APPLICATION OF ACTION CAMERA VIDEO FOR FAST AND LOW-COST PHOTOGRAMMETRIC SURVEY OF CULTURAL HERITAGE

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ABSTRACT:

The research work focuses on the growing of fast and low-cost data surveying methods (both in the acquisition and processing phases), to be used mainly as a support for the management and enhancement of architectural heritage. Attention is paid on the diffusion of action cameras, characterized by wide-angle lenses and 4K video shooting, with more and more affordable prices and on the elaboration of the data with photogrammetry software. The high-resolution videos captured by these tools, in fact, allow the selection of frames characterized by sufficient overlap, necessary for point cloud generation through Structure for Motion (SfM) processes. The focus is on indoor environment characterized by architectural value and on the data processing not only with professional photogrammetric application but also with cloud server-based system. Hence, the frames extracted from the video have been processed with different, both professional, economic, and user-friendly software tools, achieving several results. Finally, the output data have been compared with a survey method now well established in this field, such as laser scanning. The results of the analyses will be critically discussed in the paper to highlight the great potentialities and the possibility to apply this methodology in the future for heritage preservation.

1. INTRODUCTION

The 3D digitization of cultural heritage is a very important issue, widely analysed in various fields of investigation. It is fundamental for the artistic and architectural heritage at risk, but it also represents an opportunity for repository of extant assets.
3D digitization is otherwise important to foster accessibility and inclusiveness; in fact, through this process, it is possible to provide virtual access to resources currently inaccessible and offer a support for people with disabilities who visit cultural sites (Scianna and Di Filippo, 2019; Hallot et al., 2021; Agnello et al., 2022). Furthermore, although it cannot prevent risks and deteriorations, it can contribute to the protection of some historical objects (avoiding their direct manipulation) and provides a useful database for heritage monitoring (Nishanbaev, 2020; Ioannidis et al., 2021; Bruno et al., 2022).
The great attention to cultural heritage digitization by the scientific community inevitably has led to improvements in technology and methodology. The continuing advances in active and passive sensors for acquisition techniques, the improvements in data processing algorithms and the constant upgrading of existing hardware and software for post-processing purposes have improved the survey process with increasingly accurate and fast results. Instrumentation is now much more manoeuvrable, and software ensures sufficient accurate results even with automated processes, making easier the analysis and the management of the data.
In the international literature, several studies focus on multi device survey of cultural heritage as a method to produce accurate and precise documentation (Hassani, 2015; Adamopoulos and Rinaudo, 2017; Morena et al., 2021). Along with the development of active and passive sensors, the software tools used for data management have been strongly updated and improved (Kingsland, 2020).
The costs of instruments have decreased over the years; today, economic tools and fast processes provide satisfactory results and a good compromise between acquisition quality, objectives to be pursued, and data handling capacity.
The continuous growing of low-cost acquisition devices and constantly developed inexpensive photogrammetric applications is a particularly interesting subject, because user-friendly interfaces encourage even less experienced person to approach the field of heritage 3D digitization.
This growing phenomenon, however, inevitably could produce undesired effects. The wide use of digitization of cultural and architectural heritage, without well-defined procedures and a proper data management, in fact, could lead to a massification of the process and, at the same time, could fail to achieve the fundamental objectives of enhancing, preserving, and promoting the heritage itself.
Nevertheless, if developed with well-established process and if the operator is aware of the limitations (as well as the advantages) of the used instruments, the diffusion of low-cost survey could: i) lead to greater involvement and awareness of heritage knowledge among people; ii) populate digital repositories with data characterized by different details of accuracy; iii) foster attention to lesser-known and hardly accessible heritage; iv) increase the speed and hence improve the timing of acquisitions; v) in the future, the possibility to use the dataset of photos or videos to restore buildings that are lost due to natural and man-made disasters.
In this regard, the aim of this paper is to evaluate one of the economic processes that could be used for fast survey.
The paper discusses the acquisition process and the outputs of the digital survey of an architectural interior space with a video captured by an action camera. The challenge is to use not a well-designed photographic set, but a video recorded by a common built-in camera widely used today.
The analyses of this tests show the great potential of this technology and suggest that in the future such videos could be employed for agile digitization and faster survey that ensure the required accuracy.

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1.1 Action camera for photogrammetric survey

The process of digitising architectural heritage through low-cost technologies has been widely discussed in recent years. This research focuses on the increasing diffusion of economic action cameras with wide-angle lenses and 4K video, as well as the data elaboration with photogrammetry software, both offline and in cloud. In particular, the research work aims to analyse a simple approach for fast and low-cost surveying and processing to be used as a support for the digitization of heritage.
Several studies have focused on this equipment, above all on action camera calibration processes for 3D metric purposes. Different calibration methodologies and process steps, in fact, were analysed to quantify the achievable accuracy of this type of lens (Hastedt et al., 2016; Wierzbicki, 2018). In some cases, a special software, able to perform the process, was developed to overcome the presence of distortions (Balletti et al., 2014). In addition, various procedures have been proposed to improve the quality of the results despite the existence of action cameras lenses' distortions (Ballarin et al., 2015; Pepe et al., 2018). This paper, however, reports the results of the analysis of a 3D point cloud extracted from a video, say almost amateur, recorded with an action camera and without a real photogrammetric project. Previous studies have also analysed the results obtained from multiple action cameras video (Teo, 2015) comparing images acquired from fixed stations with images taken from continuous paths; or the use of the action camera for mobile mapping systems (Gonçalves and Pinhal, 2018), confirming the good results that could be achieved with these devices after a pre-calibration process. The case study, nevertheless, shifts the focus on indoor environment characterized by architectural value and on the data processing with professional photogrammetric software tools and with online platform.
Currently, different photogrammetric free software or web tools are available, and several studies show that the results are strongly related with the object and the approach to photogrammetry survey, but, at the same time, highlighting the progress reach also in this field (Gagliolo at al., 2018; Đurić et al., 2021). The frames extracted from the video, thus, have been processed with different professional and economic software tools ones. The scaled and oriented point clouds, finally, have been validated, through a Cloud-to-Cloud comparison, with the point cloud captured by a phase-shift laser scanner.
Hence, the attention of this paper is on the advantages of quick and low-cost approaches available to not experienced operators, avoiding technicalities that could make the survey arduous and difficult to implement, but at the same time ensuring acceptable results for the enhancement of the asset and as a support for dissemination and modelling.

1.2 Case study

Railway stations are buildings of special interest not only for their functionality and constant interaction with their surroundings, but also for the architectural character. They are built documents of the past and of the social and economic changes in cities. In this regard, the methodology presented in this paper has been tested within the Caltanissetta Centrale Station and focuses primarily on the main Hall of the building. The study is part of a larger investigation on the analysis of innovative methods for the digitization of Liberty 20th century buildings and artifacts in Sicily.
The history of the station began around 1869 with the drafting of the first plan that imagined a location different from the present one. However, finally the building was located close to the town centre. The new location and the centrality of the building inevitably led, over the years, to changes, and evolutions that responded to urban planning needs and, simultaneously, brought changes to the city itself. Archival investigations have, in fact, returned several projects, also very different from each other, during the years; the current layout dates to about 1929.
The building consists of a central volume highest than the two lateral ones, and two external structures that contribute to giving it the typical C-shaped conformation. The main entrance is located in the central area of the building, which is characterized by its greater plasticity and pavilion roofing.
The attention of this work is focused above all in the upper part of the inner Hall of the station. It is of particular artistic value with the presence of significant fresco that exemplify, through the symbols of the various cities, the interconnections that the railway facilitates. The room measures about 12.5 x 8.5 m, the ceiling is 8 m high and has joists that divide it into six bays, each of which is frescoed with ornamental decorations and the symbol of a city; the central one depicts that of the City of Caltanissetta.

2. MATERIALS AND METHODS

The rise of high-resolution video capture devices has made it possible to develop photogrammetry processes to obtain satisfactory point clouds even from video. In particular, the following tests focus on the analysis of the results received from a video recorded with an action camera Insta360 ONE R (Figure 1). The frames extracted have been processed in different software among which Agisoft Metashape.
Other elaborations have been performed with low-cost, free, or trial software tools (eyesCloud3d, Meshroom, Zephyr free, Regard 3D and Visual SFM) that some time required a discretisation of the acquired data (50 frames out of 323), despite this, the best results are pursued with the cloud-based platform eyesCloud3d, which data will subsequently be analysed.

2.1 Devices specification and data acquisition phase

Surveys of the internal Hall of the Caltanissetta Centrale Station have been acquired with two different instruments. The quality of the data acquired with the action camera are compared with the data acquired with the Leica HDS7000 phase-shift laser scanner, which was used to have a reference model and verify the global geometric dimensions of the photogrammetric process.

2.1.1 Insta360 ONE R: the light-weight action camera Insta360 ONE R is the economic device used in this research for acquiring the data of the Caltanissetta Centrale Station Hall. It has a small touch screen built-in display used to see the shot and some functions. The camera is equipped with a 1/2.3" sensor having a 12 Megapixel resolution.

Figure 1. Front and back of the modular Insta360 ONE R with a wide-angle lens.

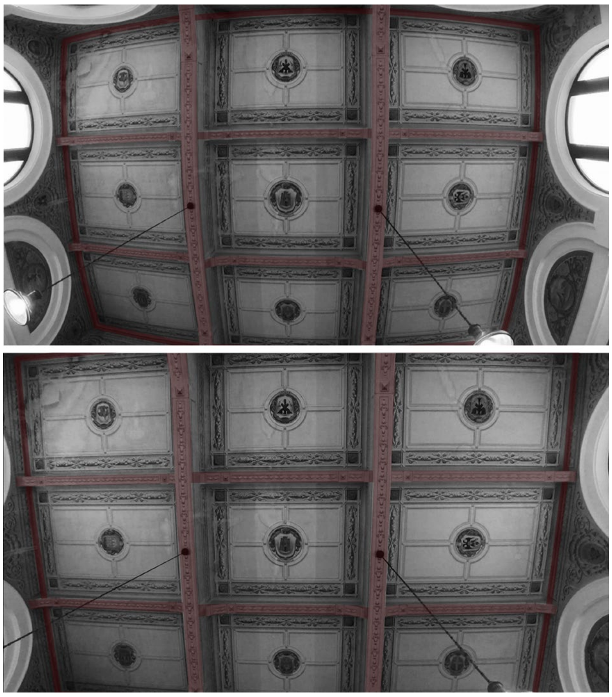

Figure 2. Corresponding frames of the video with highlight joists before and after "linear" FOV control in Insta360 Studio.

The lens is a wide-angle type, and the diaphragm has an aperture of F/2.8. Despite this kind of device doesn't permit to modify settings as a professional camera (ISO, Aperture. Shutter…) recording pre-sets exist that can be customised during its use; in this studio the video has been shot in 4K mode and 30 fps.
The action camera was moved in continuous mode inside the room by pointing the instrument towards the ceiling and following the path at different angles for obtaining good geometric intersection conditions and to try to cover the various overhangs on the structure. The FOV of the lens provides a wide overlap, which, however, also increases the complexity of the images, especially in consideration of the setting for which the main photogrammetric software tools are designed. In the surveying phase, we decided to use the action pole to conduct an agile acquisition and above all to avoid including the operator in each image.
The video, with a duration of about 3 minutes, has been uploaded in the official software Insta360 Studio and has been exported using the FOV processing "linear", which attenuates the radial distortions typical of wide-angle lenses (Figure 2). The number of images extracted is 330, each image has a resolution of at 3849 pixels by 2160 pixels and the overlap between consecutive images is of about 90%. The GSD in this case is not so immediately to estimate, in fact due to the wide FOV, there could be a decrease in resolution as the radial distance from the centre of the image increases. Although, an estimate, based on the average of the values and the recording distance (that also varies), returns a GSD value of about 4 mm. The survey was simple, versatile, and very fast especially when compared to the laser scanner survey, used for the validation of the results.

2.1.2 Leica HDS7000: The phase-shift laser scanner Leica HDS7000 is the device of the Leica Geosystems company that can capture about 1000000 points/s. It is characterized by an acquisition range between 0.3-187 m with a maximum resolution of 0.1 mm and a linearity error ≤ 1 mm. The survey of the Hall was obtained by ensuring the proper overlap between one station to another and setting a point distance of 6 mm at 10 m and a quality of 4 x. The survey was done without acquiring colorimetric information, these settings ensure fast processes, in fact each complete scan taking about 3 minutes. The device was stationing at 3 different position to cover the entire surface, trying to avoid the data gaps that would be created by the slight overhangs of joists.
Given the small size of the space, acquisition times were quick. The disadvantages were mainly the weight of the instrumentation and the need to move and set parameters of the tool at each scan station location.

2.2 Processing

The dataset obtained with the action camera Insta360 ONE R were processed in several Structure for Motion (SfM) software (Table 1). The elaborations and comparison were completed with the same workstation equipped with intel Core i7, NVidia GeForce RTX 3070 and 32 GB of RAM to produce a congruent evaluation between the results obtained from different process.

2.2.1 Agisoft Metashape: The software used in the version 1.7.1 of the Russian company Agisoft is the widely used SfM software in various fields of investigation. The frame extracted from the video have been processed in a single chunk, however, not all images were used, discretization was carried out based on the "quality" estimated by the software (disabling those with a quality lower than 0.5) and blurred images. The total amount of images used to cover the entire ceiling were 323/330.
The processing phase has been conducted according to the general photogrammetric workflow. The first phase is the orientation (alignment) and, so, the generation of a Tie Points, that was achieved with "high" value. Despite the use of images taken from a camera that was not pre-calibrated it was completed without any misalignment difficulties.
Before proceeding to the generation of the dense cloud, points were filtered according to specific criteria using "gradual selection" option, the operation is useful for the detection of points with a high internal reprojection error and for the selection of points to be removed due to the excessive noise that could be generated.
The point cloud was then oriented based on five well-distributed markers whose co-ordinates were drawn from the laser scanner point cloud. The average reprojection error (RMS) is 1.4 pix for all tie points and 1.6 pix for the control points. The dense cloud was also processed obtaining better results with the "medium" quality setting (reduced by factor 4 to the original resolution) obtaining a dense cloud of approximately 4 million points (Figure 3.a). On this base the subsequent mesh was carried out with the "hight" density (about 93 thousand faces) and finally the texture of the 3D model was obtained.
Software allows enough data management during the process as well as tools for managing the final models including the generation of the orthophoto and its export (Figure 4).

Photogrammetric Workflow	Agisoft Metashape	EyesCloud3d
Aligned cameras	323	50
Sparce Cloud	17.1x10^4 points	/
Dense Cloud	4.2x10^6 points	3.0x10^6 points
Process	Workstation	Cloud
Time	1 h	20 minutes

Table 1. Software data comparison.

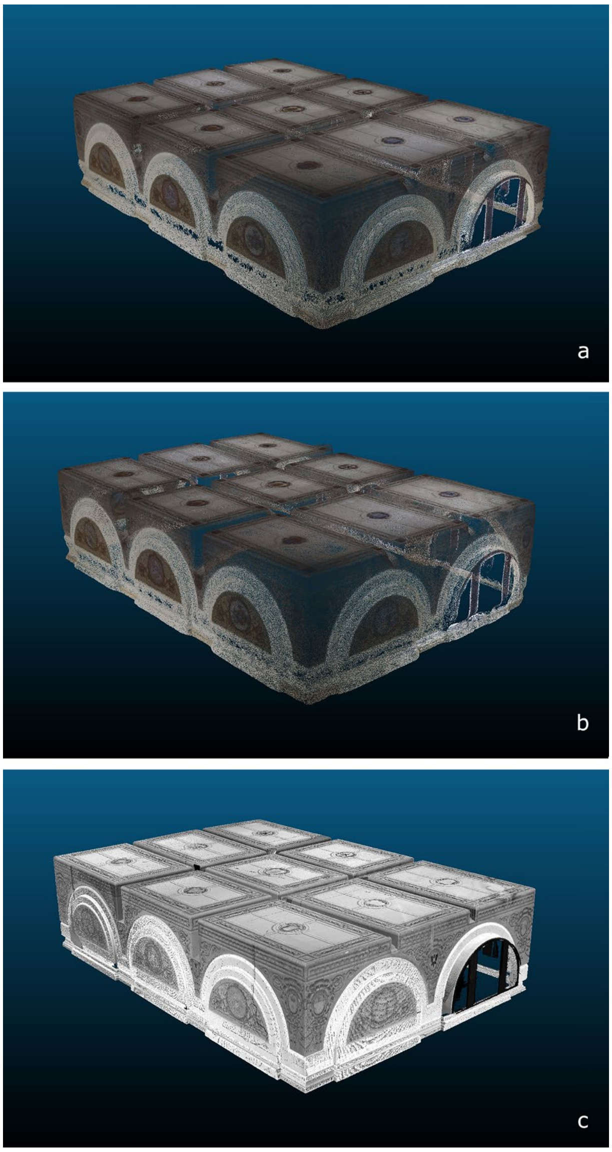

Figure 3. Point Cloud of the Hall of Caltanissetta Centrale Station acquired with (from top to bottom): Insta360 ONE R in 4K wide-angle elaborated in Agisoft Metashape (a) and eyesCloud3d (b), Leica HDS7000 (c).

The elaboration returns a sharp image with the forms of degradation clear. In some portions, however, there is a lack of information quality caused mainly by direct light from the chandeliers that illuminated the room and that at certain moments of the video inevitably hit the lens of the instrument.

2.2.2 EyesCloud3d: The frames extracted from the action camera video were also processed with the cloud server-based system eyesCloud3d. In recent years, a few of studies have been conducted analysing the characteristics of the platform (Ahmad et al., 2019; Fernández Rodríguez et al., 2021; Azri et al., 2021) and have shown its interesting possibilities.
Once the raw data (photos or videos) have been uploaded, the platform automatically proceeds to generate 3D models, facilitating the process and making the world of digitization accessible to any type of user in an economical way. It can be used from different devices, such as tablet phones and computers, and no hardware specification is required as it employs the web platform. In the following case study, the best results were obtained by directly uploading photos extracted instead of the video itself. Probably, the reason lies in the limit of video duration that can be loaded (1 minute) and consequently the discretisation of the data, covering the entire area to be surveyed, was more efficient through the manual selection of frames. As the platform allows up to 50 photos to be processed for free, in fact, was necessary to select a few frames from the 323 that were previously used in Agisoft Metashape software.
The photos were then uploaded and processed in the cloud without any type of setting to select. The returned point cloud has about 3 million points (Figure 3.b) and compared to the point cloud generated in the first software, the reconstruction of the room is partial, this occurs because the selected frames mainly covered the upper area of the room. Once the point cloud and mesh have been generated, there are several tools that allow point cloud management of the data, such as observing measurements, georeferencing, rotating, translating, and scaling the model and more. In this case, the process returned a point cloud devoid of excessive noise (especially at the top), so the data was only oriented in relation of the laser scanner point cloud (five homologous points) and exported in e.57 format.

2.2.3 Autodesk Recap: The data acquired with the laser scanner were processed with the Autodesk Recap software in its Pro version that supports a greater management of the data. It has a user-friendly and guarantees simple processes and accurate results. Once a new project was created, it was possible to import the individual scans (file extension. zfs) by setting a “standard” filter scan and a clipping range of 50 m, having operated in an internal space.
The individual scans were then manually aligned according to the workflow provided by the software. To connect the scans, therefore, three well-distributed points on different surfaces were identified and an effort was made to choose markers positioned on flat surfaces and not corners or edges. The report extrapolated from the scan recordings provided overlap values greater than 50%; overlapping points within 1/4” (or 6mm) of the corresponding feature in the project greater than 90%; and balance, which is the percentage of common features in the scan, greater than 70%.
The field of view 360° x 320° of instrument inevitably acquired data from the surrounding environment that was useful for the alignment phase but unnecessary for the final restitution. Hence, the entire point cloud was manually cleaned of any extraneous information and noise which had occurred mainly in the lower area and near the windows.

Figure 4. Caltanissetta Centrale Station Hall ceiling orthophoto generated with Agisoft Metashape.

	Agisoft Metashape Error [m]			**eyesCloud3d Error [m]**		
	x	**y**	**z**	**x**	**y**	**z**
P. 1	-0.005	-0.001	-0.007	-0.009	-0.012	0.013
P. 2	-0.004	0.002	-0.007	0.004	0.000	0.011
P. 3	-0.006	0.006	-0.005	0.019	-0.016	-0.001
P. 4	0.009	0.001	0.011	0.016	-0.006	-0.024
P. 5	0.007	-0.008	0.008	-0.018	0.017	0.003

Table 2. Deviations between laser scanner points coordinates and those of Agisoft Metashape and eyesCloud3d following manual registration.

The final 3D point cloud presents about 40 million of points (Figure 3.c), the model is very detailed, not only in the ceiling areas, and the only gaps are in the shadow areas of the cornices that are difficult to reach by the instrument. Finally, the point cloud was exported as a single scan in the compact, neutral format e.57 so that it can be used in other software as a basis for the comparison.

3. COMPARATIVE ANALYSIS

The analysis aims to evaluate the photogrammetric models obtained from the Insta360 ONE R video and processed with two different software: the first with Agisoft Metashape and the second with eyesCloud3d.
The validation of the results was conducted by comparing the generated photogrammetry point clouds with that obtained from the laser scanner survey as reference. Initially, the photogrammetric clouds were oriented, based on homologous points, with that acquired by the Leica HDS7000. However, being a manual procedure inevitably brings with its residuals, especially as in the case of eyesCloud3d where the points were inserted directly on the 3D model. In Table 2, in fact, for each Point is reported the corresponding deviation on the x, y, z coordinates and the higher value is of approximately of 1 cm for Agisoft Metashape and 2 cm for eyesCloud3d.
In this regard, to improve this process, a fine registration (ICP) was carried out. The software used for the comparison is Cloud Compere (version 2.12.0) and the Cloud-to-Cloud distance (C2C) tool was used to compute the deviation between the clouds.

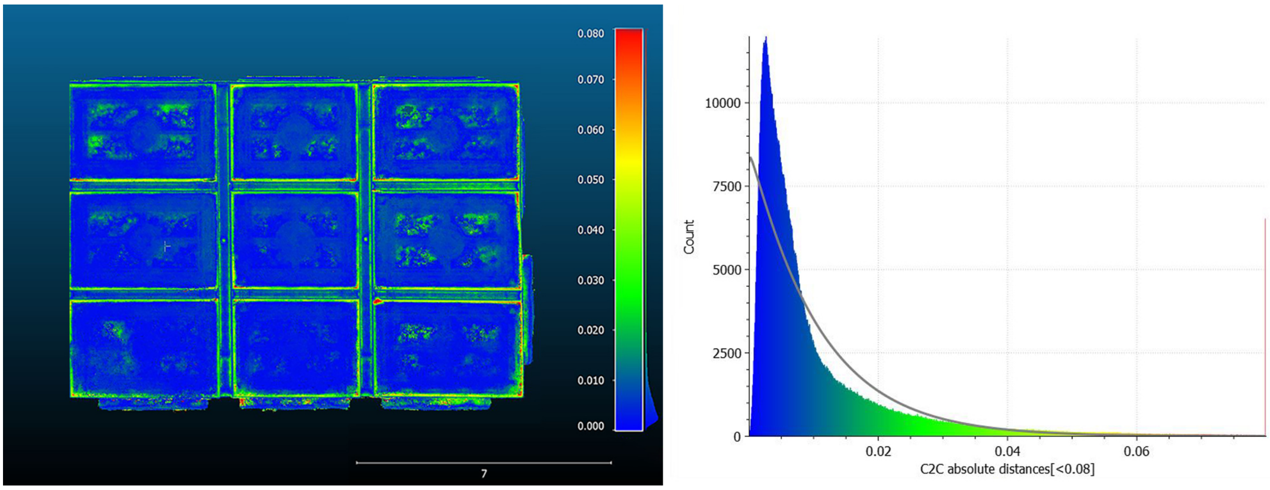

Figure 5. Comparison between the photogrammetric point cloud of photogrammetric process with Agisoft Metashape (Insta360 ONE R) with respect to laser scanning (Leica HDS7000).

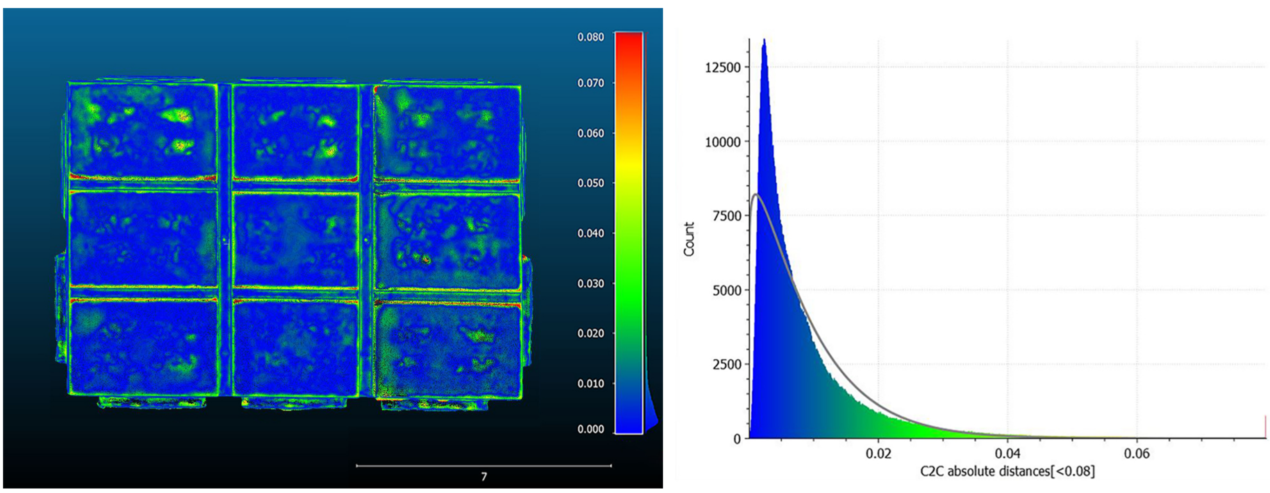

Figure 6. Comparison between the photogrammetric point cloud of photogrammetric process with eyesCloud3d (Insta360 ONE R) with respect to laser scanning (Leica HDS7000).

Figure 7. Details of the joists of the point cloud (from top to bottom) of the laser scanner, the photogrammetric point cloud processed with Agisoft Metashape and that with eyesCloud3d.

It finds the nearest point in the reference cloud to each point in the comparison cloud and computes their (Euclidean) distance. The process initially evaluates approximation distances, and this estimate is utilised to choose the appropriate octree level at which to compute real distances, results are displayed as coloured point clouds related at the determined values.

To improve the accuracy of the point clouds, initially a manual cleaning operation was carried out and subsequently with the support of the “S.O.R. filter”. This tool makes it possible to calculate the average distance of each point from its neighbours and discards points that have a distance greater than the average distance plus several times the standard deviation, the latter is the second parameter to be entered after the number of points to be considered in the average calculation. At this point, it was possible to proceed with the comparison for each point cloud and the analysis of its results.

3.1 Analysis of the results

The comparison of the results generated by Agisoft Metashape with the laser point cloud was the first test conducted. Given the high precision and accuracy of the HDS7000 data, the laser model was selected as a reference and the photogrammetric one as a point cloud to compare.
In the command window C2C a number of settings can be managed. In the present case, the octree level was set in “automatic” mode (parameter variations were also conducted by selecting values greater than 13 as the subdivision level, however apart from an increase in calculation time, the results did not vary advantageously) and a value of 0.08 m was entered as the maximum distance within which the calculation should be evaluated. The statistical comparison obtained is visible in the Figure 5 and, as it was possible suppose, shows that the parts where the distance of the point cloud reach high values, (in red, yellow and green colours) are mainly in the proximity of cornices and joists, which are characterised by a greater number of shaded areas and edges. The results, reported show that approximately 93% of the points are contained within a value of 0.03 m and only 3% exceeds the 0.05 m.

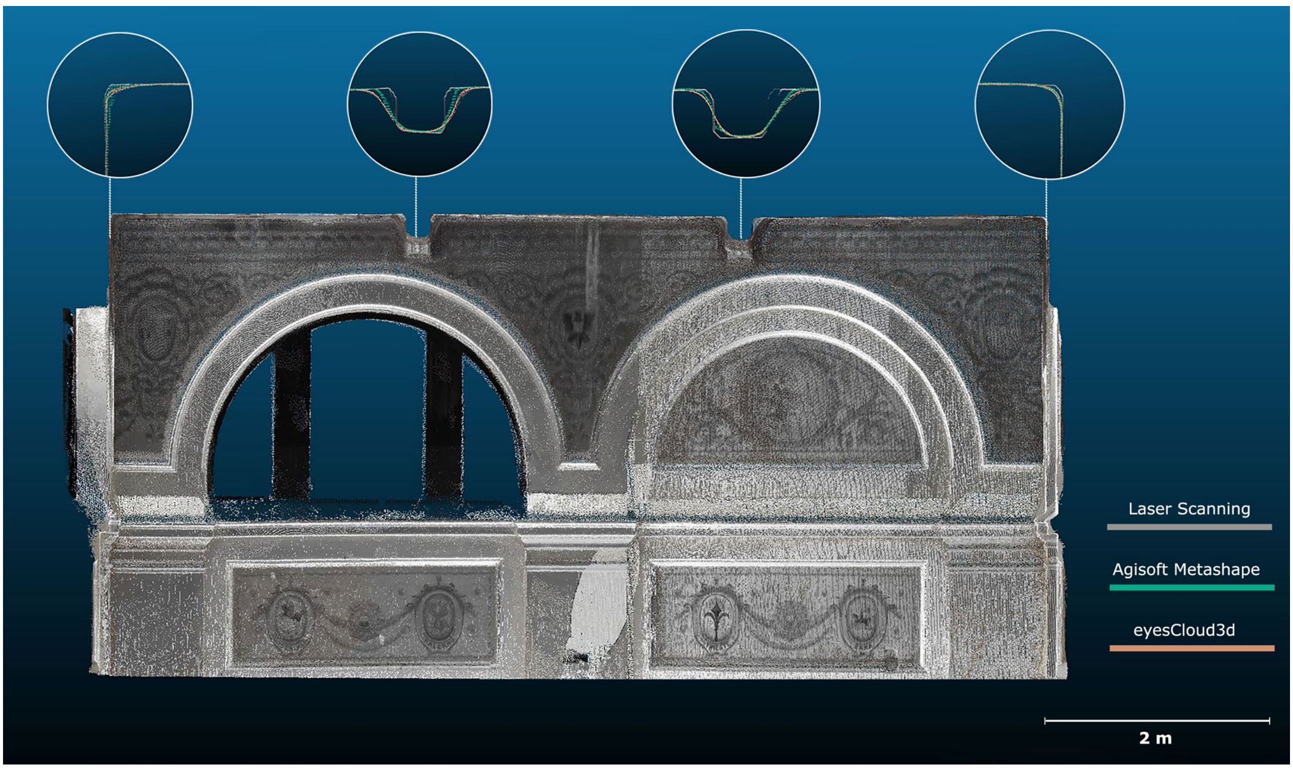

Figure 8. Zoomed-in sections of the point cloud that show the mainly differences in proximity of edges between the Laser scanner model and photogrammetric ones.

The analysis shows the test results in a scalar histogram with a grey curve corresponding to the fitted distribution. The trend is not symmetrical with respect to the peak value and is similar to the Weibull distribution.
The same comparison was made with the cloud obtained from eyesCloud3d using the laser scanner cloud as a reference. Again, the parameters entered in the comparison window (C2C) are 13 level octree (calculated automatically) and maximum distance 0.08 m. The results, visible in the Figure 6, appear similar, again with a scalar histogram with a continues grey curve like the Weibull distribution. In this case, once more the results show that about 97% of the points do not deviate from the reference cloud of 0.03 m and only 1% deviate more than 0.05 m.
However, although the number of points with high values is smaller in the latter case than in the former, the surface of the model is more irregular and the point cloud has more gaps, especially at some locations (Figure 7).
The images of the comparisons show that in the case of Agisoft Metashape, the main problems occurred near the edges, in some cases reaching high values and not perfectly following the profile of the ceiling. In the case of eyesCloud3d, in addition to the edges and corners, greater irregularity was also noted in proximity of flat surface and some areas of the model show obvious bulges that deviate the point cloud from the real model to a great extent.
These problems could stem from the height of the building (8 m) in relation to the achievable focal length of the wide-angle lens. Figure 8, in fact, presents a series of zoomed-in sections of the different point clouds and shows how the profile of the joists is hardly followed by the photogrammetric point clouds compared to the laser scanner one, which assume much smoother curvatures near the edges. Overall, the results received are of particular interest, especially considering that, unlike many tests previously conducted, the action camera was not pre-calibrated, and that the data came from a video and not from a well-structured photogrammetric project. Equally encouraging are the results obtained with the web platform where data managing is minimal.

4. CONCLUSION AND FUTURE DEVELOPMENTS

The investigations conducted in this article show the results of a close-range photogrammetry process for surveying cultural heritage with frames extracted from a video recorded with an Insta360 ONE R.
Before proceeding to conclusions, some considerations are necessary with respect to the two procedures employed: in one case, the use of an inexpensive tool and professional software, and in the other, the same device but the data management has been in cloud. These methodologies (especially the second one), with its limitations but also its peculiarities, allow even less experienced operators to approach the field of digitization, considering the right trade-offs between quality and purpose. Other considerations concern the survey methodologies conducted, an interior room with a height of approximately 8 m and the absence of photogrammetric targets to support the acquisition. Finally, the results obtained refer to an indoor environment of small dimensions and simple conformation, therefore they cannot be extended to different conditions or to entire buildings.
Thus, by critically analysing the results of the investigation, it can be deduced that, although these tools are not substitutable for the use of professional DSLR cameras for the achievement of high accuracies, the action camera brings with it encouraging results.
Hence, the work has confirmed the advantage of being able to use these instruments in heritage photogrammetric applications where the conditions around them are particularly limited, as well as the possibility of surveying architectures in economical way. In addition, the analysis showed that these results can nowadays be pursued even without the necessary pre-calibration of the instrument and with inexpensive, user-friendly programmes, to facilitate the surveying process for even less experienced operators.
The results therefore show the great potential of this technology, especially if we project the results into future perspectives and think about the possibility of using amateur videos also as support for the reconstruction of lost architectures, obviously if a previously acquired action camera video recording exists.
In conclusion, we can consider the results obtained to be satisfactory, in that, although the values returned do not present high accuracies typical of professional surveys, the data obtained proves to be effective and could be used to model simple buildings by applying processes of discretization and simplification useful for the visualisation and 3D printing of replicas.

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