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Different photogrammetric approaches to 3D survey of the Mausoleum of Romulus in Rome.

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Abstract

In recent years, digital photogrammetry has enjoyed a renewed approval in the field of Cultural Heritage. This is due both to the relative cheapness of the instruments (a high resolution camera, possibly a reflex with good lenses) and to new algorithms and software that simplified the use, perhaps at the expense of the necessary knowledge of its principles. The 3D survey of the Mausoleum of Romulus, along the Via Appia Antica, within the European project 3DICONS, provided the opportunity to test different photogrammetric techniques, with the aim to verify the results and to evaluate the positive and negative aspects. In particular two different approaches have been applied: spherical photogrammetry and dense image matching. The first technique is based on traditional photogrammetric principles, applied on panoramic images instead of frame images. The second one, the most recent and very widespread, is inspired by traditional photogrammetry and computer vision. In order to have a significant and correct comparison, a topographic support has been realized for the Mausoleum, to have all surveyed data in a single local reference system. The comparison has been made by using, as a reference, the point cloud acquired by laser scanner. In this paper, after a description of the funeral monument and its complexity, the two techniques will be described in order to investigate pros and cons, their algorithm and application fields. The acquisition and processing stage will be described in order to give all the necessary elements for the final judgement. At the end of the restitution and modelling process, the comparison will take into account many parameters: the scheme of image acquisition, the time required (on-site and in laboratory), the hardware (for data acquisition and post-processing), the results that can be obtained (2d and 3D representations with texture) and the metric accuracy achieved. Finally there will be some hints about different applications of these methods as concerning above all the visualization of data. For example, the exploration of the Mausoleum can be done through the navigation of bubbles, obtained by spherical photogrammetry.

Categories and Subject Descriptors: **[Applied computing]**: Arts and humanities, Architecture; **[Computing methodologies]**: Computer Vision: Image and video acquisition, 3D imaging; **[Computing methodologies]**: Computer Graphics: shape modelling, mesh models.

1. Introduction

In the field of survey and digitization of Cultural Heritage (CH) photogrammetry and laser scanner play a very important role [Bal99] [Boe06]. When laser scanner has started to be used in CH, photogrammetry seemed to have lost its reference role. The ease of measure, the large num of acquired information and the development of user-friendly software and hardware seemed to attribute to laser scanner technique the role of leader for the 3D digitization in CH [BM04]. In recent years, however, thanks to software developments, photogrammetry has returned to be very competitive. Some of its difficulties that characterized the classic photogrammetric survey, have been supplanted in favour of a simpler approach. It is no longer a task suited only for skilled operators. There is no longer need of large investments in software and equipment (metric or semi-metric digital camera) and is no longer a long time consuming technique.

The introduction and development of high-resolution digital camera has certainly contributed to this renewed success. But the main push probably has come from the field of computer vision, where the goal was to reconstruct three-dimensional objects and environments

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from photographs.. New software have been developed by merging together the instances of computer vision with the rigor of photogrammetry; the results are characterized by ease of approach and a good metric reliability. Also the low cost of this methods is fundamental to encourage the spread of photogrammetry. It simply demands a digital camera, preferably a high resolution SLR, and software for image processing: an investment which is certainly less expensive than buying any laser scanner. Moreover we cannot forget many open source suite that allow you to process images, thus avoiding the purchase of software (such us Bundler/PMVS2 and Micmac/Apero.

The new photogrammetric software packages we call Dense Image Matching (DIM), enable the automated orientation of many images, the extraction of dense clouds of points and the creation of textured mesh models. There are other systems that let you work with other types of photographic products such as spherical panoramas. By applying the principles of photogrammetry it is possible to orientate several classic spherical panoramas, using a topographical support or some known distances, and subsequently obtain a three-dimensional model of the object[Fan07].

All these methods allow not only the extraction of three-dimensional model, but also to implement new systems for the exploration and navigation of virtual spaces.

In this paper will be to compare two different photogrammetric approaches: dense image matching and spherical photogrammetry. The object of the comparison is the Mausoleum of Romulus, and in particular its inner cham with a torus shaper as in **Figure 1**. The survey has been done within the framework of the European project 3D-ICONS. After a description of the Mausoleum of Romulus, there is paragraph about the 3D survey by laser scanner (used as a term of comparison), then the acquisitions by the two photogrammetric techniques and comparisons in terms of operational results. A final section will describe the application of new techniques not only for digitization, but also for the exploration and use of virtual models.

Figure 1: *image of the Mausoleum, nowadays.*

1.1 The Mausoleum of Romulus.

The Mausoleum of Romulus is one of the greatest funeral monument of the late Roman Empire. The complex was built in the 4th century A.D. for M*arcus Aurelius Romulus* (292/295-309 A.D), the son of the *Emperor Marcus Aurelius Valerius Maxentius*.

The tomb and the rectangular *temenos* were enclosed by an impressive *quadriporticus* of 99.5 by 85 meter, supported by 48 rectangular pillars and covered by cross vaults. Nowadays only the perimetral wall in opus vittatum and some pillars in opus *latericium* (in the south-est side of the complex) are well preserved and allow the original shape of the portico to be reconstructed. It had two gates: the former oriented towards the *Via Appia*, the latter, in back of the tomb, connected the *temenos* with the Maxentian imperial palace built on the hill behind. In the middle of the rectangular portico, the majestic remains of the tomb are still visible. The building was re-used during the medieval age and in the 18th century, was partially incorporated into a farmhouse belonged to *Torlonia* family. These events allowed the preservation of the semi-subterranean floor of the tomb. The building as it is in the modern state, is composed by a cylindrical rotunda connected to a rectangular body.

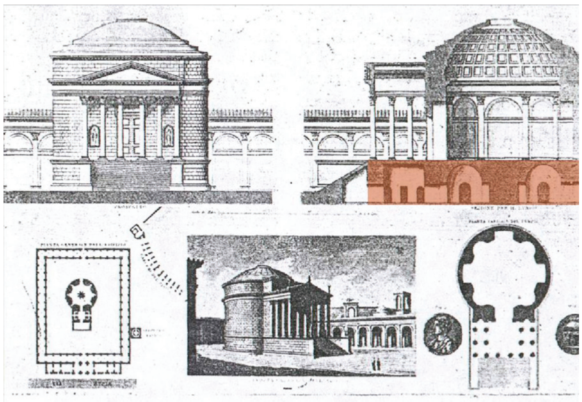

Figure 2: *Reconstructive plans, font, section and view of the Mausoleum [DIE11]. The red layer, over the section, point out the still existing part of the central monument.*

The rotunda, made of *opus caementicium*, has a diameter of approximately 33 meters and contains a corridor that encircles a big octagonal pillar of 9 meter in diameter. A 9 meters high barrel-vaulted ceiling covers the circular corridor and connects the perimetral walls with central pillar. Both pillar and corridor walls keep intact alternating rectangular and semicircular niches and the whole space is enlightened by 6 small windows included in the perimetral wall niches [JOH09]. Due to the presence of the numerous niches, where usually the sarcophagi were placed, it is likely probable that the monument was later turned into a dynastic tomb the imperial family. The rectangular body lies beneath the *Torlonia* farmhouse and its barrel-vaulted cham is connected with the circular corridor by a big passage. This space should have been used both as a crypt, where the Maxentian family were probably buried and, at the same time, as the basement of the porch that at the beginning constituted the entrance of the upper and the most representative part of the tomb [FRA76].

The preservation of the remains of the mausoleum not do justice to the prominence of the building. However the archaeological survey and the comparisons with the contemporary and better-preserved monument, the so-called *Tor de' Schiavi* at the *Villa dei Gordiani*, allowed researchers to hypothesize the original appearance. The tomb once was a two-story building, consisted of a circular corps, the rotunda, and a rectangular pronaos, while today remains only the lower floor (**Figure 2**).

The *rotunda* was completely covered in Proconessian marble blocks and covered by a domed roofing. The interior, as well as in the lower floor, contained several niche where should have placed religious and/or dynastic statuary. The *pronaos* probably had a porch made of six columns that bear an architrave and a tympanum, was crowned by a *triangula* pediment and covered by a gable roof. These architectural elements, such as rotunda, rectangular, *pronaos*, domed-roofing and niches, allude to the Pantheon - the big rounded temple built by *Marcus Vipsanius Agrippa* (63-12 B.C) in the middle of Rome and rebuilt by the Emperor *Publius Aelius Traianus Hadrianus* (117-138 A.D) - from which Maxentius was inspired by. As proven, the tomb, as well the other architectures promoted by *Maxentius,* emulated the prestigious imperial roman models rather than the tetrarchy schemes, such as the Pantheon and the mausoleum of *Augustus and Hadrianus [*WHE2013].

2. The 3D acquisition of the mausoleum

To facilitate the comparison between the different photogrammetric techniques, all 3D acquisitions were georeferenced in a single reference system. To materialize the reference system, a topographic network was realized and measured. It includes the targets (for the registration of point clouds and image orientation) and some points of the object for an initial verification of the models. The choice of working in a single reference system, in addition to making more immediate the comparison, allows also to test the behaviour of the different software packages according to the use of topographic coordinates. It is in fact a correct practice and widespread in the relief of Cultural Heritage [MA11]. In addition to photogrammetric measurements a laser scanner survey was done with the goal of obtaining a 3D model as a basis for comparison. In this way, the comparison can be made on the coordinates of the target and, in an even more suitable way for the field of Cultural Heritage, by considering the entire monument.

2.1 Laser scanning

Compared with its introduction in Cultural Heritage field in Nineties, today laser scanner is a well established and widespread instrument in the 3D survey. For this reason it was chosen to realize the 3D model of reference of the mausoleum. The instrument used is the Faro Focus 3D. It is a phase shift laser scanner, very popular, with a distance accuracy up to ± 0.002 m and a range from 0.6m up to 130m. This instrument is very handy and fast (measurement speed up to 976.000 points/second). It allows to work on the field without the use of a PC/tablet and it includes an inclinometer for the correction of errors of verticality of the system.

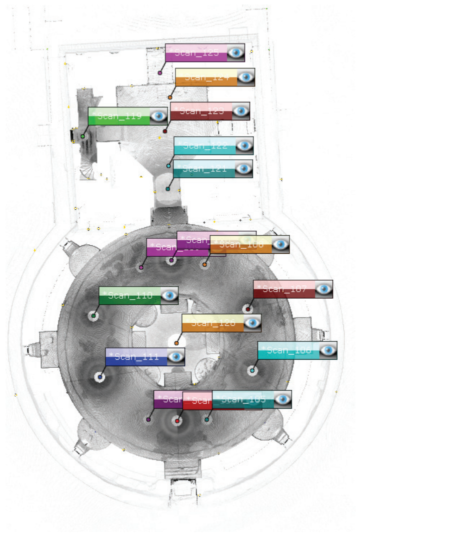

Figure 3: *top view of the Mausoleum with the position of the internal scans.*

The most interesting part for the survey of 3DICONS project is the ancient part of the monument so the focus was mainly on the interior of the mausoleum. This part is very interesting for the geometric shape very similar to a torus. The scans of the exterior were used only to contextualize the monument in its environment.

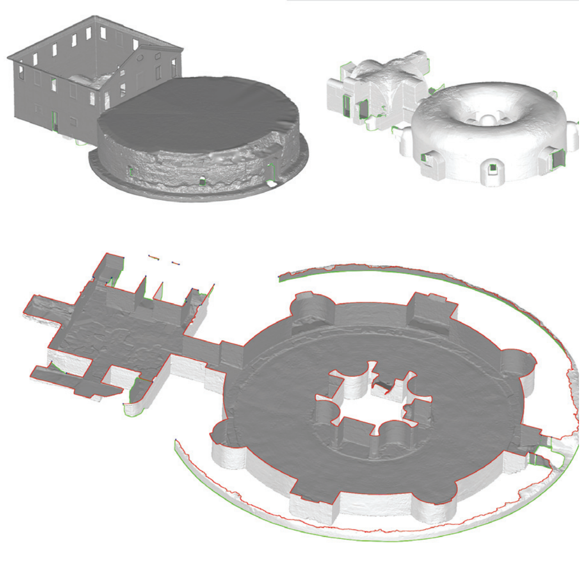

Figure 4: *3D model of the Mausoleum. a) View of the exterior and interior; b) an horizontal section.*

23 scans have been made for the whole mausoleum, including 6 scans for the exterior, 6 scans for the square burial cham and 11 scans only for the part of the torus (**Figure 3)**. Each scan is composed by 44.4 millions of points, it took about 4 minutes and the average resolution is about 0.006 m at a distance of 10 m. The total of the points leads to a model of over 1.12 billion points. With laser scanner we focused on the acquisition of the geometry so the radiometric value, even if acquired, was not used. This is due to the fact that the acquisition of colour is affected by the problem of exposition (automatic compensation of the light) and therefore the colour quality is very low.

The scans have been recorded by using Scene software, specifically designed for FARO Focus3D laser scanner, by means of the coordinates of the target acquired by topography. The registration error is less than 0.001m and this is compatible with the accuracy of the topographic network and the instrument itself. The final model, after the triangulation of the pointclouds and some filters is split into two parts: the interior and the exterior (**Figure 4**). It is possible to section the model in order to relate immediately the inner and the outer part. Finally, in the well-known software of mesh processing and rapid prototyping it is possible to obtain a grid of slices with different arrangements: they can be used to build the parametric model of the inner cham. In the case of the Mausoleum of Romulus, it is more interesting because of the well-defined geometry.

2.2 Dense image matching

Dense image matching has greatly changed the practices of survey in architecture and archaeology since it allows the 3D reconstruction of real object only by the use of photographic images. In addition, the latest software interfaces are really easy to use and it allows anyone to approach the field of surveying and photogrammetry. Regarding the research in this paper, we used two different software, Agisoft PhotoScan and Apero Micmac: the first is a commercial and very widespread solution and the second is well-known open source[RSN*13].

This technique takes advantage of automatic approaches and allows 3D models to be obtain from a set of photos referring to some photogrammetric solutions. In fact, the dense image matching approach is based on the identification of a bi-univocal corresponding points in a pair of images, but this principle is carried out in a very "dense" way. This means that the automatic identification of the corresponding points in a pair of images are not detected manually by the user but the matching process is carried out for each pixel of each image: for each point/pixel in the images the software identifies the corresponding pixel in the others images. This implies that it is necessary to pay attention to the geometry and to the conditions of the image acquisition. The entire process is carried out automatically by the software that is based on algorithms of "computer vision" without the user's intervention. These techniques, whose automation is a first goal, are based on non-calibrated photos, so all information regarding the camera must be worked out from the images so that the computation of camera calibration can be conducted automatically. Thus, to obtain good results in 3D model buildings, many pairs of photos are required. In fact it is very important that the information present in the images is sufficient.

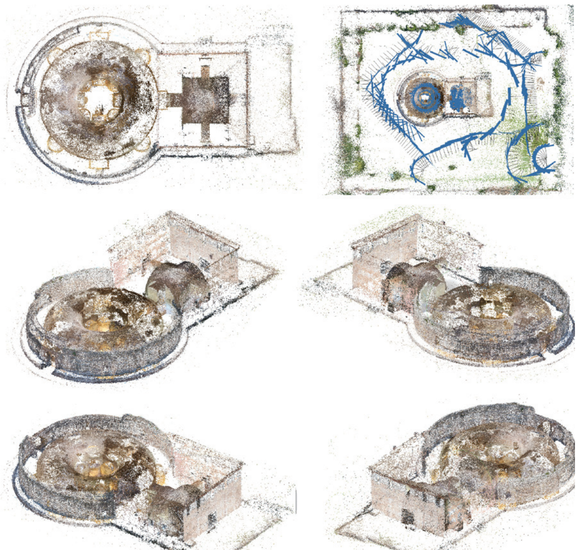

Figure 5: *3D reconstruction of camera and dense point cloud with PhotoScan.*

Once the algorithms have identified all the corresponding point in the photo sequences, the software, based on this matching process, estimates the right camera position at the moment of shooting. Starting from the camera positions, a dense 3D object reconstruction is carried out (**figure 5 and 6**) other words, for each pixel of the images the software computes, in addition to the RGB value, its xyz position in space.

Figure 6*: 3D reconstruction of dense point cloud with*

The survey was performed with a Canon 650D and was carried out in about five hours leading to get about 600 photos. Exteriors needed more photos due to the big extensions of the courtyard (320 photos) while in the interior were shot about 210 photographs. The chosen acquisition strategy was focused in the smallest possible num of photos (with no redundancy) taking into account the necessity to maintain a 60% overlap between the photos and to reach all the corners of the building. The Romolo's Mausoleum indeed is an articulated building with lots of niches and pilasters that can potentially occlude the view.

The comparison on geometric reliability is demanded in the paragraph 3.

Software	*Sparse point cloud*		*Dense pointcloud*	
	pc	human	pc	human
Micmac	2 h	1 h	2 h	3 h
Photoscan	2 h	1/2 h	2 h	1 h

Tab 2: *overall effort for the data processing*

2.3 Spherical photogrammetry

In the last ten years the use of panoramic photographs (panorama) with metric goals boosted a new methodological approach to photogrammetric survey. In the latter experience two type of technologies are used: the former is purely manual (Multi image spherical photogrammetry, MISP), the latter is more automatic (PhotoScan). These different approaches allow obtaining geometrical 3D reconstruction but they can also texturing the 3D model (its own models or the ones made by other systems). A pipeline of work is implemented and optimized. This indeed relies upon panoramic projections which aim at interactively visualize the reconstructed model (and the correlated information), not only on typical projection devices but even on immersive surfaces.

The referable scientific literature about MISP [Fan07] demonstrate the reliability, accuracy, cheapness and flexibility of the current method. Tools developed for the panorama's orientation (SPERA.EXE) and its restitution (PLOT.EXE) are able to produce points or linear entities in 3D environment. The collimation of homologous points is manual. For such reason, this technique is especially suitable for architectural survey. If the goal is to gain the 3D model in a local system, it is needed one measure only on site in order to scale the model. Likely, if the geo-referencing of the survey is needed, then the use a topographic data to scale and to orient the model is a possible choice.

The mechanism though which the architectural 3D survey happens, involve points and lines, which bring to a wireframe model. The archaeological field implies often not regular shapes, and working with them would provide an extremely long procedure 3D restitution. To overcome this issue and deepen more the methodological imprint of this technique, Image-based Modelling IBM [dAF09] [dAn11] solutions can be recalled. With computer graphics tools is possible to shape up the interested portions of the not regular 3D model using high-resolution panoramic projections as the main texture. The automated approach is differently referable to black-box software. The latter allow orientation, restitution though point clouds, reconstruction through mesh and textures. PhotoScan is one of the main tools nowadays used in the surveying and 3D reconstruction fields, given its rapidity in the system operations and easiness of practice. Tests on the current tool accuracy with the involvement of typical photos have already been conducted. Likely, the aim of the current research is to evaluate the tool with panoramic photos, proving or not its reliability in the final product restitution. To do so, orienting data has been compared with SPHERA results; secondly, point-clouds restitution has been confronted with Laser Scanner data and PhotoScan results taken from normal photos.

2.3.1 MISP (multi image spherical photogrammetry

The case of the Mausoleum shows how we proceeded with the acquisition: given the torus shape with the recesses all along the internal and external walls, full panoramas (360x180) technique has been selected, in correspondence with the n.8 recesses and after having been positioned in an average location between the walls. In this way it has been allowed reducing at the minimum the num of panoramas useful to further texture the reconstructed surfaces. Panoramic photos are the results of the automatic stitching technique given picturing shots acquired rotating the camera in two directions (yaw and pitch) around the nodal point*. The current operating solution, in the case of photogrammetric survey, even if provide discrete results from a free-hand acquisition point of view, needs to be used in accordance with the selected instruments.

Advantages with using panoramic photos are:

- Acquiring larger view (till reaching the horizontal 360° and the vertical 180°);
- Having high-resolutions with common cameras;
- Avoiding distortion lens corrected by stitching process;

For the work, the Canon EOS60D camera (18MP) have been used with 17-85 ZL and a tripod with panoramic head.

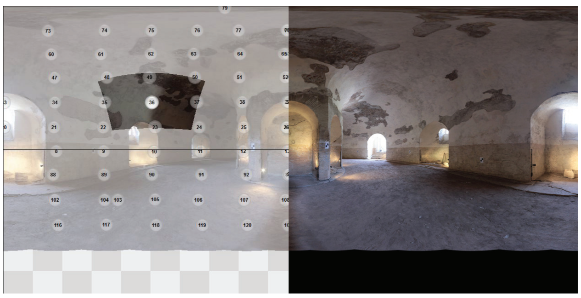

Figure 7: *single panorama with athe area covered by a single photo.*

The maximum resolution has been the one provided by camera itself (18MP) and the format selected for the final product has been .jpg. The lens used is 24mm (1,6x) and the num of shots to obtain the full panorama has been about 100. The maximum resolution of horizontal staging is 34800 pel (1 pel=0,0103 deg). Jpeg has been selected even if some limits in terms of hardware/software were highlighted, re sizing panoramas to 24576 pel (**Figure 7**).

To geo-referencing the 3D model, photos have been oriented using the coordinates of three already-known points in topography (yellow targets…). Beyond these points, others architectural points have been collimated (circa 20 in total).

To save memory throughout the orientation phases, some parts of panoramas have been excluded and secondly "added". The current crop operation gives the possibility to augment a detail referable to portions of the scene with the same maximum resolution accessible. The obtained result is remarkable, while the software report feedback us of a squared average error of x, y, z inferior to 0,01 m (**Tab 2**).

Sigma_zero = 0.1897 deg		
Sqm Average [m]		
sqmx	sqmy	sqmz
0.00156	0.00164	0.00134

Tab 2: *SPHERA's output about accuracy*

Last phase of the spherical photogrammetric process is the restitution made by relevant points' collimation, selected by the operator. The first draft provided is afterward edited till obtaining a wireframe model (**Figure 8**).

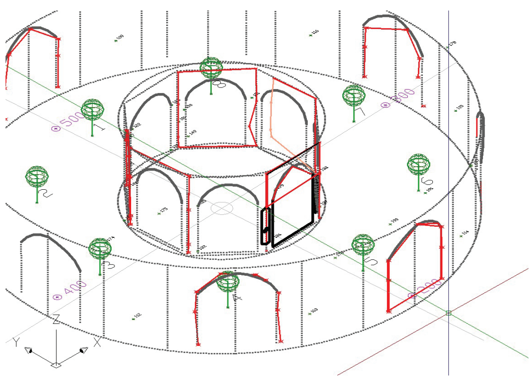

Figure 8: *Axonometric view. The restituted geometric*

2.3.2 Automated spherical photogrammetry

PhotoScan forces operator to work with full spherical panoramas (as far as for the orientation), absolutely a weakness if only a single portion of the available scene would be elaborated. Panoramas orientation is automatized as for the restitution. The software's estimated error with all the target included as control points, is about 0.015 m.

Orientation results have been compared with the ones of sphere, while differences have been included in tabs. It is possible to notice that differences among them refer to cm, as for position, and decimal degree, as for rotation.

	Position Gap			Rotation Gap		
	X[m]	Y[m]	Z[m]	Rz (deg)	Rx (deg)	Ry (deg)
1	-0,0024	0,0125	-0,0042	-0,0182	-0,2147	-0,3308
2	-0,0167	0,0001	-0,0091	-0,0017	0,1750	0,1976
3	-0,0098	0,0001	0,0009	-0,0127	1,8229	-1,7856
4	0,0007	0,0132	-0,0004	-0,0820	-0,1997	0,2769
5	-0,0443	0,0393	-0,0036	-0,1101	0,0732	-0,0764
6	-0,0540	-0,0027	0,0056	-0,1783	0,0103	0,2367
7	-0,0543	-0,0066	0,0015	-0,2516	-1,6403	1,9474
8	-0,0072	0,0004	0,0030	-0,1276	-0,2069	-0,1951

Tab 3: *comparison between MISP and automatic orientation*

In the points-cloud restitution some parts are missing. While for the accesses of the central body of the Mausoleum is possible to understand why this happens (impossibility to fill-in the points from different levels), for the others, issues related to not collimation process can be supposed (i.e. Different exposition of photos, socalled "scratch points"). An addition comparison has been made on the data provided by the n. 8 target restitutions; in this case, the values are close to cm, referable to the ones admitted in the topography of reference.

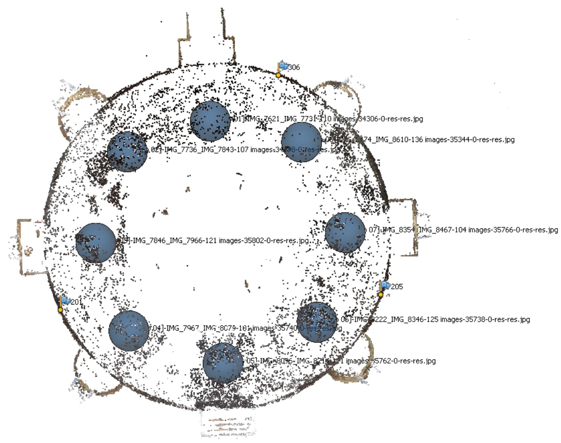

Figure 9: *top view of Photoscan sparse point cloud. The blue spheres represent the position of oriented panorama, and the blue flags the points used for georeferencing.*

2.3.3 Texturing

For an accurate comparison of the textures on the projection, it has been decided to project the panoramic photos on the mesh obtained from the laser scanner activity (surely correct). For texturing two distinct software like 3DStudioMax and PhotoScan have been chosen.

PhotoScan inconsistencies regarding both the match with the geometric features and the projection of multiple simultaneous views are highlighted (**figure 10**).

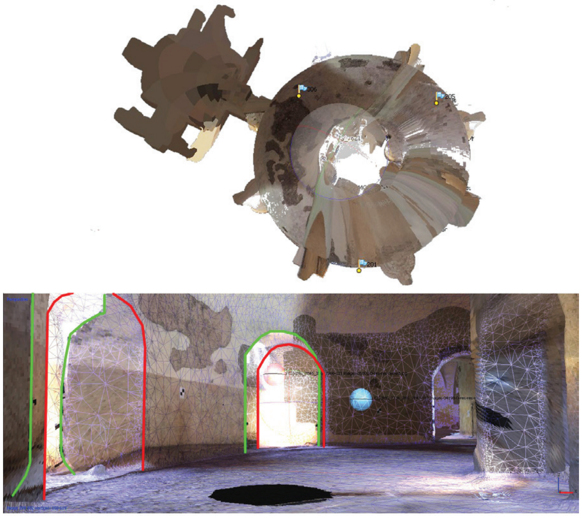

Figure 10: *Texturing with PhotoScan. (top) textured model with evident problems in the position of texture. (bottom) The misalignment in evident near the niches the green line is the correct position of the edges, the red line the position extracted from texture.*

Figure 11: *Texturing in 3D Studio Max (top) textured model (bottom) The correct alignment in evident near the niches: green and red lines correspond.*

3DStudioMax have been used for the orientation data of SPHERA. It is possible to see the perfect correspondence between geometry and texture thanks to the continuity in the transition between the projection of a level to another - further verification of the orientation's accuracy (**figure 11**).

3. The comparison

The comparison between the different photogrammetric techniques concerns not only the final results, but also the operating procedures, data acquisition and data processing. To ensure a meaningful comparison, the used camera are very similar, both with APS-C sensor and the same num of pixels (**Tab 4**).

Camera	Sensor	N pixel	Optics
Canon 650 D	APS-C	18 MP (5184 x 3456)	18-55
Canon 60 D	APS-C	18 MP (5184 x 3456)	17-85

Tab. 4: *Camera used to perform the photogrammetric survey: green for for dense image matcing and blue for spherical photogrammetry*

The acquisition modes are different because each method has its own specific needs (**Tab 5**): photos taken by rotating around the nodal point for the spherical approach and great overlap for the DIM. This involves the need, for spherical photogrammetry, to work with a tripod and calibrate the system acquisition. While DIM allows a free acquisition, without tripod, as long as the lighting conditions permit.

Time	Photos	Tripod	Format
3 h	150	no	.jpg
3 h	800 (8 pano)	yes	.jpg

Tab. 5: *Acquisition time and mode; green (dense image matching) and blue (spherical)*

As concerning data processing the two methods are really different. Spherical photogrammetry provides a longer process as it is necessary, as the first operation, to build the panoramic images with commercial or open source solutions. This fundamental operation is automatic, but a final validation is necessary to avoid stitching errors. To obtain a wireframe model, the orientation process is manual and there are no commercial solutions that for these operations. The final restitution is manual so it is time spending. Otherwise, to arrive to a mesh model, after panoramic image creation, the process with PhotoScan is almost totally automatic.

As concerning DIM approach, it is surely faster even if, also in this case, the process depends on the used software. PhotoScan allows a fast approach, but in some parts the algorithms and the results cannot be validate and it could be a problem if we want to understand exactly the whole

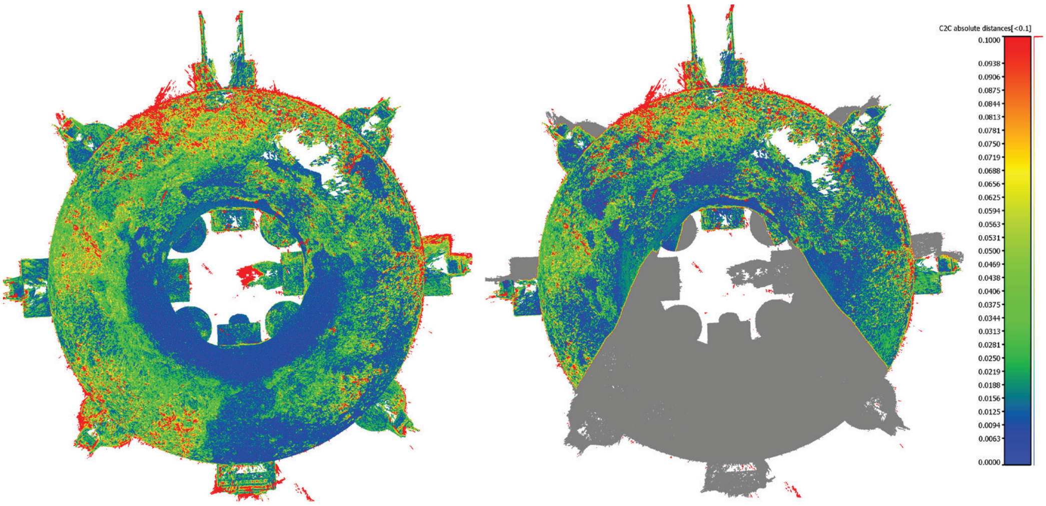

Figure 12: *Comparison of PhotoScan pointloud with laser scanner. On the left, the comparison with all registered laserscanner pointclouds, on the right with a single laserscanner pointclouds. As evident there are no significant differences.*

process. By using Micmac, the solution is surely more documented, but the interface, by command line, is not easy to use and it can dissuade the possible users.

Both methods allow to input metric information as distances or point coordinates. It allows us to make also a geometric comparison about point clouds produced in different ways. By using CloudCompare we compared three pointclouds:

a) Pointcloud computed by PhotoScan, starting from panoramic image (we call "Spherical");

b) Pointcloud computed by PhotoScan, starting from tradition images (we call "PhotoScan" Pointcloud)

c) Pointcloud computed by MicMac, starting from traditional images (we call "PhotoScan").

The comparison has been made by using, as a reference, the point cloud acquired by laser scanner. We have made some tests also by comparing each photogrammetric pointcloud (a, b, c) with a single laser scanner pointcloud in order to avoid errors due to registration (**Figure 12**).

In **Figure 14a** the errors (distances between points)are displayed according to a colour scale bar. A first observation regards the noise of the pointclouds. In this case it can depend on the hard lighting condition of the circular room. For example the panoramic imaged are affected by different exposure due to the presence of both natural light (from window) and artificial one of spot lights.

The position of errors in the"Photoscan" and "Micmac" is very similar. Some differences instead can be observed in the spherical pointcloud. And they correspond to the area of panorama n.6 which has the highest residual in orientation.

A second comparison has been made using mesh models. All the pointclouds have been triangulated in the same software (Geomagic Studio) in order to maintain the same parameters.

As evident in **Figure 14b** the process of triangulation smoothed the errors. The mean error between the meshes and the laser scanner one is about 0.015 m.

4. Data integration and possible results

In addition to the comparison, it is also interesting to evaluate the results and how they can be integrated together to obtain new elaborations. The most immediate application, already described in paragraph 2.3.3, regards the mapping of the existing model. In the case of the Mausoleum the model was obtained by laser scanner, but the same pipeline can be applied to any parametric model: the geometry of the model is textured through photogrammetry. Photogrammetric data also can be the basis for a parametric modelling of the object, which leads to a more regular pattern and with a smaller num of polygons, and then used in real time applications or web-based. Also 3D reconstruction takes advantage of this parametric models as the basis for virtual restoration. Indeed the parametric model is an optimized and sufficient reliable version of an high resolution mesh model that can be easily managed in computer graphics environment. The results from spherical photogrammetry is immediately usable for this kind of modelling.

Figure13*: section of 3D textured model.*

More than measurements and 3D models, photogrammetry can be implemented to develop and optimize the workflow to obtain a new fruition of the 3D environment [Kwi11]. VR technologies are already well known, but they have been

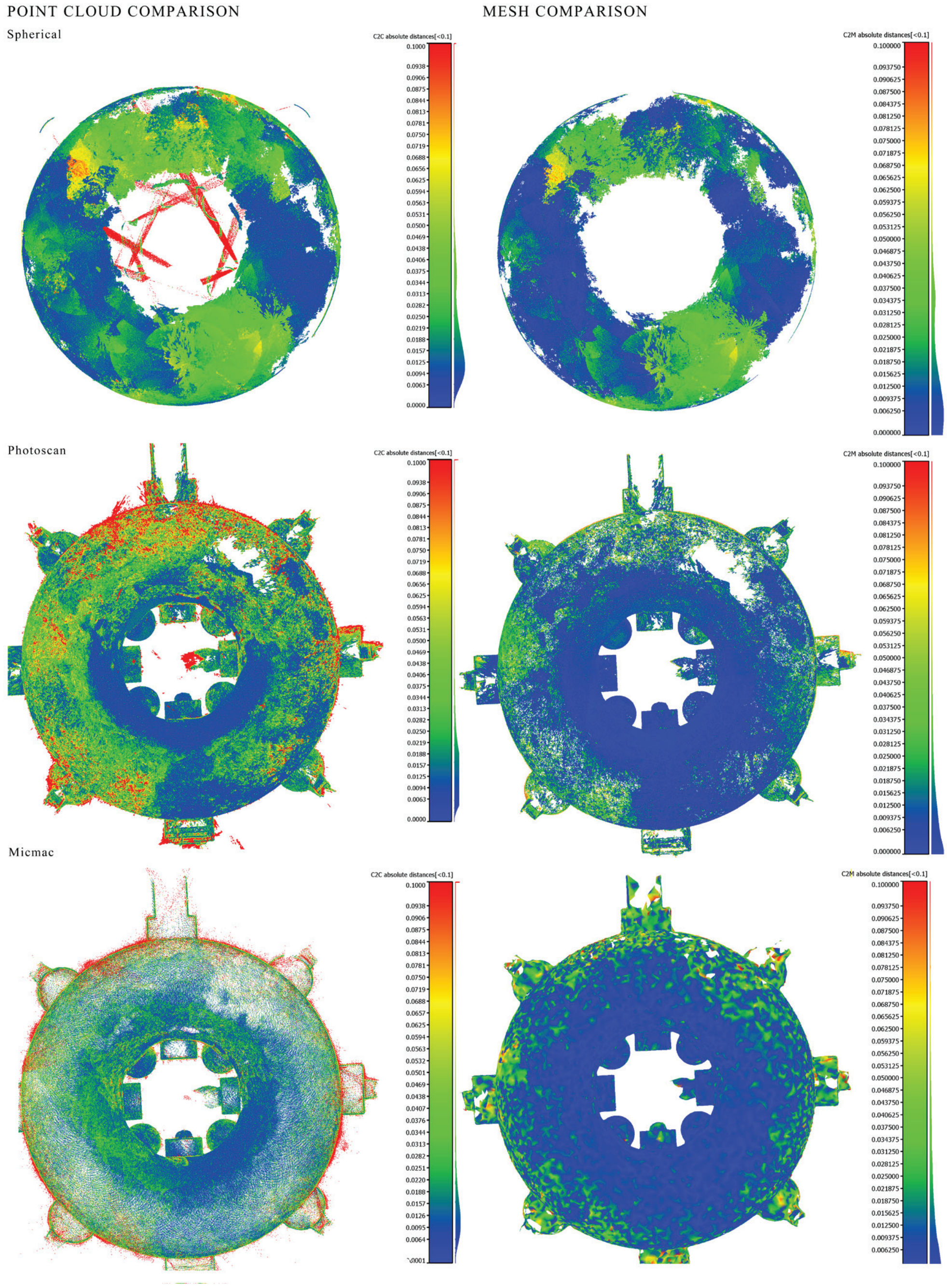

Figure 15: *Comparison between pointclouds (left) and meshes (right). The scalebar is from 0 to 0.1 m*

revised, implemented and improved with the development of tools for the interactive navigation. The virtual scene can be then not navigable in VR mode for single node, but can be possible also to switch between panoramas (oriented) through 3D environment containing the model. Limitations here to overcome have been to not only display on a single monitor and force the interaction only to the mouse usage [dAn10]. Software developed with visual programming languages (VVVV programming environment) allow to visualize complex display systems, complex interaction modes with tools like Kinect, Leap Motion, etc.

5. Conclusions

The examined photogrammetric systems provide interesting alternatives for the survey of CH. The ease of use of some systems (DIM) leads to underestimate the operating conditions. The tests about the "torus" of the Mausoleum show that the acquisition stage is fundamental to achieve a good result. The complex light conditions would have required, for example, to acquire images with bracketing to increase the image dynamic and forced to use the tripod even for images intended for DIM. These observations, mainly related to the photographic aspects, are valid in the case of automatic spherical photogrammetry. However, these photogrammetric systems are particularly suitable in case of acquisitions aimed at real-time or web based applications. The lower metric accuracy is compensated by the possibility to obtain a final model with texture. We cannot forget the economic aspects too. The use of laser scanner instruments, which ensures a more accurate result metrically and a greater awareness of achievable results, however, involves a greater financial commitment.

Photogrammetry finally can play an important role in the integration of data. The high texture quality, difficult to achieve with other systems, allows finally to apply photogrammetry also in many fields of CH, from museum visualization to educational applications.

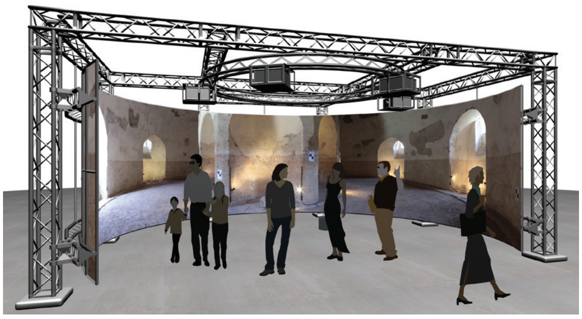

Figure 15: *hypothesis of museum installation with the multi-projection immersing system. This enhances the physical perception of the 3D environment.*

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