DIGITAL PHOTOGRAPHY AND TRACEOLOGY: 
FROM 2D TO 3D

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ЦИФРОВАЯ ФОТОГРАФИЯ И ТРАСОЛОГИЯ: 
ОТ 2D К 3D

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РЕЗЮМЕ
Цифровые технологии предоставили пользователям широкий диапазон новых, невероятных во времена пленочных фотокамер. Замена пленки на цифровые сенсоры значительно облегчила процесс фотографирования, в особенности, благодаря возможности моментального контроля результатов. Более того, как и любая новая технология, цифровая фотография не только упростила старые способы получения изображений, но и предоставила принципиально новые, невозможные ранее способы фиксации визуальной информации! Благодаря постоянному увеличению вычислительных возможностей, совершенствованию программного обеспечения и/или веб-сервисов, виртуальные изображения все более широко входят в практику трасологических исследований, создавая образы, которые уже не являются прямым переносом оптических изображений, а представляют собой результат математических построений, основанных на анализе серии фотографий. Преимущества новых технологий уже весьма убедительно продемонстрированы на примере увеличения глубины резкости при микрофотографии, однако, еще более существенные преимущества даст трехмерная фотография, которая позволит объективно фиксировать и изучать ранее по техническим причинам пропущенные признаки износа, такие как морфология окружения рабочего края или конусность рабочей поверхности.

КЛЮЧЕВЫЕ СЛОВА:
трасология, анализ износа, фотомикрография, цифровые изображения, 3D, фотограмметрия, панорамные изображения, мультифокус

ABSTRACT
Digital technology has opened a range of possibilities that was unthinkable at the time of film camera. The replacement of film by digital sensors has made photography easier in particular thanks to the immediate control of the result, but, such as any new technology, this has not only introduced a new way for doing the same things but a way for doing new things! Thanks to the constant increasing of computing power, involving software and/or web-services, virtual imaging becomes accessible to use-wear studies by making representations which are no longer a direct transposition of the optical images but a mathematical construction based on the analysis of a series of photos, taken under a single of different axes. It is already helpful for increasing the depth of field in photomicrography but more fundamentally the third dimension can help to objectively characterize use-wear attributes and particularly the ones that were neglected by lack of appropriate recording technique, such as the morphology of the edge rounding or the concavity of the working surface.

KEY WORDS:
traceology, use-wear analysis, photomicrography, digital imaging, 3D, photogrammetry, image stacking, focus stacking

INTRODUCTION
"Archaeologists have not yet introduced into their general practice all those means of establishing and documenting evidence which contemporary techniques place at their disposal. This is particularly the case in micro-photography, stereography and micro-stereography (...)” (Semenov, 1964: 26)
Since the origin the discipline visual demonstration has been fundamental in traceology. The book of Semenov (1957/1964) which opened world archaeology to use-wear study contains more than a hundred plates of illustrations combining several hundreds of drawings and photos. It is common to start reading a traceological article by looking first at the photos in order to appraise the quality of the research. At a more epistemological level, we know that few of our current theories or assumptions will resist future data and synthesis, as is normal in science, but our concrete observations will certainly remain meaningful to our successors if we are able to show them what we saw.

In this perspective photography is the more widely used solution even if sometimes complementary drawings are helpful for underlying unclear details or for pedagogic purposes.

Producing good photos is less a matter of using sophisticated instruments than a matter of knowing how to get the best from the available equipment. To date, the illustrations produced by S.A. Semenov, and even more by V.E. Shchelinskij (1977; in Plisson, 1988), in Soviet Union, or by P. Vaughan (1985), on the Western side, remain unequaled. All three were using ancient (Wild M50) or very ancient (various Lomo models) microscopes and manual cameras.

The replacement of film by digital sensors has made traceological photography easier particularly because it provides immediate control of the result and of the frame and focus before the shot. Nevertheless, the optical principles have not changed and their understanding remains critical at high magnification. The rapid progress in the automatic control of the cameras partly explains why these principles are today seldom put into practice. In the same time, mass production has considerably reduced the cost of photo equipment while its quality has remarkably increased. This equipment is far better and easier to use than in the time of the pioneers of traceology but, paradoxically, fewer scholars today know how to get good photographic results.

Various solutions are now becoming available for making 3D modeling by image correlation, however the quality of the three-dimensional reconstruction depends on the quality of the initial set of photographs, i.e. on the control of parameters which are critical in photomacro and micrography.

This is the reason why, before starting to take profit of the third dimension in wear studies, it is worth considering practical points which contribute to the quality of photographs at low and high magnification.

Since archaeologists are nomadic, I shall focus only on solutions that are easily available, flexible, and that can

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**Fig. 1.** Basic concept of optical magnification redrawn after [http://www.olympusmicro.com/primer/java/lenses/magnify/index.html](http://www.olympusmicro.com/primer/java/lenses/magnify/index.html) (DAO and photo: M. Baumann)
be used in the most remote museum or in the field. Therefore I will not discuss heavy equipment such as SEM or confocal microscopes. These equipments are not only cumbersome but also very expensive. Moreover, their use in traceological analysis is complementary to — and does not preclude — macroscopic observations or examination with an optical stereomicroscope and a metallurgical microscope.

1. WHICH CAMERA?

For recording images we need a camera. Three types are currently used in traceology: video, compact and single lens reflex (SLR) cameras. Whatever the technology involved — film or digital sensor — the most important criteria remains the size of the light sensitive surface. Despite the use of non-coated objectives, nobody has equaled the quality of the photomacrographs made by V.E. Schelminskij (1977; Plisson, 1988) who was working with a pre-war equipment and very large glass negative. On this criteria the SLR camera is far ahead with 15x24 or 24x36 mm sensor, comparing with the 2/3 or 1/1.8 inch (8.8x6.6 or 7.2x5.3 mm) for video and most compact cameras. Another criteria often misevaluated is the number of pixels. It is important to underline that this criteria is meaningless if you don’t take into consideration the size of the photodiodes on which depends: i) the dynamic range of the produced image (i.e. property to record simultaneously details in the brightest and darkest areas); ii) the diffraction which fixes the highest achievable point-to-point resolution. The smaller the photodiode is, the lower is the contrast ratio, and the more lens resolution is needed in order to match the sensor with the objective. The size of the photodiodes also affects the amount of the electronic background noise and other negative interferences such as chromatic aberration. Consequently, among digital sensor matrices of the same resolution, the best result is achieved by SLR cameras. When SLR cameras were very expensive the compact ones offered a more than acceptable alternative, and some of them performed amazingly well at macroscopic scale without any additional accessories (Plisson, Lompré, 2008: photo 1). However, this is no longer the case. Furthermore, as a result of a lack of standardization among compact cameras, the cost of the scope adapters, when available, is often higher than the price of an entry-level SLR.

2. WHICH OPTICAL SYSTEM?

Before recording the image of an object with any camera, it is first necessary to form this image by projecting on a plane the focused light rays coming from the object by using an optical device. The complexity of this optical device, which at the origin was nothing more than the hole of the camera obscura, depends on the expected magnification: the more distant or the smaller the object, the more significant are the optical aberrations that have to be controlled. In our case the range of scale is large, from centimeter to micron. Direct observation can accommodate with a mediocre optical system since it relies on the most powerful image processor, the brain. The brain can create an ideal synthetic mental image by instantly compiling multiple views, filtering non relevant features and comparing them with memorized models. Obviously, this is not the case with digital sensors. Photography emphasizes even the smallest aberration and does not afford any optical compromise. Compared with direct observation, photomacro or micrography is often deceiving. However, the final result can be greatly improved if quite simple solutions are adopted and some basic principles respected.

As for the direct observation, we can distinguish 3 steps of magnification in use-wear photography: what is visible at naked eye, what requires the help of an optical device for seeing the relevant features, and what is invisible without a microscope. Each step involves different equipment.

2.1. Close-up photography

For subjects up to a centimeter, close-up photography can be done directly with a photo macro objective of 50 or 100 mm. Each SLR camera manufacturer supplies this type of objective. The most recent models give the best since their full aperture. However, their optical design, based on an internal focusing (only the internal lenses move), reduces the focal length when increasing the magnification, and this can preclude some applications. Most of these macro objectives directly reach a magnification of 1x (fig. 4) at the sensor plane, life size, written 1:1. With a DX format sensor (15x25 mm) the frame is the same as seen in direct observation with, for example, a Leica MZ6 or Nikon SM22B stereoscope at 8X with 10x/21 oculars.

2.2 Photomacrography

Photomacrography begins at 1:1 and goes beyond. With the exception of the Canon MP-E 65 mm 1–5x Macro-Photo objective, additional accessories (i.e. macro rings or bellow) are necessary for getting more than life size at the sensor plane with the standard macro objectives. However, other solutions become available as we are entering into an optical world of compromises between contradictory parameters that become more critical as magnification increases (Eastman Kodak Company of New York, 1969).

In the image plane a real size is obtained when the subject is positioned in front of the lens at twice its focal length (i.e. distance between the center of the lens and the focal plane for focus at infinity). The image is then symmetrically at two focal lengths (fig. 1). The magnification factor of the image corresponds to the ratio between the focal length of the lens (at infinity) and the extension added by the bellow or the additional ring. Thus, an extension of 150 mm to a 50 mm lens gives a magnification of 3:1. This means that, for a same extension, the shorter the focal length of the lens, the greater the magnification and the closer the object must be. The resolving power of a lens is determined by its aperture and depends on the obliquity of the light rays entering the objective. The resolving power is thus inversely proportional to this distance (called working distance) and consequently to the depth of field (Abramowitz et al., 2012; Spring et al., 2012). In practice we have to choose between resolution and depth of field. The consequence is that we cannot expect the same quality of image from the different available solutions.

The most common solution used is to replace the camera objective by a stereoscopic microscope via an adaptive ring (a photo tube can be added to a stereoscopic microscope of common main objective type — CMO — while it has to be factory built with the Greenough type). However the optical design of a stereoscopic microscope is far from being optimal for photography mainly because it requires a very long working distance (this distance is necessary for the convergence of the two optical channels and for having enough depth of field). As explained earlier, long working distance is associated with low resolution. Furthermore for CMO type of stereomicroscope, the use of the periphery rather than the center of the objective induces various aberrations (Houssin, 2008). These aberrations do not hamper much in direct observation as the image appears sharp as a result of the stereoscopic view. But for the photomicrography, only models with costly apochromatic lenses (corrected in all waves of white light) can give decent results. This is the reason why some manufacturers have conceived high resolution scopes specifically devoted to photomacrophotography, with a single perfectly corrected...
Fig. 2. Macroscopic detail of the manufacturing traces on a fake limestone Palaeolithic Venus. Comparison between a jpg (above) and a raw post-processed (below) photo from a Canon EOS 350D camera fixed on a Leica Z16 APO Macroscope.
Fig. 3. Microscopic detail of the usewear on the cutting edge of a patinated Neolithic blade (Les Arnajons, France). Comparison between a jpg (above) and a raw post-processed (below) photo from a Nikon D100 fixed on a Olympus BH2 bright field reflected light DIC microscope. Olympus M5 Plan LWD 20x 0.40 objective and NFK 2.5x projective.
vertical optical channel, inspired by the famous Makroskop Wild M420 (fig. 2). The inconvenience of high end scopes is that they are expensive and cumbersome. Also, they are not exactly a kind of equipment that can be brought in the field or that any laboratory can acquire. However, a better and simpler optical solution exists, since the origin of photography, which can produce exceptionally good results. While it was in the past restricted to experts, digital technology has helped to make it more ergonomic, by allowing control and viewing directly from the computer. This optical solution consists of an adjustable bellow with an objective whose focal length is chosen according to the expected magnification range. For instance, one of the oldest and most famous objective in the history of small format photography, not originally designed for photomacroscopy, the Elmar f. 3.5/5 cm (1926–1959), is impressively sharp (coated version of 1951) when fixed to a bellow and surpasses most of the scopes (fig. 5 and 6). With a 25 cm bellow extension its magnification ratio is 5:1. Longer bellows are not common therefore, in order to increase magnification, it is necessary to reduce the focal length. The very best solution is then to select a microscope objective (Krebs, 2009). Its narrow shape allows the lens to get closer to the subject and its larger aperture provides a higher resolution. However not any type of microscope objective is suitable: i) it must be designed for a finite optical tube length (usually 160 or 210 mm measured from the back focal plane); ii) without cover glass thickness correction (usual correction is 0.17); iii) it must not rely on compensating eyepieces for color correction (marked with a «K» or «C»). The ancient Nikon 210 mm CF M Plan series is particularly appropriate and easily available on second hand market. Other models can be tested, with sometimes good results regardless of their corrections. The best image is theoretically achieved when these microscope objectives are extended at their designed tube length (210 mm for the mentioned Nikon), which gives the stated magnification, but the extension can be increased, and thereby the magnification, far beyond this length with still an excellent result. At a lower value the risk is to lessen the corner image quality. By following the same equation as above, the focal length of a microscope objective is deduced from the magnification value and the optical tube length engraved on its barrel: 42 mm for a 5x/210 mm, 21 mm for a 10x/210 mm, 10.5 mm for a 20x/210 mm etc.

Modern microscope objectives are infinity corrected (Abramowitz et al., 2012; Spring et al., 2012). They are designed so that light emerging from their rear aperture is focused to infinity, and a second lens, inside the microscope, forms the image at its focal plane. Such geometry allows the introduction of various components into the optical pathway without causing distortions, but it prevents to use these objectives alone. They cannot work properly on a bellow. However an alternative currently used by entomology enthusiasts is to replace the bellow with a 200 mm telephoto lens (fig. 7 and 8) which acts like the tube lens of the microscope. The telephoto lens collects the parallel rays virtually coming from infinity such as in landscape photography. Objectives that do not need chromatic correction via the ocular and/or tube lens are required. For instance, the Nikon CFI Plan Achromat 10x NA 0.25 is well appreciated for this purpose. The Olympus U-MPlan FL series, thanks to its semi-apochromatic lenses, can give even sharper images, contrary to the older achromat MS Plan series which requires ocular compensation. Again, the best quality and the nominal magnification are achieved when the focal length of the telephoto lens is the same as the one of the microscope (200 mm for Nikon, 180 mm for Olympus).

A telephoto zoom lens (fig. 7) makes a combo very flexible and more convenient to use in the field than a bellow, which is prone to dust and moisture. The microscope objective is attached in front of the telephoto zoom via a mounting adapter easily available on internet.

It is important to remember that, whatever the optical quality of the system, if the camera is not very firmly fastened, the lens sharpness will be inevitably spoiled by the vibrations. When a stable stand is not available, particularly outdoor, a convenient solution is to shot with a flash.

2.3 Photomicrography

Photomicrography requires a complete microscope and generally starts at 50x (observation scale), with a 5x objective. The most currently used objectives for microwear analysis are the 10x, 20x and 50x which allow observation at 100x, 200x and 500x magnifications with 10x oculars. Unlike photomacrography the images produced at high magnification are standardized since the path of the light is fixed by the particular structure of the instrument, which constitutes the main difference between the different types of microscopes (transmitted light, reflected light, bright field, dark field, etc.). Micro-polishes are visible under epifluorescence illumination: the incident light comes through the objective to illuminate the specimen. Light reflected from the surface re-enters the objective and is directed either to the oculars or to the photo port. Projection of the image onto the camera sensor involves a photo relay lens. It enlarges the primary image formed by the objective which gives the resolution. The combination of the photo relay lens and the objectives gives the final magnification on the sensor. An Olympus UPlan 10x LWD objective coupled to a 2.5x10 objective lens results in an image of 25.1 magnification ratio². It is 2.5x more than when attached to a telephoto zoom lens at its focal length (180 mm — but 16.7:1 at 300 mm). However, since the quality of the image depends on the characteristics of the objective, the change of enlargement does not make a significant difference (Plisson, 1989: fig. 2 and 4). In fact, the diversity in the type of illumination is more fundamental. It has not only to do with the path of the beam (through the lens or external) but also a variety of principles inherent to microscopy (Abramowitz et al., 2012; Spring et al., 2012). Among them, the differential interference contrast (DIC), which is based on interferometry, is particularly useful for the examination of translucent or transparent and clear surfaces and to see otherwise invisibles features. A translating beamsplitting prism (called Nomarski prism) is inserted before the objective with two linear polarizers. One polarizer is inserted in the path of incoming light and the second after the prism in the path of light reflected from the specimen surface. The DIC produces a bias retardation which enhances the perception of the micro topographical variations of the surface, and of the overall contrast. The effect is obvious in direct observation. DIC also reduces chromatic aberration, a phenomenon to which digital sensors are particularly sensitive. In fact, even when the sample texture or micro-relief does not require this kind of vertical resolution enhancement, the DIC still improves the quality of the photography (fig. 3, 9; Plisson, Lompré, 2008: photos 6–7). However, modern Nomarski prisms can be too strong for coarse grain stones, causing a kind of double image, and in such case it is advisable to use prisms of more ancient design...

At the opposite, recent models work fine with quartz or obsidian tools (Plisson, 2008).

¹With film cameras photomicrography of micro-wear was generally done in black and white, through a green filter for using the achromatic lenses in the wave’s band for which they are corrected, what would blind half of the pixels of a current digital sensor.

²2.5x and not 10x as for the oculars because the length of the photo tube contributes to the enlargement.

³What can be precisely measured by shooting a micrometric scale and by dividing the side of the frame, whose length is known (= sensor size), by the length of this scale.
Fig. 4. Macroscopic detail of the edge rounding of a Mousterian side scraper (Byzovaya, Russia) shot in natural light at 1:1. Post processed 6 million square pixels raw file from a Nikon D100. AF Micro-Nikkor 60 mm f/2.8 objective. Scale 1 cm, graduation 1 mm.

Fig. 5. Macroscopic detail of an experimental sandstone abrader used for shaping bone needles. Wild M7 stereoscope with 1x achromatic objective at 9x visual magnification. Crop (45% of 10 million square pixels) of a post processed raw file from a Nikon D80 fixed via a Wild phototube with a Nikon MDC 10x projective lens (the best optical coupling). Left bottom: enlarged residue. Scale 4 mm, graduation 1 mm.
An old well known technique can also help a lot for microphotography of rocks with diverse crystals (quartzite, sandstone, etc.): surface casts with acetate (Plisson, 1983; Knutsson and Hope, 1984). Color and specific optical properties of the crystals are not replicated and this reduces light dispersion while enhancing contrast. Coupled with DIC, casts are particularly effective for the analysis and photo recording of some micro-wear found on grinding stones that is not visible at 200x and requires a higher magnification for which optical parameters are more critical (Adams et al., 2009: fig. 6.7g and 6.7h).

3. DIGITAL TOOLS

Up to now, except the cameras, there is nothing unique to digital technology. We could use them in the same way as film cameras, as we did at the beginning of digital photography. However, generally a new technology does not only offer a new way of doing the same things but also introduces new practices.

There are a number of software tools which are relevant to traceological imaging.

There are three fundamental types of software: remote shooting, image processing and image analyzer. We will consider the first two types that are directly related to the quality of the images produced.

- Remote shooting software allows the control of the SLR camera from a computer or a tactile pad, as well as a direct monitoring of the frame and focus with the Live Preview function. All or most of the camera adjustments can be done on the computer or pad screen, and the automation of the shots with specific parameters is possible. Such programs are provided by the camera manufacturers or by third party editors. The programs with the most advanced options are designed only for the cameras issued by the two main Japanese companies. Among the remote programs, Helicon Remote from Helicon Soft Company is certainly the most impressive. It comes as a complementary module of Helicon Focus for automating focus and exposure bracketing. It progressively changes, step by step, the focus distance of the objective mounted on the SLR camera, taking a shot at each step, what results in a vertical photographic scanning of the sample. For Nikon users a worthwhile alternative for remote bracketing and monitoring is provided by ControlMyNikon.

- Image processing software is of two types: for converting its raw file in standard format (jpg, tif, etc.), for making a new image from several.

Each SLR camera has its own raw format, which is the digital equivalent of the film negative, that encode the image in 12, 14 or 16 bits color depth (Verhoeven, 2010). Any adjustment of the image quality made before shooting (contrast, sharpness, color balance, saturation, etc.) can be afterward corrected or cancelled when operating in raw format, which is not the case in jpg or tif. Moreover, a 12, 14 or 16 bits encoding gives a larger contrast range than the 8 bits of the jpg format since more information is recorded (fig. 2 and 3). Furthermore, even at the lowest compression ratio, each time a jpg file is saved the image is altered. For a scientific purpose it is therefore more advisable to shoot in raw format as you can get many different renderings. Depending on the camera company, the raw converter program is either included in the camera package or has to be purchased separately. In the second case, it is worth comparing the price and performance with third party software. Whatever the program used, converting a raw image independently from the camera allows taking advantage of the regular evolution of software and processors and provides access to all range of solutions to improve the final result, such as using a better converter. Obviously, that is not the case when the conversion is done by the internal graphic processor of the camera.
With virtual imaging we are entering into the digital dimension of photography. Virtual imaging allows creating a representation that is no longer the direct transposition of an optical image but a mathematical construction based on the analysis of a series of photos. Three applications are particularly useful for use wear analysis. They are based on two different principles: the treatment of several photos taken under i) a single axis (focus stacking) or ii) different axes (photogrammetry).

Image stacking (also called z-stacking, depth of field stacking, multifocus or focal plane merging) enhances the depth of field of two dimensional views (fig. 9). This is particularly interesting in photomicrography (e.g. Thiéry and Green, 2011), especially when working with high resolution lenses. Image stacking can also provide three-dimensional reconstructions (fig. 10), the resolution of which depends on the number and regularity of shots. Photogrammetry is devoted only to 3D and has the capacity to reconstruct an entire volume (Pierrot Deselligny etClery, 2011). It works by assigning absolute coordinates to each point. In practice, both solutions are complementary because they have opposite requirements: whereas photogrammetry needs a wide depth of field, image stacking requires a low depth of field. Consequently, the only modus operandi at high magnification is image stacking (fig. 9–10) while photogrammetry is more appropriate at low magnification (fig. 11–16) and for whole objects. The inconvenience of image stacking is that the steps between each shot must be equal and that the Z axis has to be calibrated according to the shooting condition (Berejnov, 2009). Photogrammetry is much more flexible, except that the lighting has to be very dull and spatially uniform, with little shadow. As a consequence, it is the camera that turns around the object and not the opposite. It is possible in some cases however to have the object rotating in front of the camera: that is when the light can turn following the object or if the light is coming from all around the object. For instance, a good compromise in close-up photography is to use a ring flash attached to the objective (fig. 14).

Fig. 7. Long working distance Olympus LMPlanFL 10x/0.25 microscope objective coupled to a 70–300 mm telephoto zoom lens.

Fig. 8. Microscopic detail of pyrite grains encrusted in the crushed active edge of a Neolithic flint lighter (Mikolas burial cave, France). Shot with the combo of fig. 7. Post processed 16 million square pixels raw file from a Nikon D7000. On a BH2 microscope the frame would cover 0.95 mm. Scale 1 mm, graduation 100 µm.
Fig. 9. Microscopic detail of a usewear micro-polish on the edge of a Mousterian point (Angé, France), under bright field reflected light DIC. Single shot (above) and stacking by Helicon Focus of 25 shots (below) made with a Nikon D90 on an Olympus BH2 microscope which was driven by a stepped motor controlled by Helicon Remote via a Cognisys Stackshot Controoler. LM PlanFL 20x 0.40 objective and PE 2.5x projective. Scale 2/10 mm, the smallest white graduation on the scale is 1 µm.
**Fig. 10.** Helicon Focus 3D reconstruction from the 25 stacked photos of fig. 9.

**Fig. 11.** Views from different angles of an experimental sandstone abrader (32 cm length) used for shaping antler points. Nikon D80 camera with an AF Micro-Nikkor 60 mm f/2.8 objective.
3.1 Image stacking

Shots for image stacking can be done by progressively changing either the focus of the objective, or the distance between the object and the objective. Both solutions are geometrically different and have to be tested accordingly to the subject. In photomicrography, there is no other choice than to move up or down the object. In the auto-focusing range of the camera objectives, the step by step shooting can be directly controlled by software such as Helicon Remote, ControlMyNikon or DSLR Remote Pro. The preciseness and minimal distance of the step depend then on the camera or lens motor. In order to implement an automatic shooting with a manual focus lens or with a microscope, a mechanical device with a stepper motor that moves the object or the optical device is required, that is piloted by software or by an electronic controller. The most affordable and flexible solution is certainly provided by Cognisys Inc with the StackShot system. I am currently using this system for photomacrography above 1:1, with a bellow and microscope objectives, and for photomicrography with a microscope (fig. 9). The StackShot system can operate alone with its own controller or interfaced to a computer with Helicon Remote, which allows screen monitoring, or with Zerene Stacker. Helicon Remote can also control Trinamic stepper motors for

Fig. 12. Colored point cloud (2,039,476 points) produced by a PMVS2 based workflow (Archéovision — Plate Forme Technologie 3D) from the series of fig. 11 (total of 17 photos). An alternative low resolution reconstruction showing point cloud, wireframe and photographic texture is available at http://www.hypr3d.com/models/4f1ccff5b002e5000100002c/embedded_view.

Fig. 13. Cross section of a 3D model built with the point cloud of fig. 12.

Fig. 14. Device for photogrammetric shots at macroscopic scale: Canon EOS 1000D SLR camera with a Canon EFS 60 mm f/2.8 macro objective, 7 cm macro extension tubes and a ring flash, attached to a tripod.
Fig. 15. Shot from a series of 32 of the used tip of a Gravettian pick (Olga Grande, Portugal) (Plisson, 2009), taken in the Museum of Art and Archaeology of the Côa Valley with the device of fig. 14. Magnification 1.5:1.

Fig. 16. Dense colored point cloud (2 830055 points) produced by Photoscan from the series of 32 views taken with the device of fig. 14 and downsampled to 3.84 MPixels before processing for compensating the low depth of field. This is a Meshlab screenshot of the point cloud, not of the meshed model, nor of the meshed and textured one.

All those examples demonstrate that the quality of digital photos in traceology does not depend on the performance of the SLR camera but on the respect of some basic technical principles, since even ten years old models — nearly prehistoric — can produce fine images.
mechanical devices which request higher torque. However, with some skill and when a precise 3D reconstruction is not crucial, manual focusing with the graduated fine knob of the microscope stand can also give satisfying results and help for increasing the depth of field of 2D images.

Once the question of the stepped shots has been solved, the photos are sent for processing to another program. Various settings are usually available in order to match with a variety of conditions and objectives; it is important to make various tests in order to find the appropriate ones. Different focus stacking programs, more or less specialized, are available from various editors, from free (e.g. CombineZ, Picolay, Tufuse, Extended depth of field and Stack Focuser plugins for ImageJ) up to very expensive (e.g. Leica LAS Multifocus, Nikon NIS-Elements, Olympus Stream, Zeiss AxioVision), and including an increasing choice of middle price products (e.g. Helicon Focus, Macnification, PhotoAcute Studio, Zerene Stacker). However, according to my experience, Helicon Focus is the most flexible and complete one, allows the largest range of application and gives the best results with micro-wear polished (Ispia and Plisson, 2009). It integrates the entire process, at both low and high magnifications, from the initial pictures through to the final 3D modeling. The program can run on Windows XP, Vista and 7 and Mac OS 10.6 or later (and also on Android for what concerns Helicon Remote) and is compatible with various external devices. It takes less time to run the complete process than what is usually necessary to find the detail and the right angle showing what is relevant with a single shot.

The so called «3D Digital microscopes» are based on the same principle but their long working distance and their very small video sensor restrict the resolution of the 2D and 3D reconstructions. Furthermore, it is important not to be misled by the very high magnification claimed (up to 5000x!) which in fact does not correspond to the actual magnification of the objective but to the final enlargement on a large screen (empty magnification).

3.2 Photogrammetry

Photogrammetry is less constraining than focus stacking for acquiring the set of photos: the shots just need to overlap each other and to cover the whole surface or the object while taken from different points of view, with a difference of 10–20° between each shot (fig. 11). The distance from the object can vary. Anyone who knows how to use a camera can make a set of photos suitable for photogrammetry. The main constraint is the computing power requested for processing the image and on which depends the resolution of the 3D reconstruction. There is an increasing offer of solutions and two possible strategies: either to perform the 3D model with your computer, or to use a web service.

3.2.1 Software

Until recently, the choice was between very expensive professional programs or a free GNU licensed package (Bundler, CMVS and PMVS2 for point cloud extraction coupled with Meshlab for meshing and texturing) (Snavely et al., 2008; Furukawa et al., 2010; Furukawa, Ponce, 2010) running only on Linux OS. Integrated solutions for this open source package, SFMToolKit and more recently VisualSFM, have been designed for Windows and MAC OS to be more user friendly, but the installation is sometime laborious. For those who are not skillful with computers, two more user friendly programs are proposed by Agisoft for Windows XP, Vista and 7, Mac OS 10.6 or later, and Linux: Stereoscan and Photoscan. StereoScan is free and processes only stereo pairs; the reconstructed topography is dull but finely textured. PhotoScan (Verhoeven, 2011), which processes series of photos, is on the professional side, even with its very affordable standard edition. This is a very flexible software with many options and useful functions (photo masking, geometry editing, model merging, pdf export, etc.). Photoscan is able to process a large number of views without the image size limit of the PMVS2 based solutions, since it is not strictly dependent on the memory, and it directly generates a meshed 3D surface. The point cloud reconstruction is so dense that at full resolution a final texture mapping is not necessary for revealing the micro-topographical details (fig. 16). Both solutions have been successfully tested in various archaeological contexts (e.g. Ducke, 2011; De Reu et al., 2013; Plets et al., 2012; Skarlatos et al., 2012; Verhoeven et al., 2012).

3.2.2 Web services

Most web services which deliver 3D photogrammetrical models cannot be compared to the software discussed above since they are not designed for professional users but for everyone. They do not allow any adjustment of the parameters. You just upload your photos and download a while later the reconstruction. However, these web services can be useful for having an overall first view of the data before starting a long processing with your computer, or when you just need the outline of the subject, which is sometime already very useful. Among the services available in 2012, it is worth mentioning Arc3D, Autodesk 123D, Hypr3D and My3Dscanner, Arc3D (Automatic Reconstruction Conduit), operated at the Center for Processing Speech and Images of the Catholic University of Leuven (Vergauwen and Van Gool, 2006), directly delivers textured point clouds which are only a bit denser than the others when downloaded in obj format, but it also provides depth maps and associated files from which Meshlab can extract a dense reconstruction. Arc3D is the least tolerant to the presence of poorly focused zones in the image that is a drawback when magnification increases, however it has proved to be efficient for modeling archaeological excavation (Dellepiane et al., 2013). The least resolute models are generally from Hypr3D although the difference by comparison with what is produced by an optimized PMVS2 based workflow or by Photoscan is negligible (fig. 12 and see mentioned link). More critical here than resolution is the capacity to cover the whole surface or volume without empty or missing parts in the reconstruction. This aspect can constitute the main criteria of selection between these online services, along with the treatment of the holes and edges (the Poisson surface reconstruction used by My3Dscanner closes all the volumes and is resilient to data noise). It is also worth considering particular options such as depth maps (Arc3D), video processing (My3Dscanner and Hypr3D) or online model viewing and sharing (Hypr3D).

Another free service, Scannerkiller, a system based on stereoscopy, is also available on line but requires two cameras and a precise calibration, which makes the system less flexible than photogrammetry.

In any case, before using non-institutional web services for scientific purposes, moreover with unpublished documents, one must pay attention to the Terms of service and Copyright policy.

4. CONCLUSION

Whatever the solution chosen, nothing is irreversible as the acquisition of the photos and the processing are independent steps. From the same set of photos it will be possible to extract more and more information as the software progresses, which is not the case of scanner technology. This means that a good knowledge
of optical and photographic principles is still required not only for taking the best from actual digital imaging but also for having good archives ready for future. So far, 3D imaging in the field of use-wear studies, contrarily to other scientific branches, has not yet reached the step of concrete applications and could be perceived as mainly cosmetic. However this is because it was until very recently an inaccessible technology for most archaeologists, and also because of the diversity of tracological scales to cover from centimeter to micron which involves different techniques. Thanks to the constant increase of computing power, a new approach is becoming available which will soon find a large range of application: as always with a new technology, for doing differently what we used to do and also for achieving what was until recently impossible or very difficult to realize. Image stacking is already indispensable for pulling out of the fog the peculiar little features observed with the microscope. More fundamentally, as already pointed out by S.A. Semenov (1957: 41; 1964: 29), the third dimension can also help characterizing objectively use wear attributes (e.g. Bello et al., 2011), especially the attributes that were neglected in the absence of appropriate recording technique, such as the rounding of edges or the deformation of working surfaces (fig. 13; Adams et al., 2009).

The advantage is also evident for sharing observations between specialists, enriching databases (e.g. Betts et al., 2011), testing hypothesis through virtual reconstitution, and diffusing our work to a larger non-scientific audience. Nevertheless everything starts with the camera.

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