A COMPARISON BETWEEN TLS AND UAV TECHNOLOGIES FOR HISTORICAL INVESTIGATION.

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ABSTRACT:

The architectural and sculptural value of the investigated Cultural Heritage has suggested a variety of possible approaches ranging from the traditional modus operandi to the implementation of innovative technology. The conducted research implemented digital and automatic photogrammetry software using Structure from Motion or SFM. These techniques which involve the convergence of different disciplines, such as Computer Vision and photogrammetry seek to generate 3D models, that is the mathematical representation of the investigated 3D objects. The integration of UAS, photogrammetry and TLS develops 3D models able to provide more detailed information. The main purpose of the present research is to test the potentialities offered by the new survey and 3D processing systems in order to carry out historical analyses and investigations in closed environments and for small scale architecture. Starting from the acquired data, the 3D models of the altars allow a 3D comparison between the works object of study and Pozzo's treatise, also allowing speculation about their possible relations, providing extraordinary outcomes from the point of view of survey integrated methodologies and from the point of view of historical and geometric interpretation.

1. INTRODUCTION

Thanks to the advancement in survey techniques and technologies, the study of Cultural Heritage makes increasingly use of 3D modelling as a methodology in order to understand, analyse and interpret buildings.

Actually, it is the most effective type of representation both for its conclusions, more and more precise and similar to real artefacts, and for the methodological approach concerning working environment, morphological features of analysed architecture and for the specific researches which can be conducted.

The present study deals with survey in closed environments and it integrates UAS and TLS technology of small-scale architecture artefacts with geometric complex shapes, aiming at the creation of 3D models to be compared with traditional representations. (Figure 1)

TLS and UAV data acquisition methodology has been applied in order to achieve the objective and to obtain a highly detailed and complete digital model.

In particular, the traditional point cloud deriving from terrestrial laser scanning has been integrated with data resulting from a UAV photogrammetry campaign carried out according to an orthomosaic photo on a very close vertical plan, integrated with oblique shots. The study approach is a consequence of the specific type of architecture to be surveyed: the big altars with two chapels developing in height and with a projection which prevents a flight plan above the building itself. Moreover, in the specific case, the relation between vertical and horizontal plans is inverted.

The research focused on two questions: UAS experimentation in closed environments for the acquisition of data aiming at the creation of a 3D model and, after the assessment of the achieved results, the historical analysis of the investigated artefacts.

Through the different digital survey instruments and the use of software dedicated to virtual visualization, a kind of representation aimed at historical investigation was started in order to trace formal and proportional correspondences between the investigated Cultural Heritage and the models found in the specific literature of the time.
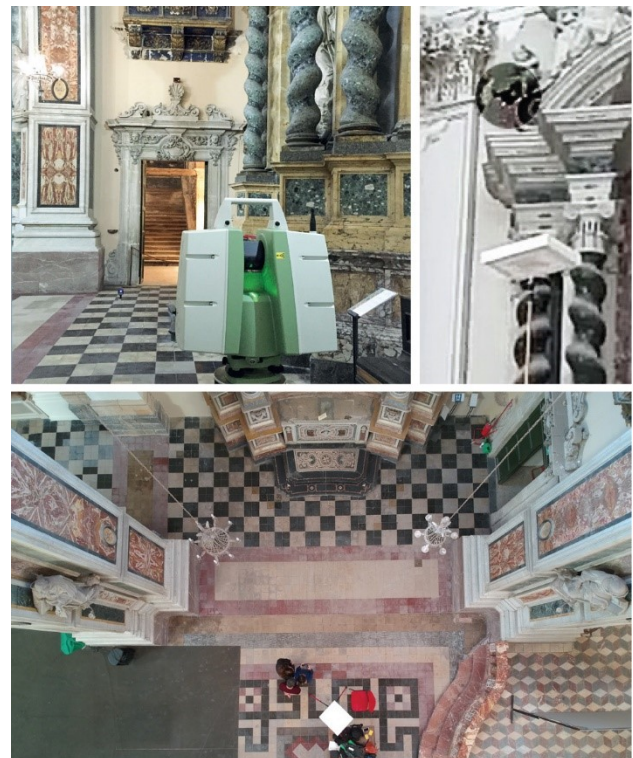

Figure 1. Survey activity with UAS and TLS technologies

1.1 Related works

The present research highlights the importance of innovative technology for the survey and documentation of Architectural Heritage. Indeed, the integration of different methodologies can effectively improve the standards of representation and precision of the final product (Balletti et al., 2015; Maiellaro et al., 2015). The implementation of UAS platforms for visual data acquisition such as images and videos, represents a consolidated technique applied in different fields such as the mapping, monitoring and documentation of Cultural Heritage. Thus, it is possible to find different case studies in scientific literature evaluating the implementation of these systems in different contexts and with different purposes estimating UAS performance and precision of final results. (Remondino et al., 2011; Nocerino et al., 2014; Georgopoulos et al. 2016; Chiabrando et al., 2017; Deris et al., 2017).

The conducted research also provides some significant advantages obtained in terms of sustainability (automated precision acquisition, time and cost reduction) integrating 3D data from aerial and terrestrial sensors. In particular, the combination of nadir and oblique imagery acquired by the UAS platform for the metric documentation has recently raised researchers' attention (Aicardi et al., 2016; Chiabrando et al., 2017). Implementing these data where the axis of the camera lens is configured with a variable inclination has a significant impact on the generation of 3D models especially in the case of complex objects or sites presenting great heights.

The study is an example of the wide interest in the implementation of aerial images for the construction of 3D models and makes an innovative contribution to the detection and solution of problems concerning the *modus operandi* in closed environments and for architectural and sculptural works when it is not possible to shoot full 360-degree field-of-view.

1.2 The case studies

The present contribution describes an experience of integrated 3D survey carried out in the Church of *St. Francesco Borgia* in Catania. Within the great Baroque season which flourished in Sicily, a relevant role is to be attributed to religious architecture with its ecclesiastical furnishings which often can be considered as real architecture (Valenti et al., 2018).

Among these, altars represent a high expression of the complexity and conformative dynamism of the tastes of that particular period.

The study develops a methodology of critical investigation based on the exact extrapolation of modular relations in order to confirm the hypotheses about some contacts in the development of these works executed after the catastrophic earthquake which struck south-eastern Sicily in January 1693, completely devastating a large area from Catania to Noto.

The cognitive process was carried out through the equipment available at the Laboratory of Representation of the University of Catania. The research primarily focused on the generation of a detailed 3D model able to produce 2D and 3D representations and on the formal and dimensional information in order to develop geometric reasoning and comparisons in the second phase.

Specifically, the research was conducted on two emblematic altars which are proof of the assimilation of reference models in a cultural area even larger than the local context. Executed around the year 1713, when specific financing was approved, and completed between 1726 and 1740, the two altars placed in the transept of the church of *St. Francesco Borgia* in Catania, directly adjacent to *Collegio dei Gesuiti*, extraordinarily refer to the altars designed in Andrea Pozzo's treatise.

The two altars set against the wall, dedicated to *St. Ignazio* and *St. Francesco Saverio*, are particularly imposing for their monumental characteristics, for the rich display of sculptures and for the symbolic references underlined by the four Solomonic columns (Figure 2). The altars bear material witness to the replica of a known model by Jesuit Father Andrea Pozzo; the altar of Blessed Luigi in the church of *St. Ignazio del Collegio Romano*, drawn in fig. 62 of the famous treatise. Unique examples in Catania of altars with spiral columns in an area such as Val di Noto very rich in festivals and events with different declinations. Priest Francesco Verzì (1916) said that "for the reconstruction of the Church after the earthquake of 1693 the General of the Order sent to Catania a Jesuit Religious Brother, a certain P. Andrea Pozzi from Trento". Forthcoming archival researches are adding new details to the historical events of the Church and its decorations.

On reflection, it is possible to observe that the column materials and colour respect all the indications given by Pozzo: "they are the four old green spiralling columns." In these altars too "in place of a picture, a white marble bas relief is set in its niche", here a high relief in white Carrara marble, work of Catania artist Marino.

No doubt, considering the complexity of the case study, a very tight connection can be established between survey methodologies and geometric-interpretative methodologies.

Figure 2. The Church of *St. Francesco Borgia* in Catania: *St Francesco Saverio* and *St Ignazio* altars

2. ACQUISITION METHODOLOGY

The topic proposed implements innovative technologies to conduct historical and geometric analyses of 3D models of complex architecture, through precision laser scanning survey technology. Survey, indeed, has always been the most appropriate instrument to analyze, know and communicate Cultural Heritage.
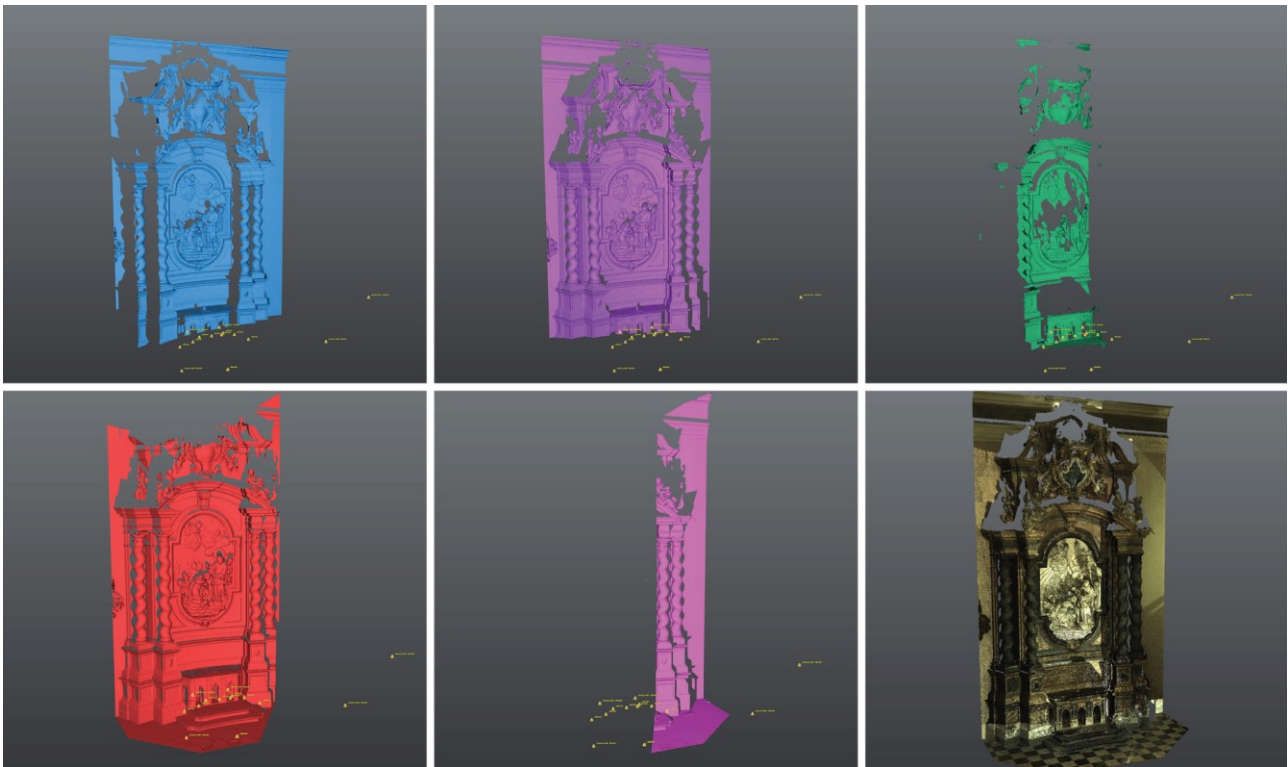
Figure 3. Laser scanning survey

The approach discussed here studies 3D acquisition, modelling and representation methods for the archiving and dissemination of Historical Heritage in the religious fields. In particular, the latest data acquisition systems are able to simplify the generative process of 3D models: technical processes of investigation which integrate with all the other diagnostic non-destructive tests (e.g. laser scanning). The possibility of metric and colorimentric data acquisition through different techniques and their matching using the same system allows the creation of high quality models.

In the specific case, two different methods have been adopted, both able to digitally survey and render the investigated altars: TLS (terrestrial laser scanning) survey and automatic digital photogrammetry.

Leica C 10 ScanStation has been used for instrumental survey. The formal complexity of the examined altars suggested that it was convenient to conduct numerous small area scans (Figure 3). Scenes were then automatically matched in the digital data post-processing phase using appropriately targeted scans during the survey activity. However, being the altars very high, this approach was not reliable enough since the laser scanner is not able to survey the highest parts of the altars which are not visible or hidden by the projecting sculptural decorations. Thus, it was necessary to implement alternative methodologies to fill the gaps. To overcome this inconvenience SfM photogrammetry technique was introduced. It is able to automatically fit the orientation of a very big set of landmarks, and to generate a dense point cloud of the investigated object.

Recently different data and image acquisition systems have been supported by UAV (Unmanned Aerial Vehicles).

In the field of Cultural Heritage these instruments are being increasingly used to integrate the acquired data through Terrestrial Laser Scanning. The possibility of adding a camera to a drone makes it ideal for capturing a wider amount of details, wider than those normally visible in terrestrial scans.

In particular, the integration of UAV with traditional TLS has produced satisfactory results: with the support of UAV an unusual type of photogrammetry has been applied. Photos are shot taking the focal plane parallel to the object of interest which in this specific case develops vertically along the z axis rather than, as traditionally happens in aerial photogrammetry, on the horizontal plane (Figure 4).

The low cost UAS platform used in the present experimentation was a DJI Spark equipped with a 2-axis stabilised gimbal with 1/2.3 inch sensor and a 12MP camera. It can record 1080p 30 fps videos. A fundamental characteristic of the Spark is it can be eased of its wrapping making it weigh only 300 grams and classifying it, according to ENAC regulations, as an inoffensive drone, appropriate for the study.

In the present case, an average of 150 photos per altar was shot keeping the drone at a distance of about 2m from the object and with the focal plan parallel to the façade. At least two flights per altar in manual mode have been made, from a take-off spot placed at a height of about 5-6m from earth, overcoming the drone factory settings of not coming with a GPS module installed, which forces it to stick to a designated area of 5 m from take-off level.

To facilitate operations a point set registration has been prepared on a grid placed on an existing drawing. Considering that the dimensions of the two case studies are similar, it was decided to make a photogram per meter, integrated then with further oblique images acquired by the drone in order to survey the hidden parts and with other photos taken from below with a Nikon D5300.

The data acquired during the survey campaigns have been subsequently processed with specific software. In particular, *3DF Zephyr Aerial* was used for the photo processing and for the management of the point cloud acquired through instrumental survey and generated by *Cyclone* (Figure 5).

The TLS point cloud was considered as the basis for the adaptation of a motion model: the photogrammetric model. After the alignment of two dense point clouds, the processing of polygonal meshes was performed. The obtained continuous model was then texturized so to provide an accurate and realistic final product.

Figure 4. Survey activity with UAS technology

Figure 5. Cloud points and texture using 3DF Zephyr

3. ASSESSEMENT METHODOLOGY

The obtained 3D model is particularly interesting to perform geometric and historical determinations (Figure 6).

Through the implemented data acquisition methodology, it was possible to obtain such a highly precise level of DSM (Digital surface Model) which cannot be influenced by any further activity in shape interpretation and discretization of the represented elements.

It is well known that the mathematical NURBS model, developed from TLS survey data is the result of the education and attitude of the single operator who is always influenced by his/her subjectivity in the final processing.

Therefore, the methodology applied in the validation phase has adopted a historical-geometric approach comparing the surveyed object (the 3D model) with Andrea Pozzo's drawings of the already mentioned Blessed Luigi altar.

The correspondence has been analysed both with the traditional vertical and horizontal representations (on the level of the dining hall) and with the perspective representations.

Through survey integrated with TLS and UAS technology the full high-resolution model, highly detailed and with very few shadow areas has been proportionally scaled to verify the constructive correspondence.

Because of the fragmentary sources (the Jesuit Order had a troubled history in Sicily) the conclusions of this research confirm the hypothesis of the assimilation of the Roman model into the altars of the Church of *St. Francesco Borgia* in Catania. There is evidence of an astonishing superimposition between the two architectural works and Pozzo's drawing to conclude that certainly that model was a reference for their construction (Figure 7).

The perceptible morphological similarity is confirmed by the geometric transposition. The applied graphical analysis has raised awareness and full understanding of Cultural Heritage posing fundamental questions for subsequent determinations.

The methodological process has produced a fruitful dialogue between experimentation of survey methodologies in closed environments, graphical analysis and historical investigation.

4. CONCLUSIONS

The research has established that the combination of different methodologies can be the most appropriate way for 3D data acquisition referred to complex architecture whose dimensions prevent the adoption of a single approach. The Aerial Photo Mode has covered a larger surface of the investigated architectural object than the laser scanning technology.

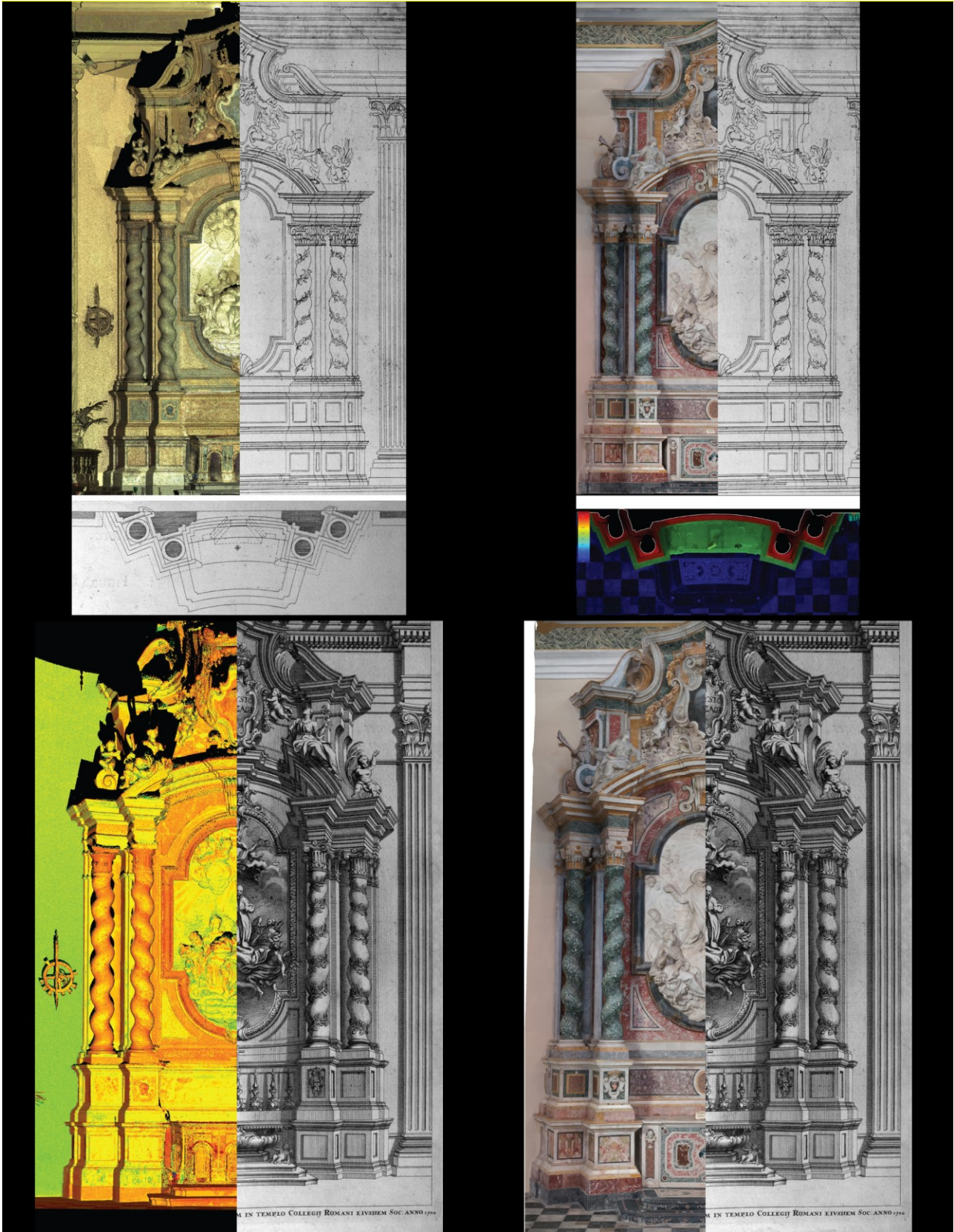Figure 6. The orthoimage from 3D final textured model

Figure 7. 3D model and drawing: 2D and 3D comparison of the altars of the church of *St. Francesco Borgia* in Catania and Andrea Pozzo's drawings of the altar of Blessed Luigi in the church of *St. Ignazio del Collegio Romano*

TLS and UAS technologies provide an accurate and non-invasive method able to acquire highly precise data and to render a high-resolution 3D model. The comparative analysis shows that the results obtained from both technologies are similar and that their combination provides accurate final results from the scientific point of view.

They are models which represent a good starting point to conduct historical and geometric analyses and comparisons with other architectural elements of the same value.

The instruments used in the survey campaigns, notably UAS, being designed for purposes not specifically connected with the present research, would require a deeper exchange of information between designers and commissioners.

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