

## 2D & 3D RECONSTRUCTION WORKFLOWS FROM ARCHIVE IMAGES, CASE STUDY OF DAMAGED MONUMENTS IN BOSRA AL-SHAM CITY (SYRIA)

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### Commission II, WG II/8

**KEY WORDS:** Archive Images, Documentation, Photogrammetry, Workflow, Comparison, Point Clouds, Photomosaic, Orthophoto

### ABSTRACT:

The paper explores the possibilities of using old images for 2D and 3D documentation of archaeological monuments using open source, free and commercial photogrammetric software. The available images represent the external façade of the Western gate and Al Omari Mosque in the city of Bosra al-Sham in Syria, which were severely damaged during the recent war. The images were captured using consumer camera and they were originally used to achieve 2D documentation for each part of the gate separately. 2D control points were used to scale the digital photomosaic and reference distances were applied for the scaling of the 3D models. Archive images were used to produce a 2D digital photomosaic of the monument by image rectification and 3D dense point clouds by applying Structure from Motion (SfM) techniques. The geometric accuracy of the results has been assessed.

### 1. INTRODUCTION

In times of war, buildings, monuments and symbols of culture can become targets of violent and oppressive actions. In these cases, the availability of historical or old images is often the only way to study and reconstruct them, because they are the only remaining documents of these damaged buildings and monuments (Grussenmeyer & Al Khalil, 2017). Studies have shown that processing old images using current recording methods have huge potential in cultural heritage (Bitelli et al, 2007). Image based techniques offer new possibilities like creation of 3D models from archive images which enable comparison of historical and current states of cultural heritage objects (Murtiyoso et al, 2017 & 2018), or even documentation of damaged or destroyed historical monuments (RodríguezMiranda & Valle Melón, 2017). The aim of our study is to document monuments severely damaged during the war in Syria, using archive images and image-based techniques. This documentation will be achieved in 2 and 3 dimensions using open source, free and commercial image-based software. In regard of image-based techniques, three basic approaches are available: mono, stereoscopic and multi-image. Traditional mono-image documentation takes the form of a rectified image in a specific coordinate system, and the resulted rectified image is then used to extract only 2D data (Hemmler & Wiedeman, 1997). Rectification is suitable for flat façades where the low relief (if present) is assumed to produce negligible deformation on the final rectified image. In the case of stereoscopic imaging, two images are captured from different camera poses so that the optical axes of both camera systems are perpendicular to the base vector between them and almost parallel to each other. The previous set of conditions is known as the normal case. The previous conditions are not required in the multi-image

photogrammetry where parallel and oblique images are combined, but images must be captured so that each point of the scene appears on at least two images (preferably more than two). The achievement of this condition requires the application of certain rules when capturing images (Snaveley et al, 2008) and (English Heritage, 2017).

In the case of extended plane structures that cannot be covered in a single image, it is possible to process a photomosaic. Image mosaicking is defined as the process of obtaining a wider field-of-view of a scene from a sequence of partial overlapping views. Controlled photomosaic is achieved using rectified images when the scene is composed of several plans. The observation-measurements of at least four 2D control points (predefined and topographically measured) on each image is required. The rectified image is finally generated through a resampling process (Remondino et al, 2014).

Structure from Motion approach (SfM) is an image-based method for creating three-dimensional models of a feature or topography from overlapping two-dimensional photographs taken from many locations and orientations to reconstruct the photographed scene (Wikipedia, 2013). In addition to ortho-rectified photos, SfM produces a dense point cloud dataset that is similar in many ways to the data produced by airborne or terrestrial lidar. The advantages of SfM are its relative cost in comparison to Terrestrial Laser Scanning, as well as its ease of use. However, the application of this method requires, on the other hand, the achievement of good overlapping between images and the presence of points on as many images as possible.

Nowadays, we have a large number of commercial, open source and freely available photogrammetric software, enabling 2D and 3D object reconstruction from digital images (Pierrot-Deseilligny & Paparoditis, 2006). However, not all of them can be used to create sufficiently accurate and high-quality documents (Bartoš et al, 2014).

Therefore, this paper aims also to compare the workflows and outputs of some open-source, free and commercial photomosaicking-based and SfM-based photogrammetric software when dealing with archive images.

## 2. MONUMENTS UNDER STUDY AND DATA AVAILABLE

Bosra al-Sham is an ancient city located 108 km South of Damascus. This city, which was once the capital of the Roman province of Arabia, was inscribed on UNESCO's World Heritage list in 1980, and placed on the agency's World Heritage in Danger list in 2013 (Unesco, 2019).

The damaged monuments studied in this paper are the Western Gate and Al-Omari Mosque (Figure 1). The Western Gate is located on the Western side of the main East-Western street. The gate, which is decorative more than defensive, is composed of one opening covered by arches. The central body of the gate is flanked by two rectangular masses adorned by pillars on their four angles. The simple architectural decoration is composed of two niches on either side of the door, pillars without capitals, protrusions laterally extending and emphasizing the door vault, and two layers of simple horizontal protrusions surrounding the upper level of the edifice (Batatu,1999). The second monument is Al-Omari Mosque (Figure 2). This Mosque is an early Islamic-era Mosque in the Roman city of Bosra. It was founded in 636AD and was completed in the early 8th Century. The Mosque was renovated in the 12th and 13th Century. Before it was destroyed, this Mosque was one of the oldest standing mosques in the world (Wikipedia, 2019).



Figure 1. Western gate, city of Bosra al-Sham (Syria)



Figure 2. Al Omari Mosque, city of Bosra al-Sham (Syria)

Five old images of the first monument, and thirteen images of the second monument are available (Figure 3). These

images were captured by a Sony DSC-H7 camera (3264 x 2448 Pixels) to ensure an accurate image rectification (object pixel size was less than 1 cm). It should be noted that the overlapping ratio between the images is good enough to generate a photomosaic but inadequate for the application of the SfM method. On the other hand, a set of natural and artificial 2D control points is available within a local coordinate system.



Figure 3. Selection of photos of the monuments

## 3. COMPARISON OF SOFTWARE PACKAGES

As it was mentioned in the introduction, there is a large number of open source, free and commercial photogrammetric software available today. The following software were selected for the 2D photomosaicking-based documentation:

1- *GaiaOrtho* free software (Figure 4). This software is a free image processing software allowing, by homography calculation, the ortho-rectification of a series of images of plane objects in order to allow a "metric" exploitation (Assali, 2015).

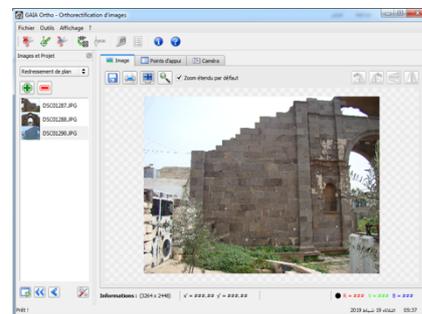


Figure 4. GaiaOrtho free software (Assali, 2015)

2- *Raster Design* commercial software. This software adds raster-to-vector tools that help us to convert raster images into DWG™ objects. Raster Design has some possibilities to rectify raster images through well-known Rubbersheet functions that enables two basic methods of rectification (triangular and polynomial).

For investigation of the automatic generation of 3D point clouds and 3D surface models from image data the following software packages were used:

1- *VisualSFM* open source software: this software is dedicated to 3D reconstruction using Structure from Motion (Wu, 2007). It includes the libraries for feature detection and matching, sparse reconstruction. For dense reconstruction, this program integrates the execution of PMVS/CMVS patch or cluster based multi-view stereo software tool chain (Furukawa & Ponce, 2010). The .ply files created here can then be opened in Meshlab (<http://www.meshlab.net>) and converted into textured 3D meshes;

**2- Regard3D** open-source SfM software: this tool is able to create 3D models of objects using a series of photographs taken of this object from different viewpoints (Regard3D, 2019);

**3- 3DF Zephyr** free-software: this software was developed by 3DFLOW (Feldman, 2019). It is a complete photogrammetry pipeline software package that includes many post processing tools, measurements, 3D modelling and content creation. 3DF Zephyr "free" can process only up to 50 images and orthophoto generation is not possible;

**4- Meshroom** open-source photogrammetry software. It is built on the AliceVision framework. The program is built around an easy to use node-based workflow that connects all the steps to generate a 3D model (Uebel, 2019);

**5- Agisoft Metashape** commercial software (Agisoft, 2019). This software offers many interesting features like photogrammetric triangulation, point cloud data, measurements for distances, volumes and areas, 3D model generation, orthophoto and textures.

Each software package is different, but most of them are built on the same workflow with three steps :

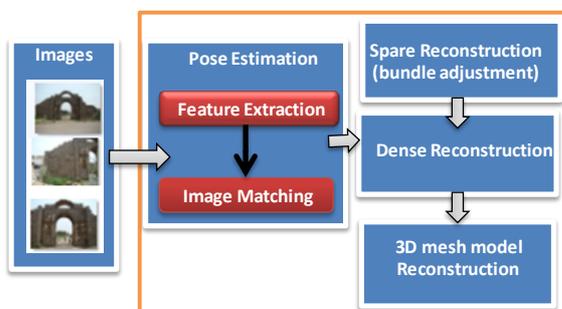


Figure 5. Basic workflow of SfM-based software

## 4. DOCUMENTATION WORKFLOWS

### 4.1 Production of digital Photomosaics

From each of the datasets (Western Gate and Al Omari Mosque), three images were selected to generate Photomosaics. The selected images met the requirements of photomosaic production, in terms of overlap and imaging distance. We can summarize the stages of digital photomosaic production of the studied monuments by the following general workflow:

#### 1-With Raster Design:

- Image rectification was achieved using a Computer-Aided Design (CAD) commercial software (Raster Design). Rectification was based on a 2D second-order polynomial geometric transformation;
- Rectified images were then exported under the GeoTif format. This format is used as an interchange format for georeferenced raster imagery;
- Digital photomosaic was produced from previously rectified images using the ArcToolBox application.

**2-With the free photomosaicking GaiaOrtho toolbox:** orthorectification of all available images was done by the options proposed within the tool (Assali, 2015).

#### 4.1.1 Rectification results using Raster Design

All the available control points were used and the calculation of the coefficients were carried out with an adjustment and a statistic evaluation. Table 2 and Table 3

show the statistics of rectification processing (number of used control points and the total root mean square error (RMS) of rectification processing for each image).

Table 2 and Table 3 show that the RMS errors based on the 2D control points residuals decrease when more control points are measured in the images.

Image	Nb of used control points	RMS (cm)
Left	9	8.7
Middle	15	4.8
Right	12	3.3

Table 2. Statistics of rectification processing for each image of the Western gate

Image	Nb of used control points	RMS (cm)
Left	12	4.7
Middle	13	4.2
Right	9	6.7

Table 3. Statistics of rectification processing for each image of Al Omari Mosque

#### 4.1.2 Generation of a digital photomosaic using the ArcToolBox application

The application ArcToolBox from ArcGIS was applied to merge the images rectified previously (Figures 6 and 7). The geometric accuracy of the resulted photomosaic is close to the RMSE of the rectification process. Pixel size in this photomosaic is approximately 5 mm.



Figure 6. Photomosaic of the Western Gate using ArcToolBox application



Figure 7. Photomosaic of Al Omari Mosque using ArcToolBox application

#### 4.1.3 Rectification results using GaiaOrtho

GaiaOrtho software was used to rectify the previous images and delivers statistics shown in Tables 4 and 5. The result of the mosaic processing is shown in Figures 8 and 9.

Image	Nb of control points	RMS (cm)
Left	9	9.1
Middle	15	4.8
Right	12	7.9

Table 4. Statistic characteristics of the rectification of the Western gate images using GaiaOrtho

Image	Nb of control points	RMS (cm)
Left	11	4.5
Middle	13	4.8
Right	9	4.7

Table 5. Statistic characteristics of the rectification of Al Omari Mosque images using GaiaOrtho

The results are very close to those obtained with Raster Design (Tables 2 & 3). For both tools, the results could be improved by considering the calibration of the camera and a better accuracy of the control points.



Figure 8. Photomosaic of the Western Gate using GaiaOrtho free software



Figure 9. Photomosaic of Al Omari Mosque façade using GaiaOrtho free software

## 4.2 3D Modelling of the damaged monuments

Theoretically, the images used to extract the 3D point clouds must achieve at least 60% overlap between each two successive images. Considering that the old available images were captured for image rectification purposes, this condition is not fulfilled. But, the majority of automated photogrammetric systems can deal with lower overlapping ratios than previously mentioned, and can handle images captured at different distances from the object. These capabilities are suitable for our study.

Five open source, free and commercial software packages were used to generate 3D data of the Western Gate. The modeling process went through the stages summarized in Figure 5. Figure 10 shows the configuration of the scene (5

images available, no oblique views) and Figure 11 illustrates the results of the 3D dense matching process for the Western Gate.

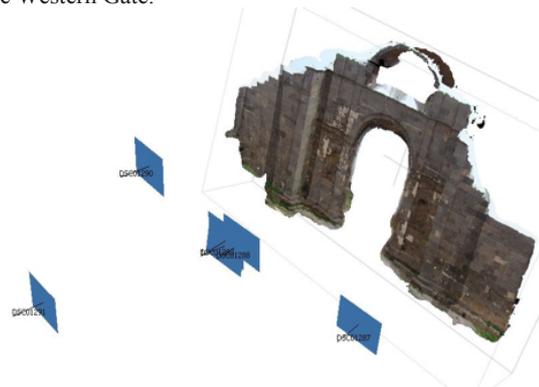


Figure 10. Images available for the Western Gate

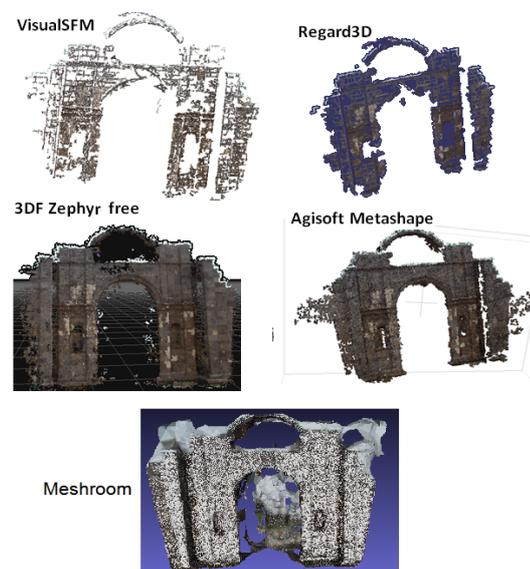


Figure 11. Dense Point clouds processed from 5 images of the Western gate

### 4.2.1 Evaluation of 3D models

To assess the 3D modeling process, we applied the methodology proposed in (Bartoš et al, 2014). The results can be compared in terms of reconstruction density, point cloud consistency and quality of 3D mesh model. We could also consider an external software to complete the modeling stages, and orthophoto production, as well as additional parameters to be included in the comparison process. Table 6 shows the results of a comparison based on the 5 software packages used.

Figure 11 shows that the point clouds generated by VisualSfM and Regard3D contain a number of small holes and more outliers compared to 3DF Zephyr and Metashape. On the other hand, 3DF Zephyr software provides the most dense reconstruction with less noise and higher visual quality. We also note that VisualSfM is the only software that needs an external tool to generate the 3D mesh model (For example, MeshLab), while AgiSoft Metashape is the only one that allows the generation of orthophotos.

	Software	Sparse Point cloud	Dense Point cloud	Mesh triangles	External meshing software	Ortho
Western gate	VisualSfM	5227	292058	-	Yes (MeshLab)	No
	Regard3D	4671	220850	395700	No	No
	Meshroom	5596	284125	122354	No	No
	3DF Zephyr	7773	3831329	885516	No	No
	Metashape	4747	1315817	263163	No	Yes

Table 6. Comparison between the results of each of tested software

#### 4.2.2 Geometric evaluation of 2D and 3D models

Orthophotos have been processed after the step of triangular meshing in Agisoft Metashape. Orthophotos are of course better than photomosaics in terms of geometric accuracy. Thus, orthophotos can be used to measure true distances (Dewitt & Wolf, 2000).

To scale the orthophotos in our study (Figure 12 and Figure 13), we use horizontal distances between two control points located in the same plan.



Figure 12. Orthophoto of the Western gate (Agisoft, 2018)



Figure 13. Orthophoto of Al Omari Mosque (the results of the dense matching are not presented in this paper)

### 5. RESULTS

To evaluate the geometric quality of the four previous digital photomosaics (resulting from Raster design and GaiaOrtho) and the two orthophotos resulting from 3D processing of archive images (using Agisoft Metashape), a group of 2D distances was defined (Figures 14 and 15). These ones were firstly calculated from control points coordinates, and secondly measured on the photomosaics and orthophotos respectively.

Table 7 shows that the differences between the distances measured on the Photomosaics and the calculated ones from the 2D control points are small due to the good coverage provided by the old images, which are perpendicular to the façade. On the other hand, the differences between distances measured on orthophoto and the real distances are generally larger than the previous ones. This can be explained by the following:

- 1- The number and direction of the images covering the façade and the overlapping ratio do not meet the ideal conditions for the implementation of the SfM method;
  - 2- Scaling the 3D model (and therefore the orthophoto) was not done using 3D control points because only 2D points (distances) were available;
  - 3- Due to the data available, the camera calibration parameters are only partially processed.
- However, we can consider that the resulting orthophoto is useful in many applications that do not require high accuracy.

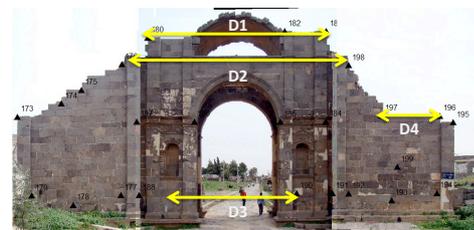


Figure 14. Evaluation distances for the Western gate

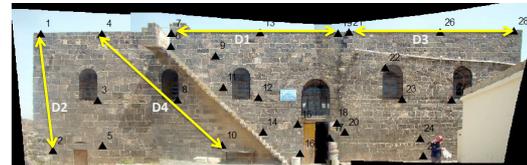


Figure 15. Evaluation distances for Al Omari Mosque

To evaluate the relative geometric quality of the resulted 3D models, we applied the following approach on the Western gate 3D dense point clouds (processed without scaling). The largest dense point cloud (generated by 3DF Zephyr free release) has been considered as reference point cloud. In a first stage, each point cloud has been co-registered manually to the reference cloud with the 'Align (point pairs picking)' tool of CloudCompare. This manual process is possible thanks to the artificial control points visible in all the point clouds. In a second stage, we used the M3C2 plugin of CloudCompare to compute signed distances directly between two point clouds. In the output section, the projection of the core points is done keeping original positions; in this way, a new cloud is generated, containing the differences between the tested point clouds (Gaglioli, 2018). The distribution of the differences has been represented with a Gaussian distribution and Table 8 shows the mean and the standard deviation. All the solutions, except Regard3D, show a bias with respect to the Zephyr point cloud: about +0.0042 (given in Zephyr software internal units) for Agisoft Metashape, -0.0133 (given in Zephyr software internal unit) for VisualSfM, and +0.0498 for Meshroom. Variance of values can be explained by the ability to accurately measure the artificial control points required to perform the co-registration operation, on the point clouds which do not appear well in the case of Regard3D, which is not very dense.

	Distance	Cal	Mosaic RD	Mosaic GaiaOrtho	Ortho	$ \Delta D $ (Cal-MosaicRD)	$ \Delta D $ (Cal-MosaicGaia)	$ \Delta D $ (Cal-Ortho)
		(m)	(m)	(m)	(m)	(cm)	(cm)	(cm)
Western gate	D <sub>1</sub>	9.89	9.9	9.88	9.81	1	1	8
	D <sub>2</sub>	12.59	12.56	12.57	12.66	3	2	7
	D <sub>3</sub>	6.36	6.33	6.31	6.26	3	5	10
	D <sub>4</sub>	3.24	3.23	3.22	3.13	1	2	11
Al Omari Mosque	D <sub>1</sub>	11.06	11.09	11.05	11.08	-3	1	-2
	D <sub>2</sub>	7.9	7.87	7.84	7.85	3	6	5
	D <sub>3</sub>	10.96	10.97	10.93	10.88	-1	3	8
	D <sub>4</sub>	10.96	10.93	11.01	11.01	3	-5	-5

Table 7. Differences between calculated distances, measured on Raster design & GaiaOrtho photomosaics and on orthophotos respectively

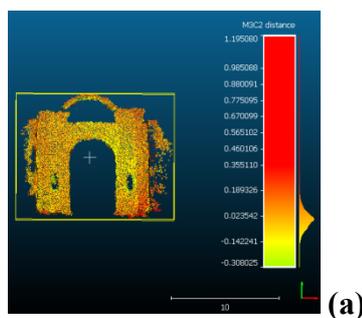
Software	Mean (Zephyr software unit)	Std (Zephyr software unit)
Metashape	0.0042	0.137
Regard3D	-0.1095	0.285
VisualSfM	-0.0133	0.221
Meshroom	0.0498	0.199

Table 8. Results of M3C2 comparisons (mean and standard deviations)

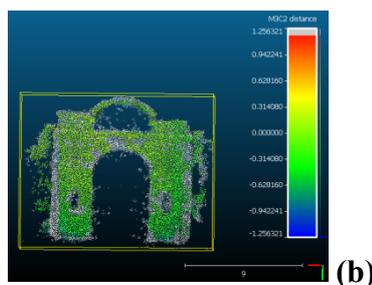
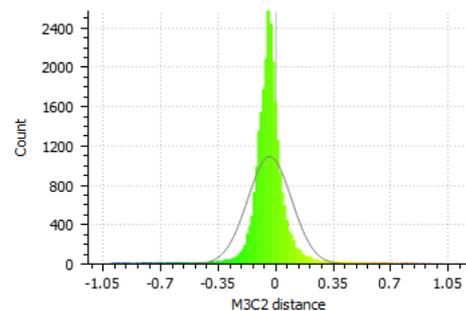
## 6. CONCLUSION

Archive images can be considered as an important source of data required for 2D and 3D documentation of destroyed or damaged architectural heritage. CAD and GIS software are effective tools for image rectification and mosaicking. The use of free photogrammetric software packages dedicated to image rectification and mosaic production are

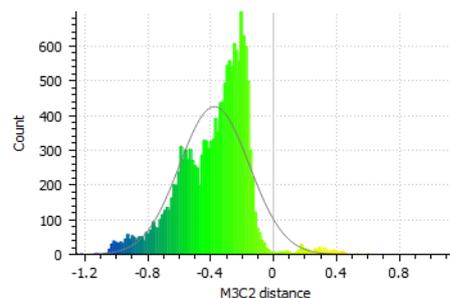
more professional, as the geometry of the camera (if available) can be defined. Commercial or free software based on the SfM method are low cost alternative solutions compared to the more expensive classical stereoscopic photogrammetry and 3D laser scanning methods. But old images often do not meet the requirements of ideal application of the SfM method (poor image overlapping ratio and no 3D control data), which in turn limits the efficiency of these software. It turns out that not all packages are suitable for a use in photogrammetric documentation. In fact, free software solutions suffer from a lack of many of the functions necessary to obtain accurate and reliable documentation (such as the generation of orthophoto for example). It is obvious that commercial software packages are better than free ones in 3D documentation, but these software can find a lot of applications that do not require high accuracy.



Gauss: mean = 0.004164 / std.dev. = 0.136524 [167 classes]



Gauss: mean = -0.109533 / std.dev. = 0.285881 [165 classes]



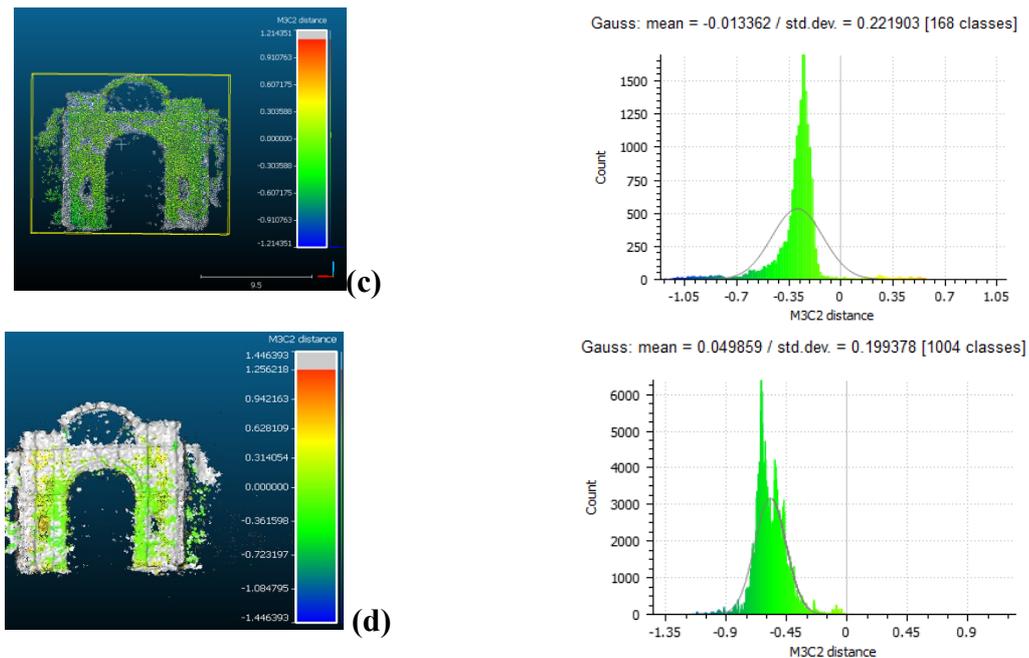


Figure 15. CloudCompare M3C2 distances processed between 3DF Zephyr and: Agisoft Metashape (a), Regard3D (b), VisualSfM (c) and Meshroom (d), with the corresponding Gaussian distributions

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