

# Methods for Ancient Wall Graffiti Documentation: Overview and Applications

Riccardo Valente<sup>\*</sup>, Luigi Barazzetti

Politecnico di Milano, ABC Department, Via Ponzio, 31, 20133 Milano, Italy

---

## ARTICLE INFO

*Keywords:*  
Wall graffiti  
Epigraphy  
Heritage documentation  
Digital photogrammetry

## ABSTRACT

Ancient graffiti are evidence of the past, scattered all over the globe and common to many cultures. Documentation is a crucial step for their study, and must allow for clear interpretation. There are a variety of traditional methods to document ancient graffiti, from sketches to frottages, to contact tracing and photography. Digital instruments and other innovative methods developed during recent years in the field of heritage documentation can also be successfully applied to graffiti, improving the quality of results and increasing their readability. This paper presents the principal methods used for graffiti documentation and discusses the trends over the last few decades; it also presents two different case studies where the principal methods are tested and reviewed.

---

## 1. Introduction

### 1.1. Graffiti: a brief overview

The word comes from the Italian term *graffito* (plural: *graffiti*), which directly descends from the Greek verb γράφω (to write) and is commonly used in most European languages. The term is indiscriminately used for both ancient and contemporary inscriptions: despite its common use, an extensive and shared definition of formal characteristics of graffiti is far more difficult, due to the extreme variability in their properties and content. Some of the most recurrent characteristics of graffiti comprehend the surface on which they are inscribed, not originally intended as a support for writing; the surrounding environment, urban or architectural; the identity between the author of the graffito and the maker; the idea of extemporariness. Despite these frequent traits, exceptions are far from being rare, with many features that cannot be included into the previous definitions. Classification of graffiti in standardized categories is even more difficult, due to the many variations and details, and to the lack of a common methodological framework as well. Many scholars have recently highlighted this challenges related to graffiti studies, trying to overcome the most common issues (Arribas, 2016; Daniell, 2011; Frederick and Clarke, 2014; Ralph, 2014; Ross et al., 2017). The topic of this paper will principally focus on the documentation of ancient graffiti traced on walls, although several techniques can be used also in

different contexts (for instance, to record graffiti on rock surfaces or other natural environments).

### 1.2. Concerns and requirements in graffiti documentation

Graffiti documentation involves different considerations that are unique to this kind of socio-historical evidence and which depend on the one hand on material characteristics and context, on the other hand on criteria for their methodological study. Tools and techniques used to realize graffiti can be grouped into two main categories, i.e.:

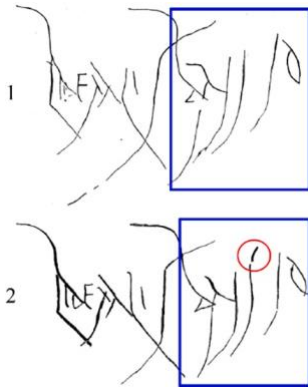
- 1- techniques that add material to a surface;
- 2- techniques that remove material from a surface;

When made through the use of paint, charcoal, graphite, pigments or any other suitable material applied by different tools, graffiti are part of the first category. When made by scratching or etching material from a hard surface, or removing it from a malleable surface, they come under the second category (a list of possible forms of graffiti and surfaces is presented in [Historic England, 2015, p. 5](#)). The two different techniques directly influence also the recording approach, which must be carefully planned considering the efficacy of each technology when applied to different features. The compresence of graffiti belonging to both categories within the same *corpus* (an assemblage of graffiti in a specific site) must be assessed in advance, in order to choose the most suitable documentation strategy combining different methods.

---

\* Corresponding author.

E-mail addresses: [riccardo.valente@polimi.it](mailto:riccardo.valente@polimi.it) (R. Valente), [luigi.barazzetti@polimi.it](mailto:luigi.barazzetti@polimi.it) (L. Barazzetti).



**Fig. 1.** Differences in reading and documenting graffiti can lead to different interpretations: the same part of graffiti (inside the blue rectangle) is read as “Basso” by Heikki Solin (1) and “Brisio” by Robert Marichal (2); both drawings from Marichal (1972), p. 86.

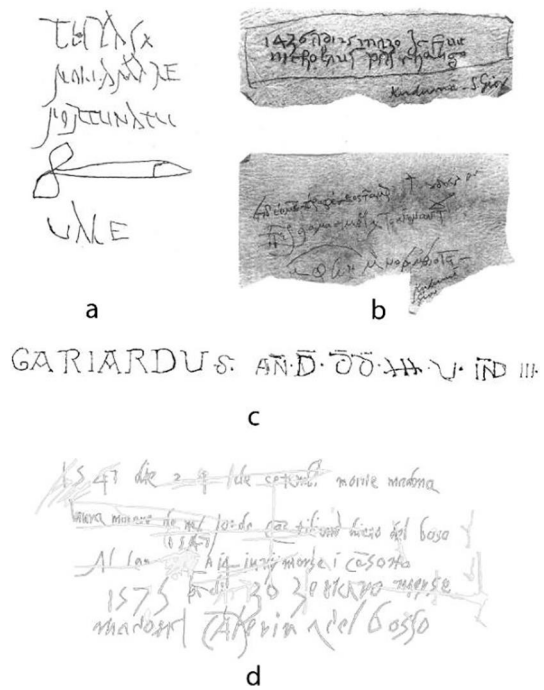
Methodological criteria is another aspect to be addressed. Graffiti require a variety of visual outputs in order to be satisfactorily studied. A single image or drawing is often not enough to aid in their proper interpretation. When approaching graffiti, documentation should display both an objective representation of what exists and its interpretation, not necessarily in a single output. A single set of recognizable graffiti can partially overlap itself or be intertwined with a dense weave of marks, scratches, and surface damages; a mere reproduction of what exists, although necessary, often does not provide enough information useful to interpret it correctly. Common constraints to a correct interpretation are (Varone, 2008, p. 125–126):

- author’s handwriting,
- author’s writing position and chosen tool,
- author’s linguistic skills,
- author’s errors,
- surface damages,
- interaction of different graffiti or marks,
- manipulation or correction of letters,
- errors of the interpreter.

The cognitive workflow in case of textual graffiti is as follows:

- a) observation of the evidence or its reproduction,
- b) stroke identification,
- c) transcription of letters,
- d) comprehension of message,
- e) edition of text.

With figurative graffiti step c) is generally omitted. Since this process can be performed only by scholars, it can be very subjective, depending on a series of variables, such as personal experience and skills, previous background and so on. This point also means that multiple interpretations of the same graffiti are valid, especially in uncertain cases (Fig. 1). The effective correspondence between the real evidence and its objective representation becomes important, because a correct interpretation is often reliant on the documentation, particularly when a direct access on the site is not possible. The efficacy of wall graffiti documentation and its methodological impact are well known among scholars, who have been debating for years about the topic. Robert Marichal, supporter of the use of frottages (2.1.2), and Heikki Solin, who preferred contact tracing (2.1.3), had a notable discussion about the documentation methods (Marichal, pp. 149–150, 1967; Solin, p. 17–20, 1970; Marichal, pp. 88–90, 1972).



**Fig. 2.** Comparison among different examples of contact tracing: a) drawing from CIL IV, 1–2, 4498; b) tissue papers of graffiti from Creta (Curuni, 1989–1990, tab. II); c) drawing from pvc sheet (Bassi and Bellandi, 2009, 171); d) digital contact tracing (Valente and Oreni, 2017).

## 2. Methods and tools for graffiti documentation and enhancement

A variety of methods and tools are available to undertake an effective documentation of wall graffiti. Most traditional methods were basically adopted from documentation techniques for rock-art and epigraphs. Most of the digital tools that appeared in the last two decades were developed for other purposes and were subsequently applied to record these features. An important distinction can be made between those methods that require a physical contact with the surface holding graffiti and those ones that do not. Frottage (2.1.2) and contact tracing (2.1.3) belong to the first category, while other methods are contactless. Traditional techniques tend to have a more invasive approach, while the increasing availability of digital technologies allow one to acquire data at close range distance, avoiding any direct contact. This is a crucial turning point in the development of recording techniques, greatly increasing the feasibility of wall graffiti documentation even in those cases where conservation needs would have prevented any contact with the surface.

### 2.1. Paper-based techniques

#### 2.1.1. Sketches

Manual sketches (also called *apographs*) are usually drawn as personal notes during on-site inspection; they seldom include measurements. While their reliability in terms of documentation is quite poor, they can aid interpretation. Furthermore, tracing the profiles of strokes can be useful to understand the shape of obscure letters, identifying an authors’ movements and writing sequence. This last point is valid also for other methods such as contact tracing (2.1.3) and digital tracing (2.4.1). They are often the only form of graphic documentation available in old publications and reports.

### 2.1.2. Frottage (direct rubbing) and casts

Frottage is an easy and quick method to obtain 2D reproduction of inscriptions made by removing material. A paper sheet or a lighter material, such as tissue paper, is laid down on the inscribed surface and fixed there. Then a graphite stick or a crayon is rubbed on the paper, automatically reproducing the inscription. This method works quite well with epigraphs, because inscriptions are often located on a planar surface. Its application to wall graffiti is more limited, partly due to small size of features and partly to the limitations of a contact method, and seems to be more effective on smooth stone surfaces (Bryan and Tovey, 2009). Frottages can be subsequently retraced, as if a contact tracing was performed on site. The use of casts is very limited for wall graffiti documentation, due to the fragility of many surfaces and to the small size of strokes (Couderc and Ledet, 1999, p. 911–912). Best results have been obtained with graffiti or small sculptures carved on ashlar, as those ones in the *Musée de la Mémoire des murs* (Museum of the Wall Memory) in Verneuil-en-Halatte (France) (Tedeschi, 2001).

### 2.1.3. Contact tracing

Contact tracing is probably the most effective traditional method to record graffiti morphology (Fig. 2). The technique is adopted from rock-art and petroglyphs documentation (Domingo Sanz, 2014, pp. 6354–6355). To obtain an accurate reproduction of marks, large transparent pvc sheets are laid over the surface where graffiti are located and secured with removable adhesives: plastic sheets must closely fit the surface, avoiding any space in between. Profiles of strokes are accurately retraced with permanent markers of different sizes. Before the second half of 20th century, tissue paper was used instead of pvc sheets, as most graffiti recorded in the *Corpus Inscriptionum Latinarum* (CIL); in some rare cases, the surface was dampened to improve the adherence (Curuni, 1989–1990).

This method offers some undoubtable advantages: correspondence is very high, as the reproductions are realized directly on site and at close distance; drawings are at 1:1 scale and in case of irregular surfaces an automatic unwrapping is performed when sheets are removed and laid on a planar surface. If large areas need to be documented, more sheets can be placed side by side, maintaining the spatial correlation among different features; last, but not less important, contact tracing allows one to observe and replicate the different overlapping elements among distinct features, recording not only the morphology but also the stratigraphic sequence, usually highlighted with the use of different colours. Nevertheless, there is a major impediment to its application to wall graffiti: conservation needs often prevent any material from being affixed or making contact with ancient wall paintings or plasters. Moreover, drawings need to be digitalized in order to be published, and during this step their metric reliability is often lost, although controlled photographic or scanning acquisitions are sometimes performed.

## 2.2. Image-based techniques

Technological advancements have established new standards in cultural heritage documentation, increasing opportunities for data gathering and analysis, and when combined with a user-friendly approach, these technologies have widened their use among the scientific community and technical operators. The methods here presented are all image-based, and are currently the most frequently used to document graffiti, a further proof of the importance of images for graffiti studies.

### 2.2.1. Analogue photography

Photography has been the most common technique to document wall graffiti in recent years, despite several constraints in correctly reproducing their shape. Photographic equipment is generally composed of a reflex camera with fixed lenses standing on a tripod, parallel to the surface to be documented. Concerning scratched graffiti, lighting is a crucial point: raking light, i.e. a light source coming from one side

(generally left) close to the wall with a low angle, between 45 and 15 degrees, can be necessary to reveal the graffiti marks. Today, analogue film cameras have been completely replaced by digital sensors (2.2.2).

### 2.2.2. Digital photography, multispectral imaging, infrared photography

While the basic principles about light placement to obtain an improved readability of marks have remained nearly the same as analogue photography (2.2.1), the use of images completely changed with digital imaging. Digital images are not just pictures but also data to be processed (2.4.2). Multispectral imaging allows one to capture images with multiple bands, corresponding to different wavelength intervals. The range can be restricted to only one band, for instance the near infrared (IR) band, or to multiple bands; visualization is based on a combination of different spectral channels with different colours. IR imaging is a longstanding practice in the cultural heritage field, even with analogue photography, since it allows to detect features otherwise not visible. Its main application was on aerial and satellite images, but it is widely applied also in enhancing the readability of inscriptions or wall paintings. IR films were used to document and read late medieval graffiti from the *cueva-sima de Cholones* in Priego de Córdoba (Spain) (Ventura Villanova and Moreno Rosa, 1986); in more recent times, IR imaging was also coupled with RTI (Cosentino et al., 2015). Ancient wall graffiti, for instance those in Palazzo Steri in Palermo (Italy), were also recorded using other bands, such as ultraviolet (UV) (Mazzeo and Joseph, 2005). This kind of investigations are normally aimed at improving their readability or, in case of graffiti realized with an addition of matter, to identify the different pigments used to trace them for conservation purposes.

### 2.2.3. Reflectance Transformation imaging (RTI)

Reflectance Transformation Imaging (RTI) is a digital image enhancement technique. It allows one to capture the luminance of single pixels with different lighting conditions, obtaining a dynamic texture map that can be changed as required by the user. One of the more popular methods is the Polynomial Texture Mapping (PTM), which also allows for colour and reflectance manipulation (Malzbender et al., 2001, 2004). Both approaches make use of a stationary camera to capture multiple images with a light source moved around the subject to create illumination conditions from multiple directions. The main difference between both approaches is related to the mathematical model used to handle luminosity. PTM uses a binomial quadratic equation, whereas RTI supports different fitting methods such as spherical harmonics and hemi-spherical harmonics. RTI is a 2D techniques, but enhanced visualization allows the viewer to highlight details and morphologic changes of recorded surfaces to simulate and increase the perception of depth. It is particularly suited to graffiti documentation because it improves on traditional photography to make the images more readable, i.e. through lighting control. While raking light typically comes only from one direction in single images, with RTI the direction of light source can be changed to improve readability, similar to an on-site inspection. These aspects made it a popular choice when documenting rock-art (Mudge et al., 2006; Duffy, 2010; Plets et al., 2012) and wall graffiti (Mudge et al., 2010; Earl et al., 2011; Kleinitz, *Reflectance Transformation Imaging (RTI) in der Bestandsdokumentation der Sekundärbilder und -inschriften von Musawwarat es Sufra im Rahmen des Musawwarat Graffiti Project*, 2012; Frood and Howley, 2014; McAttackney and Devlin, 2014; Cosentino et al., 2015; Dhoop and Cooper, 2016; Demesticha et al., 2017; Sammons, 2018; Davis et al., 2018; Valente et al., 2019). The technique was also tested with infrared images (Cosentino et al., 2015). If a 3D model of the surface is available, a virtual version of RTI is possible, changing the lighting settings and orientation directly on the digital model (Earl et al., 2010).

### 2.2.4. Digital photogrammetry

Photogrammetry has been completely revolutionized in the last decade by the introduction of computer vision and dense multi-view

reconstruction algorithms (Luhmann et al., 2006; Mikhail et al., 2001; Kraus, 2008). Structure from Motion (SfM) and image-based modelling allow for obtaining 3D reconstructions and orthoimages of complex objects with the only use of a digital camera, a computer and a software; several commercial (such as Agisoft PhotoScan/MetaShape, PhotoModeler Scanner, 3D Zephyr Aerial, ContextCapture) and opensource (such as VisualSfM, Bundler, MicMac) solutions exist, often offering data processing with a high level of automation.

An image block (i.e., a sequence of digital images) of the object is captured from different positions, keeping a high overlap between consecutive images. If the final output needs to be referenced in a local Cartesian system, some points with known coordinates (ground control points - GCPs) must be included in the area. GCPs should be measured with a surveying instrument, such as a total station or a GNSS. The image block is then processed by the software. The main steps are generally 1) orientation of different images through a series of tie points automatically detected with generation of a sparse point cloud, 2) dense point cloud generation, 3) mesh generation. The mesh can be textured or can be used to generate an orthophoto. In addition to point clouds, meshes and orthophotos, digital photogrammetry can also generate Digital Surface Models (DSMs).

The digital revolution broadened the number of possible users, introducing a user-friendly approach to photogrammetry and reducing the technical requirements for its application. The cultural heritage field has especially benefitted from this new approach, quickly integrating digital photogrammetry into the field workflow of documentation, particularly for architectural, restoration and archaeological purposes (Howard, 2006; Letellier et al., 2007; McCarthy, 2014; Grussenmeyer et al., 2016). Archaeology is one of the fields where the impact of this technology was even more significant, ranging from fieldworks documentation to 3D reproductions of finds.

Application of photogrammetry in rock-art documentation is longstanding, with first test carried out in the second half of 20th century (Belzner, 1959; Pietsch, 1963; Atkinson, 1968). Digital photogrammetry was also successfully used by epigraphists (Samaan et al., 2016; Andreu and Serrano, 2019). One of the first known applications to wall graffiti is the documentation of an inner cell in the Royal Castle of Warsaw (Poland) (Niepokólczycki and Garus, 1988). The technique was also applied at Dover Castle (United Kingdom) (Bryan and Tovey, 2009); at the underground city of Naours (France) (Balland, 2016); at the Baptistery of Castiglione Olona (Italy) (Valente and Oreni, 2017); at the underground Maison Blanche of Neuville-Saint-Vaast (France) (Murtiyoso et al., 2017); again at the Royal Castle of Warsaw (Zawieska et al., 2019); at S. Filastrio of Tavernole sul Mella (Italy) (Valente et al., 2019); at Kyrenia Castle (Northern Cyprus) (Verdiani et al., 2019); at S. Marco in Venice (Abate and Trentin, 2019), using polarized light sources.

## 2.3. Laser/light-based techniques

### 2.3.1. Laser scanning and structured-light scanning

3D scanning is a surveying technology that allows one to measure several millions of object points of a surrounding environment in a short span of time. Recent improvements have further increased portability and usability of instruments, which are going to become a standard in surveying activities. The main types of laser scanners (LS) involved in graffiti documentation are 1) terrestrial laser scanners (TLS), 2) triangulation-based LS and 3) structured-light scanners.

TLS are mainly used to provide a 3D spatial framework of the surfaces where graffiti are located (Balland, 2016; Murtiyoso et al., 2017; Palomar-Vazquez et al., 2017). This is the best use of this kind of instruments, due to their average accuracy of  $\pm 1-3$  mm, which is not enough to record the smallest details. Triangulation-based LS have a reduced range if compared with the previous type, but their accuracy is greater, with precision better than  $\pm 0.05-0.1$  mm, allowing one to achieve a great level of detail, much higher than what can be reached by naked eye. Triangulation-based LS proved to be a reliable instrument for

wall graffiti documentation (Balzani et al., 2004). However, the most popular technology used for graffiti is probably structured-light (Gründer et al., 1994; Wolf, 1999; Tenschert et al., 2019; Kleinitz et al., 2009). These instruments project on the surface a series of regular light stripes: changes in their geometry, due to surface morphology, are detected and result in a 3D reconstruction. One of the most valuable features of this technology is its portability. The latest instruments can reach an accuracy better than 0.5 mm and texturize the digital model. Laser scanning systems give the best results when dealing with scratched graffiti, because they can capture their three-dimensional nature, while with paints and pigments the results are mainly affected by the reflectance of materials. A particular type of scanner is the 3D profilometer, which is an instrument used to perform contactless and high detailed measurements, with several applications in the cultural heritage field (Carcagni et al., 2005). Its use was successfully tested also to enhance the readability of ancient inscriptions, although not traced on walls or architectural surfaces but on pottery (Montani et al., 2012). Wall graffiti could be recorded directly on site using a vertical standing profilometer.

## 2.4. Enhancement, data analysis and management

### 2.4.1. Digital tracing

Digital tracing is the contactless version of traditional contact tracing: drawings are not realized on site on the original surfaces but on digital images. The unquestionable advantage is that no contact with the object is required: this is a key point because most of the surfaces that host ancient graffiti are often fragile or decorated with paintings, and in some cases every possible contact must be avoided. Due to this limitation, digital tracing much widens the possible applications of this documentation. The use of metric images, such as rectified images or orthophotos, is even more effective when documenting wall graffiti, since architectural surfaces are generally more regular and planar than rock surfaces, where the irregular morphology necessitates a higher control of measurements and proportions (Dhoop and Cooper, 2016; Demesticha et al., 2017). Digital tracings at a 1:1 scale, or even more detailed (i.e., 2:1), can be easily produced, depending on the camera settings and gears, or can be realized after a digital acquisition of analogue images or drawings. There are still no shared norms on the representation of ancient wall graffiti: different renderings can be applied in order to increase the level of detail (Valente and Oreni, 2017), which can also be extended to the surrounding surface.

### 2.4.2. 2D image enhancement

Digital imaging can help to visualize details barely undetectable in the field. Some basic digital enhancements such as the control of contrast and sharpness, or apply an edge detection, can be used in order to change graffiti visibility. Experiments on image enhancement in the field of rock-art and prehistoric archaeology have been carried out for at least two decades (Clogg et al., 2000). While some years ago these kind of operations needed customized solutions (Varone, 2008), nowadays basic interventions can be easily performed with the use of a generic graphic software such as Adobe Photoshop®. Most image enhancement techniques for rock-art analysis use K-means, principal component analysis (PCA), and decorrelation stretch (DS). DS is an algorithm developed for the analysis of aerial and satellite images and it is principally grounded on principal component analysis and transformation of the image spectral information, increasing or decreasing the contrast values of RGB channels; the result is a false colour image that can be used to detect marks which are not normally visible. The most used tool is probably the DStretch plugin, developed by Jon Harman for ImageJ™ software (Harman, 2005), which is extremely effective when dealing with pigments rather than with scratched surfaces. Several results and tests have been carried out and published during the few last years (Domingo et al., 2013; Cerrillo-Cuenca and Sepúlveda, 2015; Rogerio-Candellera, 2015; McDonald et al., 2016; Bea and Angás, 2017; Fernández-Lozano et al., 2017). The technique was also tested on some

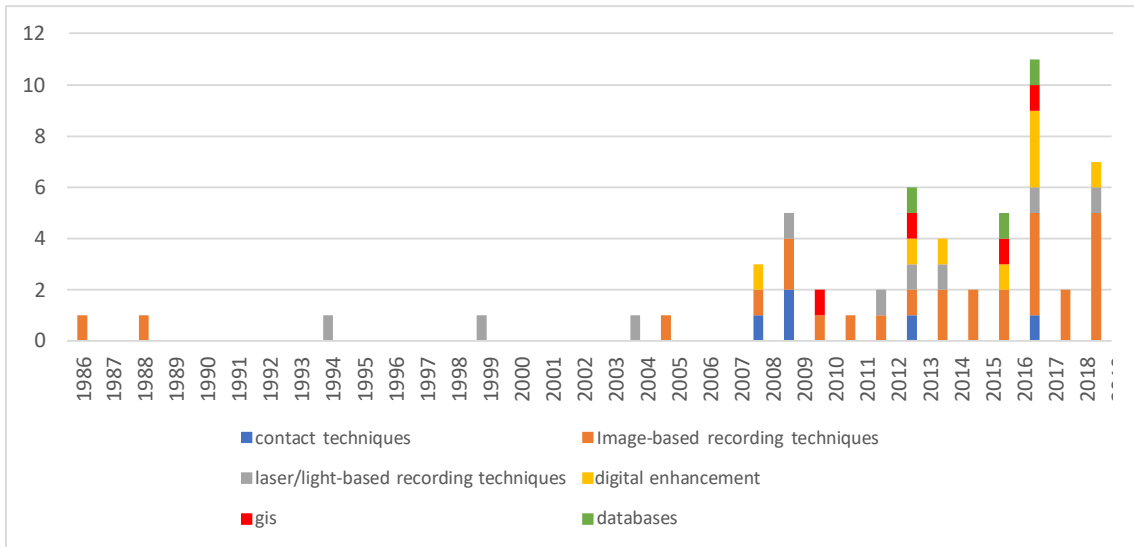
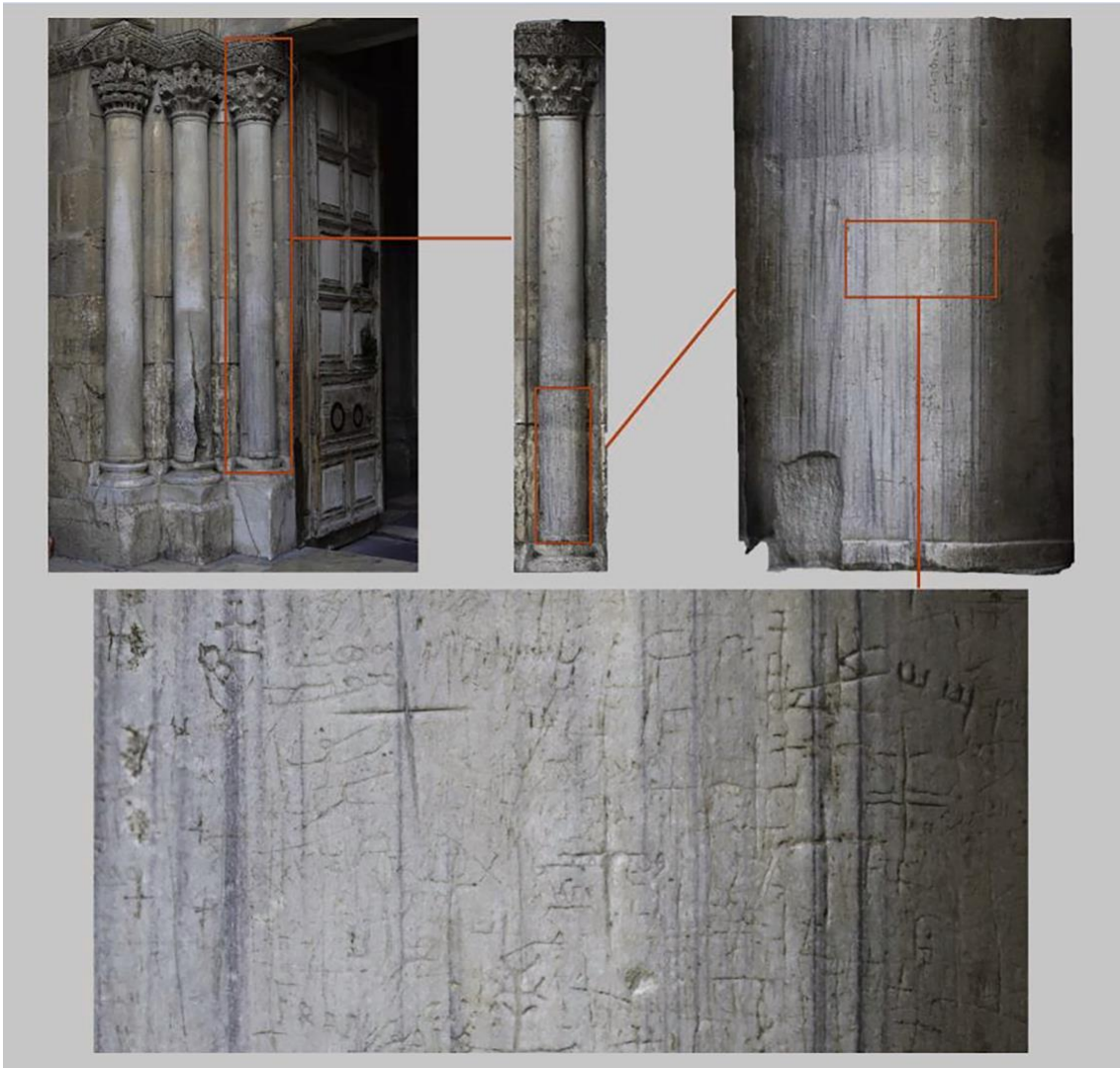


Fig. 3. Temporal distribution of the different tools and techniques used to document graffiti as retrieved by bibliography (1986–2019).



Fig. 4. Comparison between different methods and tools available for graffiti documentation: a wider area covered in the graphs corresponds to a more complete technique.



**Fig. 5.** First row: the column n. 3 at the entrance of the Holy Sepulchre (left), the photogrammetric mesh (middle) and the unroll of the lower portion. Second row: a detail of the unrolled point cloud.

historical graffiti on rock surfaces (Le Quellec et al., 2013; Defrasne, 2014). Edge detection was also combined with the Multivariate Alteration Detection algorithm, used in remote sensing (Abate and Trentin, 2019).

#### 2.4.3. 2.5D and 3D data analysis and further operations

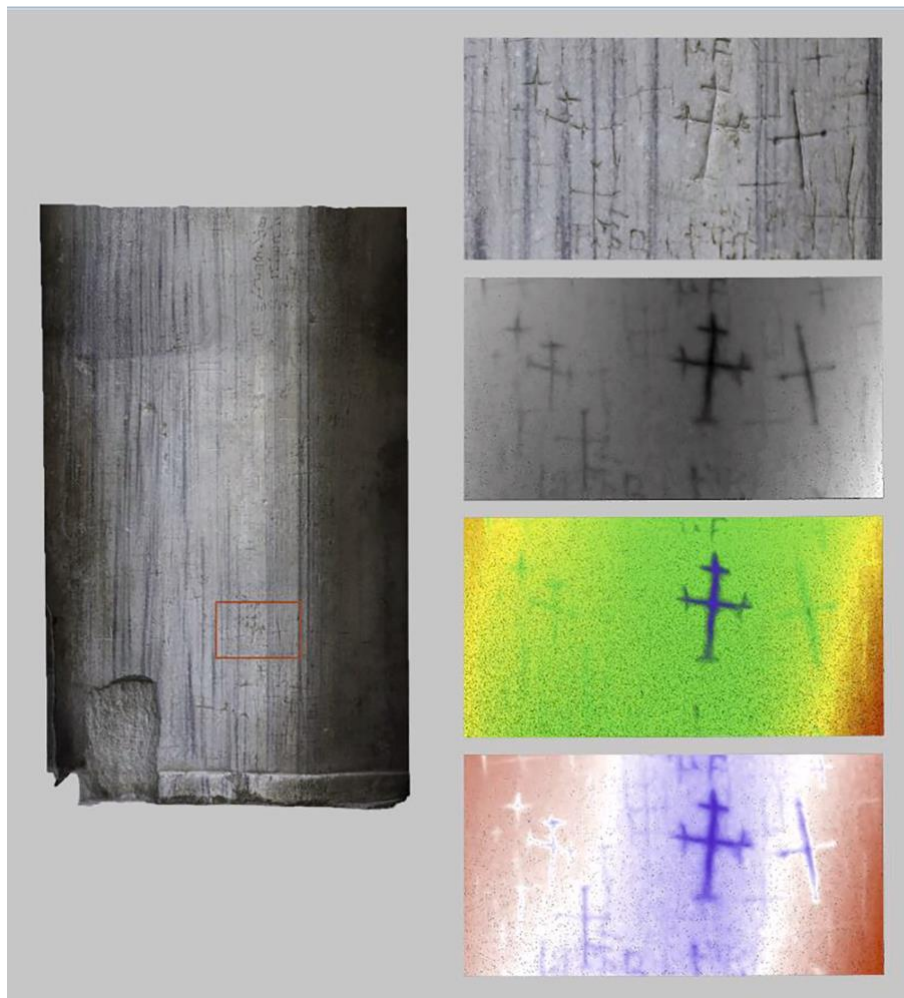
Further analysis can be performed on 2.5D, i.e. digital images with height values embedded in pixels, and full 3D data. For instance, Digital Surface Models (DSMs) of graffiti surfaces can be generated from LS or digital photogrammetry. Morphometric analysis, slope analysis, mean curvature or raster algebra can be successfully applied to enhance graffiti characteristics and improve their readability. This kind of analysis has been principally used to document rock-art (Chandler et al., 2005), but also epigraphs (Garcia-Làzaro et al., 2012; Carrero-Pazos et al., 2016). A typical example related to the topic of this paper is the extraction of sections of graffiti marks on a mesh coming from LS data (Balzani et al., 2004). A similar approach, using a DSM coming from digital photogrammetry, was tested on epigraphic material (Garcia-Làzaro et al., 2012). This kind of analysis is particularly interesting with scratched graffiti, since the physical tool used to create them can be identified from the morphology of mark sections, a detail that is difficult to measure due to the small depth of the mark. Visualization of 3D

models can be also enhanced using tools such as Radiance Scaling and colour mapping, in order to improve the interpretation of carved marks of epigraphs (Carrero-Pazos et al., 2016).

3D data can be also reproduced in tangible material through a reverse-engineering process. Digital 3D models can be printed in order to obtain artificial replicas of the originals. Some pioneering works were carried out on Pompeian graffiti, where a portion of a *lupanare* inner wall was scanned, printed in 125 tiles  $24 \times 19$  cm large which were subsequently reassembled on a standing support; single graffiti were also highlighted with different colours to be more identifiable to the audience (Balzani et al., 2004). 3D printing is a technology becoming more and more popular and accessible, so a wider application also to graffiti documentation could be expected (Balletti et al., 2017).

#### 2.4.4. Geographic information systems (GIS)

GIS have been using for decades to manage spatial data. The application to cultural heritage is long-established and they are a standard for the management of complex archaeological data (Conolly and Lake, 2006). GIS have been used to map spatial location of ancient wall graffiti on an urban and regional scale. An example of the first case is the mapping of roman graffiti in the city of Pompeii based on their content (Benefiel, 2010); Pompeian graffiti have been experimentally mapped



**Fig. 6.** A portion of the unrolled surface of column n.3 displayed with different scalar field values (from the top: RGB; grey; blue-green-yellow-red; blue-red).

on an even smaller scale, using a 3D GIS able to explore visibility and mutual visibility patterns inside a single house (Landeschi et al., 2016). On a regional scale, ship graffiti on the island of Cyprus have been mapped depending on their number and typology (Demesticha et al., 2017). The use of GIS to manage graffiti analysis is usually combined with digital databases.

### 3. Trends and comparisons

Some comments can be made when observing the recent bibliographical review of works concerning the documentation of ancient wall graffiti; data were plotted giving priority to those papers focused on documentation methodologies and techniques rather than analytical studies. The progressive increase of the use of digital documentation techniques is a clear trend, as shown in Fig. 3.

Some of the oldest retrieved entries attest that the use of techniques other than contact drawings or photography dates back to the end of the 1980s, but only during the last decade (2009–2019) there is a noticeable increase in the number of both applications and tested technologies. The use of digital methods is also constantly increasing, as one would have expected.

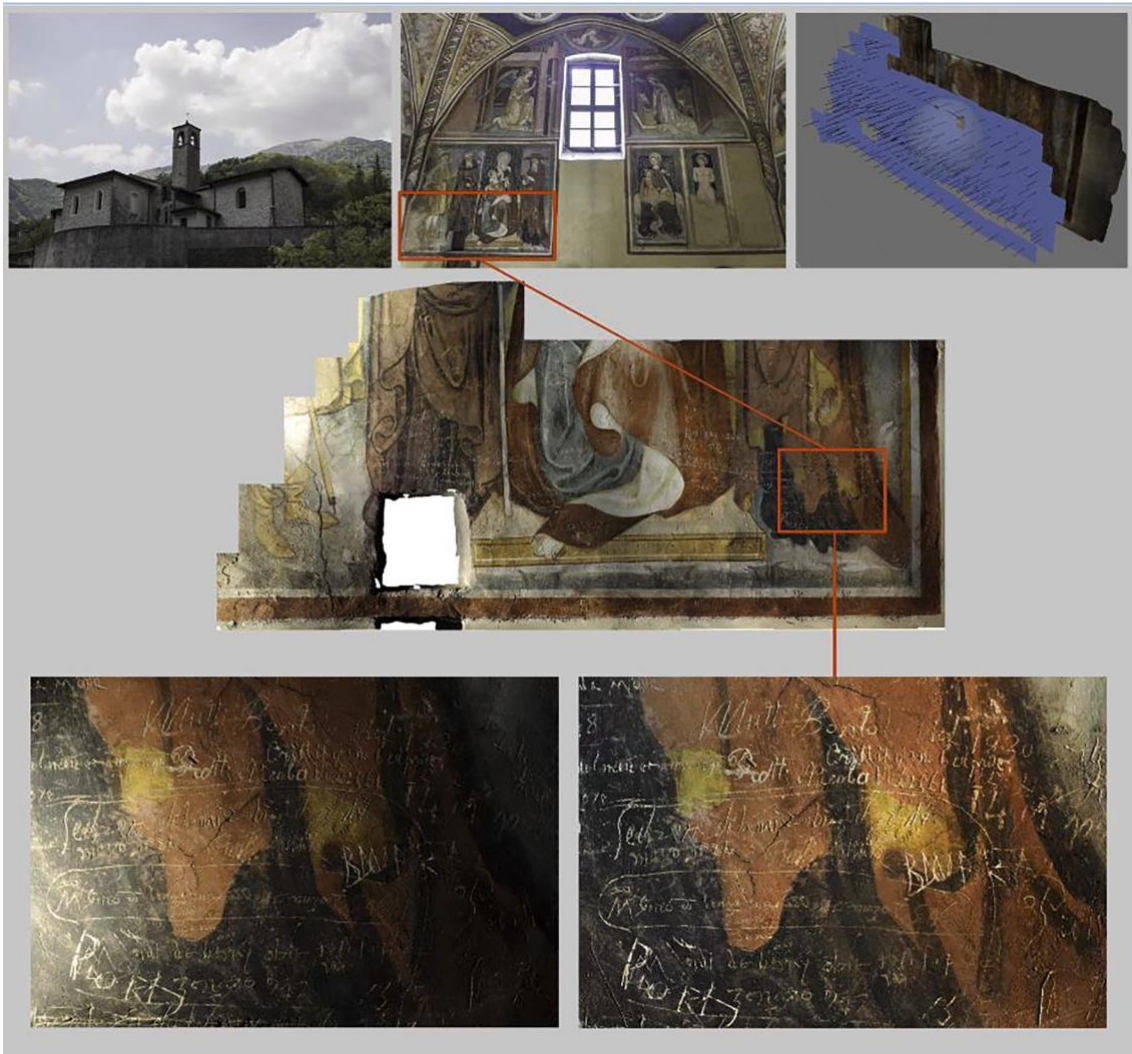
Another aspect which appears from this review and that can be briefly discussed is the frequency of use: RTI is the most popular technique, followed by photography; structured light scanners occupy the third position, while other techniques are homogeneously distributed. Overall, more than 50% of the published graffiti documentation is based on images. This reveals how much image-based techniques are

effective for this kind of recording and widespread, probably due also to their easy use and the lower cost: some of the most popular pieces of software, like RTIbuilder and RTIviewer, are open source, making this approach affordable in most occasions. Moreover, traditional images are an essential output for graffiti documentation that cannot be omitted, and the possibility to collect more information only with limited changes in gear is a clear reason for the favouring of the use of imaging.

A comparison is here presented to evaluate the main features of the different techniques. Techniques were divided between traditional (sketching, frottage, contact tracing, paper cast, analogue photography) and digital (digital photography, RTI, digital photogrammetry, digital tracing, laser scanning, 3D profilometer). Four different parameters were taken in consideration, with a different score assigned for each parameter:

- 1- human intervention (0,5 = result totally dependent on human skills; 1 = result partially dependent on human skills; 1,5 = result little dependent on human skills, and 2 = human intervention limited to setup phase),
- 2- geometry reconstruction (1 = 2D; 2 = 2D/3D),
- 3- range of application (1 = scratched or painted graffiti; 2 = scratched and painted graffiti),
- 4- degree of contact (1 = contact needed; 2 = contactless).

Fig. 4 show that digital methods generally offer more advantages than traditional ones, especially when concerning the degree of contact:



**Fig. 7.** First row (above): the church of S. Filastrio, the interior of the chapel and the camera positioning of the photogrammetric block; second row (central): the orthoimage of the fresco with graffiti; third row: a detail from the orthoimage (right) and the comparison with a traditional image captured with raking light (left).

all of the presented digital methods are contactless, a feature that expands in a relevant way the field of application also when conservation requirements prevent any contact with fragile surfaces, a rather likely conditions for graffiti on ancient wall paintings. Another important common feature is the recording of third dimension: this is a crucial aspect not only because additional data are collected, but also because third dimension, i.e. the thickness of marks in case of scratched graffiti, is a key point in graffiti perception; the flattening that occur in two-dimensional documentation is a serious obstacle to graffiti interpretation.

Concerning the effective adoption of these techniques, a few aspects have to be considered. All of the presented methods need a certain degree of professional skills. A general background in epigraphy or palaeography is expected also for surveyors in order to obtain good recordings. Photography is probably the most accessible technique, due to its widespread use, although an accurate lighting control has to be mastered. Contact methods require a professional training aimed to avoid any possible damage to surfaces and nowadays contactless methods should be preferred when possible. All digital methods require specific skills as well; while digital tracing or some image enhancements require a basic knowledge, the use of digital photogrammetry or specific instruments, like laser scanners, requires a further level of specialization. Considering costs, traditional techniques are generally cheaper

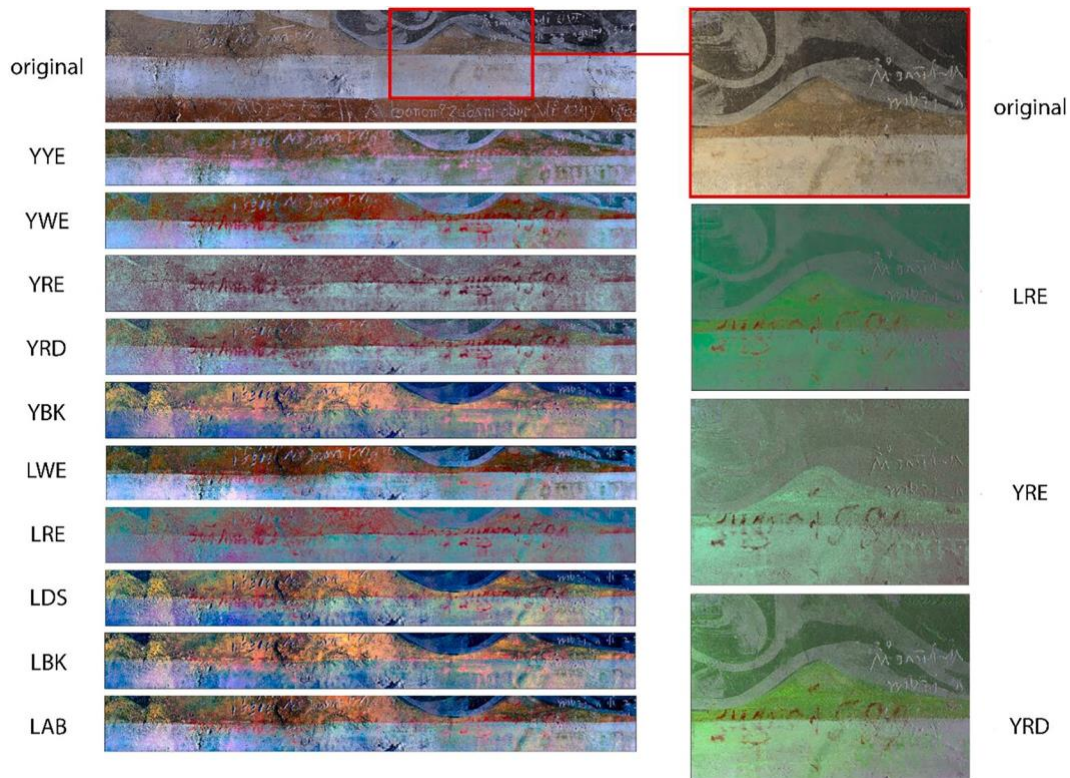
compared to digital ones. Digital photogrammetry can be considered a good balance of cost-effectiveness: basic equipment is composed by a camera, a computer and a piece of software. In-field practical workflow could be structured as follows: digital photography can assure a basic level of documentation. Digital Photogrammetry adds metric information to images and provides 2.5D and 3D data to exploit for further analysis: it is the right candidate to become the standard documentation for wall graffiti. RTI is a further step towards a complete documentation, and it could be used especially in those cases where readability is difficult. Laser/structured-light scanners represent the last level of graffiti documentation and depends on the scope of the project and on fund availability.

#### 4. Graffiti documentation: Two case studies

In order to show the potential of digital surveying tools for wall graffiti documentation, two different photogrammetric datasets are here presented along with results and discussion of results.

##### 4.1. Holy Sepulchre, Jerusalem

The Holy Sepulchre in Jerusalem holds many ancient graffiti spanning from Middle Ages to current days. The columns aside the



**Fig. 8.** Results after the application of DStretch to the orthoimage: a graffito realized with red pigment is made visible (the entire graffito on the left, a detail on the right).

main entrance of the church are covered by a large number of graffiti dating back to several historic periods. Due to the popularity of this holy place, one of the most important religious buildings frequented by hundreds of devotees, the first dataset was expected to be acquired through a quick surveying procedure. A full frame Nikon D610 equipped with a 50 mm lens was used to shoot images; a freehand acquisition phase was carried out using natural daylight, the use of any support or lighting gear being difficult. For each column a series of images (from a minimum of 50 to a maximum of 251) was taken, following the circular geometry of the objects and assuring a very high overlapping ratio. The average GSD (ground sample distance) for the project was 0.08 mm.

The images were processed with ContextCapture, to generate a point cloud and a texturized mesh. This software was chosen for its ability to deal with large image sets and produce point clouds with density of 1 pixel. Ancient graffiti are clearly visible on the digital mesh, despite some issues in texture definition caused by the reduced depth of field, necessary to keep a high shutter speed. The point cloud was uploaded in CloudCompare for further processing (Fig. 5). The point cloud had not any absolute reference system measured by instruments, so a manual scaling, based on field measurements, and rotation was performed aligning the vertical axis of the column with z axis, which corresponds to the axis of revolution of the unrolling procedure; a digital fitting of a cylinder helped the rotation, estimating the average radius of the column through the measurements of intermediate sections.

Then the rotated point cloud was clipped and unrolled, to obtain a planar output which helps the observation of graffiti. Some of the deepest graffiti marks were clearly visible also in three dimensions. Different scalar field values were applied in order to improve the visibility of strokes, obtaining a depth map (Fig. 6). While with a traditional approach only detail images could have been acquired, with this workflow the general surrounding context of wall surface and interconnections between different graffiti are preserved even on a curved surface.

An important consideration deserves to be mentioned. Although photogrammetric results can be obtained with using different software packages offering a very high level of automation, the acquisition of images featuring a good geometry in space is fundamental to reveal the fine details of graffiti. The use of convergent images improves metric precision with an improved triangulation in space, which is the base of a photogrammetric bundle adjustment. On the other hand, the short camera-graffiti distance causes a significant reduction of the depth of field, increasing the risk of low-quality images.

Finally, the use of visualization techniques on 3D models or 2.5 DEM able to enhance the variations along the depth can simplify graffiti interpretation. This is mainly an approach that depends on the characteristics of the considered surface. The example reported in figure 6 shows the result of the unrolling of a cylindrical digital model. The unrolled shape does not follow the perfect geometry of the reference surface used to approximate the real column and the irregularities of the unwrapped results can be used to highlight small graffiti.

The possibility to change the visualization using both radiometric (RGB in this case) and geometric (point cloud) information coupled with dynamic tools allows the operator to improve the readability of the solution. In the case of the unrolled surface here used, a set of georeferenced images reporting such information can be exported and visualized in GIS/CAD software, where manual retracing can be carried out by the operator. The portability of the equipment is surely an attractive aspect for the proposed method. The needed equipment is just a digital camera with several calibrated lenses, and a metric scale bar to properly scale the photogrammetric project.

#### 4.2. San Filastro, Tavernole sul Mella (Italy)

San Filastro is a small church situated in Trompia Valley, Lombardy; a side chapel, decorated with 15th century frescos, holds a large number of wall graffiti created from the end of 15th century and the beginning of the 19th century. Digital photogrammetry was selected also in this case

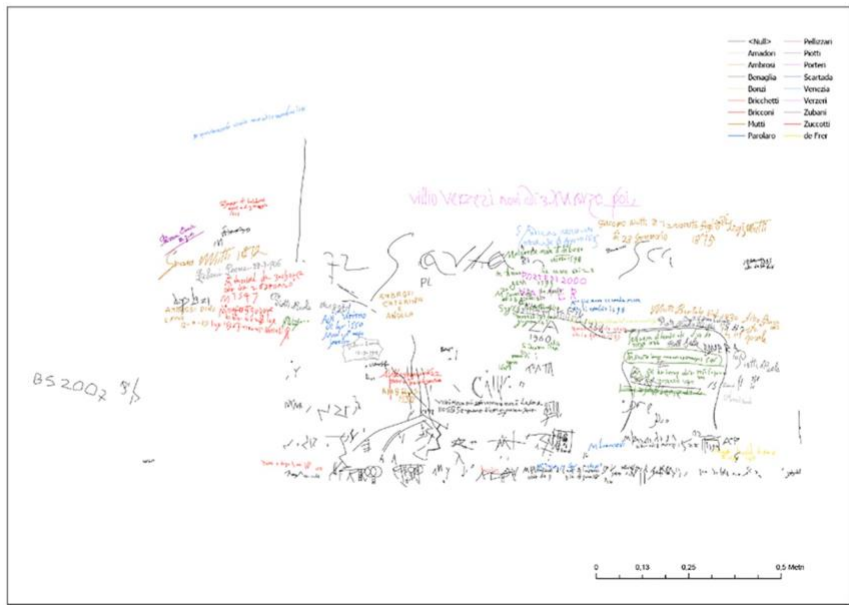
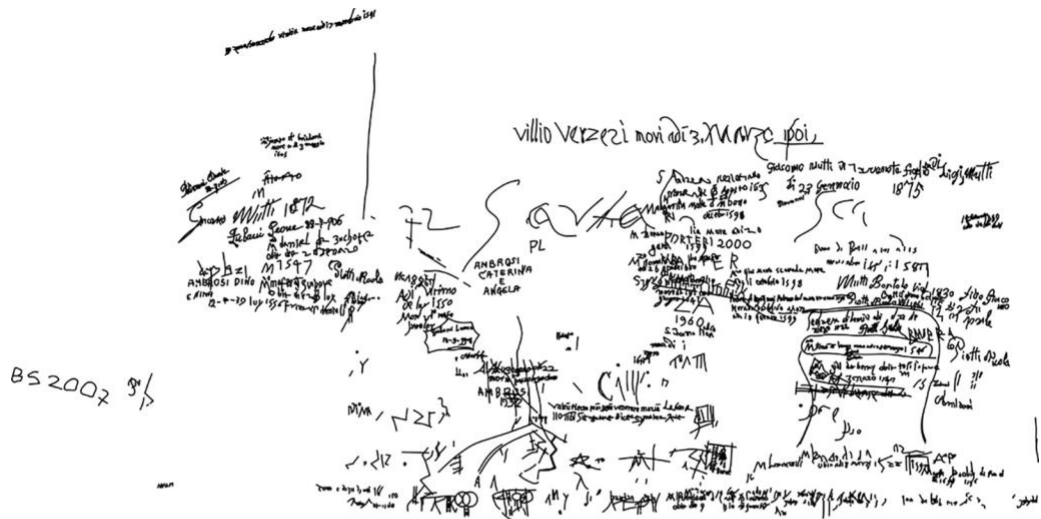


Fig. 9. Vector tracing of graffiti on wall n.4 (above), classification in GIS based on chronology (middle) and surname of subjects (below).

to document the graffiti, but a more rigorous camera positioning was carried out. In addition to *structure from motion* techniques, a total station (Leica 1203) was used to establish a rigorous local reference system. Conservation issues prevented the application of any kind of target on the walls decorated with frescos. One of the main aims was to preserve the spatial connection among the different graffiti over a wide portion of surface, enhancing the clusters generated over the decades: single detail images cannot sufficiently record this characteristic, while panoramas are likely to have lighting issues, resulting in poor visibility of graffiti. A six metres frescoed wall (n°2) was documented in its entirety, obtaining a single orthophoto that clearly shows graffiti and offers an excellent output for both research and documentation purposes (Valente et al., 2019). The results and the method applied also to a second shorter wall will be here presented and discussed.

A photogrammetric block of 330 images was acquired to record the inferior part of another frescoed wall (n° 4) characterized by graffiti (approximately 2.30 m<sup>2</sup>) using a Nikon D90. A high overlapping ratio was assured also in this case. Unlike the previous example, here the camera positioning was kept regular at a fixed distance on both a vertical and horizontal alignment. Furthermore, lighting was strictly controlled, keeping the same angle of raking light for every image, in order to make visible most of the strokes: this is so far the most effective procedure to highlight the graffiti, while an incident lighting is very likely to dramatically decrease their visibility. A local reference system was established as previously presented. The final GSD of the project was 0.66 mm, a value that assures a good visibility of graffiti. The automatic colour correction helps to minimize the different lighting effects: while traditional images recorded with raking lighting present strong contrast and are not useful in recording long size graffiti, because readability decreases with distance from the source of light, the orthophoto has an acceptable level of lighting uniformity and a good detail of graffiti strokes (Fig. 7).

A portion of the orthoimage documenting wall n° 2 was also processed with DStretch plugin, namely where vanishing traces of a red pigment were visible. The use of different filters of DStretch allowed to completely recover what appeared to be a new graffiti, presumably made with *sanguigna*, an achievement that would have not been possible without the use of this technique (Fig. 8).

Grffiti visible on the orthoimage were retraced in AutoCAD, following the profiles of strokes. The vector file was successively uploaded into a GIS software (ArcGIS Pro by ESRI) and converted into vector feature layer. Different strokes belonging to the same graffiti were merged into a single feature, grouping in this way all the identified graffiti, while not understandable marks were just retraced as single entities. A series of attributes, extracted from an external relational database, were linked to features, adding informative content. This operation allowed one to obtain distribution maps of graffiti setting significant values such as chronology, typology or other attributes (Fig. 9). These maps are extremely useful to communicate in a more immediate way the results of studies, especially when the number of graffiti is relevant and there is a high level of entanglement among the features. A normal output of graffiti studies, i.e. a map with ID numbers, was also generated in GIS and kept updated while the analysis was in progress. The management of this kind of data through a GIS can help in minimizing time-consuming activities such as the review of data before the final publication.

## 5. Conclusions

Digital techniques applied to graffiti documentation can offer an advantage that have been pursued for a long time, i.e. the realization of more objective reproductions of material evidence. Every output has a degree of subjectivity, due to the direct intervention of a human operator, and accuracy, due to the intrinsic errors of instruments. However, these last errors are often inferior to human perception. For what concerns ancient mural graffiti, this means that the digital reproduction of

an entire wall surface with a controlled and limited range of error is possible, even when dealing with a large number of small features that are often likely to be missed in the field. The more relevant aspect is that maybe for the first time in graffiti studies it is possible to separate in a more effective way the objective recording, i.e. the documentation of the morphological and geometrical aspects of a surface with graffiti, from the subjective recording, i.e. the interpreted reading. In the past, photography was considered the most objective recording, but variables are still too many: lighting has a major impact on their readability and many images of wall graffiti do not solve doubts and ambiguities; frotages are affected by similar issues. Traditional casts, a good solution to obtain copies of archaeological finds and epigraphs, are basically impossible. Contact tracing are fine, but often not applicable to fragile supports. A digital reproduction of a surface could be used as an accurate copy on which the individuation of graffiti can be carried out, as one would do in the field; a further documentation that shows the personal interpretation would be realized in any case, but it would not be the only output available. This would also improve the use and analysis of data by other scholars, who could propose alternative readings and interpretation directly from the copy of the original and not from a re-elaborated version. The shared availability of this kind of digital outputs would also increase a remote and collaborative study of graffiti *corpora*, improving the chances of interpretation and comprehension. The increase of contactless methods has expanded the range of applications also to those frequent cases of fragile surfaces that cannot sustain any contact. Moreover, most of them assure a better, or at least equal, accuracy than the most used contact methods. These two factors, along with the versatility of digital data that allows for multiple uses and a wide sharing, bring effective improvements to graffiti studies. Digital photogrammetry is probably the best solution at the moment for graffiti documentation, because it balances limited costs with a user friendly approach, and allows for documenting every kind of graffiti, although the completeness of data is higher for scratched graffiti documented with scanning instruments.

## Fundings

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Acknowledgements

The authors want to thank Paolo Forlin, Wendy Rose and the anonymous reviewers who helped to improve the quality of the paper.

## References

- Abate, D., Trentin, M., 2019. Hidden graffiti identification on marble surfaces through photogrammetry and remote sensing techniques. In: *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W15, pp. 1–8. doi:10.5194/isprs-archives-XLII-2-W15-1-2019.
- Andreu, J., Serrano, P., 2019. Contributions of the digital photogrammetry and 3D modelling of Roman inscriptions to the reading of damaged tituli: an example from the Hispania Tarraconensis (Castiliscar, Saragossa). *Digital Appl. Archaeol. Cultural Heritage* 12, e00091. <https://doi.org/10.1016/j.daach.2019.e00091>.
- Arribas, J.L., 2016. Grafitos medievales. Un intento de sistematización. In: Reyes, F., Viñuales, G. (Eds.), *Grafitos históricos hispánicos I. Homenaje a Félix Palomeron*. Madrid, pp. 43–58.
- Atkinson, K.B., 1968. The recording of some prehistoric carvings at Stonehenge. *Photogramm. Record* 6, 24–31.
- Balland, M., 2016. Numérisation 3D dans les souterrains de Naours et intégration des données de la base de données Graffiti. *mathesis, Institut National des Sciences Appliquées – Strasbourg*.
- Balletti, C., Ballarin, M., Guerra, F., 2017. 3D printing: state of the art and future perspectives. *J. Cult. Heritage* 26, 172–182.
- Balzani, M., Callieri, M., Fabbri, M., Fasano, A., Montani, C., Pingi, P., Santuopoli, N., Scopigno, R., Uccelli, F., Varone, A., 2004. In: *Digital representation and multimodal presentation of archeological graffiti at Pompei*. The Eurographics Association, pp. 93–103.
- Bassi, S., Bellandi, G., 2009. L'applicazione delle metodologie di rilievo dell'arte rupestre della Valcamonica nella documentazione di graffiti su affresco. *Bulletin d'études préhistoriques et archéologiques alpines* 20, 257–264.



- Samaan, M., Deseilligny, M.P., Heno, R., Vaissière, E.D., Roger, J., 2016. Close-range photogrammetric tools for epigraphic surveys. *J. Comput. Cult. Herit.* 9 (3), 1–18.
- Sammons, J.F., 2018. Application of Reflectance Transformation Imaging (RTI) to the study of ancient graffiti from Herculaneum, Italy. *J. Archaeol. Sci.: Rep.* 17, 184–194.
- Solin, H., 1970. L'interpretazione delle iscrizioni parietali. Note e discussioni, Faenza.
- Tedeschi, C., 2001. A proposito di un museo dei graffiti storici: il Musée de la Mémoire des murs. *Scrittura e Civiltà* 25, 371–376.
- Tenschert, R., Rahrig, M., Drewello, R., Kempgen, S., 2019. Scratches? Scribbles? Scripture! Revealing the unseen – 3D scanning of Glagolitic graffiti of the 10th century at Saint Naum. In: Reds, J. (Ed.), *Proceedings of CHNT 23, Vienna 2018*.
- Valente, R., Oreni, D., 2017. Survey and Drawings for the study and enhancement of ancient wall graffiti: the case of the Baptistery of Castiglione Olona. *DISEGNARECON* 10, 71–710.
- Valente, R., Barazzetti, L., Previtali, M., Roncoroni, F., 2019. Considerations on the use of digital tools for documenting ancient wall graffiti. In: *ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLII-2/W9, pp. 731–737. doi:10.5194/isprs-archives-XLII-2-W9-731-2019.
- Varone, A., 2008. Inseguendo un'utopia. L'apporto delle nuove tecnologie informatiche alla lettura "obiettiva" delle iscrizioni parietali. In: Brandt, O. (Ed.), *Unexpected voices: the graffiti in the cryptoporticus of the Horti Sallustiani and papers from a conference on graffiti at the Swedish Institute in Rome, 7 March 2003*. Stockholm, pp. 125–135.
- Ventura Villanova, A., Moreno Rosa, A., 1986. Pinturas y graffiti medievales de la cueva sima de Cholones. In: *Actas del primer Congreso de Arqueología Medieval Española*, I. Zaragoza, pp. 239–255.
- Verdiani, G., Bertocci, S., Sevketoğlu, M., 2019. Graffiti photogrammetry, extracting the signs from the walls of the Kyrenia Castle. In: Reds, J. (Ed.), *Proceedings of CHNT 23, Vienna 2018*.
- Wolf, P., 1999. *Arbeitsbericht über die Dokumentation der Sekundärbilder und Sekundärschriften von Musawwarat es Sufra. Der Antike Sudan* 9, 44–51.
- Zawieska, D., Markiewicz, J., Luba, M., 2019. Macro Photogrammetry in Inventory of Historical Engravings at the Royal Castle in Warsaw. In: *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W9, pp. 795–800. doi:10.5194/isprs-archives-XLII-2-W9-795-2019.