The Virtual Reconstruction of the Minaret of Mansourah Mosque (Algeria)

Sara Morena
Dept. of Civil Engineering
Faculty of Engineering
University of Salerno
Salerno, Italy
smorena@unisa.it

***Abstract*—This contribution synthetically addresses some of the photogrammetric solutions available today in the field of architectural-archaeological survey and the related applications outcome, evaluated during both the acquisition phase of metric data than in those of effective yield of refunds infographics.**

Therefore, we have focused on the virtual reconstruction of one of the most emblematic and symbolic building of the Algerian culture, the mosque of Mansourah, returning the minaret as it appeared before its partial collapse, namely correspondent in geometry, textures and colours.

The work is part of a larger research project to promote knowledge and dissemination of Algeria cultural heritage, with 'original' approach about the validation of an integrated methodology. In particular, the analysis has led to the application of the theory of errors on the survey of the elevations obtained by the two different methods of photogrammetric survey, multi-image and stereoscopic.

The documented example shows how it is possible to achieve reliable reconstructions of each structure, although presently destroyed, bringing to light traces of a story now lost.

***Index Terms*—Photogrammetry, Digital Cultural Heritage, Virtual conservation and Digital documentation.**

I. Introduction

The possibilities currently offered by digital photogrammetry applied to the survey of cultural heritage are numerous and extremely flexible, both as regards the acquisition of data and for processing procedures and the quality of the final products. Exactly this flexibility has made it so successful in the field of cultural heritage. The acquisition of images is often rapid and can even occur with medium-low cost camera; relevant factors in an industry where often economic and temporal resources are scarce.

In this context, we can present the study concerning the minaret of Mansourah, an ancient historical site of the Algerian province of Tlemcen.

Developing some "indirect" photos – anonymous tourists' or professional photographers' image, found on the Internet or on photo-sharing websites – we proceeded to the representation and, subsequently, the virtual reconstruction of this building.

The methodological approach has provided the use of multi-image photogrammetry for the generation of textured three-dimensional model. Therefore, based on the restitution of the actual state of the minaret – and necessary historical investigations – we proceeded to the realization of 2D and 3D drawings of the original state.

The second phase of the process concerned, with the progress of state of the art, the validation of the methodology used. We proceeded then to a statistical analysis of type 'absolute'. Through this analysis it is assessed the results from multi-image photogrammetry compared to those of classic-stereoscopic photogrammetry, by estimating the standard deviation between the coordinates of points-type that are collimated on the corresponding refunds.

Starting from this exemplification we can explain that it is possible to sustain the recovery activity – virtual and not – of each building, from old photos, with the possibility to apply this method to promote the enhancement of those architectural heritages, so-called minor, of which our country is rich and are still in a state of complete abandon.

II. State of the Art

The particularity of the research work, in very brief, was to experiment with a methodology in which the photographs, unlike what usually happens, have been acquired from indirect sources.

In the international context, a similar technique of virtual recovery finds a first application in the 3D reconstruction of the two enormous statues of the Buddha in the valley of Bamiyan in Afghanistan (around two hundred kilometers from the capital Kabul), carved in the rock and destroyed in 2001 from the Taliban (the authors of the project were A. Gruen, F. Remondino, L. Zhang of the Swiss Federal Institute of Technology, Zurich).

Subsequently, in 2010, following the earthquake of Haiti, another project was introduced – even if with less fortune, given the small number of images of photogrammetric quality then found – for the virtual restoration of the Port-au-Prince Cathedral (among the authors F. Remondino, P. Ortiz Coder and S. Barba).

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Fig. 1. *Mosqée et Minaret, Ruines de Mansoura* by Alexandre Genet.

III. Brief historical notes on the Mosque

The mosque of Mansourah, built in the XII-XIV century, is an important example of Arab architecture. The first archaeological excavations were carried out in 1872 and already in 1875 the mosque was classified as a "Historical Monument" by proceeding its first restoration with the funds of the "Commission des Monuments historiques" of France.

Built on a rocky peak and situated not far from the port that is coming to Morocco, the work was commissioned by Prince Abu Yaqub in 1299, but not completed until after his death.

Today, unfortunately, not much remains of this magnificent structure. The minaret is definitely the most important and preserved part: it is a square tower (with the side of about 10 m), about 49 m high. Exceptionally this tower was built with cut stone, a kind of travertine worked not far from the place of installation. These stones, laid with thick layers of mortar, allowed to create a stonework with a good solidity and resistance but, despite that, today we consider almost exclusively the main facade and North facade, while the South and half of the side facade no longer exist (Fig.1).

The measures taken in the past to rebuild the mosque are now useful to understand the history of the monument, now altered through time, and compare it with hypothetical reconstructions. We have information and studies concerning the mosque right in consequence of the investigation took place during the restoration from those of 1872.

IV. The acquisition of images and measures

The study on the mosque of Mansourah represented a good example to experiment digital integrated methodologies for the preservation of historical and cultural heritage.

Given the logistical difficulties of reaching the place, we collected some significant images on Internet concerning the artefact. The photo-sharing websites such as Panoramio and Flirck, facilitated not only the search for quality images but above all have identified tourists and photographers who were in those places. The information retrieval has concluded with the recovery of 44 pictures. In the next step, these pictures were opportunely analysed and selected on the basis of the characteristics of size, focal length, etc. reducing our data-sheet in 38 photos (Fig.2).

ID foto	Origine	Cartella di destinazione	Formato	KB	Focale	ISO	Esposizione	Programma	Modello fotocamera	Produttore	Profondità	Risoluzione	Versione EXIF	Dimensioni
0D8T5379	F. Almagro	Agisoft	JPEG	9032	28 mm	100	1/160 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5382	F. Almagro	Agisoft	JPEG	9242	105 mm	100	1/160 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616
0D8T5383	F. Almagro	Agisoft	JPEG	10190	105 mm	100	1/160 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
R0012331	F. Almagro	Agisoft, 123D Catch	JPEG	3653	6 mm	100	1/500 sec.	Normale	GR DIGITAL 2	Ricoh	24 bit	72 dpi	0221	3648x2736
R0012336	F. Almagro	Agisoft	JPEG	3787	6 mm	100	1/320 sec.	Normale	GR DIGITAL 2	Ricoh	24 bit	72 dpi	0221	3648x2736
R0012340	F. Almagro	Agisoft, 123D Catch	JPEG	3642	6 mm	100	1/500 sec.	Normale	GR DIGITAL 2	Ricoh	24 bit	72 dpi	0221	3648x2736
R0012341	F. Almagro	Agisoft, 123D Catch	JPEG	3700	6 mm	100	1/500 sec.	Normale	GR DIGITAL 2	Ricoh	24 bit	72 dpi	0221	3648x2736
R0012351	F. Almagro	Agisoft, 123D Catch	JPEG	3528	6 mm	100	1/320 sec.	Normale	GR DIGITAL 2	Ricoh	24 bit	72 dpi	0221	3648x2736
R0012352	F. Almagro	Agisoft, 123D Catch	JPEG	3759	6 mm	100	1/500 sec.	Normale	GR DIGITAL 2	Ricoh	24 bit	72 dpi	0221	3648x2736
Le Mansourah Tlemcen Sept 2013 010	F. Andrea	Agisoft	JPEG	3062	18 mm	400	1/4000 sec.	Priorità diaframmi	D3200	Nikon	24 bit	300 dpi	0230	3165x4761
Le Mansourah Tlemcen Sept 2013 035	F. Andrea	Agisoft, 123D Catch	JPEG	2754	18 mm	400	1/2500 sec.	Priorità diaframmi	D3200	Nikon	24 bit	300 dpi	0230	3261x4905
Le Mansourah Tlemcen Sept 2013 045 01	F. Andrea		JPEG	6761	18 mm	400	1/4000 sec.	Priorità diaframmi	D3200	Nikon	24 bit	300 dpi	0230	6016x4000
Le Mansourah Tlemcen Sept 2013 049	F. Andrea		JPEG	4887	18 mm	400	1/4000 sec.	Priorità diaframmi	D3200	Nikon	24 bit	300 dpi	0230	4813x2365
Le Mansourah Tlemcen Sept 2013 071	F. Andrea	Agisoft, 123D Catch, Ortohware	JPEG	10944	18 mm	400	1/4000 sec.	Priorità diaframmi	D3200	Nikon	24 bit	300 dpi	0230	4000x6016
0D8T5350	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	11542	28 mm	100	1/320 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5351	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	11585	28 mm	100	1/250 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5355	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	1196	28 mm	100	1/250 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5356	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	11053	28 mm	100	1/250 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5357	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	10396	28 mm	100	1/250 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5358	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	11864	28 mm	100	1/200 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5359	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	10612	28 mm	100	1/200 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5360	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	10476	28 mm	100	1/160 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5361	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	7714	28 mm	100	1/160 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5362	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	9206	28 mm	100	1/125 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5369	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	7841	28 mm	100	1/100 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5373	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	6616	28 mm	100	1/100 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5374	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	6609	28 mm	100	1/125 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5375	F. Ortohware	Agisoft, 123D Catch, Ortohware	JPEG	6895	28 mm	100	1/100 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5350	F. PoivilliersF	Poivilliers	JPEG	11516	28 mm	100	1/320 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616
0D8T5351	F. PoivilliersF	Poivilliers	JPEG	11566	28 mm	100	1/250 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616
0D8T5353	F. PoivilliersF	Poivilliers, 3ds Max	JPEG	13284	28 mm	100	1/250 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5354	F. PoivilliersF	Poivilliers, 3ds Max	JPEG	13408	28 mm	100	1/320 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	5616x3744
0D8T5357	F. PoivilliersF	Poivilliers	JPEG	10373	28 mm	100	1/250 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616
0D8T5358	F. PoivilliersF	Poivilliers	JPEG	11843	28 mm	100	1/200 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616
0D8T5361	F. PoivilliersF	Poivilliers	JPEG	7682	28 mm	100	1/160 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616
0D8T5362	F. PoivilliersF	Poivilliers	JPEG	9173	28 mm	100	1/125 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616
0D8T5373	F. PoivilliersF	Poivilliers	JPEG	6597	28 mm	100	1/100 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616
0D8T5374	F. PoivilliersF	Poivilliers	JPEG	6593	28 mm	100	1/125 sec.	Normale	EOS-1Ds Mark III	Canon	24 bit	72 dpi	0221	3744x5616

Fig. 2. "Indirect" photographs used.

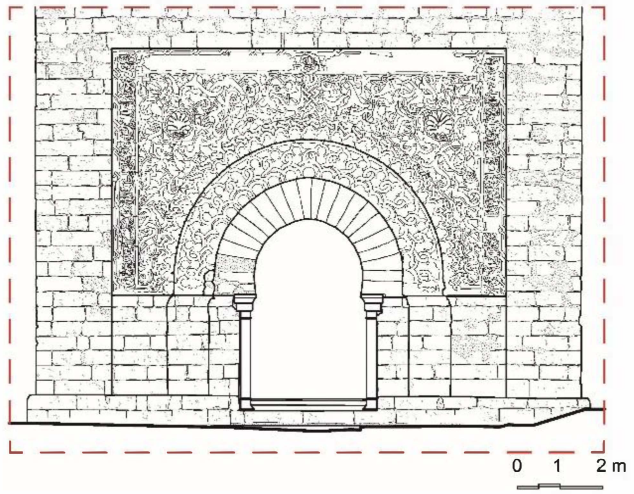

Fig. 3. Detail of historical building survey.

V. The Photoreconstruction from Indirect Data

The elaboration of data involved the use of photogrammetry multi-image. This step has been possible through the use of the application PhotoScan professional edition, the well-known product of the Russian software house Agisoft, based on a multi-viewing 3D reconstruction. The implementation of the version available at the time, the 0.9.1.1703, made possible the photo-reconstruction of the minaret of Mansourah, based on the different photographs at our disposal. The principle of operation of the software, in fact, allows to obtain a three-dimensional model from photos taken from different sources and cameras (even in the absence of a calibration certificate), in different light conditions and from each point of view; reason for which it was possible to treat the acquired photos via internet.

Subsequently, following the generation of the textured 3D mesh model, we proceeded to extract a raster orthophoto necessary for the historical building survey. The graphical representation has, therefore, become essential: historic survey of the building has become an essential instrument for reading it, studying all the characteristics and peculiarities (alignments, diversity of wall thickness, continuity solutions, etc.). The focus on materials and the degradation of the stones has been analysed by the following virtual restoration of the same monument (Fig. 3).

VI. The Hypothesis of Virtual Reconstruction

At the end of the survey and with the restitution of the drawings on the actual state, we proceeded to the study of what could be the initial configuration of the minaret. The relative hypothesis was substantiated by historical investigations and comparisons with similar buildings. The high symmetry that often exists between the facades of these edifices, in fact, allowed to assume a reconstruction of the minaret on the basis of what is today preserved.

The upper part of the tower had a succession of five windows characterized by particular lancet arch and, in the area below, the typical geometrical coloration and arabesque, a pair of arches and a number of central openings. Another particularity of facade was the presence of slender columns made in white marble on which to set the different arches, besides the presence of glazed ceramic used for the ornament of the same tower (which gives it a strong originality).

It is a shared thought that the side decorations and those of the dome of the minaret were completely covered by these colorful majolica that today are visible only in few areas. Currently it presents only a part of the ancient minaret: the highest area, in fact, it is supposed ended with the typical tower, also square-shaped and with the representative lantern of each minaret, so we can hypothesize in addition to the presence also the eventual shape (Fig. 4). The inner side of structure, however, was made up of six rooms accessible by ramp that extended to “spiral” along the perimetral walls of the tower, topped by typical barrel vaults, characterized by a slight slope and wide enough to allow the passage of two people.

To realize these hypothesis it has been used a “solid” modelling, with the rendering phase implemented in the software 3ds Max Design, chosen for the efficient rendering and visualization engine.

VII. The Verification Methodology

The second phase of the work, as already stated above, consisted of a mutual validation of the results. The theme of errors that concern the photo-plans[4] will be deepening and developing by a statistic analysis between the results (Fig. 6) the vector orthophotos from stereoscopic photogrammetry (elaborated in Poivilliers F) and raster orthophoto from multi-image photogrammetric (PhotoScan).

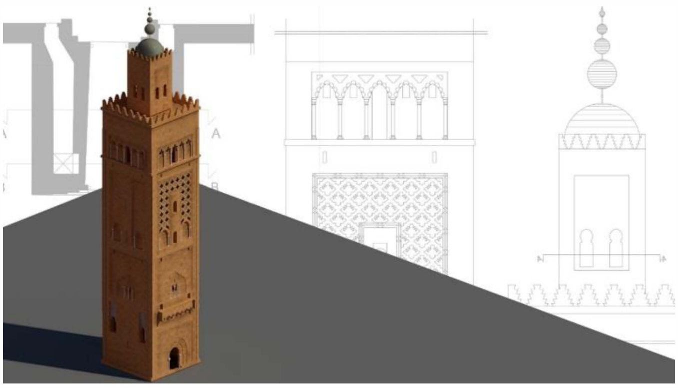

Fig.4. The 3D reconstruction of the minaret.

Fig.5. The virtual representation of the minaret.

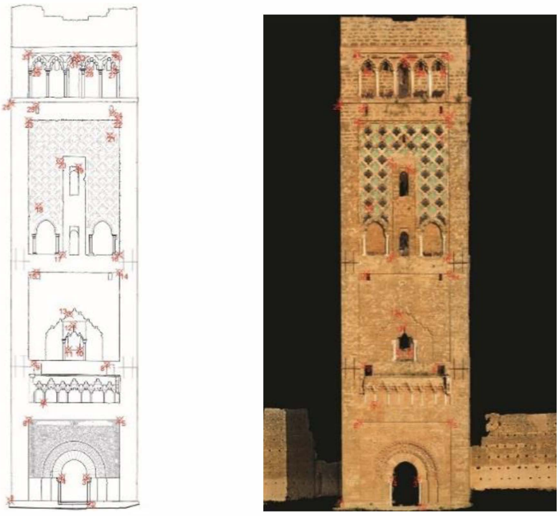

Fig. 6. Orthophotos by PoivilliersF and by PhotoScan, with 33 control points.

n	x_t [cm]	y_t [cm]	x_f [cm]	y_f [cm]	x_m [cm]	y_m [cm]	$s_{x,t}$ [cm]	$s_{x,f}$ [cm]	σ_x [cm]	T_x [cm]	$s_{y,t}$ [cm]	$s_{y,f}$ [cm]	σ_y [cm]	T_y [cm]
1	100,00	100,00	100,00	100,00	100,00	100,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	567,16	78,53	565,91	80,44	566,53	79,48	0,63	-0,63	0,88	2,65	-0,96	0,96	1,36	4,07
3	545,75	237,30	544,85	237,27	545,30	237,28	0,45	-0,45	0,64	1,91	0,01	-0,01	0,02	0,06
4	403,52	237,16	402,67	238,74	403,09	237,95	0,43	-0,43	0,61	1,82	-0,79	0,79	1,12	3,35
5	741,80	572,52	738,10	572,49	739,95	572,50	1,85	-1,85	2,62	7,86	0,01	-0,01	0,02	0,06
6	208,33	574,23	207,72	572,38	208,03	573,31	0,31	-0,31	0,43	1,30	0,93	-0,93	1,31	3,93
7	296,37	677,13	293,90	677,38	295,13	677,25	1,23	-1,23	1,74	5,23	-0,13	0,13	0,18	0,55
8	898,92	666,45	901,85	662,74	900,39	664,59	-1,46	1,46	2,07	6,21	1,85	-1,85	2,62	7,86
9	238,61	904,88	232,69	904,29	235,65	904,58	2,96	-2,96	4,19	12,56	0,29	-0,29	0,42	1,25
10	509,94	985,78	505,21	987,24	507,58	986,51	2,37	-2,37	3,35	10,04	-0,73	0,73	1,04	3,11
11	440,66	986,04	435,03	986,73	437,85	986,38	2,81	-2,81	3,98	11,94	-0,34	0,34	0,48	1,45
12	470,15	1129,93	465,36	1128,81	467,76	1129,37	2,39	-2,39	3,39	10,16	0,56	-0,56	0,79	2,38
13	449,19	1194,72	443,55	1195,52	446,37	1195,12	2,82	-2,82	3,99	11,97	-0,40	0,40	0,57	1,70
14	740,65	1439,85	732,29	1436,92	736,47	1438,38	4,18	-4,18	5,92	17,75	1,46	-1,46	2,07	6,20
15	254,40	1441,83	248,72	1439,59	251,56	1440,71	2,84	-2,84	4,01	12,04	1,12	-1,12	1,59	4,77
16	740,51	1542,52	732,37	1539,94	736,44	1541,23	4,07	-4,07	5,75	17,26	1,29	-1,29	1,82	5,46
17	406,98	1545,16	399,83	1541,69	403,40	1543,43	3,58	-3,58	5,06	15,17	1,74	-1,74	2,46	7,38
18	265,43	1831,02	257,88	1828,31	261,65	1829,66	3,78	-3,78	5,34	16,02	1,35	-1,35	1,92	5,75
19	500,45	2059,61	490,20	2055,82	495,33	2057,72	5,13	-5,13	7,25	21,75	1,90	-1,90	2,68	8,05
20	388,98	2095,71	380,65	2090,89	384,81	2093,30	4,17	-4,17	5,89	17,68	2,41	-2,41	3,41	10,23
21	682,46	2244,07	671,39	2240,79	676,92	2242,43	5,53	-5,53	7,82	23,47	1,64	-1,64	2,32	6,96
22	737,34	2335,05	725,06	2333,37	731,20	2334,21	6,14	-6,14	8,68	26,05	0,84	-0,84	1,18	3,54
23	208,19	2332,69	197,98	2331,16	203,08	2331,92	5,10	-5,10	7,22	21,65	0,76	-0,76	1,08	3,23
24	699,25	2375,20	687,54	2373,90	693,39	2374,55	5,85	-5,85	8,28	24,84	0,65	-0,65	0,92	2,75
25	251,14	2416,53	242,42	2412,16	246,78	2414,35	4,36	-4,36	6,16	18,49	2,18	-2,18	3,09	9,26
26	105,80	2435,05	95,26	2433,53	100,53	2434,29	5,27	-5,27	7,45	22,35	0,76	-0,76	1,08	3,23
27	707,70	2629,22	695,25	2628,78	701,48	2629,00	6,23	-6,23	8,81	26,42	0,22	-0,22	0,31	0,94
28	564,14	2629,52	553,19	2624,69	558,67	2627,10	5,48	-5,48	7,75	23,24	2,41	-2,41	3,41	10,24
29	259,67	2628,41	249,12	2624,14	254,39	2626,28	5,27	-5,27	7,46	22,38	2,14	-2,14	3,02	9,07
30	718,61	2721,30	703,73	2708,00	711,17	2714,65	7,44	-7,44	10,52	31,56	6,65	-6,65	9,40	28,20
31	475,82	2686,33	463,58	2681,43	469,70	2683,88	6,12	-6,12	8,65	25,96	2,45	-2,45	3,46	10,39
32	489,28	2715,27	477,06	2700,65	483,17	2707,96	6,11	-6,11	8,64	25,91	7,31	-7,31	10,34	31,01
33	207,67	2727,99	194,96	2727,51	201,32	2727,75	6,36	-6,36	8,99	26,96	0,24	-0,24	0,34	1,02
						TOT	0	0		TOT	0	0		

Fig. 7. Statistical parameters of the 33 points identified in the two orthophotos.

Initial available data are represented by the coordinates of 33 collimated points on two orthophotos. The most effective statistical parameters, therefore, for our purposes were the "arithmetic mean" of the data; "variance" or the "standard deviation" (σ_x).

It proceeded, so, with an 'absolute' analysis that is a comparison of the punctual variables related to the two photogrammetric methodologies, so indicative of deviation that the coordinates of the points assume in the two orthophotos and the difference that exists between the same. In the Fig. 7 it is possible to deduce the trends – not generalizable – of the deviation.

We have to note that the results obtained are the consequence of a series of local factors that affect, in a non-uniform and indifferent way, the distribution of the error.

VIII. Brief Conclusion

Therefore, the multi-image photogrammetry allows to obtain still significant results, starting from images acquired in non-direct way and also with the possibility of returning destroyed artefacts.

Based on these studies we can further demonstrate the potential of photogrammetry in the field of architectural survey, whether stereoscopic, multi-image or low-cost for the dissemination, exploitation and the recovery in that field.

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