

Roman fragmentary painting: surveying technologies and methodological approaches.

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Abstract – Fragmentary painting, starting from recent years, after being treated for long time exclusively from a stylistic point of view, has entered into the broader material culture’s theme. In this new perspective, this material has assumed a growing dignity as a source of architectural, structural, social and economic information, opening up new perspectives that are currently being adopted also in Italy. For fragments filing there are some well-established protocols, however less attention has been devoted to discuss detection methods and graphic documentation standards for this class of material. This paper, albeit with a limited number of cases compared to what would require the vast topic, proposes, through the analysis of three groups of material, to illustrate and compare relevant techniques and methodologies, including photogrammetry, laser scanning and microscopic photogrammetry, in order to identify good practices and solicit a hoped for broader discussion.

I. INTRODUCTION

A study of fragmentary painting going beyond the essentially historical-artistic approach, presents two thematic points to consider: that related to the analysis of materials (support and pigments), and that deriving from the circumstances and conditions of discovery. If very often, recently, archaeometric investigations for materials have been used, so much so as to be able to consider consolidated the type of intervention [1, 2, 3], not so much can be said for what concerns surveying technologies and graphic restitution. Although numerous cases of indirect relief techniques have been applied [4] it is not possible to trace in bibliography a unitary and organic attempt to systematically deal with both the case related documentation procedures and the documentation to be returned.

This contribution, in order to illustrate procedures as specific as possible, proposes the analysis of three cases, aimed at discussing methods of intervention, acquisition procedures, informational and reconstructive potential of discussed technologies for this material class. Aware of the necessarily preliminary aspect of this paper, which would undoubtedly require the analysis of a larger number

o scenarios, we hope that the stimulus to a more articulated critical discussion may evolve from this first step.

II. STATUS QUAECTIONIS

The study of fragmentary painting is a relatively recent research field, born during the 70s in France with the creation of CEPMR (Center d’Étude des Peintures Murales Romaines) in Soissons. The team working at the Center, under the guidance of A. Barbet, has since devoted itself to the formalization of a new discipline for those times completely unknown and revolutionary as it went beyond the traditional stylistic approach reserved to painting, and in this case to the ancient one, to observe instead the fragment as product of material culture [5]. In this new perspective, the fragment assumed its dignity as source of numerous architectural, structural, social and economic information, opening up new perspectives that are recently being adopted also in Italy and other countries [6]. From this point of view new requirements related to the cataloging and documentation of this material class emerged, still a subject of discussion, in an attempt to standardize language and methodologies. For the cataloging activities some databases are now available, (TECT for example [7, 8]) whose use is now frequent and tested. Less attention has been devoted in recent times discussing survey methods and graphic documentation standards for fragmentary painting. If the fundamental steps in the documentary approach to the subject remain the same as those expressed in the "intervention protocol" formalized during these forty years [9, 10] the contribution of new technologies can’t certainly be ignored.

III. AIMS

The study of fragmentary painting has some documentation requirements that are partly shared with those of paintings *in situ*, while other needs and possibilities are quite peculiar.

The documentation techniques vary, first of all, depending on discovery condition. Primary deposition, represented for instance by collapses found *in situ*, imposes, more than the other cases, a rigid documentation protocol during the

excavation. The documentation of laying conditions turns out sometimes to be indispensable for understanding decorative schemes. In this case, the integration of manual surveying techniques with indirect ones guarantees, together with speed, a considerable accuracy. With this assumption we are not saying that photogrammetric and laser scanner surveying should replace direct contact with fragments, but rather standing alongside it, as only a deep knowledge of the materials and a “mental acquisition” of motifs and technical details allows to better read and intuit decorative patterns. If manual “by - contact” drafting can offer some advantages [11, 12], and mainly that of obliging the designer to observe the fragment in detail and provide already in this phase an interpretation of ornamental elements or figurative scenes, photogrammetric survey, in addition to greatly speeding up work, especially in emergency situations and logistic difficulties, it provides a more objective documentation that can be reinterpreted during reconstruction phases. The realization of successive orthophotos accompanying the micro - dig allows, in situations of this kind, to be able to reconstruct also the collapse phases and modalities, relocating more likely the fragments in the original position. Such situations provide, on closer inspection, valuable information also in relation to the architectural structure, obtaining data that would otherwise be lost.

A different approach to documentation can be formulated for materials in a non-primary deposition or for the ones stored in warehouses, which having lost the original reciprocal connection and that with the architectural space, present greater difficulties in relation to the reconstructive possibilities of decoration. For this second type of intervention, frequently resulting in accumulations in which fragments from different structures can be mixed, sometimes with similar decorative patterns, the surveying operations will take place mainly in the laboratory and will be centered around the attempt to recover every little useful data for the subdivision of the fragments into homogeneous groups and (when possible) their repositioning within the decorative scheme. In this perspective, having mobile material available makes it possible to more easily investigate surfaces, backs and layers of pigment in search of meaningful data for understanding specific technical and executive aspects.

From a technical point of view it is possible to distinguish the acquisition methods to be used for the documentation of the decorated surfaces from the one reserved for the sections and the traces on the back of the fragments.

A. Surface

For the documentation of the surface, data of particular interest are the ones related to the detection of the color's overlap and the composition of some of them (in particular those derived from the mixing of more pigments), as well as the preparatory layout (often hidden under the layers of pigment and therefore not visible to the naked eye), which

can be indicators of specific executive modalities and therefore help in the recognition of groups of homogeneous fragments. Where possible, even the detection of traces relating to the polishing of the pictorial surface and to the direction of the brushstroke can provide, as is known, useful indications regarding the repositioning of the fragments. In order to evaluate the best procedures for surface survey, various detection techniques will be compared.

B. *Tectorium's structure and thickness*

Differences and affinities between the structure and the composition of the mortars are often a fundamental element in the reconstruction of a decorative scheme. This detail, together with the mineral-petrographic composition of the mortars and the sequence of layers that make up the *tectorium*, is another useful, though not exhaustive, aspect in the division of decorative groups of homogeneous fragments, especially when they belong to a unitary chronological horizon [13]. A useful aspect to evaluate is therefore the detection of the overall thickness of the plaster, whose visualization can help in the correct positioning of the decorative elements. In the case of wall paintings, for example, it frequently happens that the portion relative to the plinth is thicker as well as of a coarser composition, while the plaster of the upper register is thinner and lighter. Likewise, in the case of vaults and flat ceilings, fluctuations in the thickness can help in the positioning of the fragments at the edges or at the center of the composition. For the purposes of the methodological investigation, a comparison will be made between manual measurement performed with the caliber and orthophotos obtained with the use of micro- photography processed in structure for motion software.

C. Back of the fragments

The informations obtainable from the study and documentation of the imprints preserved on the back of fragmentary paintings are well known. In addition to providing, in combination with the surface data, useful indications for repositioning the fragments, they prove to be indispensable in understanding the architectural structure from which they come, conserving negatively the shape of elements that can be completely disappeared such as doors, windows, niches, beams or pillars. In the event that the restoration and recomposition of the painting is made, for instance before musealization, the documentation of the back is extremely important before its thinning. With regards to this aspect, results from photogrammetric and laser scanner survey of the traces in question will be compared to evaluate if there are, and are significant, qualitative differences between the two techniques in this particular application.

IV. CASE STUDIES

In order to compare the techniques used, three case studies have been chosen. The choice was made to

allow discussing both methods and approaches.

A. *Castrum Inui*

The first case study comes from the site of *Castrum Inui* in Ardea. It is a group of materials dating back to the second half of the 2nd century AD. This group of fragments, coming from a collapse, was found during systematic excavations at the site. The group is useful in order to illustrate the documentation procedures for materials which, even in conditions of high fragmentation, nevertheless allow a satisfactory reconstruction of the whole decoration, both as regards the pictorial patina and the traces on the back of the fragments. This first context therefore represents an ideal condition of intervention (Fig. 1).

B. *Domitian villa in Sabaudia*

The second case study presented concerns a context of highly fragmentary materials, recovered from stratigraphic excavation and datable at the beginning of the 1st century AD. This materials, re-used for leveling, allow few possibilities to rebuild the decorated surface, but represent an excellent opportunity to illustrate some documentation procedures for the most frequent case-finding [14].

C. *Tres Tabernae*

The last group of materials presented is related to a collapsed ceiling dating back to the second half of the 1st century AD. In this case part of the fragments has reached the study phase already restored and reassembled into panels. This case study allows us to illustrate both the documentation procedures for materials that have already been restored and the integration, during the interpretation and documentation phases, of fragments that were neglected during of restoration. (Fig. 2)

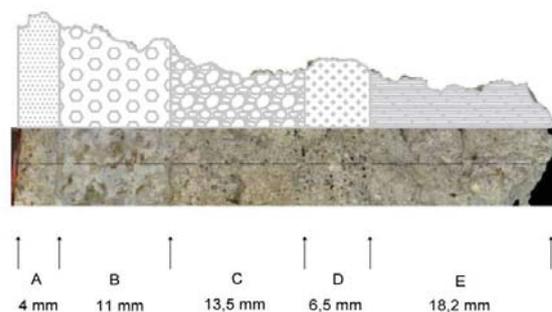
V. DATA ACQUISITION

A. *Photogrammetry and microscopic photogrammetry*

For surface and back documentation, the first operation have been a photogrammetric survey (case study B) using *SfM* technology. The chosen camera for this test is a Canon Eos M10, a low-end mirrorless characterized by an 18 mpX APS-C sensor (5184 x 3456 pixels, 22.3 x 14.9 mm - pixel size of 4.3 μ m), and a fixed 24 mm Canon lens. The choice for this sensor derived from its low cost in relation to the average - good quality of resulting image.

The photos, in total 58, were acquired, under natural light conditions, at three different heights (about 30 cm, 1 m, 1.6 m), and were taken both obliquely and parallel to the fragments. The acquisition operations, including the time spent on testing to refine lighting and focusing, took about 10 minutes.

To document via *SfM* the section of some fragments



(case study A), it was used a Dino-Lite AM4113ZT, a digital microscope characterized by a 1.3 mpX photographic sensor (1280 x 1024, pixel size 0.008mm), polarized lens, magnification factor up to 200x and linear distance measuring capabilities.

Fig. 1 Section ortophoto obtained with microscopic photogrammetry (case study A)



Fig. 2 Ortophoto obtained with SfM photogrammetry (case study C).

With the microscope connected to the PC, through the dedicated procedure (DinoCapture 2.0), 180 images were acquired using maximum resolution at an average operating distance of about 2 cm with a magnification factor of 30x. The capturing operations required 35 minutes, including metric calibration for the chosen magnification factor. The need to acquire such a large number of images for derived from the fact that the digital microscope is characterized, at the operating distance chosen for the acquisition, by a 13.0 x 10.4 mm FOV and by a 1.9 mm DOF [15]. In Fig. 1 is displayed the example of a 0.2 mm/px ortofoto, derived from this survey.

B. *Structured light scanning*

The same fragments (case study B), both the front and the back, have been surveyed using a structured light scanner, the Artec MH. This scanner, which requires power supply and connection to a PC, stands out for its compact size, lightness and speed, has an acquisition distance between 0.4 and 1 m. 3D data collection is realized by a camera and a light source emitting a luminous pattern, whose distortion on the irregular surface of the object is translated into a range map through the ARTEC Studio

Professional software. The use of this tool, which does not produce photorealistic texture but does not require the use of targets or scale bar for scaling and orienting, guarantees a 3D resolution up to 0.5 mm, a 3D point precision up to 0.1 mm and an acquisition speed up to 288,000 pt/s. The acquisition operations, including the setup, took about 5 minutes.

C. Manual “by contact” drafting

In order to be able to perform a comparison among recent and traditional techniques, the surfaces documented with photogrammetry and structured light laser scanners (case study B) were also reproduced using the “by contact” technique. This methodology involves the use of transparent sheets of polyester, or other material, to adhere to the surface in order to trace fragment’s perimeter, decoration and any traces detectable. The contact survey, performed by an expert operator, took about 35 minutes. Also for comparative purposes, a series of measurements using a caliper were carried out on the section, the activity took less than two minutes.

VI. DATA PROCESSING

A. Photogrammetry and microscopic photogrammetry

The 58 images (case study B) have been processed in two different *SFM* (Structure from motion) software: Agisoft Metashape and RealityCapture, to evaluate possible differences in quality or processing times.

This two versions of the project were processed using the same PC equipped with an Intel I9 9900k CPU, RTX2080ti GPU, 64GB RAM, both projects, with relative temporary files, were placed on SSD M.2. In Agisoft Metashape, data processing is articulated into four consecutive steps, reconstruction parameters were chosen to obtain a resulting mesh as accurate as possible: 1) Align Photos (Accuracy Highest, key points 70,000 tie points 70,000), 2) Build Dense Cloud (Quality: Ultra High, Depth Filtering: Disabled), 3) Build Mesh (Surface type: Arbitrary, Face count: High), 4) Build Texture. The time taken to complete the batch process was approximately 35 minutes. In Reality Capture the data processing is divided into three steps 1) Align Images (Max feature per image 70.000), 2) Reconstruction (High detail), 3) Texture. The time needed to complete the process was approximately 11 minutes. Basically the same procedure was used to create the photogrammetric model of the section (case study A), in this case 180 photos were processed, using only Reality Capture, in about 35 minutes.

At the end of the process, a textured mesh and an orthophoto were exported from the *SFM* software. The operations took no more than two minutes. The photogrammetric model, using CloudCompare (Multiplay / Scale command), was brought into real world units (mm) through a direct scaling. This operation was possible, for the surface model (case study B), by placing in the scene two metric references: one used to scale the model and

one to verify the accuracy of the operation.

The section model (case study A) have been scaled using the caliper measure and checked using measures obtained from Dino Capture 2.8. Scaling operation took less than five minutes.

B. Structured light scanning

During scan operations the Artec MH acquires up to 15 fps saving them directly in Artec Studio. The dedicated software aligns the range maps in real time, so it’s possible to see a preview of the digitized object. To scan an object, the scanner, or the object, have to be moved until each point of interest is captured. At the end of the scan, each individual range map is automatically aligned in a single 3D model generating a mesh with no photorealistic texture. The output from Artec Studio is a format commonly used for 3D data (.stl; .obj; .ply; etc), directly available without further steps. The processing operation (case study B) took less than 3 minutes.

C. Manual “by contact” drafting

Manual “by contact” drafting gives as a result a sheet of polyester, or other material, showing in scale 1:1 perimeter and decorative elements of the fragment being documented. This sheet must be digitally acquired, to transform it into a raster image, through the use of a common office flatbed scanner. The digital acquisition time is therefore practically zero.

D. Tracing

Whatever the technique of shape detection used, in order to finalize the documents to be delivered, it is necessary to acquire vectorial graphics in CAD environment, digitizing both the shape of the fragments and any features present on their surface (traces, decorations, etc.). This operation is burdensome in terms of time, especially when working on the digitization of very detailed orthophotos. A great help to reduce acquisition time is the use, as input tool, of a graphic tablet, possibly equipped with an LCD, in our case a 16 "Wacom Cintiq. The vector acquisition (case study B) took about 40 minutes.

VII. DATA COMPARISON AND EVALUATION

The aim of comparing the outputs of different acquisition techniques is to evaluate and identify best practices regarding: accuracy, precision, data quality, cost-effectiveness and expeditiousness.

A. Structured light scanning – Photogrammetry

In order to produce a homologous comparison for active and passive survey techniques, the paragon was performed, for both model of the same subject coming from different sensing technologies, within the same software: CloudCompare 2.10.2. In order to compare the meshes the following actions have been taken: 1) Manual registration using homologous points; 2) Global

registration by automatic alignment algorithms. Once the meshes were imported into CloudCompare, after the first alignment, a first evaluation of deviations was performed, showing evidence of a rotation on the Z axis of the compared model with the reference one.

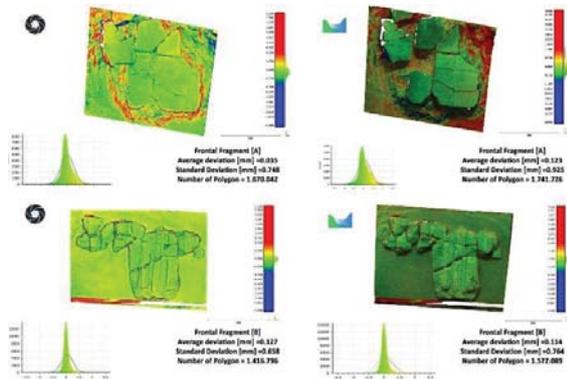


Fig. 3 Comparison between photogrammetric and Structured light meshes. (case study B)

For this reason, after the first manual alignment, an automatic one was performed using ICP. The ICP (Iterative closest point) is an algorithm used to minimize the difference between two surfaces or point clouds. Because of its iterative nature this approach can only guarantee the convergence to a local minimum. The error in the final registration is expressed through the *RMSE*, or the *RMS* of the Euclidean distance between the match point pairs of the alignment process.

For each *ICP* iteration the maximum number of matches was set to 500,000 and the number of iterations for the process equal to 100. The accuracy assessment for photogrammetric survey with respect to that performed with the structured light scanner was carried out using CloudCompare *C2M* command. This tool searches, for each point of the cloud, or triangle of the mesh, that is being compared, the closer one in the reference entity, thus defining a shift value of the first with respect to the second. The main parameters for this calculation are: 1) *Ocree* level: the chosen level of subdivision of the octree defining the distance for performing computation. By default it is set automatically by CloudCompare; higher the subdivision level is, than smaller the octree cells are. Generally, big clouds or meshes require high octree levels but if the points of the compared cloud are rather far from the reference cloud then a lower octree level is preferable. 2) *Max dist* : if the maximum distance between the two entities is high, the computation time might be awfully long (as the farther points are, the more time it will take to determine their nearest neighbors). Therefore it can be a good practice limiting the search area below to a reasonable value to the computation time (in this case max distance was set to 25 mm); 3) *Signed distances*: whether computed distances should be signed with the triangle normal or

not (in this case was activated); 4) *Flip normals*: if signed distances is checked, then CloudCompare can automatically invert the sign (in this case it was not activated). In conclusion, using the mesh generated by the Artec MH as a reference, the meshes obtained from the photogrammetry were compared.

The Fig. 3 shows in false colors the deviations of the polygonal surfaces between -5mm and +5 mm. Through the calculations carried out it is noted that the mean deviations do not exceed the instrumental accuracy of the Artec MH, while the standard deviations are in the order of accuracy. As for color documentation and creation of photorealistic textures, the comparison between this two methodologies is, in this case, impractical, considering that Artec MH does not record this type of data. However, it should be considered that similar scanners (Artec EVA, Peel 3D etc) are able to acquire such informations, which are often characterized by a lower resolution compared that obtained with the photogrammetric survey. From the point of view of acquisition times, the survey carried out with structured light scanner, with its total 8 minutes between acquisition and processing, clearly exceeds the photogrammetric process that required, between acquisition and processing about 25 minutes. This velocity, about three times higher, of structured light scanner corresponds to a cost more than three times higher than photogrammetry.

B. Photogrammetry - Manual “by contact” drafting

It is very complex comparing such different techniques. The comparison, for the shape detection, was carried out by superimposing, in a CAD environment, the vector acquisition of the manual “by contact” drafting on the orthophoto obtained from the photogrammetric survey. It was possible to note an adequate descriptive precision, comparable to that obtained from the image based survey. However, this accuracy would have been destined to decrease if scene size to be acquired had been greater, considering the need to use more sheets of polyester to be combined during the survey phase with consequent increase in the times and possibility of introducing deformations difficult to verify. It was not possible, for obvious reasons, to compare the color data. As for acquisition times, the 35 minutes used for manual survey are longer than the time required for photogrammetric processing. The costs of manual “by contact” drafting are infinitely lower compared to the other two techniques, but only considering the instrumental cost as unique comparison factor, when the hourly cost is taken into account manual survey, although remaining more economical, shortens the distances from what is necessary for set up a photogrammetric set. Fig. 4 shows a schematic comparison between techniques.

Sensor	Price	Acquisition			Processing		Result	
		Battery	Acquisition Time	Operation Work	Hardware	Processing Time	N. Polygon	Noise
ArtecMH	€€€€	🔋	⌚	⚙️	⚙️	⌚	🏠	🔊
PhotogrammetrySfM	€	🔋	⌚	⚙️	⚙️	⌚	🏠	🔊

Fig. 4. Techniques comparison.

VIII. CONCLUSIONS

Considering accuracy and precision absolutely comparable with those obtainable through structured light scanners, the high photorealistic resolution of the textures, the expeditious acquisition, the possibility to detect, also through the use of microscopic photogrammetry, tiny details relative to both surface and section, from our observations photogrammetry is the most advisable solution for the documentation of this class of materials. To these factors must be added the relative cost-effectiveness of the necessary instrumentation, also considering the possibility to develop *SfM* projects exclusively based on open source software.

IX. DATA DELIVERY

A. Surface documentation (Fig. 2)

- Orthophotos and vectorial acquisition of the decoration. In case of highly fragmented conditions (case study B) it is advisable to create orthophotos of single fragments or, when possible, of groups of repositioned fragments (case study A), which will then be virtually recomposed in CAD environment.

- Reconstructive design of the decorative motifs

- Vectorial acquisition of the traces present on the surface

B. Section documentation (Fig. 1)

- Orthophoto of the section with notation of the thickness of the identified layers

C. Back documentation

- Acquisition of orthophotos and orthophotos in false colors (Hillshade or others) from the DEM of the back of the recomposed fragments

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