3D CAMERAS ACQUISITIONS FOR THE DOCUMENTATION OF CULTURAL HERITAGE

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ABSTRACT:
Photography has always been considered as a valid tool to acquire information about reality. Nowadays, its versatility, together with the development of new techniques and technologies, allows to use it in different fields of application. Particularly, in the digitization of built heritage, photography not only enables to understand and document historical and architectural artifacts but also to acquire morphological and geometrical data about them with automated digital photogrammetry. Nowadays, photogrammetry enables many tools to give virtual casts of reality by showing it in the way of point cloud. Although they can have metric reliability and visual quality, traditional instruments – such as monoscopic cameras – involve a careful planning of the campaign phase and a long acquisition and processing time. On the contrary, the most recent ones, based on the integration of different sensors and cameras, try to reduce the gap between time and results. The latter include some systems of indoor mapping who, thanks to 360° acquisitions and SLAM technology, reconstruct the original scene in real time in great detail and with a photorealistic rendering. This study is aimed at reporting a research evaluating metric reliability and the level of survey detail with a Matterport Pro2 3D motorized rotating camera, equipped with SLAM technology, whose results have been compared with point clouds obtained by image-based and range-based processes.

1. INTRODUCTION

The construction of three-dimensional punctiform models starting from photographs is now a well-established practice; nevertheless, the desire to acquire information more and more rapidly, by keeping the precision of metric data, led in the last years to new kinds of experimentation. In fact, recent studies show researches focused on photogrammetric surveys based on the acquisition of panoramic (cylindrical and spherical) images where special attention is given to verify the accuracy of data collected (Barazzetti et al., 2018; Gottardi and Guerra, 2018). Constructing panoramic views for documenting and spreading Historical and Architectural Heritage is not a new practice, just as the use of spherical photogrammetry to obtain metric information from them (Fangi, 2007, Luhmann, 2004. Barazzetti et al., 2010). But the development of new digital cameras and support tools has again drawn attention to the use of panoramic photos, which can be considered as a right balance between the amount of possible information, connected to the large field of vision, the speed of data capture and the precision of resulting metric data. Moreover, with the same workflow, in the creation of a point cloud with SfM processes, panoramic images do not need previous camera calibration phases because they are considered to be without deformations. On the contrary, this process is necessary in a traditional data capture with a central perspective camera, in order to allow software to find mistakes and distortions of the lens in use. Finally, the possibility to build through the same photos both the geometric model, to obtain technical data, and the virtual model, for the interactive analysis of an artifact, show the advantages of the application of panoramic photos to built heritage.

There are many instruments for the creation of panoramic images. Some of them were born for commercial purposes and tourism promotion, such as the so-called spherical cameras; on the contrary, some others have been developed for survey activities.

Spherical cameras are equipped with wide angle lenses they use to capture two or more frames – Nikon KeyMission 360, Samsung Gear 360, and Xiaomi Mijia Mi sphere 360 are dual-lens cameras, whereas Panono 360 camera and iSTARpulsar of NCTech are multi-lens cameras –. Assembled in owner software or in cloud, these frames automatically give photos and/or spherical videos. Therefore, the final quality of the image, that will be more or less defined, will depend on the camera in use, and it is given in an equirectangular projection.

A similar result can be obtained by using traditional cameras together with support instruments allowing to keep fixed the center of the lens, corresponding to the center of projection of the camera. Therefore, with the help of a pano-head, the camera is rotated around its center so as to cover all 360° in the horizontal plane; by repeating the same operation with the camera inclined downwards or upwards, also the vertical plane will be completed. In order that stitching software can recreate a scene in panoramas, there must be a certain overlap between the different photos, whose number will change according to the lens in use (Mastroiaco et al., 2008). Nevertheless, even if a proper overlap in the capture of frames is assured, misalignment and distortion or color irregularities can't be always avoided, thereby influencing the final result. However, some studies on this subject (Gabriele Fangi) show that a control of this process is possible in order to achieve valid results.

If it is true that multi-camera systems reduce capture times and misalignment in the construction of panoramic views, it is equally true that the final rendering of an image, in terms of resolution, is qualitatively lower than results achievable by single-camera systems. In fact, the capture of a scene with a double-lens spherical camera, although at the maximum resolution allowed, will be given by the overlap of two frames – coverage of a scene of at least 180° horizontally and 360° vertically – showing an equivalent distribution of resolution. To remove the effects of a distortion, the spherical image, navigable at 360° through specific viewers, will be a magnification of the equirectangular projection with a lower resolution. Given the same level of quality of an instrument, the greater will be the number of cameras composing the spherical camera, the greater

will be the resolution of the spherical image, because there will be more frames to compose the equirectangular projection. Similarly, assuming to capture the same scene from the same center of projection but with a single-camera supported by a pano head, the maximum resolution will characterize every single frame, remarkably increasing final quality, almost to achieve the same resolution between the panoramic view and its projection.

Both in multi-camera and in single-camera systems, it is necessary to elaborate the equirectangular projections (Fangi, 2010) of panoramic images to acquire metric information. In particular, processes of spherical photogrammetry and SfM software make it possible to obtain a point cloud following the same workflow of traditional digital photogrammetry, characterized by the integration between parallel and converging photos. In fact, even panoramic photos need a proper overlap between consecutive images to allow SfM software to find similar points from which to recognize depths and to create the point cloud.

The situation is different when using rover multi-cameras, expressly created with the purpose of producing a three-dimensional result, which can be measured and managed in a virtual environment in the way of point cloud or mesh. These instruments integrate the advantages deriving from multi-cameras, because of the capture speed, with the abilities of more sophisticated sensors specially designed for the three-dimensional mapping of built heritage. An example of the cameras commercially available is V10 Imaging Rover by Trimble, a base station system with 12 cameras with a GNSS receiver that can be integrated. Recent studies (Kampouris and Lambrou, 2016; Brunn and Meyer, 2016) show that this instrument can give results strongly dependent on the distance of the object to be examined, which becomes the crucial parameter to be managed during capture phases. In fact, large distances and absence of GNSS receiver lead to discrepancies up to 10 cm. In particular, the accuracy of V10 Imaging Rover is about of 1 cm on distances of 10 m, and this can be considered an acceptable resolution.

As regards the rover multi-cameras, the instruments having sensors linked to SLAM technology (Simultaneous Localization and Mapping) include the motorized rotating camera Matterport Pro2 3D, used, in this study, to obtain metric and colorimetric information about the Church of Rosario di Palazzo in Naples. As it is well-known, SLAM allows the instrument to determine its position with reference to a certain scene and, at the same time, to detect it, through some algorithms enabling it to orient itself. In particular, SLAM based on RGB-D images (Endress et al., 2012) – that is a combination of RBG image and depth image – uses SIFT and SURF algorithms to find corresponding points.

2. RELATED WORKS

In the documentation of Historical and Architectural Heritage, to identify the most appropriate survey methodology is not simple and clear; in fact, there are many factors able to influence data capture, thus affecting its result. For example, internal factors and various kinds of interferences may restrict the placement of instruments, as well as the field of vision, reducing the amount of acquired data. Moreover, it is always necessary to assess technological resources with reference to aims and precision required or to make choices according to morphological and geometrical characteristics, geographic position and available time.

As it is well-known, survey methodologies include some processes that, although similar – survey planning, data capture, point cloud recording, clearing, etc. –, considerably vary according to the technology in use, especially in terms of accuracy, resolution and realistic rendering of the point cloud. Each technology has its own advantages and handicaps, and often their integration is not only recommended but also necessary to optimize data capture and processing, in order to saturate any area of shadow and improve the global quality, both geometrical and visual, of the result. In fact, on the one hand, a highly realistic rendering of photogrammetric surveys is more suitable in projects of communication of built heritage, but, on the other hand, metric accuracy of laser scanner surveys is necessary to obtain a more precise survey. On the contrary, the handling of an instrument and the possibility to acquire large areas in short times, as well as a more immediate data management in terms of weight and visualization, make photogrammetry the most used survey technology in the last decades.

The most updated studies in this field (Chen et al., 2018; Lehtola et al., 2017; Virtanen et al., 2018), concentrate on the results of different reality-based capture methodologies, assessing and comparing them according to quantity and quality factors. In this respect, experimentation with Matterport Pro2 3D focuses on the analysis of capture methodology, with reference to the configuration of the area to be surveyed, verifying typology and accuracy of achievable data in relation to survey purposes. In order to obtain elements of reference for the comparison of results, the Church of Rosario di Palazzo has also been involved in range-base and image-based acquisition, with central projection cameras.

3. CASE STUDY

The case study of this research is a church, built in the 17th century at the edge of the historical center of Naples and part of the larger complex of Rosario di Palazzo, that is so called since the Spanish domination for its proximity to the Viceroy Palace. It defines the surrounding area together with the Maddalena Palace so that they form a single mainly religious insula. This church has often been transformed over time, especially in its decorations, and today it still shows severe structural damages provoked by Second World War bombs.

The main façade, with composite pilasters mounted on a piperno base, does not reveal that the hall is placed at a level higher than the street and that it can be accessed through a staircase. This building has a single nave surmounted by a pitch covering system in sheet metal and steel beams, which was installed during safety

Figure 1: Indoor view of the Church of Rosario di Palazzo.

works after the collapse of the pre-existent covering system. The apse is closed by a barrel vault with lunettes and is characterized by an altar on the wall with coupled fluted columns in composite order and triangular pediment. Supported by a wooden structure, the choir is opposite the apse and can be accessed through a narrow staircase. All the openings of the Church are square, with the exception of the opening at the bottom of the choir which has a quatrefoil shape (Figure 1).

Historical sources describing the Complex of Rosario di Palazzo (Cautela et al., 2013; Ferraro, 2002) indicate that in the past its hall had elegant wooden decorations and several works of art, including in particular a painting of the Virgin by an unknown author of the 18th century, which was placed on the high altar and now is unfortunately disappeared.

Its state of dereliction and the presence of several foreign elements, linked to its use over time as a warehouse, on the one hand led to a careful planning of the different surveys, on the other hand once again highlighted that, in such situations, data capture is helped by reality-based technologies, both for the speed and for the amount of information that can be obtained.

Figure 2: Managing of the laser scanner point cloud in Autodesk Recap Pro software: segmentation and clearing operations.

4. SURVEY METHODOLOGY

4.1 Laser Scanner Survey

Range-based surveys have been carried out through Faro Focus 3D s120 phase modulation scanner, with an integrated camera which allowed to acquire also RGB values, together with the scan. Considering the area configuration and the laser characteristics – maximum distance of acquisition of 120 m and precision of about 2 mm upon 25 m -, it was decided to perform 12 scans inside the church, five of which for the hall, four for lateral areas, three for the stairway to access, while only two scans for the main façade in view of logistical difficulties for the limited size of the road section and the continuous flow of vehicles.

Scans of the interior show the same characteristics because the area to be surveyed did not demand special measures, except for the identification of station points of the instrument in order to avoid losses of data because of areas of shadow. Therefore, it was decided to set the scanner with an average resolution involving the acquisition of a point approximately each 7 mm on distances of 10 m. On the contrary, scans performed outside has different characteristics – about 6 mm upon 10 m – to achieve a greater amount of information since it was impossible to place the instrument in more points. But not all scans contain RGB value because the low lighting of some areas of the church, especially the side ones, would have extended time of data acquisition and processing without giving further results.

In order to align clouds with semi-automatic processes inside Faro Scene proprietary software, flat and three-dimensional targets were placed in the church, so as to allow a certain level of automation in the identification of known points useful for orienting and repositioning single scans for the construction of the entire point cloud. Instead, for outdoor scans, the impossibility of correctly placing artificial targets needed the identification of natural elements as reference planes, during data processing. At the end of Faro Scene processing, the cloud was imported in Autodesk Recap Pro software, for data management. More specifically, the noise was eliminated and clouds were segmented in groups respectively for indoor and outdoor scans, in order to isolate the results useful for the comparison with data acquired with other instruments (Figure 2).
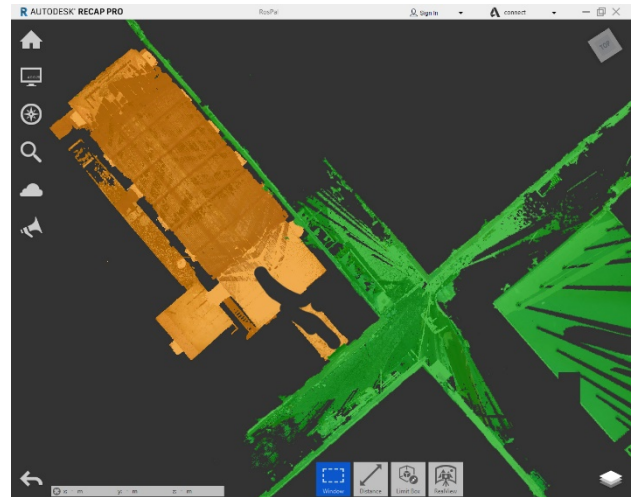
4.2 Matterport Pro2 3D Survey

Subsequently of laser scanner surveys, were performed surveys inside the church with Matterport Pro2 3D. In fact, this system has been created as an indoor mapping instrument, although it has been tested also for outdoor surveys (Gardin and Jimenez, 2018), with positive outcomes in spite of the low range of acquisition, the overlap among the different station point and the impact of natural light, which can remarkably influence the correct functioning of the sensors.

This camera is formed by three different lenses – a photo camera, a thermal imaging infrared camera, and a depth camera –
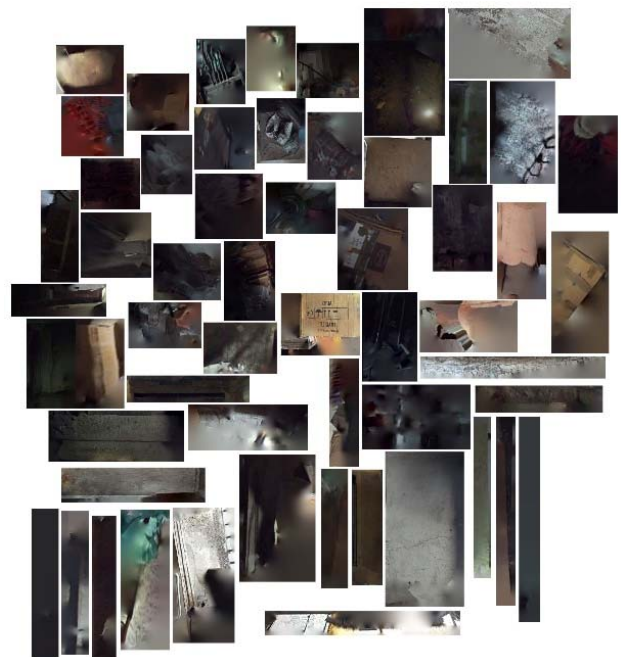

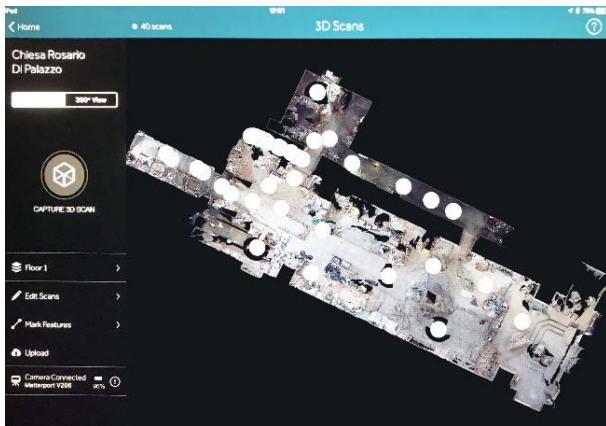Figure 3: Mosaic of pictures taken by Matterport Pro2 3D.

Figure 4: Displaying of three-dimensional data capture in Matterport Capture App.

allowing to capture images in HDR and three-dimensional data, that are subsequently connected to obtain a single 3D result, in the way of polygonal mesh. In addition to the mesh, data processing, through an external server, gives an equirectangular photo of 134.2 MP (whose dimensions are 1280x1024 px), formed by 18 images.

The cameras (in total 9, 3 for each kind of lens) are horizontally oriented and slightly inclined upwards and downwards so that the three projection centers converge in a single point. This orientation delineates the method of shooting, which takes place through a complete rotation on the horizontal plane, generally divided into six steps; in each step, the camera takes the frames who will form the final image. Then, the horizontal field of acquisition is covered at 360°, whereas the vertical one is limited at 300°, for the inclination of the cameras, excluding a portion of the top and the bottom from the shooting (Figure 3).

The whole system is managed through mobile devices, with IOS App for Matterport Capture, allowing to control the camera through a WI-FI connection among the devices. For every station point of the instrument, this App displays a first processing of the plan enabling to continuously verify the acquired areas and their scans and to saturate any area of shadow. Unfortunately, this data visualization in real time is limited only to planimetry, and, although an experienced operator is able to identify areas of shadow in advance, it is not always possible to verify in situ the quality of an acquisition (Figure 4).

The absence of markers does not affect the final result; in fact, Matterport Pro2 3D can align two consecutive shootings in different points according to similar points it finds on the scene. In practice, the automated alignment algorithm of this software uses elements from the previous picture – of which it identifies both spatial data and RGB values – to position the following shooting and to reconstruct correctly its geometry without the aid of known points. If it is true that shooting is facilitated, it is also true that variations in lighting conditions and displacement of objects inside the scene can affect the final result producing errors in the different connections, while guaranteeing a suitable overlap among consecutive pictures.

For the whole church, 40 acquisitions were necessary, following a semi-closed way (even if not necessary) to allow software to calibrate again the alignment of the various station at the end of shooting, in order to obtain a better final result. But it was not always possible to respect distances suggested by the producer with reference to the object to be surveyed (4.50 m) and the overlap between the different acquisitions (1.00 m for outdoor surveys, 2.50 for indoor surveys). In some cases, they were

dilated because of the impossibility to place the instrument correctly for the presence of many obstacles in the scene; in other cases, the station points were brought closer together to better detect morphological and geometrical complexities. In spite of a careful evaluation of scan positions, supported by the preview of previous images that a tablet can display through Matterport Capture App, the campaign phase revealed some difficulties in alignment, especially near the stairway to the choir, which is scarcely large, with very bad lighting conditions and totally without points of discontinuity. This leads to readjust the position of the instrument and to perform a new acquisition to help the alignment with previous acquisitions and to go on with the following ones.

At the same time and before uploading data in the cloud, reflecting and glass elements have been identified, because, as it is well-known, they produce areas of high noise, so as to exclude them from the final point cloud and, consequently, to reduce noise and fasten the cleaning phase. The automated cloud computing associated with the instrument gives the possibility to download results in obj format (Figure 5).

Figure 5: Matterport Pro2 3D point cloud.

4.3 Photogrammetric Survey

Image-based acquisitions required the use of a 20 MP Nikon Coolpix L330 with an optical 26x zoom. The sequence of pictures was performed in view of the processing with SfM Agisoft Photoscan, according to well-established rules of horizontal and vertical overlap and integration between parallel and converging photos (De Luca, 2011), so as to correctly read depths and obtain a more reliable result. The church spaces have been divided into significant portions and their photos have been grouped according to a direct correspondence with the data-set, or chunk, of this software, so as to better control the processing result, and to reduce processing time and dimension of the final file. In order to improve the matching of data set and obtain a single result from the photographic campaign, equal images have been added to the groups of consecutive photos, to make it easier to identify similar points, or similar portions of the point cloud, on which the alignment of different models could be based.

Although Photoscan identifies the camera in use and automatically associates the parameters of deformation of the lens, before processing images, calibration was carried out through the dedicated tool. As it is well-known, this operation allows to correct deformations in the pictures and to improve the construction of the point cloud, which occurs by consecutive stages. In particular, for the Church of Rosario di Palazzo, it was decided to complete the entire process up to the creation of a dense cloud, so that data can be compared with other acquisition processes, because the knowledge of metrical data is considered

Figure 6: Indoor view of the Matterport Pro2 3D's point cloud: note, in particular, the covering

more necessary than the photo-realistic rendering which can be obtained by texturing of the polygonal model.

5. RESULTS

Surveys have been examined according to two different approaches, the first of which included evaluations about the visualization of the point cloud obtained by Matterport Pro2 3D, whereas the second one takes into account more specific assessments with the support of some software for comparisons cloud-to-cloud.

Therefore, the first approach involves a direct observation of the point cloud, which generally shows a good three-dimensional reconstruction of the church, except for some areas. There is no doubt that the total absence of rebuilt parts or the high noise in some of them may depend on the obstruction of the visual field and the maximum acquisition range. As regards the hall covering, for example, the presence of a network of beams is discernible, but the high distance from the instrument (about 8.50 m) has produced data full of noise from which no metric information can be extracted (Figure 6).

On the contrary, an unexpected revelation was the regular mesh on which the points are distributed, more similar to the mesh of

a range-based survey – but with a significantly lower density – than to an image-based one. Matterport Pro2 3D is one of the instruments for photogrammetric acquisition producing a strongly irregular point cloud which is dependent on the algorithm in use for its creation. However, data downloaded from the cloud are connected with the construction of the point cloud starting from a polygonal model, and this is the reason why they are different from traditional photogrammetries, being more regular in their top.

In the cloud-to-cloud approach, a pre-comparison editing was necessary to decimate the point cloud generated by the laser scanner, which showed a much higher amount of points than others. In particular, the cloud obtained by Faro Focus 3D s120 was composed by about 150 million points, while the cloud of Matterport Pro2 3D contains about 15 million points. On the contrary, photos by Nikon Coolpix L330 showed about 10 million points (Figure 7).

Despite this, it kept a good thickening, so it has been considered as a reference for the comparison with data obtained by Matterport through open source Cloud Compare software. Results have been examined at the different detail scales – from the building as a whole up to its decorations – and, at the same time, further reflections have been made about the accuracy and the speed of data acquisition and processing.

In order to carry out the operations of comparison, it was necessary to align Matterport Pro2 3D point cloud to the laser scanner one, manually identifying similar points between the two models. This choice has been made by assessing the elements on the scene and by finding the most recognizable ones in the clouds: edges of door and windows, frames or obstructions. Just three points may be sufficient to software for a proper roto-translation of a cloud in comparison with another cloud, but more points, placed on different levels, allow to reduce mistakes and to better control the final result. Then ten points have been identified and the alignment process has been started in Cloud Compare, avoiding, in this first test, to resize Matterport Pro2 3D in comparison with the laser cloud, set as a reference.

The same alignment process has been carried out also for the point cloud processed through photogrammetry; but in this case, it has been necessary to resize the model from the beginning because it is known that it is correctly proportionate but not in real dimensions.

The first comparison between models highlighted that Matterport Pro2 3D cloud has excessive discrepancies in its total dimensions, although the producer assures a very high reliability of measurement – precision of 99% – (Matterport, 2018). In fact, by carrying out some sections on horizontal and vertical planes
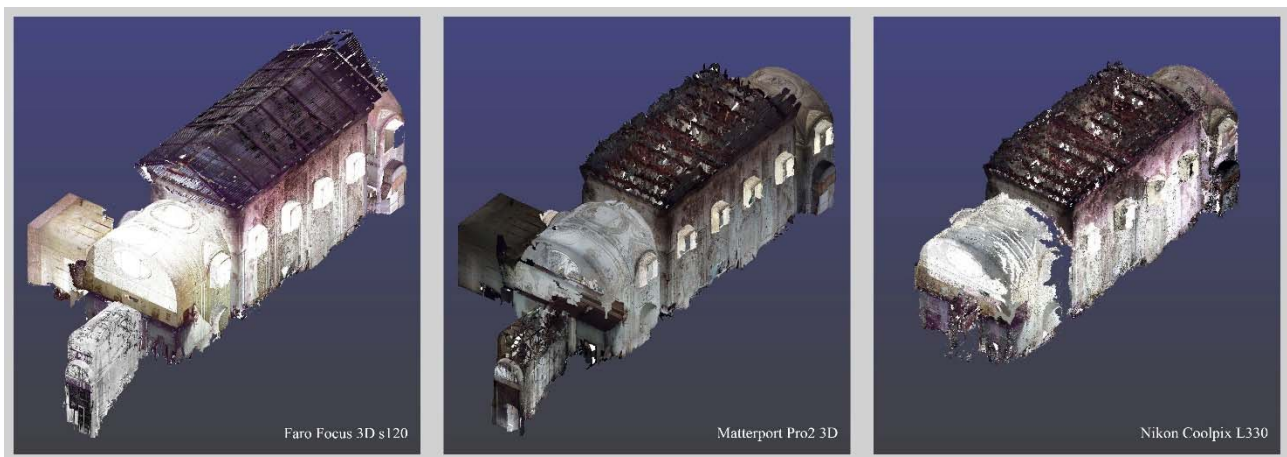

Figure 7: Point clouds of different acquisitions: Faro Focus 3D s120, Matterport Pro2 3D, Nikon Coolpix L330.
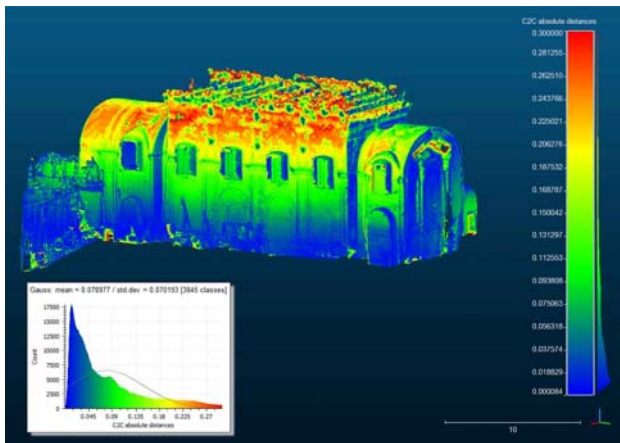
Figure 8: Results of the comparisons of point clouds in Cloud Compare: Faro Focus 3D s120 and Matterport Pro2 3D.
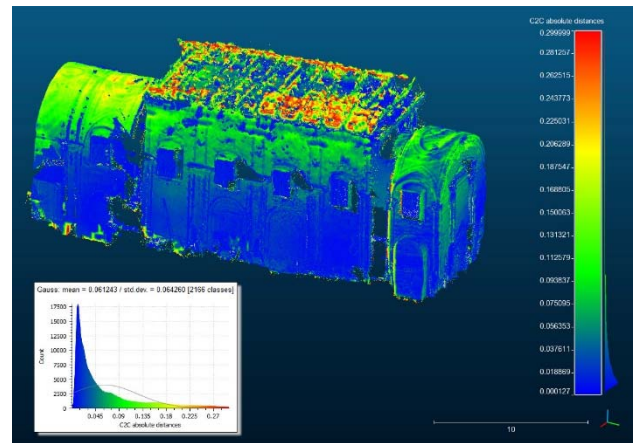

Figure 9: Results of the comparisons of point clouds in Cloud Compare: Faro Focus 3D s120 and Nikon Coolpix L330.

and by extracting contours with automated processes, it was possible to verify that the cloud has an error of about 4 cm in the transversal direction, 7 cm in the longitudinal one and 15 cm in height. Instead, the alignment of point clouds obtained with photogrammetry was proportionally more correct although there are many areas without data. Therefore, it was necessary to repeat alignment operations, this time allowing the system to scale the cloud created by Matterport Pro2 3D, in order to assess its general dimensions regardless of initial scale. This process has been restarted on more occasions in order to identify the most proper correspondence between the two point clouds and to reduce as much as possible size differences, both in plan and in elevation (Figure 8 and 9).

A detailed analysis of the profiles of the horizontal sections showed that the difference in size is probably due to a propagation of the instrument error of measurement in the scan direction. In practice, although along a not straight course, the linked acquisition led to a series of errors in the single acquisitions; in fact, once the cloud portion representing the hall has been extracted, its length – the direction chosen for acquisition – showed an inadequate size, while its width is more consistent with laser scanner data. Vice versa, in secondary areas, since the direction of the scan has changed, the analysis of the same data indicates that the width is outsized. For this reason, the overall effect is that the point cloud shows mistaken data in both directions.

The evaluations of details also revealed some errors, in smaller and more complex elements, such as the moulded cornices and the fluted columns of the altar. More specifically, as regards the columns, while the first analysis of their point cloud in three-dimensional environmental suggests that they are adherent to reality, the horizontal section shows an element with a different morphology, a smooth profile and without grooves (Figure 10).

The most of the inconsistencies of Matterport Pro2 3D model are due to the method of data capture and to their processing (impossibility to choose resolution, limited visual field, as well as evaluation of connections between the instrument station points). Another disruptive factor in the camera shooting derives from the management of the mesh producing points: generally speaking, in the final phase of mesh construction, software for photogrammetry tend to fill the voids in the point cloud, thus recreating an unreal surface. In this way, the virtual mode is not consistent with what it represents, and its degree of inconsistency is directly proportional to the size of the empty space. The polygonal model of the church is adherent to this reconstruction, as shown in the apse. In fact, the analysis of the longitudinal section indicates the construction near the higher arch of a surface connecting the arch wall and the barrel vault, with an inclination that does not exist in the reality (Figure 11).
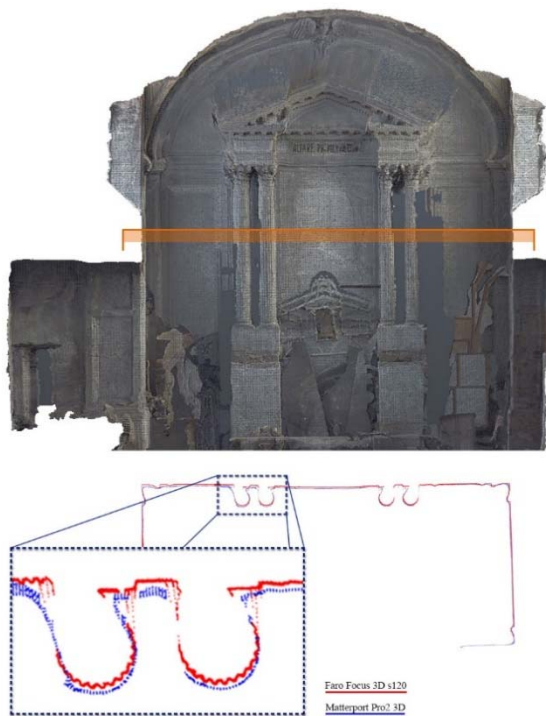

Figure 10: Detail of the coupled columns of the apse altar. Comparisons between laser scanner cloud and Matterport Pro2 3D cloud: plan view and three-dimensional view.

6. CONCLUSIONS

If, on the one hand, range-based technologies allow to obtain accurate metric results and image-based technologies photo-realistic results, on the other hand, both of them need a planning
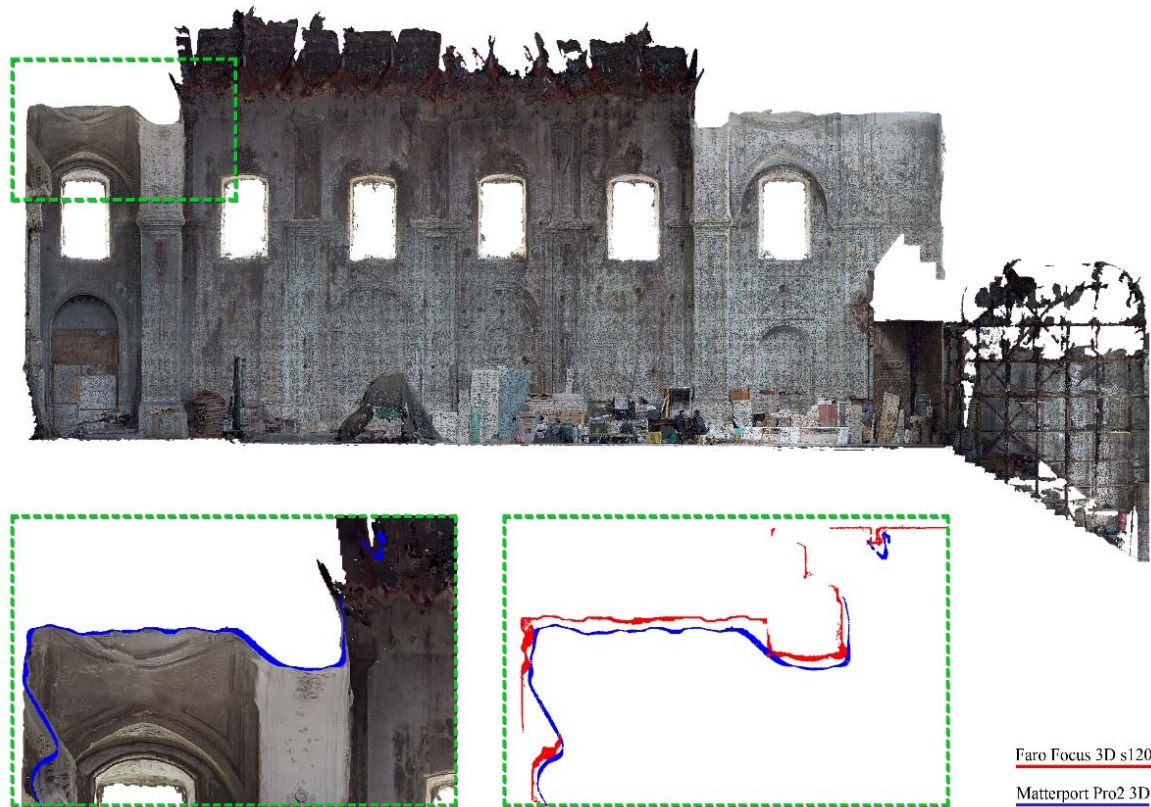
Figure 11: Detail of the longitudinal section in the apse. Comparisons between laser scanner cloud and Matterport Pro2 3D cloud.

of survey and long times of data capture and processing, especially for indoor areas characterizing built heritage, where morphological and geometrical complexity and the reduced visibility of places requires that scans increase to minimize the areas of shadow. Consequently, not only times extend but also file management, growing in size, becomes onerous.

In this situation, indoor mapping devices with SLAM technology, such as Matterport Pro2 3D, are good alternatives. The possibility to manage and verify acquisition during the campaign phase – and not after data processing, as in most of reality-based technologies - to correct any error or area of shadow is a strength in optimizing times and results. In spite of the errors detected in the specific case of this church, with sometimes excessive discrepancies in comparison with reality, special measure may be taken to improve outcomes. In fact, for example, by decreasing the distance between station points of the instrument and by making acquisition following a closed course, the metric error propagation in data is reduced, thereby facilitating more accuracy in the total measurement. Obviously, it is not always possible to carry out surveys in optimal conditions; the complex morphology and geometry of built heritage (successive places, prevailing development of a dimension in comparison with another one, etc.) often limit the ideal scan. Moreover, also high levels of automation in the entire process play an important role for the quality of the result: the impossibility to establish which parameters and procedures must be used to create a point cloud leads to a homogenization of results which can be not completely consistent with survey purposes.

Nevertheless, the management of survey campaign, the speed of shooting, the quality of RGB-D images and the acquisition of even complex spaces, without the aid of targets, make Matterport

Pro2 3D a tool – placed at an intermediate level between range-based and image-based traditional technologies – in the knowledge and in the rapid virtualization of built heritage.

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