

High-resolution 3D surveying in support of Cultural Heritage

Francolini Chiara¹, Gabriele Bitelli¹, Beatrice Borghi², Filippo Galletti²

¹ *Department of Civil, Chemical, Environmental and Materials Engineering (DICAM) - University of Bologna, viale Risorgimento 2, 40136 Bologna, Italy*

² *Dept. of Education Studies "Giovanni Maria Bertin" (EDU) - University of Bologna, via Filippo Re 6, 40126 Bologna, Italy*

Abstract – The paper shows, on an interesting study case, an application of the surveying technologies belonging to Geomatics and investigates the advantages provided by them to the Cultural Heritage field. The technologies analysed here are the digital photogrammetry and the 3D scanning, as they represent two very versatile and accurate solution in this field. Moreover, are presented the potentialities of the digital models obtained as they are suitable for both geometric and historic analysis of an object.

Keywords – Geomatics, 3D modelling, Cultural Heritage, historic analysis

I. INTRODUCTION

The Italian national territory owns an enormous patrimony in the field of Cultural Heritage that deserves to be properly preserved and valorised.

An important requirement for the valorisation of the Cultural Heritage is its knowledge, both in historic-artistic terms and in geometrical-positional one, and Geomatics, nowadays, can meet these needs: the recently developed technologies, in fact, are particularly effective in the surveying phase and in terms of the data representation for objects of architectural, artistic and archaeological interest [1]. They allow creating geometrically rigorous three-dimensional models, which are characterized by a high degree of accuracy, are manageable and searchable over time, and can be progressively integrated with new data [2].

For the mentioned reasons, the fields related to Cultural Heritage and the Geomatics area are particularly suitable for the development of applications with a strong interdisciplinary connotation [3]. The work described in this paper refers to the contribution of geomatic engineering to the medievalist historical research; in this context, the geomatic survey is considered not only as a form of documentation and support for restoration but also as a tool for historical research and interpretation of the sources.

The study case is a stone-made basin, also called "Pilate's basin, located in the "Jerusalem" of Bologna, Santo Stefano Basilica [4].

The Pilate's Basin is a rare artifice which testimonies the Longobard presence in Bologna: originally located in the Church of San Giovanni Battista, it was intended to collect donations from the people to the Church, and the inscription on the upper edge of the basin testifies that the period when the basin was used for this function was that in which Liutprando (736-743) and Ildebrando (744) ruled Bologna.

Pilate's basin has come down to us at the present time not without alterations and some tampering. The basin has been recently restored (2017) but, until that moment, its state of conservation was rather precarious. The reason for that resides in the fact that it has been exposed over the centuries to the atmospheric pollution, which has accelerated the physical mechanical decay of its glazing patina. Due to exposure to the atmospheric agents, the superficial stone layer has been subjected to severe damages, which has led to the decision to restore it. The restoration has acted on the numerous drip dark marks on the outside surface, on the patina covering its foot and the inside part of the basin (Figure 1).

In addition, the basin is the subject of numerous debates concerning the interpretation of the inscription reported along the upper perimeter of the basin itself. The reading of the acronym IHB is uncertain and is strictly related to the interpretation of its last character. Before 1800 it was variously interpreted as *Johanni Baptiste* (IHB), *in honorem loci* (IHL), *in honorem loci religiosi* (IHLR), *inhabitants* (IHB), and *Iherusalem* (IHER); but, during the nineteenth century, another interpretation was hypothesized by the scholar Gallinetti, that read the acronym as *in homorem (ecclesiae) pro luminaribus* (IHPL).

The present work focuses on the application of two advanced surveying methodologies for the survey of the Pilate's basin. Among the numerous methods provided by modern Geomatics, digital photogrammetry and 3D

scanning are the two selected for this experimentation. Both, in fact, ensure an objective and accurate survey and provide geometrically rigorous final models in digital format. Moreover, the instrumentation is, in both cases, contactless and user-friendly, thus permitting a rapid and simple acquisition process.

The two geomatic techniques were used to build the digital models of the whole basin. Subsequently, the high precision 3D scanning survey of the inscription was performed in order to reconstruct a more accurate 3D model of it, which is able to be used to conduct more detailed analyses on the debated acronym, thus constituting a concrete support for its interpretation.

II. PHOTGRAMMETRIC SURVEY

Digital photogrammetry is nowadays widely used in Cultural Heritage field and takes advantage of the camera affordability and of the rapid surveying phase. Especially in the Cultural Heritage field, photogrammetry relies on the Structure from Motion (SfM) Multi-View approach, that allows to directly estimate both internal and external orientation parameters and to reconstruct automatically the 3D scene by the identification of homologous points in two or more photos representing the same scene by different points of view (Figure 1).

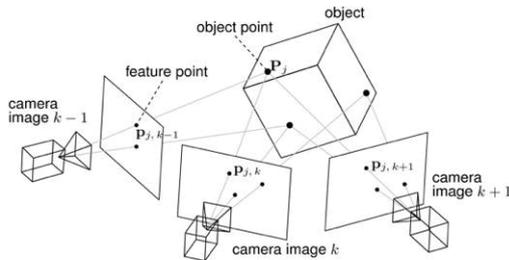


Figure 1. *Structure from Motion approach: the same camera takes pictures of the object from several positions around it.*

For this experimentation, the photogrammetric survey was done using a full frame DSLR camera (Canon EOS 6D equipped with a wide angle lens) and the software used for the 3D model reconstruction is Agisoft Metashape Pro.

Two surveys were performed, the first one before the last restoration in 2017 and the second one after it. They are aimed at giving a global three-dimensional representation of the basin, pedestal included. Since the basin is located outside, in the Pilate's courtyard, both surveys have been done without any artificial light source but taking advantage of the natural illumination. Coded targets were used, and the model was scaled using the measured distances between couples of them.

Table 1 shows some numerical data characterizing the photogrammetric reconstruction with Agisoft Metashape.

	N° photos	Sparse cloud n° points	Dense cloud points	n° Final mesh resolution
Before restoration model	63	13.757	4.682.996	3,5 mm
After restoration model	175	80.052	49.158.813	1,5 mm

Table 1. *Photogrammetric model characteristics (processing done with Agisoft Metashape).*

As a result, two 3D models are now available of the basin: they are digital entities that have the real dimensions, contains radiometric information, can be fully explored with dedicated software, and digitally analysed. One of the main advantages provided by these two surveys is the possibility to conduct comparison analysis of the object before and after the restoration (Figure 2).



Figure 2. *3D models of the Pilate's basin before (left) and after (right) the restoration.*

III. HIGH PRECISION SURVEY

The survey of the circular strip containing the inscription was conducted using both the 3D scanning technology and the close-range photogrammetry: the objective is to carry out a high-precision survey of the inscription in order to reconstruct a 3D model of it as faithful as possible.

The structured light projection scanners used are MHT and Spider, both from Artec3D (Figure 3). They are portable devices capable to reconstruct the shape of the objects of interests taking advantage of the classical triangulation principle. They basically use a 3D camera to capture video, whose single frame is a three-dimensional image. During the survey, the operator continuously walks around the object, while the dedicated software automatically combines the frames to reconstruct a single mesh.

Table 2 shows the specifications of MHT and Spider 3D scanners.



Figure 3. 3D scanners MHT (left) and Spider (right), from Artec3D.

	3D resolution	Accuracy	Working distance	Data acquisition speed
MHT	0,5 mm	0,1 mm	0,4-1 m	500.000 pt/s
Spider	0,1 mm	0,05 mm	0,2-0,3 m	1 mln pt/s

Table 2. Specifications of 3D scanners MHT and Spider.

In general, a 3D structured light projection scanner can be considered as a slit triangulation scanner where slits, instead of moving horizontally until covering the whole object, are all projected at the same time; for this reason, the set of slit can be seen as a pattern. So, the technique is based on projecting the light pattern on the object and viewing the illuminated scene from one or more points of view.

Since the pattern is coded, the correspondences between image points of the projected pattern can be easily found. The decoded points can be triangulated and 3D information is obtained. Figure 4 shows the working principle of a structured-light scanner.

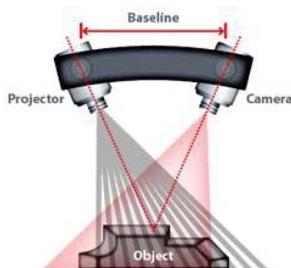


Figure 4. Structured-light 3D scanner scanning principle.

As Table 2 shows, the two instruments have different characteristics that influence the scale of the survey. MTH scanner can scan the object from a higher distance (up to one meter) with a wider field of view with respect to the Spider (whose working distance is less than half a meter). In addition, the latter can reach an accuracy of 0,05 mm which in fact is twice as high as that achievable by MHT. For this reason, in this work the MHT scanner was used on the whole basin and Spider scanner on the only inscription. Considering the close-range photogrammetric survey, it was conducted with the same instrumentation previously

described.

The survey was conducted on a small part of the inscription, considered as a test part; the 3D model of this reduced portion of the inscription was compared with the one created through the 3D scanning; The aim is to build a high-detailed 3D model of the inscription capable of penetrating as deeply as possible into the incisions; for this reason, the comparison is fundamental in order to understand which technique is the best one in term of accuracy.

The comparison is shown in the next paragraph.

IV. GEOMETRICAL ANALYSIS OF THE MODELS

Firstly, the 3D model of the whole basin is analysed. Considering the mesh modelled by the MHT scanner and the photogrammetric reconstruction, it can be noticed that, in terms of detail and accuracy, the first one results better than the second. Table 2 reports the number of vertices and faces of the models.

	Vertices	Resolution
MHT Scanning	7.728.506	0,5 mm
Photogrammetry	2.606.755	1 mm

The models are rigorous and scaled entities, through which is possible to perform geometric analysis. An interesting applications is for instance the calculation of the internal volume of the basin and its fitting sphere (Figure 4).



Figure 4. Internal volume of the basin and its fitting sphere.

	Radius	Volume
Basin	0,55 m	0,249 m ³
Fitting sphere	0,57 m	0,749 m ³

Table 2. Radius and volume of the basin and its fitting sphere.

The 3D models obtained from the close-range photogrammetry and the Spider 3D scanning were compared on:

- the resolution of the meshes;
- the distance between them (Figure 5).

The first phase consisted in aligning the two 3D models: this step was done taking advantage of Geomagic Design X software, through which different type of data can be managed and analysed together.

A first rough alignment was done manually, using the local based alignment on picked points of the 3D models. Then the data were accurately aligned with a method which is based on geometric feature information with the lowest possible amount of deviation in overlapping areas.

Once put the model in the same reference system, the analysis begins with the extraction of a longitudinal section profile obtained from the intersection of the model with a horizontal plane (Figure 5).

The measurement of the distance between the models in correspondence to the incisions follows. In figure 5 it is represented the highest distance achieved in the whole area considered.

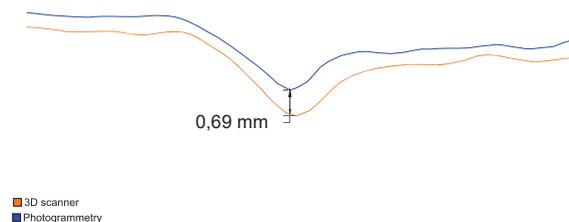


Figure 5. Polylines representing the longitudinal section profile of a part of the inscription; the distance is in mm.

From the analysis came up that 3D scanner is more capable of penetrating the incisions than the close-range photogrammetry; the 3D scanner profile is at most 0,69 mm from the photogrammetric one.

For this reason, the model obtained with 3D scanning technique has been used for the survey of the inscription. The final 3D model is characterized by a resolution of 0,1 mm and it is composed by 16.349.694 vertices (figure 6).



Figure 6. 3D model of the inscription

II. HISTORICAL ANALYSIS

As it is a high detailed reproduction of the inscription, the digital model has also been useful for carrying out the analysis of the engraved text and in particular of one character. The letter which is object of debate is the B belonging to the acronym HIB: contrary to what Gallinetti and previous scholars believe, in our opinion it should be read as HIR, acronym of Iherusalem. [5] If this interpretation was correct, the meaning of the whole inscription would change, inducing us to look at the connection of the Pilate's basin with the symbolism of Jerusalem on the monumental complex of Santo Stefano which is dated back later than the original Longobard artifice.

The study is performed taking advantage of the high degree of detail of the model; the first phase of the approach adopted consists in the enhancement of the incisions: it was possible by the unrolling of the circular strip containing the inscription and by the application of digital algorithms and artificial lights [6][7].

Secondly, a depth analysis of the engraved letter has been performed: it consisted in digitally reconstructing a plane tangential to the letter B and then generating parallel planes with an offset of 0,5 mm in depth (Figure 7).

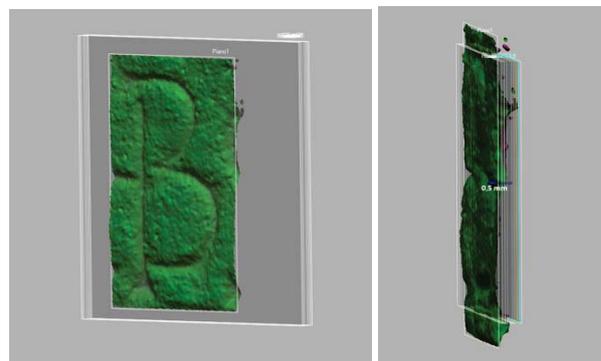


Figure 7. Tangential planes with an offset of 0,5 mm

Subsequently, the section profiles were extracted and compared to the ones extracted (using the same procedure) from a generic letter R and a generic letter B taken from

the inscription. From the analysis came up that at 1,5 mm of depth, can be noticed a discontinuity on the bottom part of the letter B, that could indicate an adjustment (yellow arc) to a pre-existing letter R, then turned in a B (Figure 8). Further analyses will be performed to confirm this hypothesis.

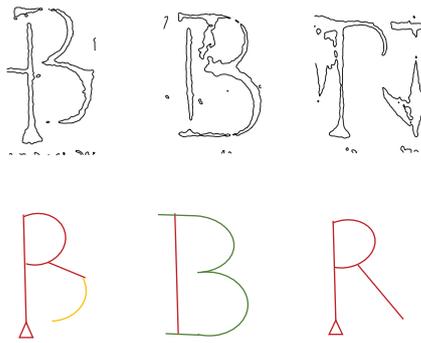


Figure 8. Depth analysis at 1,5 mm of depth; from left to right: B belonging to the acronym IHB, a generic B and a generic R. The yellow arc represents the adjustment which could have turned the R into the B.

V. CONCLUSIONS

The results obtained show that advanced surveying methodologies provided by Geomatics give a concrete support to the Cultural Heritage filed, in particular when high-resolution survey is necessary. There are various technologies available and each of them is appropriate for surveying on different scales and solve different types of issues. The digital photogrammetry and the 3D scanning are considered as two advanced surveying techniques, versatile and rapid. The 3D entities generated are high-detailed models representing with an elevated degree of accuracy the object and can be used to perform geometric and historic analysis of the Cultural Heritage, or to support other multidisciplinary studies, for example in conservation or restoration.

In this work, they allowed on the one hand to reproduce entirely and faithfully an object of historical importance, and, on the other hand, to analyse it in a rigorous way,

inserting new elements into the context of a long historical debate about the object itself.

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