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Gjergji ISLAMI, Denada VEIZAJ (Eds.)

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Gjergji Islami, Denada Veizaj
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Study and representation of the bastion of San Maurizio in Turin: an educational experience

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Abstract

This paper presents the activity carried out as part of the Ph.D. program in Architectural and Landscape Heritage at the Politecnico di Torino entitled "An Integral Approach to the Study of Fortifications". A survey was conducted on a still-existing seventeenth-century portion of the fortifications of the city. The course included the organization of a survey campaign that integrated TLS and photogrammetric techniques, an interesting field of application concerning the operational difficulties derived from the steep terrain and the important vegetation presence, which guided the choices and programming of the work. The interpretation and analysis phases led to digital representations at different scales, including some focus on the wall face apparatus, mapping of degradations, and identification of the mean plane of masonry and its deviations.

Keywords: TLS survey, SfM survey, integration of techniques, representation.

1. Introduction

This paper (1) presents the activity carried out as part of the Ph.D. program in Architectural and Landscape Heritage at the Politecnico di Torino entitled "An Integral Approach to the Study of Fortifications". On the occasion of this third-level course, a survey was conducted of a portion of the curtain wall of the bastion of San Maurizio, a still-existing seventeenth-century portion of the fortifications of the city of Turin, which corresponds to the last platform of the defensive front that protected the eastern expansion area to the north. The portion of interest consists of a straight section of masonry about 90 meters long supporting the gardens of the Cavallerizza Reale.

The Ph.D. course included the organization of a survey campaign of the object of the study conducted by the Lower Royal Gardens, which integrated TLS and photogrammetric techniques to obtain data necessary for the representation of the surface of the curtain wall as well as, through the use of telescopic rod, the summit portion of the masonry: this phase was an interesting field of application concerning the operational difficulties derived from the steep terrain and the important vegetation presence, which guided the choices and programming of the work. The students, divided into groups, oversaw the SfM survey of portions of the wall: in the subsequent stages of the work of analysis and restitution they were able to compare and integrate them with data derived from the TLS survey conducted by the teaching team.

The interpretation and analysis phases of the acquired data led, following a process on the verification of data reliability, to uninterpreted graphical returns (such as orthophotos) and digital representations (Canciani et al., 2016) at different scales, including a focus on the wall face apparatus, mapping of degradations, identification of the mean plane of masonry and its deviations (Tapinaki et al., 2019).

2. TLS survey

The TLS survey campaign was a fundamental step, allowing a fully detailed version of all the fronts (Mateus et al., 2019), getting details in any sector that was reachable from the front of the walls. The resulting point cloud was a complete documentation of all the geometries and architectural features of the fortification, and also a fundamental reference in terms of dimensions, allowing us to apply the right measures and to check the ratio to the following photogrammetric operations. The operations were all done from the ground, moving along the meadow in front of the walls.

The 3D laser scanner in use was a Leica RTC, characterized by high-speed scanning time, high accuracy, and good integrated photographic functions. The accuracy of 1.9 millimeters at ten meters of distance, the scanning range of up to 130 meters, and the integrated GPS function make this scanner excellent for automatically aligning medium to generous datasets even without specific targets.

All the scans were taken in high resolution with a grid of six millimeters at a distance of 10 meters. All the scans were taken using the HDR photographic function, to produce a colorized version of the walls with a full description of the chromatic features of the gathered points. This last aspect is worth underlining how the photographic feature tends to reduce the apparent quality of the scan. At the same time, the resolution of the cameras integrated into the scanner unit, even if high (36 megapixels for each of the three cameras, producing 432-megapixel full panoramic images), results in pixels that cover more than one single point if not a very close distance, while the reflectance value, expressly gathered for each point is capable to give back a specific greyscale value and the distance and the density of the point cloud.

In this way the resulting point cloud, even if colorful and more pleasant to the view will appear coarser as much as its points are far from the scanning position. This lack in the result is partially compensated by the use of multiple scans and the overall result turns out to be better suitable for multimedia uses and appreciable in distinguishing the different parts of the architecture, leaving the option for greyscale visualization to the occasion where a more detailed graphical representation is truly needed. The sequence of scan stations was organized in 12 total positions, covering the whole front from the exterior and capturing all the elements from the surrounding area with plenty of details about the shape of the terrain and the urban furniture elements. In the selection of the scan stations, specific attention was given to the possible creation of occlusion spaces, so the scanner was placed in a way to capture for the best all the interstices and intersections from the masonry and details in the bastion. The Leica RTC360 scanner archives all the gathered datasets in a specific format directly compliant with Leica Geosystem Cyclone. While the format is strictly proprietary and not shareable with a large set of users, the first passage was the complete exporting into a shareable format, in this case in E57 files, easily compliant with various software, capable of keeping the original features of the dataset unaltered and also giving good options for preserving data from obsolescence even in the long run.

The resulting exported point clouds were aligned using Autodesk Recap applying automatic processing. The whole operation turned out in a strong and effortless path, with the whole set of scans being aligned in fully automatic mode and with no need for manual interventions. The sequence was the most classic: import, automatic alignment, and indexing. The aligned resulting cloud was then used for extracting sections, views, and direct measurements for investigating the shape of the bastion and for supporting the following photogrammetry operations.

3. Photogrammetric survey

The Bastion of San Maurizio in Turin is a suitable case study from an educational point of view. The curtain wall extends for a linear length of 100 meters for a height varying from 50 cm up to 8 meters. The area in front of the rampart is accessible, with an elevation change of 6.5 meters, allowing a working distance of 20 meters. There are several obstacles, such as plants, hedges, benches, and children's public games placed 10-12 meters from the wall (Fig. 1).

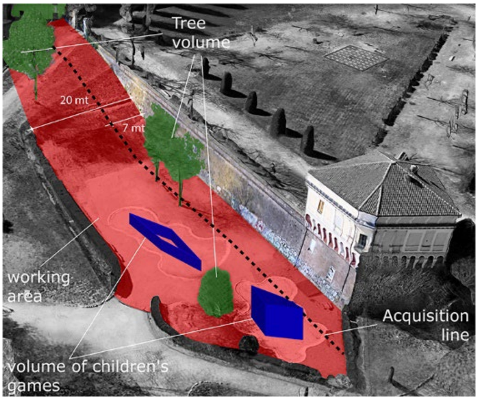

Fig. 1- General acquisition schema (Elaboration: M. Russo)

The overall size, the linear development, and the boundary conditions support the understanding of the photogrammetric process, its limitations, and its capacities (Russo, 2021). The textural characterization of the curtain wall ensures reliable recognizability of homologous points between pairs of frames, avoiding problems of orientation between images or the definition of dense point clouds (Gaiani et al., 2016).

The plan of the photogrammetric survey considered all these aspects. The acquisition distance has been evaluated regardless of the type of camera used, identifying the distance of 7 meters as an ideal acquisition line (Fig. 1). Such a line maximizes the distance of the wall curtain, bringing back all the elements present in the work area that may limit or afflict the quality of the acquisition (Russo et al., 2018). It was decided to use three different cameras, listed below (Table 1) with the main characteristics and acquisition set-ups, to emphasize the didactic approach.

Table 1- Main data of cameras (M. Russo)

DSC-HX60 (Sony)	**GFX 505 (Fujifilm)**	**A7R Mark IVa (Sony)**
5184x3456 px	8256x6192 px	9504 x 6336 px
6.03x4.62 mm	43.8x32.9mm	35.7×23.8 mm
f/8		
1/200 sec	1/450 sec	1/400 sec
ISO 200		
F. D. 4 mm	F. D. 23 mm	F. D. 28 mm

Using different cameras allowed for comparing the performance of the individual cameras on the one hand and evaluating the GSD, image brightness, data processing time, and noise of the acquired data on the other.

The constraint of a close working distance has been required using a telescopic rod in the acquisition phase (Fig. 2). Four shots have been caught for each footprint position. The horizontal and vertical baseline was calculated to preserve the 1/4 ratio between acquisition distance and baseline to guarantee a 50-60% overlap between the frames. This corresponded to a horizontal and vertical movement of approximately 1.7 meters, acquiring a total of 204 images to cover the entire area. This number includes both the images with nadiral and sloped axes to stiffen the photogrammetric system.

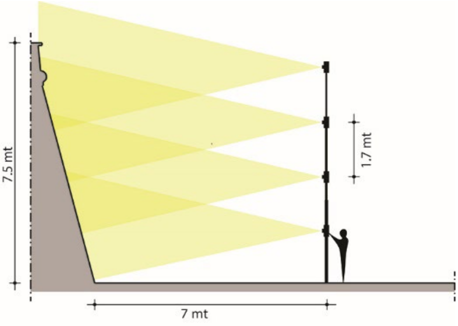

Fig. 2- Vertical acquisition schema (Elaboration: M.Russo)

The use of the telescopic rod allowed us to define horizontal stripes for each height at the beginning of the stripe. This constraint, however, caused some problems in the 6-meter altitude variation of the terrain facing the wall. This latter obliged us to evaluate the camera positions after calculating the altitude to the base plane. The different photogrammetric blocks were oriented within the Metashape software, building the sparse, dense clouds and texturized polygonal models of the curtain wall, with a variable density depending on the image resolution. It finally allowed us to obtain orthoimages of the masonry (Fig. 3) with a GSD varying from 0.2 to 0.4 mm concerning the camera, allowing a complete reading of the palimpsest and its conservative conditions (Wu et al., 2023). The different outputs allowed a comparative evaluation both in terms of process and instruments (Vrettou & Georgopoulos, 2016).

Fig. 3- Orthoimage of the whole wall (Elaboration: M. Russo)

4. Integration of the survey techniques

In the present day, the surveying of buildings and archaeological complex sites is often in need of different methodologies to achieve complete and exact results. That's how, more and more, it takes the integration of different techniques. For many years direct surveys and topographic field support were increasingly integrating, making up what might be called a first integrated survey. Nowadays, digital multi-image photogrammetry or SfM (Structure from Motion) with the 3D laser scanner (TLS) is undoubtedly the most precise and complete method that we may find. Furthermore, the advances that have taken place during the last decade, provided the required maturity for them to be used without significant difficulties. These advancements are evident in both the software, far more complete, exportable, and user-friendly, as well as in the hardware with more powerful computers, lightweight, fast, and precise scanners, and high-quality digital cameras that can be carried anyway thanks to drones; all of this unimaginable not so long ago (Pérez-García et al., 2023).

The integration of these two survey methods, SfM and TLS, can be performed with different aims. On the one hand, it is possible to carry out partial surveys choosing the ideal method in each part, to integrate later in a unique survey. This would be the typical case of an exterior survey through photogrammetry and an interior one, in a narrower and more complex space, with the laser scanner. It is often also used drone photogrammetry to take the upper parts not captured by TLS.

In our case, as it wasn't possible to use the drone for a survey of the upper parts, the surveyed area with the two methods was the same. Nevertheless, it's also possible to use the integration of the techniques as an accuracy control tool for our survey. Thus, we are aware of the errors of our TLS survey as it is possible to obtain from the scanner's specs, as far as from the report of the registration software. Regarding the photogrammetric survey, ten natural points present on the masonry (GCPs) were selected for scaling and orienting the point cloud in the range-based reference system, extracting the coordinates 3D range point cloud.

The horizontal sections extracted from the photogrammetric models were demonstrated to preserve the masonry linearity, due to the high accuracy in the frame's orientation. Besides, we used the software CloudCompare to assess the error of our SfM surveying the space. First of all, we exported the dense cloud in .e57 format from the survey performed in Metashape. Likewise, once it was registered the laser scanner's clouds, the result was exported as a unique cloud in the same e.57 format. Both clouds were imported in CloudCompare to begin the scaling and aligning process of the photogrammetric cloud on the TLS one. After having manually roto-translated the first, through the 'Align - point pair picking' tool it was aligned and scaled choosing a set of homologous points between the two clouds. Right after, to make more precise this first alignment, it was performed a cloud-to-cloud registration using the 'Fine registration-ICP' tool that, through an iterative process (Iterative Closest Point) allowed obtain an optimal overlap.

It then proceeds to the deviation computation between the two clouds using the 'Cloud/Cloud dist.' tool, which estimates the distance values and creates at the same time a scalar field to be chromatically mapped. It is so obtained a point cloud whose colors will be a function of the estimated distance, and in this specific case, it can be appreciated a distribution of values ranging from a minimum of 0,05 mm and a maximum of 15 cm (Fig. 4-5).

In the comparison between the image to range dense cloud, the peak deviation values refer to specific parts of the masonry. This problem is probably due to errors in camera orientations, linked to the GCPs choice. So, we decided to increase the number of GCPs to avoid the distortion effect.

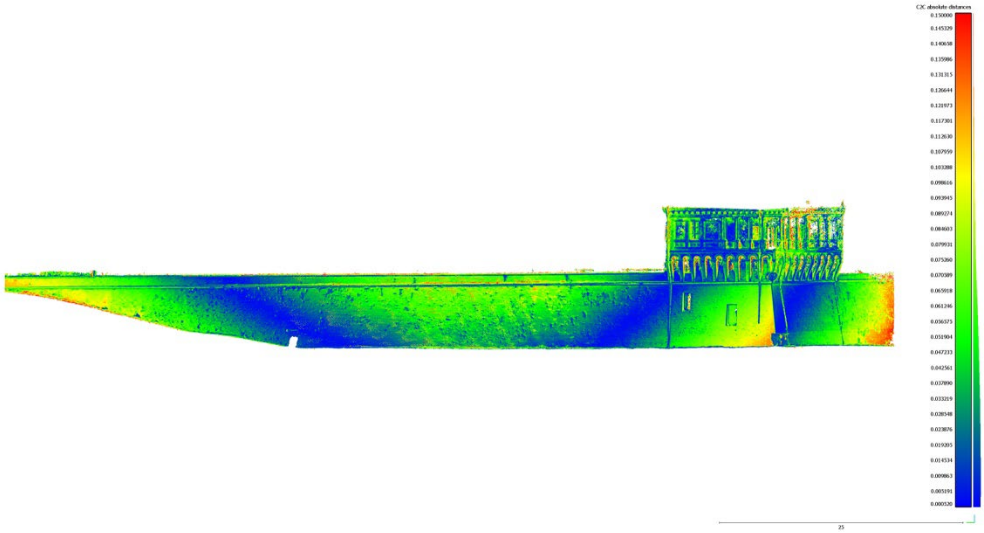

Fig. 4- Photogrammetric cloud mapped with deviation values, orthographic view (Elaboration: P. Rodríguez-Navarro).

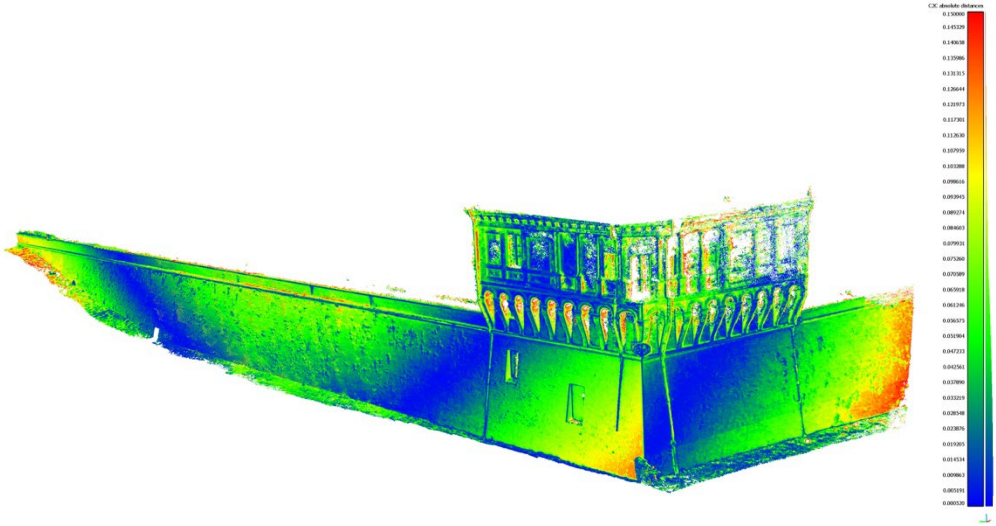

Fig. 5- Photogrammetric cloud mapped with deviation values, perspective view (Elaboration: P. Rodríguez-Navarro).

5. Analysis and graphical restitution

As part of the didactic experience centered on the Bastione San Maurizio area, each of the students participating in a multidisciplinary Ph.D. course (2) contributed insights based on their prior knowledge and personal interests. These contributions were a valuable complement to the thematic introductions provided during the course.

Fig. 6- Detailed elevation view of the study area: mesh from photogrammetric point cloud, laser scanner point cloud, vector drawing (Elaboration: G. Malavasi, F. Natta)

The raw data generated during the survey phases with LiDAR and SfM technologies offered each student, placed in working groups, the opportunity to create point clouds and three-dimensional mesh models with textures of a specific portion of the study area. The first stages of common work involved the extraction of reference coordinates from targets positioned directly in the point cloud acquired by laser scanner, processed using Autodesk Recap Pro software. These recorded data are of fundamental importance for the subsequent development of the photogrammetric project.

The subsequent stages of case study and restitution led to the translation of the acquired raw data into detailed and sectorial comprehensible elaborations, obtained through the use of various specialized software (Fig. 6).

The most common practices were:

- Redrawing: this well-established documentation phase is carried out to return the state of the art by two-dimensional elaborations through representations at different scales and in different views of the architectural object (Bertocci, Bini, 2012). Starting from the easy interchange of information between the Autodesk software, the point cloud obtained from the laser scanner and processed in Recap Pro is exported (or linked) within AutoCAD, where the vector elaborations required for the specific analysis are carried out (Fig. 7).

- Modelling: Using the acquired information, detailed 3D models of the surveyed subjects are created and categorized to represent terrain, buildings, objects, or any other elements of interest. These models were constructed and managed from the raw survey data and/or two-dimensional reworkings within the Rhinoceros software for processing efficiency even with models with a high amount of points/mesh.

- Survey data analysis: the processed data obtained from the surveys with LiDAR and SfM technologies were compared with each other and re-processed within the photogrammetric process to analyze the point cloud data obtained from cameras with different sensors. This study, by classifying the different processed data, makes it possible to assess the reliability and trustworthiness of the raw data either within the same software with which the point cloud is created (Agisoft Metashape) or with external applications (CloudCompare).

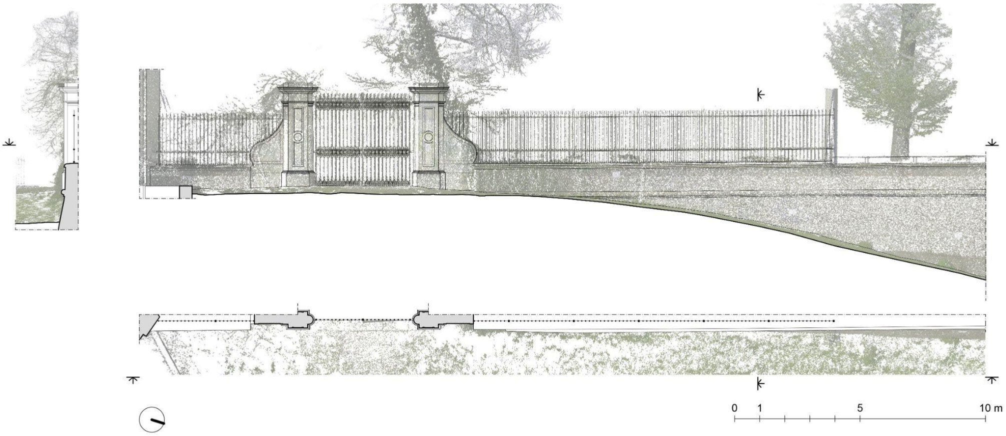

Fig. 7- Orthogonal projection drawings of a portion of the study area. Superimposition between vector drawing made in AutoCAD and laser scanner point cloud (Elaboration: G. Malavasi, F. Natta)

- Degradation analysis: mapping of the main degradation pathologies readable on the portion of the wall face examined by superimposing the various architectural, biological, and anthropic elements found in two-dimensional drawings.

This multidisciplinary approach allowed students to apply their skills and interests within a practical context, contributing significantly to the analysis and three-dimensional representation of the study area. Furthermore, it promoted effective collaboration between participants, fostering the exchange of knowledge and ideas in a stimulating learning context.

6. Conclusion

The activities presented above demonstrate how the attention of the discipline of representation, declined according to the phases of analysis, interpretation, and communication has profitably integrated within a multidisciplinary doctoral curriculum dedicated to architectural and landscape heritage. The topic selected for application was particularly suited to the exploration of the analytical potential of digital survey through the technologies of terrestrial laser scanning and photogrammetry, and activated interpretive practices through the integration of these techniques and the production of 3D models and drawings that constituted the communicative aspect of the work.

Finally, the training of the students, linked to the different disciplines that compete in the doctoral program, enabled them to decline their respective attention to heritage, leading the outcomes of the course to particularly satisfactory and varied results.

Notes

(1) While the research is the result of the collaboration between the authors, paragraphs 1 was written by M. Vitali, paragraph 2 by G. Verdiani, paragraph 3 by M. Russo, paragraph 4 by P. Rodríguez-Navarro, paragraph 5 by F. Natta and paragraph 6 by R. Spallone.

(2) The Board includes lecturers from the disciplines of Restoration, History of Architecture, Representation, Architectural Composition, Geomatics, Building Technology and Technical Physics.

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