Salvatore Barba
Sandro Parrinello
Marco Limongiello
Anna Dell'Amico
editors

D-SITE

Drones - Systems of Information on culTural hEritage. For a spatial and social investigation

PaviaUniversityPress

D-SITE, Drones - Systems of Information on culTural hEritage. For a spatial and social investigation / Salvatore Barba, Sandro Parrinello, Marco Limongiello, Anna Dell'Amico (edited by) - Pavia: Pavia University Press, 2020. - 392 p.: ill.; 21 cm.

(Prospettive multiple: studi di ingegneria, architettura e arte)

ISBN 978-88-6952-120-1
ISBN 978-88-6952-129-4 OA

The present publication is part of the series "Prospettive multiple: studi di ingegneria, architettura e arte", which has an international referee panel. "D-SITE, Drones - Systems of Information on culTural hEritage. For a spatial and social investigation" is a scientific text evaluated and approved by the Editorial Scientific Committee of Edizioni Pavia University Press of University of Pavia.

The translation of the chapters and the treatment of citations and bibliography are due to their or respective authors.

Edizioni dell'Università degli Studi di Pavia
Via Luino, 12 - 27100 Pavia (PV)
Tel: +39 0382 987743 / 985047
Fax:+39 0382 985047
Email: unipress@unipv.it

EDITORS
Salvatore Barba, Sandro Parrinello,
Marco Limongiello, Anna Dell'Amico

GRAPHIC PROJECT
Anna Dell'Amico

PRINTED BY
DigitalAndCopy S.A.S., Segrate (MI)

ISBN 978-88-6952-120-1
ISBN 978-88-6952-129-4 OA

On cover: Drawing by Francesca Picchio and Sandro Parrinello.

The volume consists of a collection of contributions from the conference "D-SITE, Drones - Systems of Information on culTural hEritage. For a spatial and social investigation". The event, organized by the experimental laboratory of research and didactics DAda-LAB of DICAr - Department of Civil Engineering and Architecture of University of Pavia, and MODLab of DICIV - Department of Civil Engeenering of University of Salerno.
Publication co-funded by the University of Salerno, the University of Pavia and the Italian Ministry of Foreign Affairs and International Cooperation.

D-SITE Conference is organized by:

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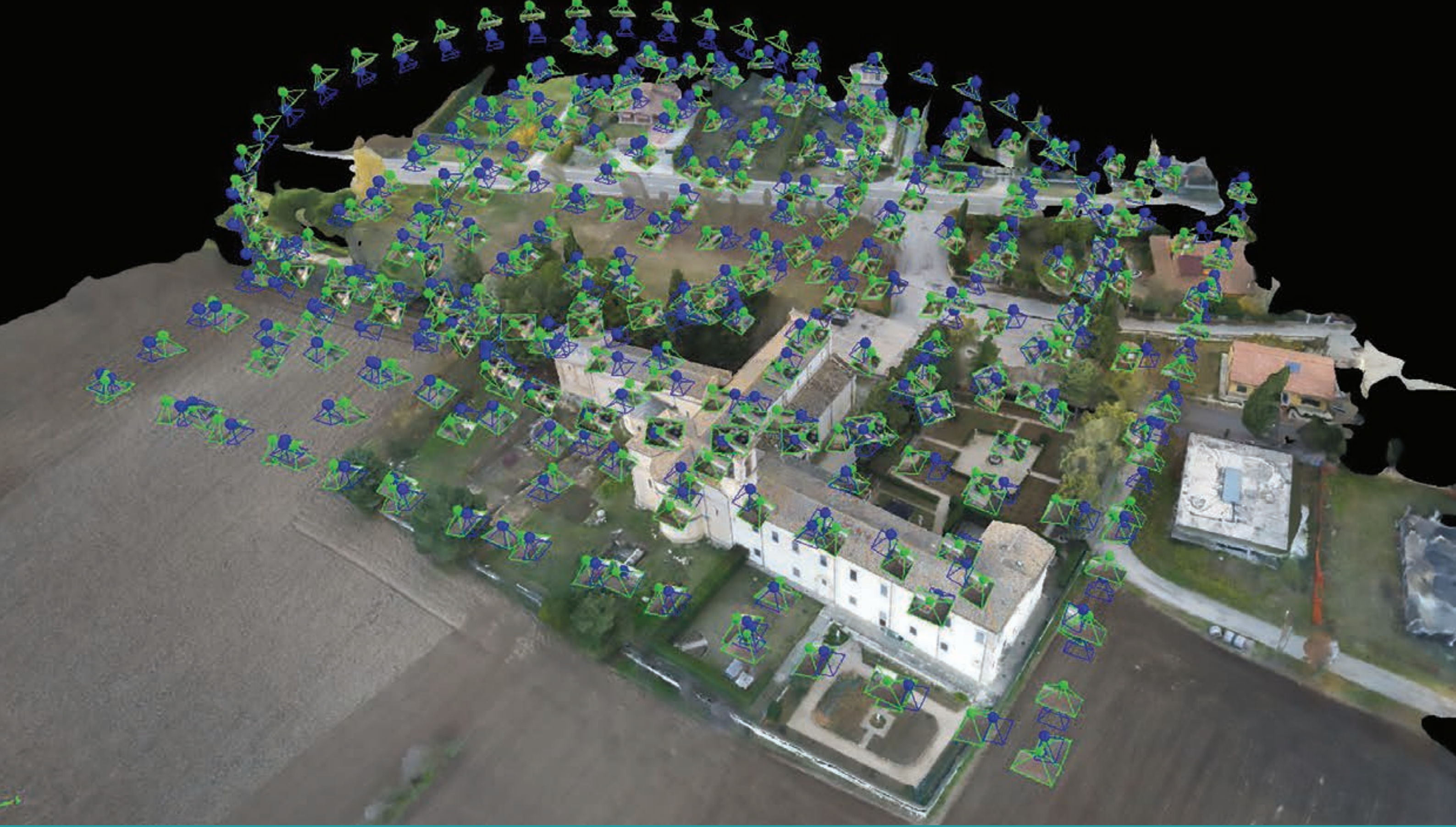

Caterina Palestini[1], Alessandro Basso[2]

[1] Department of Architecture, University of Pescara "G. d'Annunzio", Pescara, Italy
caterina.palestini@libero.it

[2] Free University of Bozen, Faculty of Education, Bozen, Italy
alessandro.basso@unibz.it

Keywords:
Survey, photogrammetry, Meshroom, Metashape, heritage.

ABSTRACT

The contribution reports a research experience, aimed at the documentation of Cultural Heritage in Abruzzo, conducted with the help of drones, with the combination of methodologies of acquisition and processing data acquisition and photo-modelling, integrated in a comparative and experimental way. Specifically, the study themes suggested by the conference concerned the Valvense Complex, which has been little analysed from the point of view of architectural survey, and which is one of the most important Romanesque monuments in the Peligno area, near Sulmona (AQ), located on the remains of the ancient Italic capital, on the access axis to the Roman town of Corfinium. The research focuses in particular on the comparison of two photomodelling methodologies, one open source and the other commercial, where the advantages and criticalities are highlighted by analyzing workflows and results.

The UAV survey of the Valvense complex in Corfinio, comparison between two photomodelling methods

1. Introduction

The use of IUAV instrumentation for surveying in the last period has increased considerably, at the same time there is an improvement in the software for the processing of photogrammetric data aimed at three-dimensional photomodelling, which over time become increasingly accurate and easy to use. Also, open source applications that offer good results almost superimposable to those obtained by the commercial counterpart are multiplying. The contribution compares two different processing workflows structured from a single three-dimensional dataset, based on photographic images and obtained with Structure from Motion drone methods, with the aim of verifying, starting from the same acquisitions, the correctness in terms of results of the two different methodological approaches applied to a particular case study, the ancient Romanesque Valvense complex, a very large area consisting of several related compartments. The survey thus illustrates a twofold development, related to the dynamics of data acquisition by exploiting the drone system and the comparison between the two different workflows, of which the open source one, Alicevision Meshroom, which is developed through a node system, very interactive but with less precise results, and the commercial one, Agisoft Metashape, more solid and cumbersome but with more accurate metric results. The planned study of the different levels of depth, starting from the recognition phase necessary for the knowledge and documentation of the cultural and artistic heritage, is oriented towards the aspects of relief typical of geomatics and architecture, aimed at the conservation and territorial enhancement of culture.

Figure 1. Valvense complex, facade of San Pelino.

2. Historical background on the case study area

The area where the architectural structures created in memory of the martyr Pelino are located reveals the presence of fortified structures dating back to the 5th and 6th centuries, within which there was a large palace, as evidenced by the studies conducted on the archaeological site (Giuntella 1990) and on the building traces found under the episcopal complex started in 1075 by Bishop Trasmondo with recycled materials, as attested by the Chronicon Casauriense. (ChCasaur, coll. 866). The stratified structure is currently composed of several buildings connected to the Basilica of San Pelino, which for its historical importance plays the role of co-cathedral of Sulmona. The articulated complex houses the Cathedral Basilica to which on one side, towards the middle of the right aisle, connects the oratory of St. Alexander and the tower of the same name and on the left, at the height of the transept, the bell tower and the eighteenth-century Episcope, now the seat of the cloistered monastery. Historical and archaeological studies (La Salvia, Somma 2015) confirm several interruptions suffered during the construction started by Trasmondo; a first suspension dates back to 1092, which identifies the first church dedicated to Saint Alexander, which has remained unfinished and probably erected together with the square tower used for the site's sighting and defence (Fucinese 1971). The completion of the Cathedral of San Pelino dates back to the 12th century, with several consecrations, the first of which was attributed to Bishop Gualterio (1014-1128) and the second, when the work was completed, to Bishop Odorisio (1172-1181). (Vinegar 2007) The survey data confirm construction inhomogeneity, successive reconstructions derived from earthquakes, baroque renovations and subsequent restoration work in 1970 that forced the Romanesque structures to come to light (Fucinese 1974). In this sense, the survey methods used provide an objective basis to support the historical complexity of the controversial construction phases (Paura 2018) and allow a three-dimensional analysis of the architectural complex from the whole to the detail, finally allowing to monitor the important cultural heritage.

Figure 2. Valvense complex: 1) tower of Sant'Alessandro 2) oratory of Sant'Alessandro 3) Church of San Pelino 4) bell tower 5) eighteenth-century episcope6) Archeological area.

3. Plan preparation

The photogrammetric 3D survey through IUAV instruments is generally divided into three phases, a phase of data acquisition, in which it is essential to define the areas of interest that directly influence the path of the drone and the shooting modes, by placing a specific survey plan, a data processing phase in which photomodeling software is used and a post-production phase relating to mesh correction and the definition of a 3d model. In the case study, before embarking on the data set acquisition phase, it was essential to take some macro-measures relating to some of the complex's perimeter walls with the aim of obtaining a return in scale of the architectural artefact in the second instance. The weight of the drone used, Parrot Anafi, is about 400 grams and during takeoff it has a flight autonomy of 30 minutes in normal conditions of absence of wind. Through remote control via smarthphone, it was possible to control the flight of

Figure 3. On top, flight plan, Pix4DMapper interface.

Figure 4. On right, flight plan remote system.

the UAV (aircraft system remote pilotage) by managing the camera stabilizer so as to direct the inclination of the camera itself. Another possible function is to take single photos or to start/stop video recording. The main advantage in the use of drones for surveying works is related to the possibility of scanning parts not visible from the ground or inaccessible, flying at low speed near the objective. Thanks to the help of cameras consisting of focal lengths with variable pixel size, it is possible to obtain high resolution images, with a sampling distance on the ground (GSD, pixel size on the ground) of the order of centimeters. The video from which 5344x4016 frames were extracted was obtained, getting a GSD (Ground Sampling Distance) calculation of 1.17 cm / pixel, useful for processing the point cloud. For flights carried out by the drone, some rules have been taken into account that allow to determine the flight height of the drone, the frequency with which to take the frames and the variable distance from the object of study according to the return scale. The fundamental parameter to be defined in the design of all the steps necessary for the correct execution of an aerial photogrammetric survey is therefore the choice, based on the objective of the survey, of the representation scale, that is the final definition of the obtainable drawings. This factor is always contained in the GSD which briefly expresses the “quantity of territory” represented by 1 pixel of the 2d image. It is essential to prepare a well-structured survey program to better define the paths to be carried out by UAV tools, keeping in mind the rules and calculations we discussed earlier. The aim is always to provide, through the use of specific equipment, a measurable and scaled 3d photogrammetric model of the detected object which reports all its geometric, chromatic and material characteristics. During the flight about 300 frames were taken, useful to elaborate the point cloud of the survey area. The flight plan was structured using Pix4DCapture apps for smartphones and the flight phase and the acquisition of aerial images were almost completely automatic, providing data with a permissible error in centimeters, considering the flight altitude and the resolution of the optics. The breadth of the analysis area required the use of two datasets, in particular

Figure 5. Definition of the cameras based on the acquisition data set within the Meshroom interface.

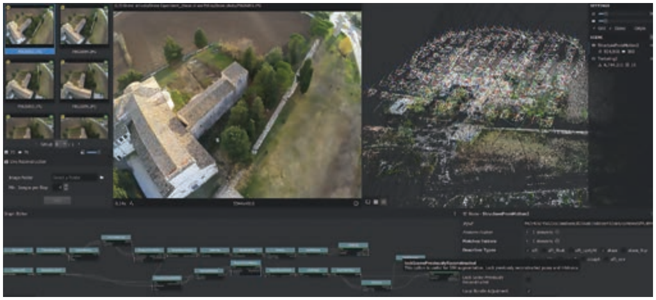

Figure 6. On the right top, Meshroom, processing of the dense point cloud through the fluid node-graph workflow.

one acquired at close range following a “convergent photocentric” path, the other one instead following a linear checkerboard path with zenithal framing[1]. The results obtained from the various acquisitions were then compared and examined to verify the level of accuracy of the data useful for the achievement of the required purposes, with the consequent elimination of the data that cannot be used in the survey such as photographs with excessive motion blur or particularly under or overexposed.

4. Data processing through the comparison of two photomodelinf software

Moving on to the data processing and photomodeling phase, two well-known photogrammetry software were used to survey the monastic complex, Agisoft Metashape, one of the most used commercial programs in the field of territorial and architectural survey, and Alicevision Meshroom, open source software, using the full hd frames from drone, in order to make a subsequent comparison between the two 3d models obtained from the same data set. The use of systems that work with photography, using passive sensors and using precisely the light present in the environment, allows to obtain models of a remarkable level of detail, both at a metric level, in relation to the restitution of geometry and proportions of the compositional elements, both aesthetically and chromatically, in relation to the material information. Image-based detection systems are mainly based on SfM algorithms, Structure from Motion, through which an automated 3D digital reconstruction is generated from frames acquired in motion sequences where a pixel matching condition occurs, and therefore an overlap, between the various images acquired in progression. Being a system based on the image, it is therefore essential to define a data set in an optimal condition of diffused lighting and a rapid data acquisition timing in order not to change the light conditions.

4.1 Data processing and analysis using Agisoft Metashape commercial software

Following the workflow of Agisoft Metashape commercial software, the photos were imported (http://www.agisoft.com/) (Aicardi et al. 2016) to start the alignment steps and generate the dense point cloud by structuring a procedure that is divided into four main steps. The first one, after entering the photographic data in the computer, consists in the alignment of the different camera shots: in this phase the software analyzes all the photos, looking for the homologous points in relation to the chromatic peculiarity and the light exposure factor; for each image the camera orientation and the related calibration parameters are identified, from which the lens distortion coefficient is also obtained. From this processing is generated, through an automatic collimation, a "Point Cloud Based", i.e. a diffused point cloud composed by the "Key Points" necessary to hook in a Cartesian coordinate system the spatial model of the detected object: in this phase, we can start outlining the contour of the object in a three-dimensional environment with the indications related to each single shot of the camera capture[2]. In the second phase of the workflow a thicker "Dense Point Cloud" is configured, obtained based on the positioning of the estimated shooting points, from which the program extracts information about the color and plastic details of the object. The Dense Point Cloud, which requires several hours of computation using the CPU and GPU together, can be modified, cut and optimized according to the next step, i.e. mesh construction using meshing-triangulation algorithms, which "wraps" the point cloud with a network of triangles to generate a mesh surface, or TIN " triangulated irregular network ", considering each point in the cloud as a vertex of a triangular contiguous and irregular polygon with a Z coordinate, effectively transforming the point cloud into a polygonal model[3]. The two photographic datasets, one relating to the photocentric-convergent shooting, the other obtained following a linear checkerboard path, are then unified in Metashape using the chunk alignment technique through the use of markers. Topology was also addressed[4] of these self-generated 3D models and their polygonal density based on the desired graphic-visual quality in relation to the scale of the investigation required. It is therefore necessary to make some corrections, reducing the polygonal density of the mesh, removing unnecessary disturbing components, accidentally calculated because they are present in the frames or closing the mesh holes. So we opted for the inclusion in the workflow of Pixologic Z-brush, a program used in the film and art industry that can exploit the power of Voxel algorithms to easily manage hundreds of thousands of pixels. Among the various features of the software were used automatic retopology, digital painting, detail projection and corrective sculpting through polygonal subdivision. The result at polygonal weight level is a model of about 20,000,000 polygons and after the optimization of about 800,000.

4.2 Fluid workflow thorough node editor of the open source software AliceVision Meshroom

The other 3d photogrammetry software used in the project is Meshroom, which despite being a completely free open source, turns out to be a really interesting software with innovative features, despite using essentially the same open source algorithms common in other three-dimensional applications of photogrammetry. The substantial difference in the executive pipeline consists in the fact that the various phases of work are structured through a graphic node editor that allows to simplify the quick management of each step. The visual interface is suitable for different levels of professional knowledge, from the already

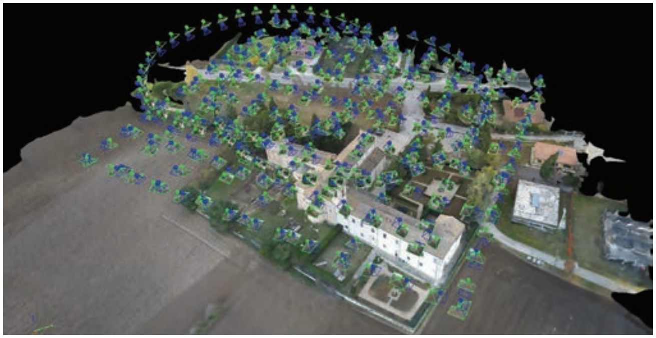

Figure 7. On the right bottom, definition of the cameras based on the acquisition data set within the Metashape.

Figure 8. Metashape Mesh result.

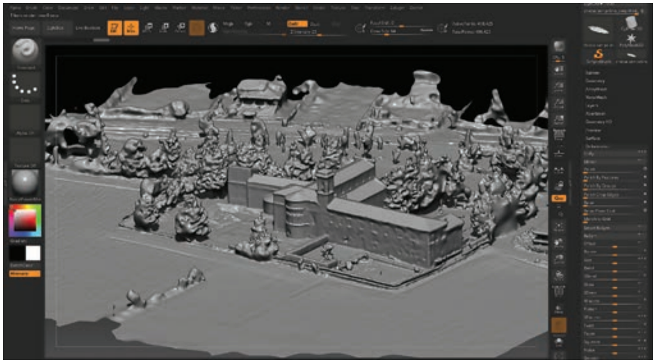

Figure 9. Zbrush optimization of Metashape mesh model.

pre-compiled standard, which allows anyone to use Meshroom without the need to modify anything, to a fully configurable structure based on personal creative needs. The first step of the workflow is the classic image acquisition where the quality of the photographic dataset is the most important part as the software seems to work better with less high resolution images as it is able to detect pairs of homologous points very well. The system displays all the steps of the photogrammetry pipeline as nodes with configurable parameters, while all the steps will be recorded by the program and saved in a "Meshroom Cache" folder that can be recalled at any time. The software, based on a database where the characteristics of the camera sensors are stored, through which you can determine the internal parameters in the form of metadata, simplifies the steps by automatically implementing configuration presets. Fortunately, for the case study, the metadata has been clearly recognized and processed node by node for each step of the process.
The photo modeling pipeline also in Meshroom consists of two main steps, managed by specific algorithms.
SfM: It provides the rigid alignment structure of the scene (3D points) with the position and orientation of the filmed objects and the internal calibration of all cameras.
MVS: The MultiView-Stereo (dense cloud reconstruction) uses the calibrated structure from motion cameras to generate a solid geometric surface. The result is a structured mesh that can be exported in OBJ format with corresponding MTL and texture files.
For the Sparse Reconstruction the features present in the default pipeline have been used such as "FeatureExtraction", able to recognize the correct number of cameras involved in the project, and "FeatureMatching" with "Guided Matching" enabled, which allowed a second more accurate step in the matching procedure: once the descriptor matching has been performed (with a global distance ratio test) and a first geometric filtering, the software identifies the most substantial geometric transformations.
In doing so "Guided Matching" uses this geometric information to perform the matching descriptors a second time, but with a new constraint, improving the search for further homologous points.

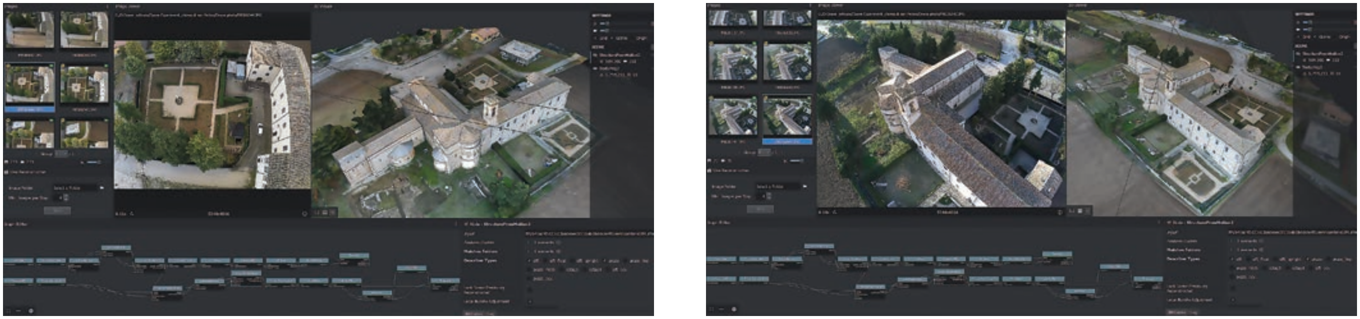

Figure 10. Open source meshroom software interface, calculation of the textured mesh model.

This geometric approach prevents the early underestimation of fundamental matching points and improves the number of matches, particularly with repetitive elements.

For the Dense Reconstruction, Meshroom provides other algorithms, such as the fundamental DepthMap, Dephtmap Filter, with which based on the potential of its graphics card it is possible to calibrate the final quality of the reconstruction of the dense point cloud, obtained on the basis of interpolation, managed by the AII of the program, of the points of the scattered cloud. In the case study it was necessary to divide the dataset into two parts relating to the two photographic acquisition methodologies, exactly as happened for the calculation of the chunk session in Metashape, so that the software, when uploading the photos, used an advanced recognition system named "Augmented Reconstruction", involving not only the standard SIFT algorithm but also the new AKAZE algorithm, capable of recognizing over 60000 + 60000 homologous points thanks to the metadata of each shot such as GPS indications.

The software was thus able to complete autonomously, following two independent workflows initially and then reunited, rejoining the point clouds, generating the complete model during the meshing phase without having to use any manual recognition marker. The result is a 758,000 polygons model.

5. Conclusions

On a visual level, a comparison of the two mesh models, generated with standard settings using the same computer, immediately reveals more details for the Agisoft product mesh than the denser but less detailed model generated by Open Source software. A technical comparison between the two systems was then performed to verify the validity and the obtained results in the specific case. For this purpose and with the help of the Cloud Compare software (http://www.danielgm.net/ccl), we were able to verify the actual distance of each vertex between the two meshes using Octree calculations[5], which define in specific units the amount of mesh or point cloud overlap compared. After the alignment of the models carried out through the overlap obtained with the convergence of three clearly visible points, taken in specific areas such as the tops of the roofs and edges of the structures, the software proceeds providing a numerical feedback from which we can infer a good correspondence between the two models at macro level, i.e. the proportions and heights seem to coincide despite a greater lack of details evident in the model generated by AliceVision's product. The results show a general Compute Distance of about 0.191625/ std deviation equal to 0.641589, so a coincident result for meshes generated by different software and workflows. For the complexity and extension of the survey an error of this size can be

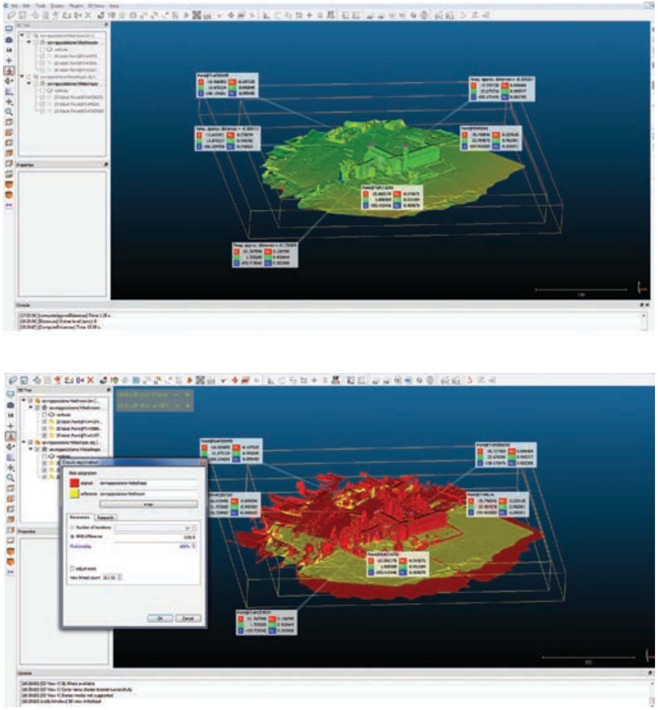

Figure 11. CloudCompare, calculating the marker for both models and distance of overlap Octree.

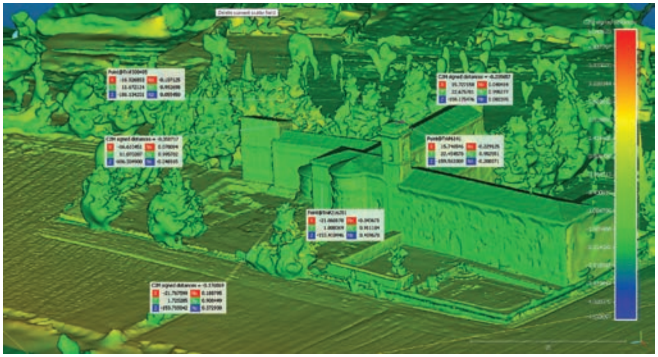

Figure 12. Cloud Compare, Cloud-to-mesh distances, color gradient graph.

considered acceptable, also considering that the cloud points processed by Metashape seems to be much more complete and clearer than the one processed by Meshroom, without some parts. It must be underlined that with the use of textures the models improve and maybe the quality of the textures of the open source version seems to be higher. The images show what is exposed and document the related steps.

Note

1 The management of the drone flight plan and the acquisition of the photographic dataset for the elaborations were carried out in collaboration with Franz Lami.

2 The alignment phase is essential to understand, before starting other calculations, the problems related to the images inserted, the error rates and any distortions to be corrected.

3 It is useful to underline that, unlike the Laser Scanner, from which you get an "ordered" point cloud with a scanning phase consisting of rows and columns, image-based systems create a very dense but "messy" point network, producing polygonal meshes with irregular topology, configured according to a calculation logic produced by the data and photographic information entered.

4 The topology is to be considered in computer graphics as the hidden geometry of a 3d model identifiable in the mesh configuration. Re-Topologizing thus means replacing the mesh conformation without modifying the apparent geometry of the 3d model.

5 An octree corresponds to the recursive partition of a cubical volume of space. From an initial box, octree cells are formed by dividing cubes into 8 equivalent sub-cubes. By default, the octree subdivision is initiated from the square bounding box of a cloud, but it can also be computed from an arbitrary cube is space (to optimize comparison algorithms such as distance computation for example).

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