GEOMATICS SUPPORTING KNOWLEDGE OF CULTURAL HERITAGE AIMED AT RECOVERY AND RESTORATION

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ABSTRACT:

The study presented aims a practical contribution to the use of the Terrestrial Laser Scanner and the Close Range Photogrammetry geomatic techniques and to their integration for the knowledge and development of the historical-architectural heritage, both in the step of planning a restorative conservation project, and in the subsequent step of the restoration works. In particular, these techniques and their integration were applied at the process of study, planning and execution of the restoration of the San Giovanni Battista church in Fonni (Sardinia, Italy), founded in the 16th century. The building, due to structural problems and humidity infiltrations, was subject to a serious intervention for consolidation and conservative restoration.
In the first phase of the work, preliminary to the design, a TLS survey was made that allowed to obtain an accurate 3D model of the church. In a second phase, during the restoration work, CRP surveys were carried out and the accuracy of this technique was verified through a comparison with TLS surveys. The integration of the two techniques to improve the texture of point clouds detected with TLS was also tested.

1. INTRODUCTION

In the last several years, in Italy, the conservation and development of the cultural and historical heritage have accrued a great importance, due both to the economic income they generate, and to a renewed sensitivity of the younger generations towards their cultural heritage. Italy also holds the record for the number of international sites included in the UNESCO World Cultural Heritage (unesco.org, 2022), and over 70% of said heritage is on Italian territory. Even if the cities and territory of Italy are rich in protected historical and architectural sites, both public and private, those are often in a bad state of conservation and not open to the public. According to Federculture (https://www.federculture.it/), Italy does not spend much in culture: the expense is at the fourth-last place in Europe (0.8%) when compared to GDP (Gross domestic product) and third-last (1.7%) compared to the total public expense. But in the last decade the situation is improving, as the public administrations want to reverse this course, realizing the importance of the cultural heritage and its economic value. This has brought them to involve architects, cultural heritage technicians, and other professional figures in the study and development of their own heritage sites.

An important role in this context is played by the scientific community, which has worked for years on developing a multidisciplinary approach to the study, conservation and development of the cultural heritage using methods and techniques that allow to meet their goals in short time and at a low cost. An important step in this process is the geometric, historical, architectural, material, chronological and state-of-decay knowledge of the site, such as to provide a complete picture of its health and to effectively plan its conservation and restoration. (Delegou et al. 2019). In this step, most institutions for heritage conservation forbid or discourage the taking of material samples, preferring non-destructive techniques and methods without direct contact with the object (Letellier, et al.

2007). Among the most used and preferred procedures, we can cite the laser scanning and image-based geomatic techniques, that can provide enough data to extract geometric, dimensional, material and decay information without any contact with the object. These also concur to the decision process on the approach to the conservation and development of the heritage (Giannattasio et al., 2013, Vacca et al. 2017). These methods offer great advantages in the survey and study of historical buildings on the operating level: they are fast, non-invasive, and contribute in a complete and accurate way to the examination of the object even where the construction elements have complex and/or irregular shapes (Buil et al. 2020). They can work separately or by combining the two techniques; they can use data from land-based or UAV-mounted cameras (Vacca et al. 2018). The accuracy of terrestrial laser scanner (TLS) systems has been extensively tested and verified (Fassi, Fregonese 2011), (Grussenmeyer et al. 2008) and (Monego et al., 2019), while the image-based techniques and their integration with TLS are still the object of study (Pepe et al., 2016). The TLS technique has been used in the study of deformations of ancient structures, of which there are several examples (Bonali et al., 2013), (Pesci et al., 2012) and (De Catalunya et al., 2017).

High density point clouds can also be produced by multi-image Close Range Photogrammetry (CRP) using the Structure from Motion (SFM) approach (Remondino et al., 2006) and (Guidi et al., 2004), a technique that has shown to be more versatile, low-cost and fast than TLS. Nevertheless, this technique too tends to become more complex and costly when using many Ground Control Point (GCP) or professional software. Thus, we can see that the CRP can be used with different methods and instruments, leading to great differences in performance and costs (Pe˜na-Villasenín et al., 2017). The main advantage of this technique is surely its ability to accurately acquire the color of the surveyed object. This is a substantial difference with the TLS technique, due to the nature of the data acquisition method

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(Zhang et al., 2016) and (Carraro et al., 2019); for this reason, the two techniques are often used together.

The study presented here aims a practical contribution to the use of the TLS and CRP geomatic techniques and to their integration for the knowledge and development of the historical-architectural heritage, both in the step of planning a restorative conservation project, and in the subsequent step of the restoration works.

The paper presents the potential and the accuracy of the two techniques and their integration in the process of study, planning and execution of the restoration of the San Giovanni Battista church in Fonni (Sardinia, Italy), founded in the 16th century. The building, due to structural problems and humidity infiltrations, is currently subject to a serious intervention for consolidation and conservative restoration.

The paper is organized as follows. Chapter 2 describes the history and the most relevant features of the case study. Chapter 3 presents the methods and techniques used for the survey of the building. The results are analyzed in chapter 4. Finally, chapter 5 presents the discussion and conclusions.

2. CASE STUDY

The church of San Giovanni Battista is located in Fonni, a town in central Sardinia (Italy). It is a historical building that was subject to several interventions, expansions and modifications through the centuries, of which no documentation remains. Currently, the church occupies a surface area of about 550 m^2 and is composed of three naves divided into six spans, one of which is the presbytery. A square bell tower is built next to the sacristy. Figure 1 shows the map of the church in its current state.
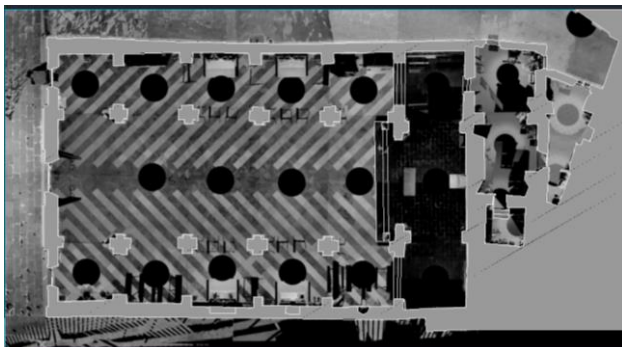

Figure 1. Map of the Church of San Giovanni

In 2017, following the appearance of humidity on the walls, rising water on the floors, and fractures and fissures on the pillars, it became necessary to begin a study of the building both on a structural and material level.

The architectural firm in charge of the restoration project involved a group of geomaticians with the task of supporting all phases of work. The geomatic surveys consisted in using terrestrial laser scanner, multi-image photogrammetry, traditional total station surveying, and GNSS positioning.

3. MATERIALS AND METHOD

Different geomatic surveys and in different phases of restoration work were carried out. In the first phase, preliminary to the design and characterized by the objective of knowing the church dimensionally and verifying the state of decay of the same, a geomatic survey was carried out in order to obtain a 3D model

with high accuracy. For this purpose, a TLS survey was chosen which involved the interior, exterior and roof of the church. In a second phase, with the restoration work started, both a TLS survey and a CRP survey were carried out to support the work and the construction manager.

The two relevant phases and the results obtained are described in the following paragraphs.

3.1 Phase I

The goal of the first phase of the work was to survey the entire church with high accuracy in order to obtain the dimensional and conservation state of the building.

It was therefore decided to perform a Terrestrial Laser Scanner (TLS) survey that would allow to obtain a complete 3D model from which to extract all the graphic outputs of the church. For the choice of the instrument and for the design of the scans, we started by thinking about the geometry of the church, the architectural details and the state of cracks and deterioration present to be detected. From these considerations we decided to use the Faro Focus 3D (Figure 2) Terrestrial Laser Scanner. It is a compact scanner characterized by an operative range that varies between 0.6 and 120 m, with a ranging error of ±2 mm for scanner–object distances between 10 and 25 m.

JRC Reconstructor software v. 3.1.0 by Gexcel Ltd was chosen as software for the management and processing of point clouds.

The scans were performed at a resolution of ¼, quality 3x (resolution of 7 mm / 10 m) and an overlap between the scans of at least 30%. A total of 40 scans were performed with these parameters, of which 28 internal and 12 external scans (see Figure 3). The survey was carried out on 19 October 2017.

The 40 scans were initially preprocessed and subsequently, using only natural features, were pre-aligned and then aligned obtaining closing errors of less than 1 cm.

The complete point cloud of the church was, subsequently, georeferenced in the ETRF2000 reference system, through 20 Ground Control Points (GCP) placed outside the Church and surveyed through a GNSS survey in RTK mode, using differential corrections coming from the network of permanent stations of Sardinia SARNET [http://www.geodesia.biz/sarnet/]. After processing the 40 point clouds, the mesh and then the 3D model (Figure 4) was generated with the JRC 3D Reconstructor software. From this the following graphic output have been extracted:

- horizontal sections at different heights from the floor: floor height; altitude +3 m; altitude +6 m;
- vertical sections;
- orthophoto of the vertical and horizontal elements, internal and external, with GSD (Ground Sample Distance) equal to 2 cm.

From the sections and orthophotos, all the graphic output of the plans, sections and elevations of the church have been prepared.
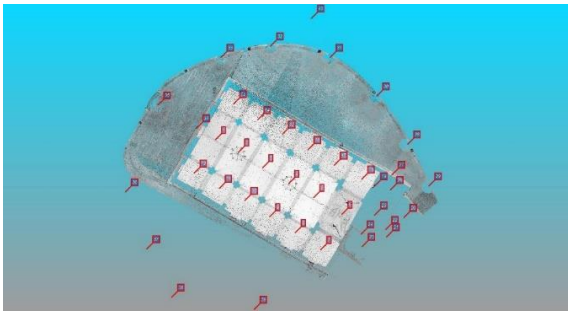

Figure 2. Faro Focus 3D

Figure 3. Points of TLS survey

Figure 4. Church 3D Model

From the study of the 3D model began the analysis of the degradation of the surfaces, referring to the UNI 11182: 2006 standard "Cultural Heritage. Natural and artificial stone materials. Description of the form of alteration – Terms and definitions". In particular, analyses were carried out aimed at:
-Chromatic alteration
-Surface deposit
-Detachment of plasters
-Erosion
-Fracturing or cracking
-Ascent front
Following these investigations and the results obtained, the architects-restorers have identified a series of interventions to be carried out. One of the first was to remove the layer of plaster from the inner walls of the church. Thanks to the removal of the plaster layer, several construction details dating back to the church plant and subsequently hidden in the various subsequent construction interventions have come to light.
Figures 5 and 6 give a clear example. On the wall of the presbytery was brought to light an opening certainly dating back to the implant of the church and subsequently closed. Other openings, niches and paintings were found in the walls of other chapels.

Figure 5. Presbytery before plaster removal

Figure 6. Presbytery post removal with opening

The discovery of new and interesting construction details led the team to design a new series of surveys with the Close Range Photogrammetry (CRP) technique, in addition to the TLS technique.

3.2 Phase II

The second phase of surveys became necessary following the first works carried out on the church and in particular following the removal of the plaster from the internal walls of the Church. This intervention has, in fact, brought to light construction, architectural and painted details that have remained hidden from the expansion and modification interventions suffered by the church over the centuries and that have contributed to a better knowledge of the construction history and have been of fundamental importance for the design choices of restoration.
In this second phase, two different geomatic methodologies were performed and integrated: TLS and multi-images photogrammetry with SfM approach. The TLS survey affected the interior of the factory while the photogrammetric one affected only some parts of the church where new construction details were brought to light.
As for the TLS survey also in this case the Faro Focus 3D Terrestrial Laser Scanner and the JRC Reconstructor software v. 3.1.0 by Gexcel Ltd were used. The scans were carried out at a resolution of 1/4, 3x quality (resolution of 7 mm/10 m) and an overlap between the scans of at least 30%. A total of 18 internal scans were performed with these parameters (see Figure 7). The survey was carried out on May 7, 2021.
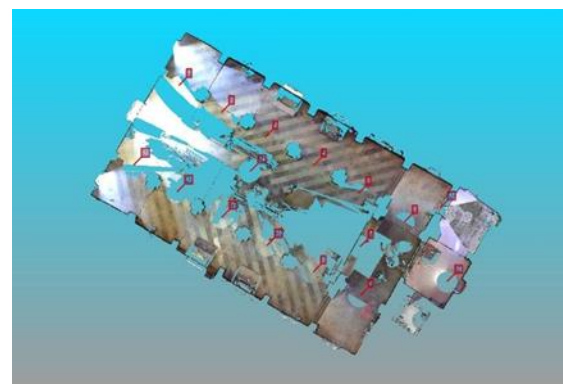

Figure 7. Points of TLS survey – Phase II

The 18 scans were initially pre-processed and subsequently, using only natural features, were pre-aligned and then aligned obtaining closing errors of less than 1 cm. The point cloud was,

therefore, georeferenced in the ETRF2000 reference system, through the use of GCP from the 2017 point cloud.

The CRP survey was made using a Canon digital camera EOS M3 with a sensor CMOS 22.3 × 14.9 mm sensor (3.7 mm pixel dimension), Field of View (FoV) 81.5g, and 24.2 Megapixel resolution; objective EF-S 18–55 mm; the output data formats are Exif 2.3 (JPEG) and RAW (CR2 Canon original). The image processing was performed with Metashape commercial software by Agistoft.

The CRP survey was carried out only on the vertical walls of the chapels where the plaster was removed for a total of 13 surveys. Table 1 shows the data of the individual surveys and the processing parameters set in the Metashape software.

Through these surveys it was possible to obtain the dense clouds of points of all the walls of the chapels and a high-resolution photographic survey of the same.

Chapel	n. images	Metashape parameters	n. points
Presbitery	20	High/Mild	7889671
1	11	High/Mild	
2	14	High/Mild	7143196
3	22	High/Mild	9498291
4	16	High/Mild	9098953
5	16	High/Mild	9438301
6	12	High/Mild	7351020
8	25	High/Mild	7250258
9	16	High/Mild	6285021
10	13	High/Mild	5978851
11	15	High/Mild	5875266
12	14	High/Mild	6254973
13	7	High/Mild	6412544

Table 1. Parameters CRP surveies

4. RESULTS

From the surveys described in paragraph 3, several results have been obtained that have made it possible to verify, the accuracy and potential of the CRP surveys, as well as its integration with TLS technique, in the process of design and restoration of architectural heritage.

In particular, the TLS 2017 and TLS 2021 surveys were used for the calculation of the volume of the plaster removed and for the validation of the CRP 2021.

Finally, the results obtained from the integration of CRP with TLS for the improvement of the texture of the TLS point cloud and the extraction of orthophotos are presented.

4.1 TLS 2021 – CRP 2021 comparison

The first part of the work was dedicated to validating the CRP as a methodology to support the survey operations of an architectural asset of historical-cultural importance. As previously mentioned, CRP is considered a low-cost and expeditious geomatic survey. In the restoration work of the Church of San Giovanni the CRP was used in the demolition phase of the plasters for the evaluation of the removed material and for the production of orthophotos. In a first phase the

methodology was validated with the comparison with the TLS 2021 survey and subsequently it was used to estimate the material removed by comparing the CRP2021 and TLS2017 point clouds. This was done comparing the measurements of distances taken on the point clouds obtained from CRP surveys and TLS surveys using the CloudCompare software. To perform this comparison, equal portions of point clouds were taken. Comparisons were doing on parts of point clouds of chapel 6 and the presbytery (see figure 8).

Tables 2 shows the results of the comparisons between the point clouds obtained with TLS 2021 and the point clouds from CRP 2021.

Figures 4 and 5 show the discrepancy map between the TLS point cloud and CRP point cloud for 6 chapel and Presbytery chapel, respectively.

	Chapel 6	Presbytery
Min (m)	0	0
Max (m)	0.172	0.719
Mean (m)	0.003	0.034
Dev. Stand (m)	0.012	0.110

Table 2. Statistical values of the comparisons between the TLS and CRP point clouds
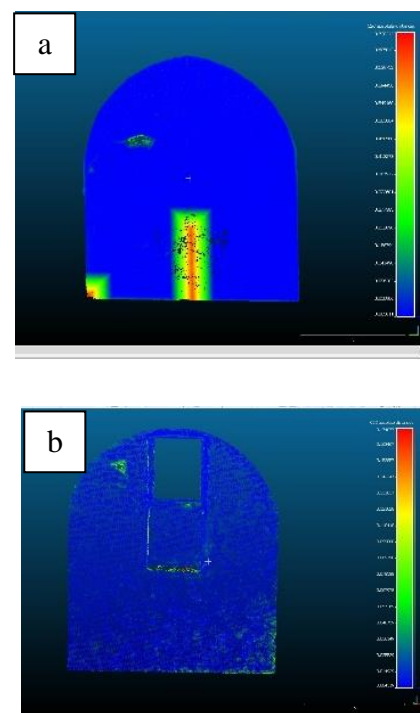

Figure 8. Discrepancy (m) map between the TLS2021 and CRP2021 point cloud for Presbytery (a) and 6 chapel (b)

4.2 TLS 2017 – TLS 2021 Volume measurement

The volume of removed material was evaluated by comparing the point clouds of the 2017 and 2021 TLS survey. This calculation was performed on the various parts of the asset where this removal was carried out, by way of example the one relating to the wall of 6 chapel and Presbytery is given. This calculation was carried out with the Cloud Compare software, the results obtained are shown in Table 3.

	Volume (mc)	Surface (mq)
Chapel 6 TLS_2017 vs TLS_2021	1.378	15.238
Chapel 6 TLS_2017 vs CRP_2021	1.333	15.239
Presbytery TLS_2017 vs TLS_2021	2.327	38.163
Presbytery TLS_2017 vs CRP_2021	2.347	38.184

Table 3. Comparisons between the Volume measurement from TLS and CRP point clouds

4.3 TLS – CRP integration

In the restoration phases of the Church of San Giovanni, 3D models and orthophotos were required that were accurate both from the geometric point of view and from the point of view of texture and colors of fundamental importance for the study of the degradation of materials and architectural details returned to light after the removal of the plaster.

Analysis of the TLS 3D model showed that the textures were not true due to the imperfect illumination of the walls during the survey phases. To improve the texture, the TLS survey was integrated with the CRP survey by testing the algorithms offered by the Reconstructor software to perform these operations. To this end, two portions of the church were chosen that presented obvious problems in the texture of the 3D point cloud of the TLS survey, a problem that is also found in the orthophotos generated by the point clouds.

In figures 9 and 10 the TLS and CRP point clouds of Chapel 6 where the difference in the texture of the two types of survey is evident.

Through the use of Reconstructor it was possible to test a procedure to reproject the RGB values of the images coming from the CRP survey on the TLS point cloud. From the point cloud with the new texture are extracted the orthophotos and these compared with those obtained previously and with those coming from the CRP survey leaving the original resolution and accuracy unchanged.

In figures 11 and 12 the orthophotos TLS, CRP and TLS+CRP for chapel 12 and chapel 6.

Figure 11. TLS (a), CRP (b) and TLS+CRP (c) ortophotos
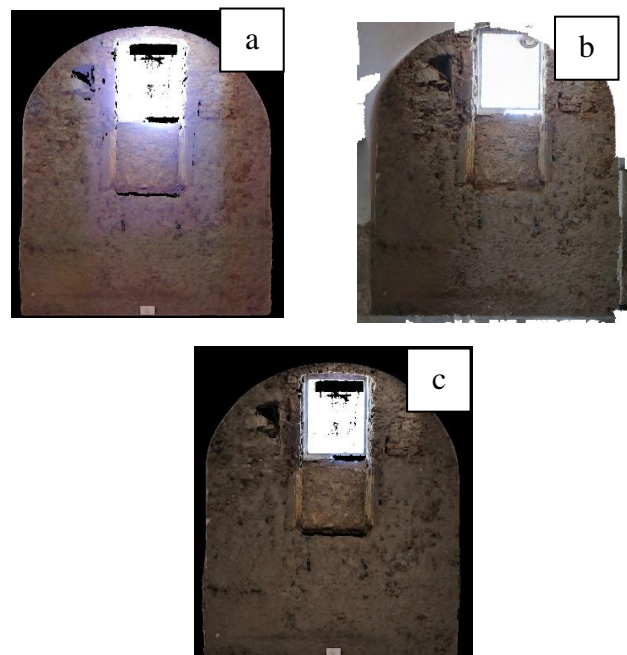
Figure 12. TLS (a), CRP (b) and TLS+CRP (c) ortophotos

Figure 9. TLS cloud point   **Figure 10**. CRP cloud point

5. DISCUSSION AND CONCLUSIONS

The paper presents the contribution made by of geomatic surveys to the process of study and restoration of a cultural heritage asset. In particular, the contribution, in terms of accuracy and potential, of Close Range Photogrammetry compared to the Terrestrial Laser Scanner was analyzed. The results obtained show what so much of the scientific literature has already demonstrated, namely that CRP with the SfM approach can be used for the generation of point clouds for the survey and study of architectural heritage (Lewinska P. et al. 2022, Grillo et al., 2019). The comparison between the point clouds CRP2021 and TLS2021 showed a good accuracy with a standard deviation between 1 cm to 11 cm. The calculation of the volumes also produced good results with an error of less than 3%.

A second part of the work concerned the integration between the two techniques TLS and CRP to improve the texture of the point cloud and orthophotos of the TLS survey. Also, in this case the results reported in the scientific literature (Pepe et al., 2016) and (Aita et al., 2017) confirm what has been achieved in this paper. With the use of the algorithms implemented by the Reconstructor software, the texture of the point clouds coming from the TLS survey has been improved using the CRP survey and its images. The results are clearly visible in Figures 9, 10, 11 and 12.

From the work done so far it emerges that the TLS and CRP techniques were very important both in the study phase and in the phase of the first restoration work. They supported the designers and the works manager in the crucial phases of knowledge of the asset and supported them in the design choices and further investigations.

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