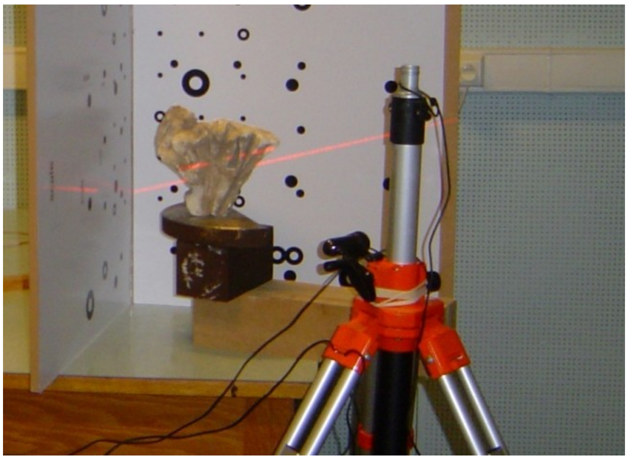

Figure 1. Experimental system, calibration corner, limestone fragment, red line laser, webcam and tripod

Figure 1 shows the experimental system. The known background (calibration corner) consists in two printed boards forming a right angle. A set of 25 coded circles are necessary for the camera calibration and orientation. On figure 1, much more than these 25 circles are visible. Indeed, a set of three groups of 25 points has been printed to make the system capable of being adapted to different object sizes. Figure 2 shows the laser line distorted by the shape of the object.

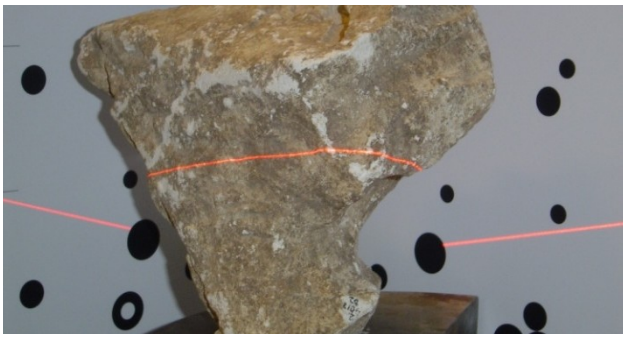

Figure 2. Intersection between laser plane and the limestone fragment by daylight

However, when scanning, the camera settings must be so that the image consists in bright points of the laser line (partly on both part of the background and partly on the object) as shown on figure 3.
The system may be operated by daylight using proper camera settings but the darker the room is, the better the results are.
Since at this stage, the known background is not visible anymore, the experiment must begin with an initial stage of camera calibration which is necessary for correction of the camera optics and for positioning of the background on the camera image.

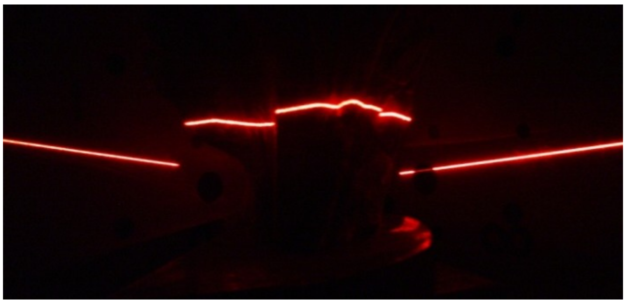

Figure 3. Intersection between laser plane and the limestone fragment in the dark.

In this early stage, the settings of the camera must be so that the black circles appear on a perfectly white background. Hence, one has to be able to set the camera acquisition parameters. Though the laser line may be operated by hand, it has been fixed in our experiment on a tripod. The laser line is hence slowly translated from top to bottom. One has to care for the position of the object to digitize, as regards to the reference background and camera positions. To take benefit from the high resolution of the camera, it is important that the object covers a large surface on the image.

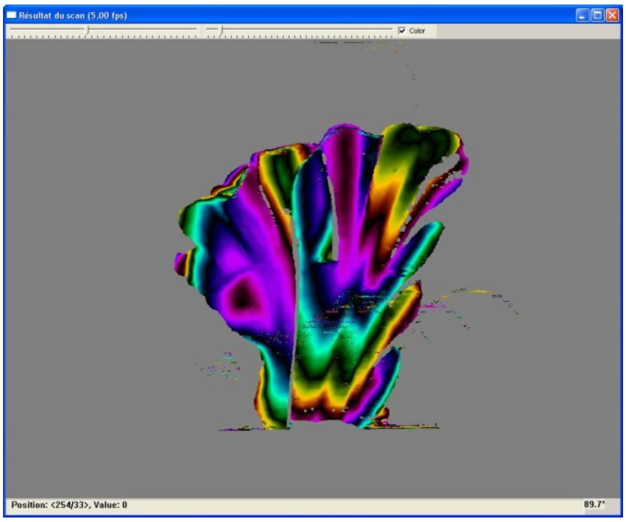

Figure 4. Range image of the object during real time acquisition

The webcam is fixed at the bottom of the tripod's mast, the laser line on the top forming an angle with the horizontal so that the intersecting lines with the boards are tilted. The slower the translation of the line is (from top to bottom), the better the results are (in terms of number of points, accuracy and noise).

Figure 4 shows the range image formed real-time while scanning the object. To obtain a complete 3D description of the object, one has to repeat the recordings with different object's positions to obtain as many views which are then aligned and merged. Depending on the object's complexity, a dozen of rotation along the z axis may be necessary as well as a couple of rotation along the two complementary axes. Figure 5 shows three different views obtained for small rotations along the z axis. In such a case, the automatic registration process of the software enables to align efficiently the three views.

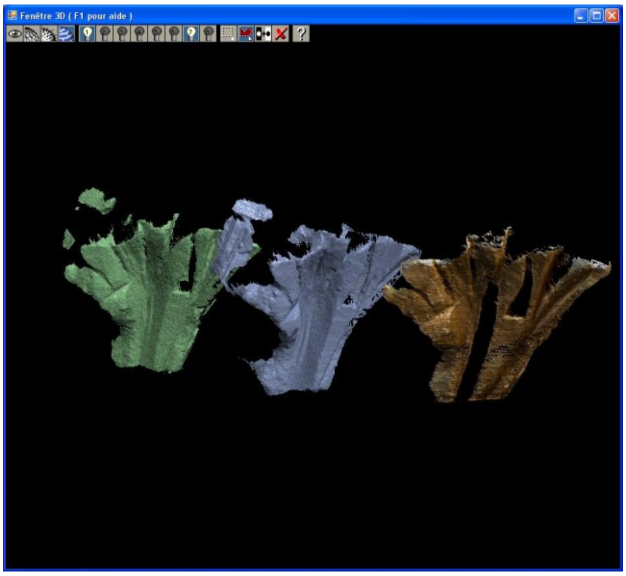

Figure 5. Multiple meshes of several point of views needed to obtain a complete 3D model

2.2. Photomodeler Scanner

Basically, photogrammetry is a 3D coordinate measuring technique that uses photographs. The fundamental principle used by photogrammetry is again triangulation (Remondino, El-Hakim, 2006). By taking photographs from at least two different locations, so-called "lines of sight" can be developed from each camera to specific points on the object. These lines of sight are then mathematically intersected to produce the 3D coordinates of the points of interest. As the involved mathematics are not the purpose of this paper, we present the method by describing a complete progress of an experiment from the early stage, i.e. from taking the pictures until the final point cloud processing.

The process begins with the camera calibration. The camera optics are not perfect. By imaging a reference background (coded circles on a white plane board), the optics defects may be calculated and the future pictures corrected (one speaks about "idealized" pictures). Once calibration is done, one can take a pair of pictures of the object to digitize. It is of course important to work with the same objective which means that the zooming capabilities of the camera should be avoided since the calibration corresponds to only one fixed position of the zoom.

To obtain a dense point cloud, one has to work on pairs. The two photos have to be taken with the same camera orientation and the translation distance of the camera between the two photographs has to be around $D/8$ where D stands for the average distance from the camera to the object. One has to find a trade-off between the dimension of the object in the image which has to be as great as possible to benefit from the camera resolution and the object translation on the image when taking the second photo of the pair. Figure 6 shows such a pair with satisfactory conditions. Good skills for photographs are needed and it is recommended to not use the full automatic mode of the camera in terms of focus, speed and aperture. One has to make sure that the maximal depth of field is reached through the diaphragm aperture. Lighting conditions should also be controlled.

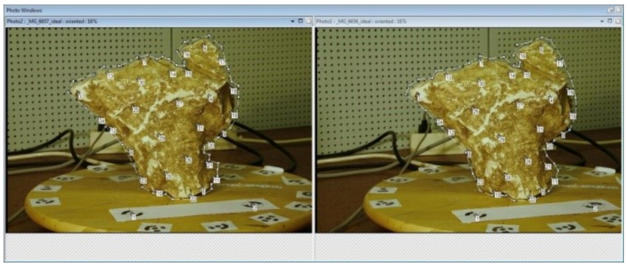

Figure 6. Stereo pair of limestone fragment with a favorable base/distance ratio.

The determination of the lines of sight which have been cited in the introduction are obtained by marking pixels on both photos which correspond to known points in the scene. Automatically recognized targets may be used (coded circles as illustrated on figure 6). However, to obtain the dense point cloud, it is also necessary to regularly spread points directly on the object especially on the areas where there are edges and important variation of coordinates.

Once enough points have been marked, the orientation may be processed. It results in the camera positions for the pair of photos as seen on figure 7.

Then, the dense point cloud generation can start. This functionality is quite recent in commercial software and originates from the so called stereo matching issue (Dianchao, 2008). On a mathematical point of view, the software uses similarity of the images to determine the corresponding pixels on both photos of the same object point and, by triangulation, determines the xyz co-ordinates. The process will work with well textured objects, i.e. pixels with color variations. In other words, for very uniform objects, the results will be quite poor.

Figure 8 shows the obtained model which is easily textured by the colors of the pixel on the original photos. To obtain a complete 3D model, it will be necessary to repeat the process on as many pairs as needed after rotation of the object along the 3 axis depending on the geometry complexity.

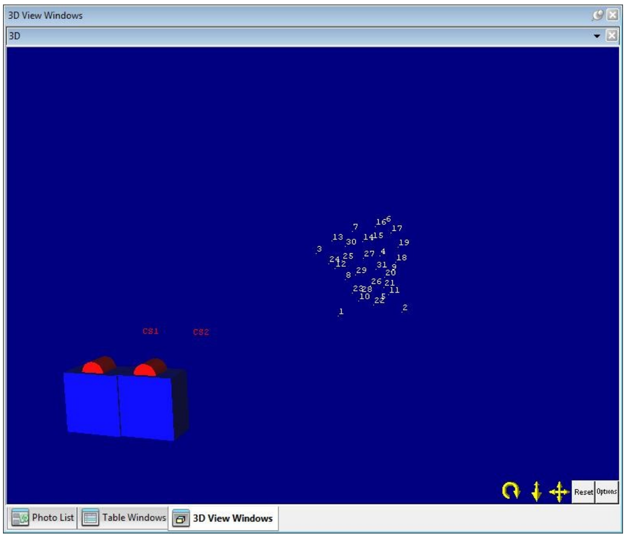

Figure 7. 3D view of the geometric configuration (cameras in relation to the marked points on the object)

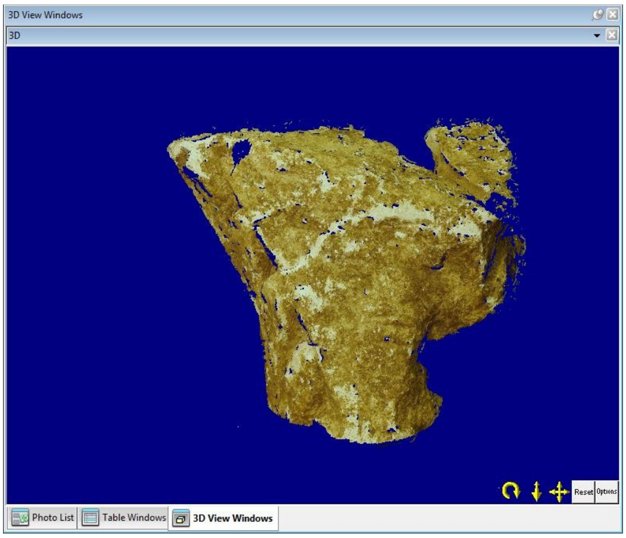

Figure 8. Textured 3D model obtained in PMS from one stereo pair

3. EXPERIMENTS

This section describes the experimental conditions and puts the stress on the important points to watch out.

3.1. Reference fragment

The object is a single small fragment of a Corinthian capital corresponding to an element of decoration. Its volume is about 4 cubic decimeters. The longest dimension is around 20 cm.

A much denser point cloud of the capital fragment has been acquired with a scanning arm with an accuracy of one tenth of a millimeter (FARO Laser ScanArm). It will be considered as a cloud of reference for this study. It may therefore be possible to make a full quantitative control over an object of arbitrary geometry.
The process applied to the point cloud ends with a mesh. The resulting mesh makes possible the visual comparison with the real object.

3.2. Laser scanning

The acquisition of the model with the DSL is quite basic. The ease of use is mainly related to the software interface.
Depending on the object configuration, the number of acquisition viewpoints is variable. 17 scans were done during our study. This is mainly due to the “Shapefusion” function of the software. It requires large common areas to perform the automatic registration. Time spent for scanning allows a faster and automatic registration of the scans.
The acquisitions characteristics are as follows:

- Scan duration: 30 seconds to 1 minute per viewpoint (the longer the scan, the denser the pointcloud)
- Camera used: 2 mega pixel Logitech
- Red Line Laser, Adjustable Focus, 5mW
- Distance to object: 50 cm

3.3. Photogrammetry

The production of the virtual model of the fragment has needed 7 stereo pairs with PMS. Two different stages can be distinguished.
The acquisition stage depends on the abilities of the user in photography field. He has to know how to make proper shots in terms of focus, speed, aperture and lightning conditions. The second stage can be processed fully independently from the first one, spatially and temporarily possibly by another person.
The acquisitions characteristics are as follows:

- Acquisition: a few seconds
- Camera: Canon EOS 5D 12 megapixels
- Focal Length: 50mm
- Distance to object: 80cm

4. RESULTS

The evaluation of the models obtained by both systems is realized by comparison to the reference model.

4.1. David Scanner Laser :

Figure 9 shows the model obtained with DSL and meshed without any color. Fine details can be well distinguished.

Figure 10 illustrates the results of inspection between the model obtained with DSL and the reference model. Dark colored parts are due to missing data from deep holes in the fragment. Triangulation may cause this kind of lake of data.

After comparing the point cloud from DSL to the one from Faro arm, 82% of points are below a distance of 1 mm to the reference. These points are represented by dark green color in figure 10 for a better visualization.

DSL can reach a submillimetric precision in our configuration.

Figure 9: Complete mesh from DSL system

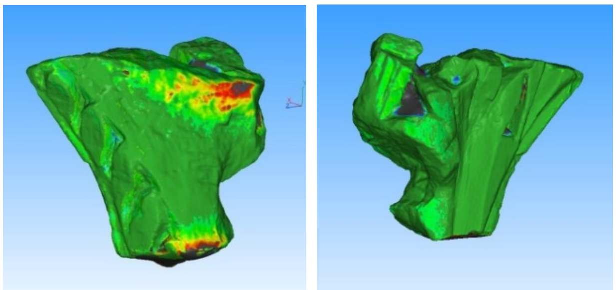

Figure 10. Error mapping of the comparison between DSL model and reference model

4.2. Photomodeler Scanner :

Figure 11 shows the model obtained with PMS and meshed without any color as it has been done for DSL. The mesh looks a little bit more smoothed than DSL one, but details can well be distinguished too.

Figure 12 shows the comparison of the results between the PMS model and the Faro arm reference model. Different dark colored parts are revealed by the inspection. The same reason (triangulation) can be invoked here but it has to be noticed that the configuration of DSL is quite different from PMS in the fact that triangle is vertical with DSL and horizontal with PMS.

To analyze the precision of measurement that PMS allows we also compared to the model reference and found that 77% of points have a difference of ± 1 mm with the reference. These points are represented in dark green in Figure 12 for a better visualization.

PMS also reaches the submillimetric precision in our configuration

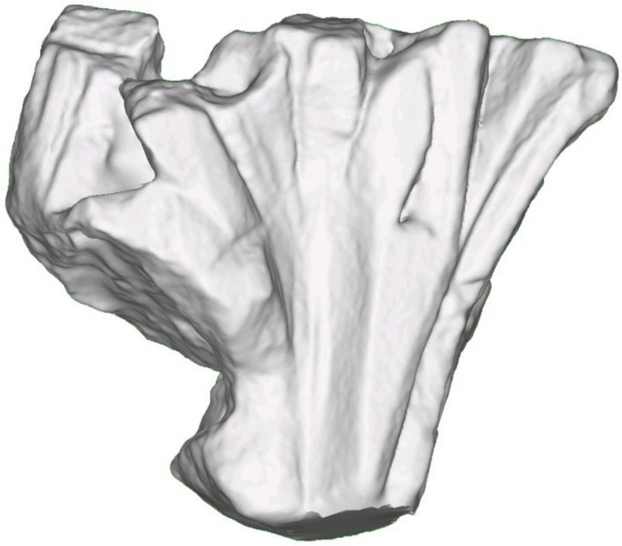

Figure 11: Complete mesh from PMS system

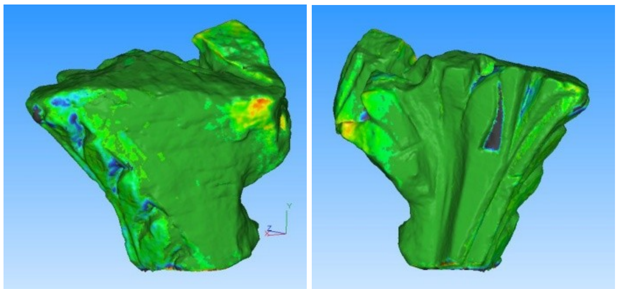

Figure 12. Error mapping of the comparison between PMS model and reference model

4.3. Comparison

The quantitative results show similar performances for data acquisition of the limestone fragment. It has to be recalled that the former precisions are obtained with the corresponding equipment and depend for instance on the camera resolutions. As part of the study of systems in terms of usability and ergonomics, it is important to detail the other factors. The aim of this paper is to enable a user without advanced knowledge in the field of data acquisition, to make a choice between the two techniques presented. The simplicity of the acquisition protocol is a very important criterion. Indeed, to be used by a newcomer, the system must be operated easily and have the capability to minimize unintended user errors. PMS differentiates from DSL by separating the use of the camera and software. With DSL, the use of the software, synchronization with the camera and finally acquisition may cause difficulties for modeling. On the other hand, the model is obtained in real time. The acquisition conditions (stability, lighting) are another standard of comparison. The absence of light and the calibration corner impose laboratory conditions to use DSL. An ambient light and a tripod can lead to very good results with PMS.

Ergonomics (hardware and software) comes into play when selecting an acquisition system. For this study this criterion is difficult to take into account because, for equipment, it depends on manufacturers (webcam, laser line, NPC). We only consider the ergonomics of software. DSL is organized as a wizard. This allows managing all steps in the right order, without missing any. PMS does not include this sequence, and requires therefore a longer learning. The DSL interface is centered on the user contrary to PMS.

System	DAVID Laserscanner	Photomodeler Scanner
Cost	Very low	Low
Ease of use	Software very easy to use, manual skills required for the experimental setup	First steps and learning of software quite laborious
Object size	Adaptable with lower and upper limits (5 to 50 cm)	Fully adaptable to any dimension
Precision	Submillimetric	Submillimetric (in this study) depending on the acquisition scale
Model texture	Obtained by webcam with medium quality	Obtained by camera with high quality
Result export	3 formats available	Large possibilities

Table 1: summary of technical comparison between DSL and PMS

Table 1 summarizes the advantages/drawbacks of both systems and the authors hope that it may help interested readers in making a choice.

We finally add versatility as a criterion. Our study focuses on a particular acquisition scale, a common scale corresponding to fragments and artefacts in archaeology. DSL does not, without an explosion of means for acquisition, allow the modeling of objects whose dimensions exceed 50 x 50 x 50 cm. This is due to the use of the calibration corner, while the use of PMS is independent of scale.

5. CONCLUSION

In this paper we showed that 3D modeling is now fully available at low cost and with great efficiency to the community of the archaeologists. However an initial learning remains necessary which should be carried out with specialists. To give an idea to newcomers, a period of one week training per system (independently from basic computer manipulation) should be enough to be able to start independently a 3D modeling project.
To conclude with the topics of comparison, though it is difficult to give a final answer, we think that PMS is more adapted to the world of cultural heritage: indeed the taking of photographs should not raise any particular difficulty, the system is adaptable to any object dimension (from tiny fragment to whole buildings as shown in *Hullo et al., 2009*), the acquisition stage is fully independent from the modeling stage and may be operated on site. In the specific case of a collection of objects of similar size, DSL is also well suited but a little less flexible.

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