CMPLab

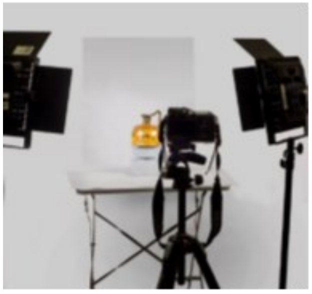
Centro Universitario de Mérida

METHODOLOGY NOTEBOOKS

HERITAGE DOCUMENTATION TECHNIQUES AND METHODS

3D modelling, digital photography and information dissemination

This series of notebooks aims to describe a set of techniques used mainly to construct and document the three-dimensional (3D) models and high-resolution photographs of archaeological objects. These techniques can be used to build models with a contrasting metric quality, calibrated colour and high resolution, to be disseminated on the Internet using various platforms and web services. The used material is integrated in the CMPLab of the University Centre of Merida and Kraken research group of the University of Extremadura (UEx).



Photoshoot preparation (above), Pentax 645Z camera and Go!Scan structured light scanner (below).

What are 3D models?

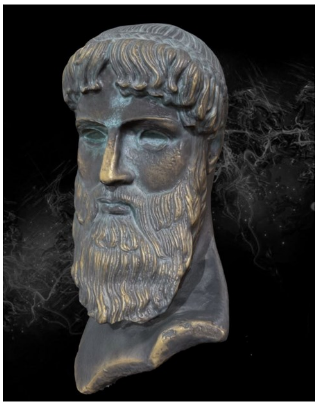
3D models are digital replicas of a real object that can be treated, represented and disseminated as any digital file.

The object is measured (digitized) to determine the shape of the object surface, and the measurement can also include colour, thereby achieving a more realistic representation of the original object.

At present, we can create 3D models of objects or scenes using two specific forms, which are treated in the notebooks: 3D scanning and digital photography.

A **3D scanner** is a device that analyses an object to obtain data regarding the object shape and geometry, and, in certain cases, the colour of the object. The collected information is analysed using specific software that allows the construction of three-dimensional digital models for many applications. Therefore, a 3D scanner can help digitize objects to ensure their availability in the virtual form and to access more information. A wide range of these devices with different characteristics and accuracy, and thus, different prices is available.

Another approach to generate 3D models is to obtain digital photographs using **image-based modelling** systems (IBM). IBM systems create a 3D model of an object or scene from a set of overlapping digital images that cover the entire object to be represented. Invariable elements are extracted from the consecutive images, and the geometry of the object is resolved simultaneously.



3D model of a reproduction of the bust of the god Zeus. See in: https://skfb.ly/6S8AT

Material used in the notebooks

Two Creaform Go!Scan 20 and Go!Scan 50 structured light scanners and a NextEngine desktop scanner were used to realize the scanning.

The digital photographs and IBM models were obtained using a Pentax 645Z medium format digital camera, Pentax fixed-focus lenses of 120 mm (macro) and 55 mm with automatic geometric correction, and NanGuang LED lighting panels with a colour reproduction index, IRC > 95. In certain cases, a Nikon D7000 camera with a Tokina macro lens with a macro of 100 mm was used, along with auxiliary material (backgrounds, tripod, etc.).

The computer applications were diverse, emphasizing the following:

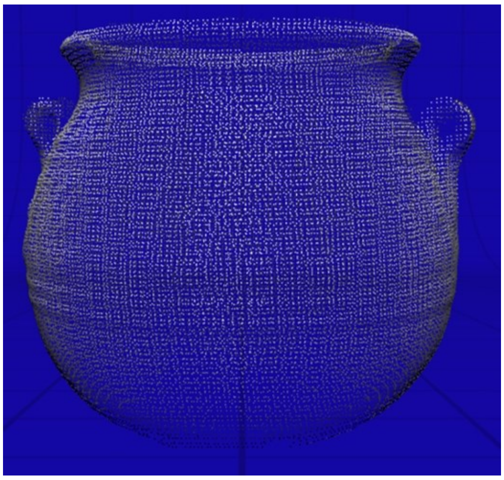
- VXScan/VXModel
- Agisoft Metashape
- Meshlab
- Cloud Compare
- Adobe Photoshop
- ImageJ
- DStrech
- Helicon Focus
- ICE Image Composite Editor

Basic concepts

When 3D model of an object is created using a scanner or digital photography technique, first, a **point cloud** or unorganized set of 3D points (X, Y, Z) is generated. This set is a discrete representation of the continuous surface of an object. The point clouds that constitute the object are initially dispersed and may be densified in subsequent steps or according to the selected resolution.

The point clouds are transformed into meshes of polygons or triangles in the surface reconstruction process. In a triangular mesh, the points in the cloud are used as the vertices of the triangles, and they are assigned topological properties. The number of meshes can be reduced by using generalization algorithms.

If colour information from a camera is available, we can determine the colours of the object surface and add texture or photorealistic information regarding the object mesh. The quality of the texture is of significance in the models of archaeological objects.

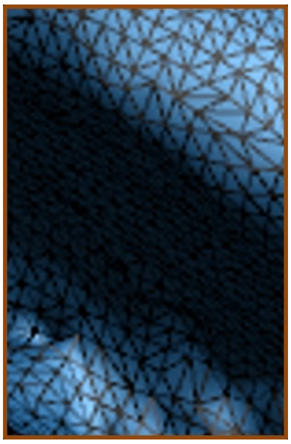


Point cloud from a vessel scan. The points constitute the object; however, the structure must be meshed to ensure that the vertices (points) have an associated topology.

We must limit the metric accuracy of the device used to generate the model (3D scanner or IBM systems) to determine the uncertainty in the shape and size of the model.

Moreover, we must evaluate the quality of the texture representation to create a model that is sufficiently realistic.

Mesh



Texture

Above left, image of the mesh built from the point cloud.
Above right, detail of the mesh.

Below left, 3D model without texture. The texture is not always necessary to perform a metric analysis.
Below right, final 3D model with texture.

3D scanner vs. IBM systems

As mentioned above, the 3D models of archaeological pieces are mainly developed using 3D scanners and image -based modelling. In the latter case, the models are derived from a set of overlapping digital photographs of the object, as explained in the following notebooks.

Both the techniques may be compatible and have specific strengths and differences:

3D scanner

• The metric accuracy is usually high, as high as a tenth of a millimetre, in certain equipment.

• The generated models are scaled and can be measured in real units.

• The learning curve is usually larger than that of IBM systems.

• The quality of the texture depends on the quality of the camera associated with the scanner.

Image-Based Modelling Systems

• The metric accuracy is often lower and less controlled than that of scanners.

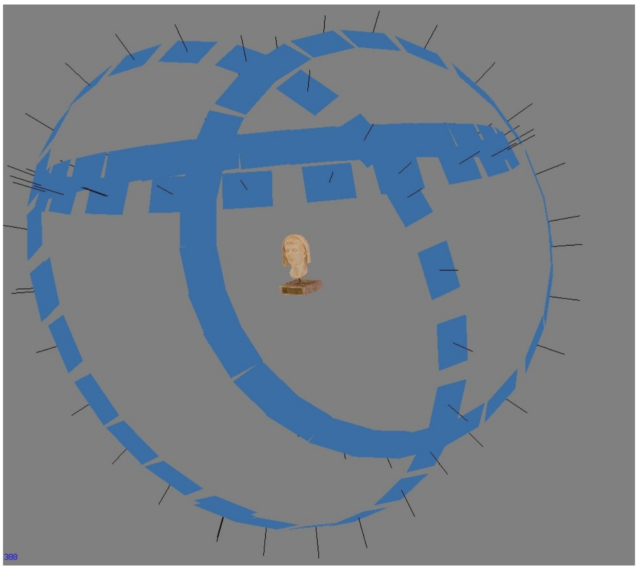
• The texture is of high quality, and this quality can be increased using colour calibration methods.

• Free or low cost applications and web services are available that can realize the model generation in an automated manner.

• The models have arbitrary units, and thus, we recommend photographing an element of known magnitude to later scale the result.

• Since only a camera is needed to perform the modelling using this system, and the cost of the equipment if reasonable, IBM systems have been widely applied in recent years.

Scanning a Roman glass cup reproduction by using the NextEngine desktop scanner.



Creation of a 3D model using IBM systems. Specific applications must be used to process a set of overlapping photographs (represented by blue rectangles) that cover the whole object to be modelled.

Weaknesses

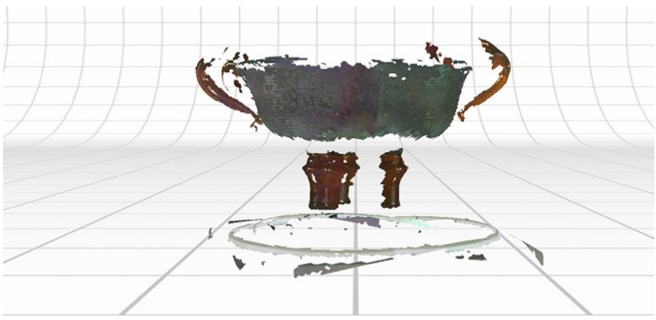
Both 3D scanners and IBM systems exhibit the following weaknesses:

• The processing time increases exponentially as the resolution required by the scanners or number of photos captured using the IBM systems increases.

• The final model is often very heavy and difficult to handle if extremely high resolution is selected (scanners) or many high resolution photographs are used (IBM systems).

• Not all objects can be scanned. It is often extremely challenging or impossible to model objects with a low reflectivity or transparent, extremely bright or specular objects. In such cases, the computer applications cannot find the homologous points due to optical problems.

The ideal surface is one that is light and opaque and exhibits Lambertian reflectance.



Erroneous result of scanning the glass cup reproduction. The scanner cannot create the model correctly due to the semi-transparent characteristics of the object.

CMPLab is the acronym for Data Capture, Virtual Modelling and Production/Prototyping Laboratory. CMPLab emerged from a project of the Infrastructure and Scientific-Technical Equipment Aid from the Secretary of State for Research and began operating in 2016. This laboratory works on research areas related to the construction of 3D models of archaeological objects, very-high-resolution photography, geophysical prospecting and applications of geomatics to cultural heritage.

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Kraken Group http://kraken.unex.es/

The Kraken research group is formed by people from different knowledge domains: geomatic engineering, earth physics, biology, telematics, agronomy, etc. Our nexus pertains to the capturing and processing of spatial data both at a detailed (3D models, graphic documentation of objects) and territorial scale (geographic information systems, remote sensing, geophysics, etc.).

Part of the production of these notebooks has been financed through the project GR18028 (Research Group RNM026), co-financed by the European Regional Development Funds (ERDF) and Government of Extremadura (Spain).

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Other notebooks in the series (methodology)

Left: 3D model of a Roman ceramic replica of black sigillata. The replica has a diameter and height of 10 cm and 14 cm, respectively. Photographed using a Nikon D7000 camera with a Tokina lens and 100 mm macro and processed using the Agisoft Photoscan Standard. The model can be accessed at **https://skfb.ly/VrYG**.

Middle: Projection of a structured light pattern on the surface of the object.

Right: 3D model of a Palaeolithic tool (approx. 10000 BC), captured without texture (see at **https://skfb.ly/6JOWJ**).

CMPLab

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METHODOLOGY NOTEBOOKS

CREATION OF 3D MODELS BY USING A SCANNER

Creation of 3D models by using scanners

This notebook describes the construction process of three-dimensional, high-resolution digital models of small and medium objects through scanning using a 3D scanner. These models reflect not only the shape but also the colour and can be distributed in standard formats (OBJ, U3D, etc.) for subsequent analysis. Moreover, the models can be used to build a virtual catalogue for dissemination on the Internet or to provide a basis for morphological and metric analyses.

Decisions:

Resolution and accuracy: from a few millimetres to microns. Scanner models suitable for the spatial resolution requirements at the 3D points must be selected. The scanners used in our projects have an error of less than 0.5 mm.

Texture: The simultaneous capturing of the colour of the object's surface is of interest in archaeological objects but dispensable in others applications.

Special interest points:

- Objects can be scanned to build digital models with the correct shape, colour and measurements.
- The models can be easily disseminated on the Internet, and on certain web sites, the models can be displayed in a virtual catalogue.
- The models can be used to measure the dimensions, prepare sections and, in general, allow the analysis of the object while eliminating the need to manipulate the object directly.

What is a 3D scanner?

A 3D scanner is a device that analyses an object to obtain data regarding the shape and geometry of the object. In general, objects are digitized to obtain their virtual form and to access more information.

An object is measured (digitized) to determine the shape of the object surface; however, the measurements can also include colour, thereby achieving a more realistic representation of the original object.

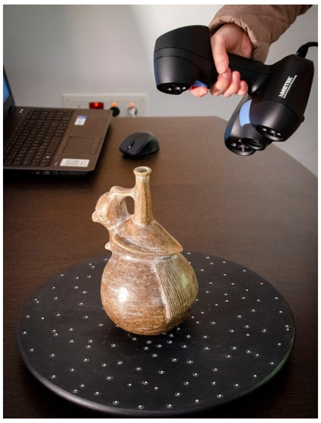
The general process usually includes the following steps:

Scanning: Using a 3D scanner, the coordinates of thousands of points on the object surface are measured in a non-contact process.

Construction of a metric model: Using computer applications, the possible errors are corrected, and a solid model with exact dimensions is constructed.

Colour capture: Performed along with the scanning by using built-in digital cameras.

The metric model can be used to attain measurements, profiles and sections, considering the fact that the distances involve an uncertainty ranging between 0.1 and 0.5 mm when using the above mentioned scanner models.



Go!Scan structured light scanner with colour capture.

Internet publication: The models can be transformed to be in a format that can be presented in a virtual catalogue, in which each piece can be rotated, enlarged and reduced at will.

3D modelling projects in museums

With the reduction in the price of 3D scanners and the consideration that this technique can add value to the observation and analysis processes, digitization projects are being commonly implemented in museums, galleries and other cultural institutions. Many such institutes use a specific hosting site for 3D models: *Sketchfab*. The site provides facilities to showcase the objects, illuminate the objects with lights of different types and tones, define the reflective properties of the surface, apply post-processing filters, allow downloads and write metadata. Several institutions have chosen this platform to disseminate the 3D models of their most iconic pieces:

- Museo Arqueológico Nacional
- Museo Maya de Cancún INAH
- Museu d'Arqueología de Catalunya
- The British Museum
- Museo de Pontevedra
- National Gallery of Denmark
- Archaeological 3D VM of Prague
- Natural History Museum of Barcelona
- Royal Museum for Central Africa
- Rnm-Grand Palais

Scanner characteristics

Several 3D scanner models are available. However, two main types of models are used for archaeological pieces: laser and structured light.

Laser scanners work by triangulation: A point illuminated by a laser sweeps the object, and its position is detected by a sensor. Based on the position of the transmitter and receiver, the XYZ coordinates of each point on the object in a local coordinate system can be estimated. **Structured light scanners** project a pattern on the object, similar to a QR code, which is read by photographic sensors. As the scanner and the object move relative to one another, the pattern is deformed as a function of the illuminated surface, which is interpreted to restore the shape of that surface.

A Go!Scan 20 and a Go!Scan 50 scanner are employed. The first scanner is used for objects with a size of up to 20–30 cm, and the second scanner is used for larger pieces with a size of up to 2 m.

Projection of a structured light pattern on the surface of the object.

In general, an object can be scanned without targets as the system can use the surface topography to identify and create the reference points. However, the use of the target on the turntable, or targets on the object, facilitates the task, allows higher scanning speeds and reduces the possibility of the scanner being "lost".

Preparation

For moderately sized pieces, the object is first placed on a black-surfaced turntable with a series of white reflective targets. The targets function as reference points that help the software determine the relative position of the scanner to the object (self-orientation). The scan is performed by slowly rotating the table to sweep the entire object and moving the scanner over the piece. The occasional loss of auto-orientation can be easily corrected considering the targets. The targets are adhesive and can be placed, if necessary, on the object itself if the integrity of the piece is not compromised. The diameter of the targets depends on the scanner model, and the distribution of the targets should preferably be irregular.

Below: Scan of the Jarro de Siruela. (7th to 6th centuries BC) Archaeological Museum of Badajoz (Extremadura, Spain).

Scanning process

Once the object has been placed, scanning is performed by sweeping the object with the scanner at a distance ranging from 30 and 50 cm from the object surface. Since light is projected, the area should be in darkness to introduce as little noise as possible. The scan is directly visible on the computer screen, and it can be easily verified if any hidden areas or places have been overlooked. The process can be easily stopped (as the scanner operates through a trigger) and continued in the same area. Raw data appear on the screen, and in certain periods, the scanning can be stopped and the data can be processed; this process, depending on the resolution that has been defined, can take several minutes. The scan of an object can be single or composed of several independent scans. The latter approach is adopted when the object cannot be completely scanned without changing its position. In the case of two or more scans, the scans must be merged in the post-processing phase.

Video of the scanning process

The video shows the scanning process, as seen on the screen. The light blue area indicates the active area. In the first few seconds, a dark blue area can be seen, which means that the scanner has not yet been oriented. The vertical coloured bar on the left of the active window shows the distance from the scanner to the object. If the distance is correct, the bar appears green and the measurements can be obtained. If the distance is excessively small, the bar first appears in yellow (caution) and later in red (out of range); similarly, if the distance is excessively great, the bar appears in blue. When the scanner is out of range, it cannot record the measurements. The blue circles that appear on the figure are the points of support created during the scanning process. In the case of a plaster bust, as in this case, the figure does not need to be moved, and the non-scanned base can be closed through a plane. In other cases, two scans are performed, which are later merged in the post-process phase to obtain the complete figure.

The video can be viewed on YouTube : https://youtu.be/QzClCSS5wAM

Post process

After scanning an object, we obtain two or more point clouds; typically, one of the clouds includes the upright piece and the other one includes the inverted piece, to scan the base and lower parts of the object. If the piece is large, several partial scans may need to be performed.

The first phase of the post-processing process involves removing all the points in the cloud that do not belong to the object (table or bottom, for example), as well as the incorrect or disconnected points.

The second phase involves the merging of the point clouds on the screen by identifying a minimum of three homologous points in each scan. The software does not require perfect alignment; specifically, the software seeks the best fit from an approximation and automatically aligns the scans.

Once the point clouds have been merged, the corresponding mesh is generated, and any problems (holes, improper triangles, etc.) are detected and corrected. Finally, the mesh is simplified to reduce its size, and the colour of the object is superimposed on each point.

The final stage usually involves exporting the model to a certain format readable by other programmes. When only the shape and no texture is present, the STL format is used. When the model involves colour, the OBJ format is suitable; in this case, the texture is associated with a JPG or BMP file. The review and edit processes are realized using free programmes such as Blender or Meshlab.

Known issues

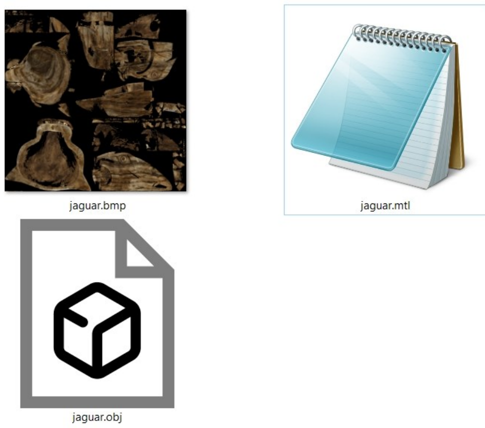
Not all objects can be scanned. As the method consists of projecting light on a surface, certain characteristics may prevent the scanning from being realized. Specifically, it is not possible to scan glass or transparent objects; moreover, objects with low reflectivity or specular surfaces cannot be scanned. The ideal surface is light and opaque and exhibits a Lambertian reflectance.

Above left: 3D model of a jar (7–6th century BC) approximately 15 cm high, from Aliseda, Cáceres (MAN 28583): Example of a complex object with partial transparency and reflections (see at **https://skfb.ly/6JPot**).

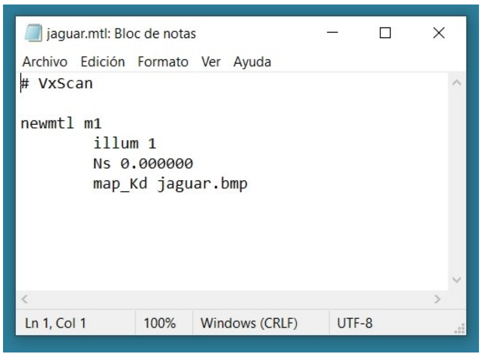
Above right: 3D model of a Palaeolithic tool (approx. 10000 BC), captured without texture (see at **https://skfb.ly/UBnP**).

Formats

Among the formats applied to 3D models, **OBJ** is one of the most popular mesh file formats used in 3D applications. Developed by Wavefront Technologies, an OBJ file contains the 3D coordinates (polygonal lines and points), texture maps and other object information. This well-known format consists of 3 files: one file with the texture map (bmp, jpg or png), one file with the geometric information and one mtl file that relates the two other files.



Another format of interest for the considered 3D modelling process is the **U3D** (Universal 3D), a standard compressed format defined by the consortium 3D Industry Forum, which involves companies such as Intel, Boeing, HP, and Adobe Systems. This format was later standardized by ECMA International (European Computer Manufacturers Association).



The **STL** (stereolithography) format developed by 3D Systems is commonly applied for 3D printing. The format was implemented to promptly transfer data from 3D CAD models to 3D printers. The main limitation is that the format contains information regarding only the object geometry and not the texture or colour.

Above: OBJ format, retains geometry and texture. The format is composed of 3 files: bmp, jpg or png (texture map), mtl and the obj.

Below: mtl file that corresponds to the texture.

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KRAKENGROUP
SPATIAL DATA ANALYSIS, GIS AND REMOTE SENSING

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LOW-COST DESKTOP SCANNER

Desktop scanner NextEngine

This notebook describes the mechanism of operation of the low-cost NextEngine desktop scanner designed for scanning small objects. The operation is based on an original technology known as multi-stripe laser triangulation (MLT), which involves projecting a multiple laser band using two twin arrays of four lasers (red, 650 nm) and recording the position of the points through a CCD camera. More information can be found at http://www.nextengine.com/

Low-cost Next Engine desktop scanner.

Points of special interest:

- A desktop scanner requires a flat surface for operation, on which the scanner and turntable are located.
- Portable (weighs approximately 3.2 kg) and can be mounted on a tripod.
- Two working modes: macro (small objects with a size of up to 96×129 mm, accuracy of 0.13 mm) and wide (objects with a size of up to 420×570 mm, nominal accuracy of 0.38 mm).
- Proprietary software (ScanStudio and ScanStudio Pro) with functionalities to export the model to CAD.

Workflow 1: scanning by planes

Scanning is performed by placing the object in front of the scanner on a turntable. The scanning mode is selected depending on the shape of the object. The most complete mode is the 360º scan, which is performed in planes (number ranges from 4 to 12).

The scanning time depends on the size of the object, resolution and number of planes required. The time can be several hours in extreme cases.

In the process, the scanner automatically merges the scan planes to generate a unique set of tens of thousands of points with 3D coordinates, on which it superimposes the colour captured by the cameras.

The hidden areas are covered by moving the object and performing the scan in another position. The different models are later merged by identifying the common points.

The scanner has a 1248×864 pixel camera. The camera has a limited resolution, which is sufficient for the model but not for the documentation involving certain quality requirements.

To record the photographs, the object is illuminated using LEDs, and thus, the scanner can be operated in an environment without light.

The colour is captured through LED lighting and an internal camera.

Left: side view of the ceramic piece used in the example (Minoan cup replica).

NextEngine is a short distance scanner and cannot be applied to scan large parts.

As in other cases, it is difficult to scan glass or shiny pieces, although the objects can be coated using inert or magnetic powder.

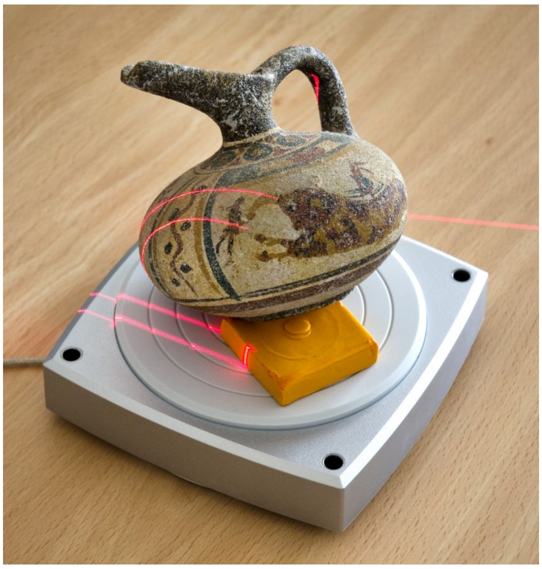
Workflow 2: fusion of models

A triangle mesh is built from the point cloud, which can be simplified according to the project requirements. Since every model involves hidden areas (such as the base, in most cases), it is necessary to build at least two models and later merge the models.

It is usual in the case of potteries to scan in 90º positions (vertical and lying down).

When two or more different scans are available, the scans must be aligned. This process is a semi-automatic operation and implementing by selecting at least three common points between both scans. As the final model is not error -free, a series of topological error correction, hole closure, noise reduction, and mesh smoothing operations must be performed before exporting the model.

As only a few software options (ScanStudio) are available, the mesh can be exported for debugging in another specific application.



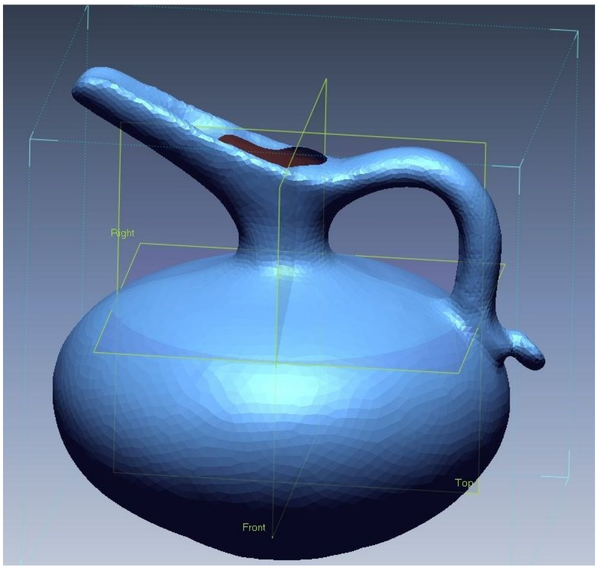
Scan in oblique position to cover areas not visible in other positions.

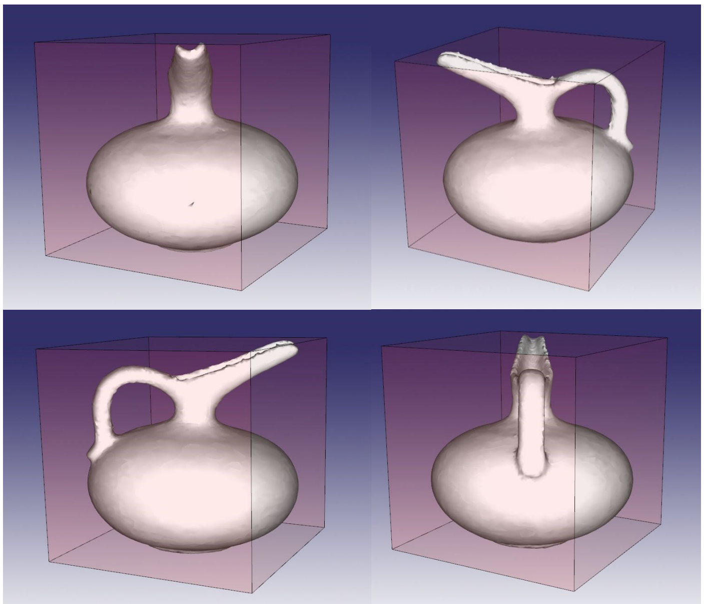
Workflow 3: views, sections and dimensions

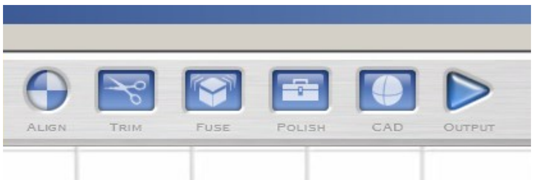
A general utility is to obtain normal views to the symmetry planes. These views are with reference to a reference system that enables the realization of the measurement, sections and dimensions. Similarly, on a computer, the model can be rotated, enlarged and reduced for observation from any point of view.

If necessary, incomplete objects can be "filled in" by assuming certain axes or planes of symmetry, and thus, the basic measurements and shapes can be estimated even in the case of missing fragments.

The Scan Studio Pro software provides a set of tools, for instance, to extract the boundary splines, compare the scan data and CAD data and perform the orientation to define the origin and position of the scan in a global coordinate space global coordinate space.







The workflow is simple and mostly automated. After scanning the object in several positions, if necessary, the remaining parts are cut out and the different scans are aligned. After correcting the topological errors, the scan can be saved in the CAD format (if the option is available in ScanStudio Pro). For more complex adjustments, another mesh treatment application can be used.

Shape and measurements

The models allow the extraction of metric data of various types and not only the dimensions; the data may include the volume of the piece or the relations among singular points. The graphs that connect these points can be compared using statistical techniques such as the Procrustes method to implement morphological changes in a time series objective, among other operations.

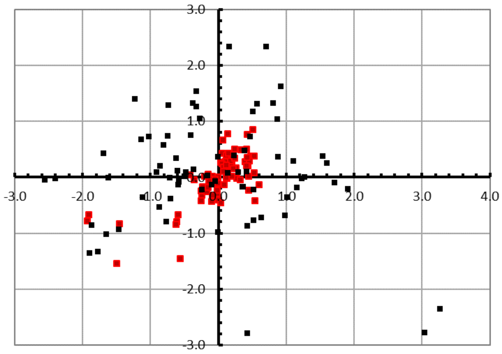
The graphs and all other statistical objects can be part of the metadata associated with the piece.

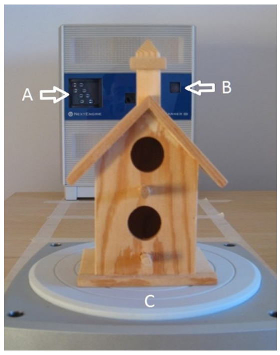
Errors and uncertainties

Repeatability studies of this scanner show that the uncertainty in the macro mode is approximately half that of the wide mode, and the determined accuracy is significantly less than that indicated by the manufacturer.

More information is available at:

Polo, M. E.; Felicísimo, Á. M. (2012). Analysis of uncertainty and repeatability of a low-cost 3D laser scanner. *Sensors*, 12 9046-9054. DOI: [10.3390/s120709046](https://doi.org/10.3390/s120709046)





The material needed to scan is limited: only the scanner, turntable, computer and specific software are required. The turntable is an auxiliary element of the scanner and must be placed with the cable fully extended when using the wide mode.

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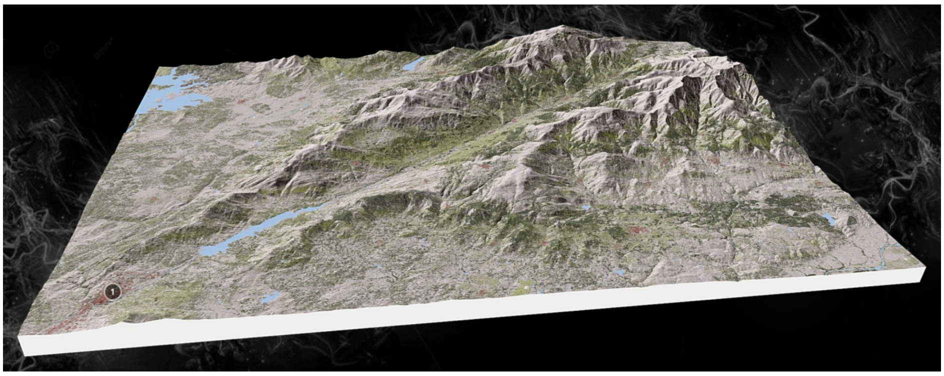
Other notebooks in the series (methodology)



A ***block diagram*** *is an image that represents the terrain in perspective, to provide a better understanding of the topography, land cover or other features that may not be available in two-dimensional representations, such as plans and maps. An* ***interactive block diagram*** *is a 3D model that can be rotated, enlarged or reduced through a specific application.*

This block diagram represents the Valle de Jerte (Cáceres, Spain) and can be observed here.

Espigüete Peak, Palencia, Spain

Using the interactive diagram blocks, animations simulating flights or, as indicated on the left side, rotating the block can be generated. The diagram blocks are hosted on the Sketchfab platform, and we have created a channel on YouTube with themed playlists to display the animations in which the model rotates 360º. In this case, the original block diagram corresponds to the environment of Espigüete Peak in northern Palencia, Spain.

Centro Universitario de Mérida

PHOTOGRAPHY NOTES: EXPOSURE

Photography notes

This notebook and the following notebook summarize certain basic notions of digital photography. This section is focused on the aperture, shutter and sensitivity of a camera.

Aperture

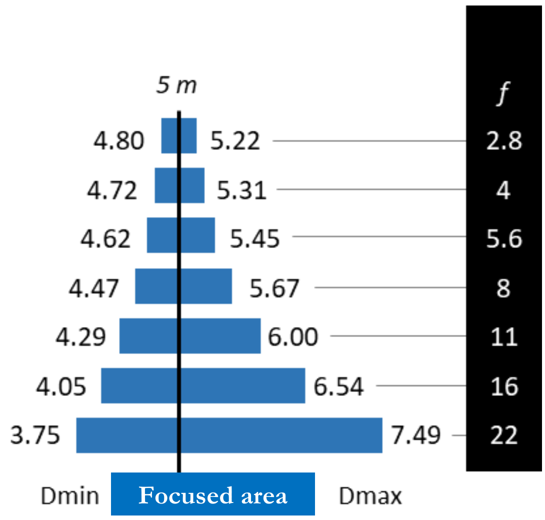
The **aperture** controls the amount of light that falls on the sensor. The control is realized by opening or closing the **diaphragm**, a device that functions similar to the pupil of the eye.

Aperture values (f)

The different apertures or pupil sizes in the diaphragm follow an unintuitive numerical scale based on the parameter f. The standard series of f-numbers is 1.4, 2.0, 2.8, 4.0, 5.6, 8, 11, 16, 22, 32, and so on. The f-numbers increase as the diaphragm closes, and the difference between two numbers corresponds to half the amount of light: specifically, an f=5.6 lens allows two times as much light through as an f=8 lens and half as much light as an f=4. lens The availability of specific values depends on the lens: certain lenses have maximum aperture values of f < 1, and many lenses have maximum aperture values of more than 32. To attain the correct exposure, when the f-value changes, the shutter speed must also change as compensation.

Examples of diaphragm aperture value

Nikon D850, depth of field
Focus at 5 m; 100 mm lens



Effect of the depth of field

Depth of field (DoF) represents the area between the nearest and furthest points at which the image is considered to be in focus. The depth of field increases as the aperture decreases. Other influential factors include the focal length of the lens and focal distance.

The graph on the right shows the minimum and maximum distances corresponding to a focal distance of 5 m (16 ft.). At f=16, the DoF is 2.49 m (between 4.05 and 6.54 m). However, at a focal distance of 10 m (33 ft.), the DoF increases to 12.28 m (between 6.78 and 19.05 m).

The DoF should be checked to ensure that the object is completely in focus or if the background is diffuse.

The PoC values can be determined using specific calculators.

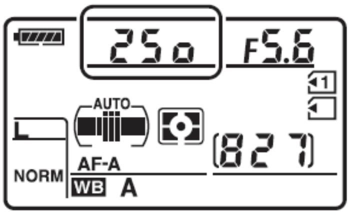
Effect on image sharpness

The sharpness and presence of chromatic aberrations and distortions of an image vary according to the aperture f-value, mainly due to the diffraction effects on the pupil of the diaphragm. At the optimal f-value, these problems are minimized. Less sharp diaphragms are always at the extreme values, and an intermediate f corresponds to the optimum value, usually, approximately f:8. In the case of a zoom lens, the aforementioned properties may vary for each focal length value. When seeking the highest possible sharpness, the f-value must be close to the optimum, and the whole object must be included within the limits of the depth of field (unless a different effect is desired).

Shutter

The **shutter** controls the time for which the light penetrates the lens and strikes the sensor, using movable curtain or blade systems that open or close the light path.

The shutter speeds or **exposure times** are expressed in seconds or fractions of a second: 1/100, 1/250, 1/500, etc. where, logically, an exposure of 1/50 of a second means twice as much light as that for 1/100 and half as much light as that for 1/25. To ensure the correct exposure, if the shutter speed changes, the aperture f must also change to compensate for the total light. Specifically, if the shutter speed is doubled, the aperture must open one passage to ensure that the total light incident is preserved.



f	*s*
2.8	1/800
4	1/400
5.6	1/200
8	1/100

Above left: Equivalent combinations aperture and speed.
Above right: gear control on an analogue camera.
Left: information display on a digital camera.

Shutter and movement

The use of higher or lower shutter speeds depends primarily on the available light, as the correct exposure must be ensured. Within this general condition, several speed–diaphragm combinations can be applied. Low speeds (1/1000 s, for example) are selected when the subject to be photographed is moving and we wish to "freeze" the object to achieve sharpness. High speeds are selected when the subject is static or the objective must be "moved" for a specific application.

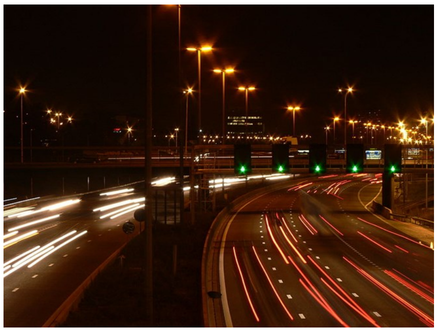


Figure: On the left, a speed of 1/60 s has been applied, to limit the movement of the cars even though the cars are not perfectly "frozen". On the right, an exposure time of 1 s has been used, and the movement of the headlights is considerably more evident. The illumination of the streetlights is the same in both photos as the lights are static. This principle applies both to cases involving moving subjects or a moving camera (on board a train or car, for example).

Long exposures

Holding the camera manually is not suitable beyond an exposure time of approximately 1/60 s, as it is difficult to prevent movement. Long exposures are necessary when ambient light is scarce or when a depth of field corresponding to a decreased aperture is necessary. In these cases, it is necessary to use holding systems such as tripods, monopods, or copy stands. All these systems can help keep the camera fixed, while the shooting is performed using cable, infrared or timer based systems to ensure that the camera remains static when shooting.

Left: remote infrared trigger.

Right: fixed camera on rail.

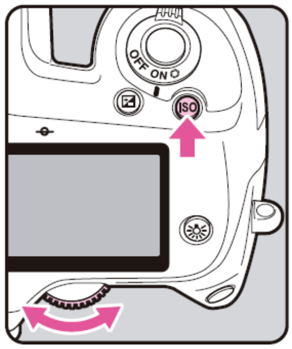
Sensitivity

Each sensor exhibits a **sensitivity** to light that is defined by an ISO value. This value can be modified until appropriate lights condition settings are implemented.

Sensitivity values

The values on the ISO scale (standard 12232) are derived from analogue photography, in which each film had a specific sensitivity that made it suitable for various light conditions. The common values are: 100, 200, 400, 800, 1600, and so on, and in each step, the sensitivity is doubled. If the value changes from 200 to 400, the aperture can be closed by one step or the shutter speed can be reduced by half.

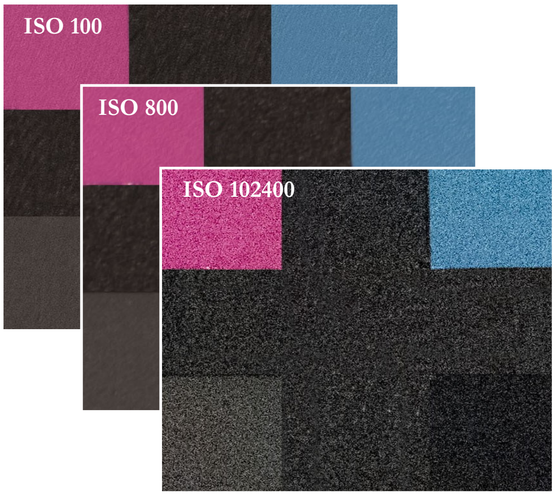
In general, the sensitivity should always be set at the lowest value, which coincides with the native and actual value of the sensor. The ISO value should be increased only when necessary because, as described in the following section, an increased value negatively influences the quality of the photograph.



Sensitivity adjustment in the Pentax 645Z camera.

Sensitivity and noise

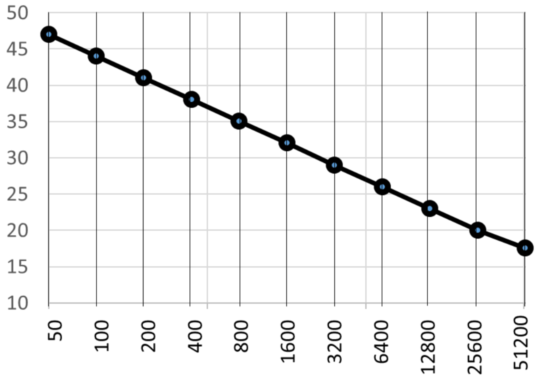
The increase in sensitivity is implemented artificially through the electronic amplification of the sensor output. This amplification increases both the signal intensity and noise, and in low light, the relationship between the two aspects weakens. The noise appears as a random dotting, which is especially visible in uniformly coloured areas and dark areas. It is advisable to perform testing to establish the maximum acceptable ISO that can be used in low light situations.



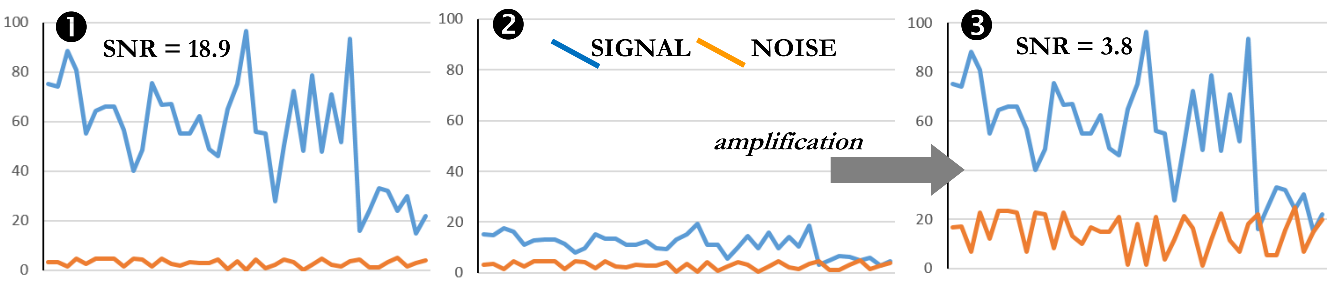
Right: Correctly exposed shots with different ISO values for a Pentax 645Z.

Sensitivity and signal/noise ratio

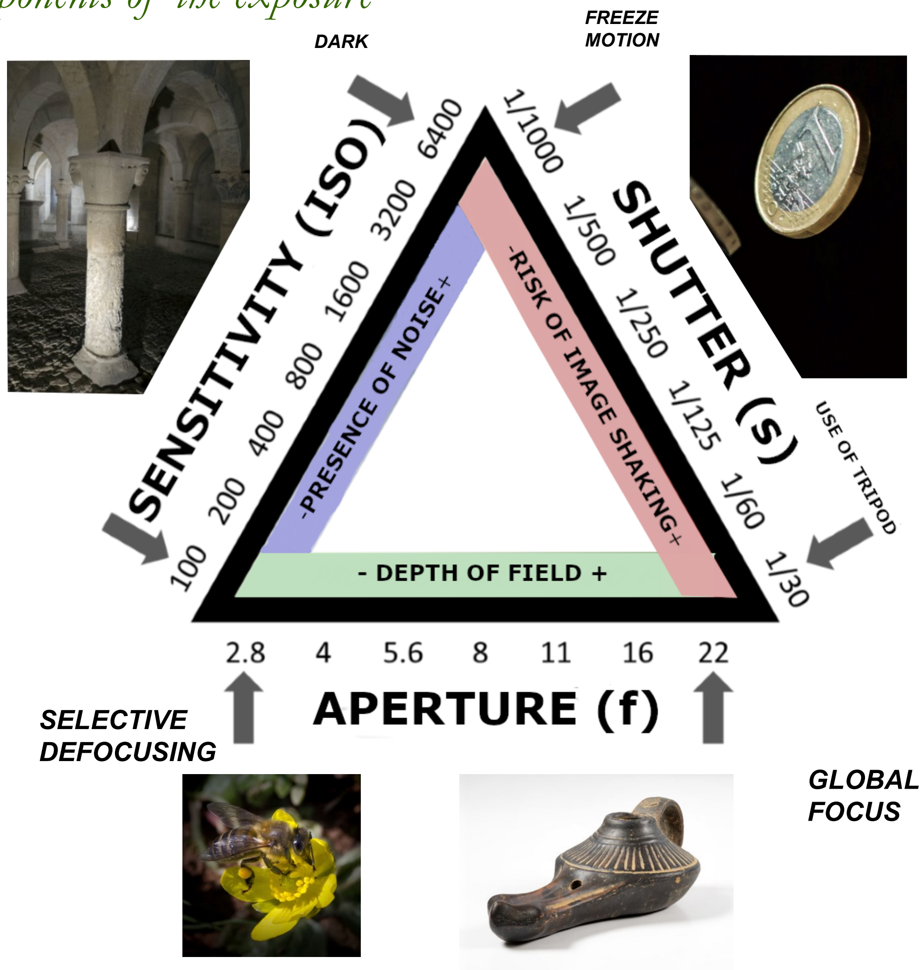
The signal to noise ratio (**SNR**) indicates the relationship between the actual image information levels and the random, non-significant values generated by the electronic activity of the sensor. The effect of increasing the sensitivity ISO value is that the SNR decreases, thereby degrading the image. The figure on the right is a graph of the relationship of the ISO and SNR, where the SNR is presented in the logarithmic scale. The minimum acceptable SNR should be set according to the lens of the photographs. For a photograph of archaeological objects, the SNR should not be less than 35.



Below: Signal and noise in 1) a well-light image, 2) in a low-light image, 3) number 2 magnified, increasing sensitivity.



The components of the exposure



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CMPLab
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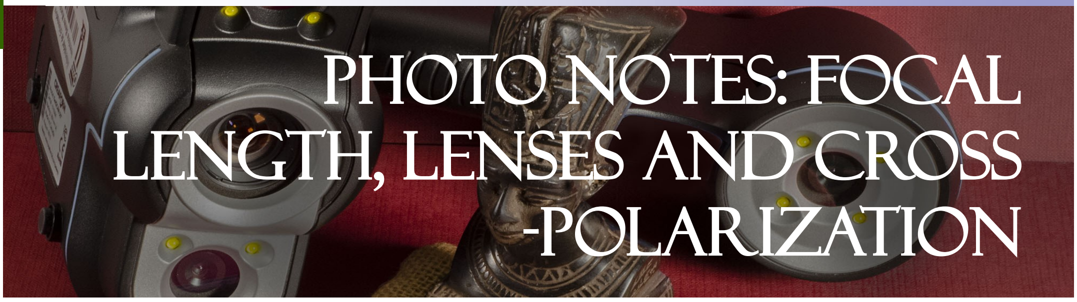


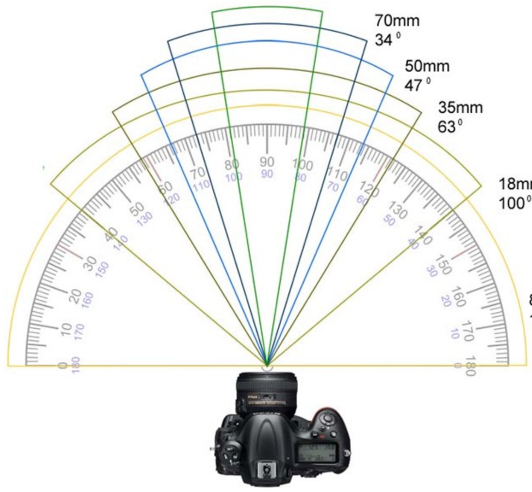
PHOTO NOTES: FOCAL LENGTH, LENSES AND CROSS -POLARIZATION

Focal length and shooting angles

The **focal length** (FL) is a property of lenses that determines the angle of view or coverage of lenses, and consequently, the part of the scene captured by the sensor.

Formally, the distance or focal length of a lens is the distance between the sensor plane (focal plane) and optical centre of the lens assembly. The focal length and angle of view (α) exhibit an inverse relationship. A larger focal length corresponds to a smaller angle. The image on the right shows the correspondences among certain values. For instance, a 35 mm FL lens captures images with a viewing angle or coverage of 63°.

Nevertheless, this angle depends on both the focal length and sensor size. The angles in the figure correspond to an FF sensor (full frame, 24 × 36 mm) considered as a reference. Note that an 8 mm lens covers 180°.



18 mm

50 mm

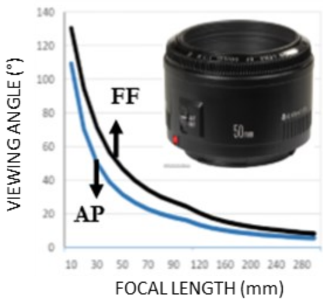
200 mm

Angles and sensors

$$\alpha = 2 \cdot \arctan\left(\frac{d}{2f}\right)$$

The angle of coverage or view α depends on two parameters (upper equation): **d** and **f**, where d is the diagonal of the sensor in mm (43.3 mm for an FF sensor) and f is the focal length of the lens, also in mm. To calculate the angle of coverage for a 100 mm lens when using sensors larger or smaller than an FF, the value of d can be changed. For example, the APS-C sensor of the Nikon D7000 (23.6 × 15.6 mm) has a diagonal of 28.3 mm; for this value, the angle α of a 100 mm lens and FF sensor is 16.1° and 24.4°, respectively.

In this regard, the same lens has different coverage angles depending on the size of the sensor: smaller sensors correspond to smaller angles for the same lens. In the case of the Nikon D7000, the 16.1° coverage angle of the 100 mm lens corresponds to a 150 mm lens on a full frame sensor. The ratio df(s)/df(FF), where df(s) is the apparent focal length of a lens for a given sensor, and df(FF) is the focal length of the same lens on an FF sensor, is known as the crop factor. For the Nikon D7000, with an APS-C sensor, the crop factor is 1.5: the coverage angle of a 100 mm lens corresponds to that for 150 mm on an APS-C as the size of the sensor is different from that of an FF.



Viewing angles for full frame (FF, black line) and APS-C (blue line) sensors. The values correspond to a 50 mm lens.

Types of lenses

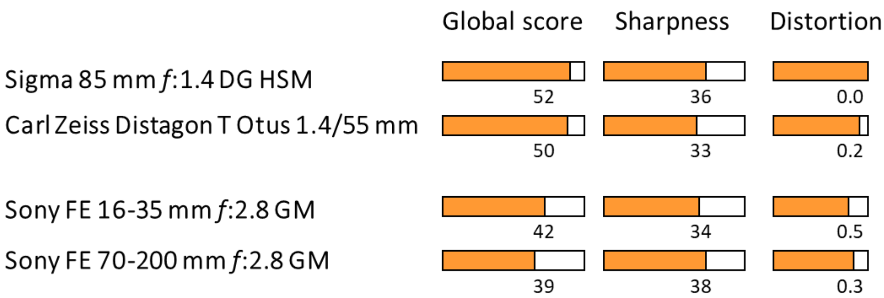
The lenses allow the image to form clearly on the sensor. Different types of lenses can be designed to solve various problems and situations.

Based on the stability of the focal length, lenses can be classified into two classes:

- Fixed-focal length (*prime lenses*).
- Variable focal length (*zoom lenses*).

Zoom lenses have a variable focal length, and therefore, the angle of view can be changed using either a manual ring or a motorized system that reconfigures the position of the lenses. An examination of the lens analyses in DXOMark shows that in terms of the optical quality, fixed-focal lenses systematically outperform the zoom lenses. Similarly, the maximum aperture is usually smaller in the zoom range and variable in the focal length range. The quality–versatility balance must be ensured according to the purpose of the photography.

28-105mm zoom lens.



The figures on the left show the two best fixed-focus and zoom lenses analysed using DXOMark, along with the associated overall score, sharpness, and distortion values. The full analysis is presented in

https://www.dxomark.com/Lenses/

Macro lens

The **magnification factor** of a lens is the ratio between the size of an object and its projection on the sensor at the minimum focusing distance. The magnification factors and minimum focusing distances of normal lenses do not allow small objects to be photographed in detail. Macro lenses are designed to perform **macro photography**, i.e., the photography of small objects such that the lenses occupy as much of the sensor as possible, thereby achieving a high resolution.

Right: Image captured using a 120 mm Pentax macro lens and FA = 1: 1. The original image has a resolution of 51 megapixels, and the theoretical resolution is 0.0025 mm/pixel (415 pixels per mm).

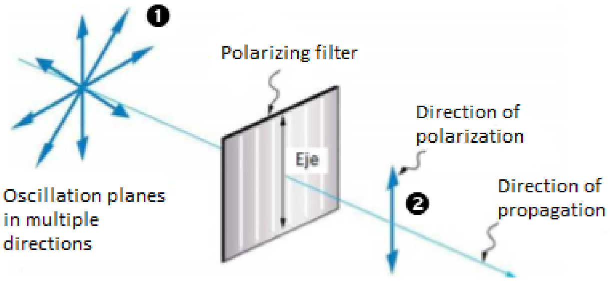
Extreme Focal Lengths

Typically, the focal lengths range from approximately 10 to 500 mm. A lens with DF<15 mm or DF>300 mm is termed as a wide-angle lens or telephoto lens, respectively. The choice of the DF depends on the purpose and conditions of the picture. A wide-angle lens has a wider shooting angle, greater depth of field and greater brightness.

Right: image captured of the Temple of Diana (Mérida, Spain) at a wide angle with DF = 15 mm.

Cross-polarization

Cross-polarization is a lighting technique that aims to reduce the brightness of the object by using a polarizing filter for the light and camera.



Light polarization

Light is a form of electromagnetic radiation, whose electric and magnetic fields oscillate in multiple directions perpendicular to the direction of propagation ❶. A polarizing filter allows the light to pass only in a certain direction of oscillation of the electric field and absorbs the remaining light ❷.

The light transmitted by the filter is known as **polarized light** and, logically, the intensity of this light is lower than that of the light incident on the filter since the light has been partially blocked. In photography, the difference corresponds to two aperture points.

Procedure outline

Photographic equipment

- camera (Pentax 645Z with Pentax 120 mm lens).
- LED panels (Bicolour NanGuang with IRC > 95).
- tripods (cross-polarization reduce light ~4 *f-steps*).
- linear polarizing sheet (Polarization.com) ❶.
- circular polarizing filter for the lens ❷.

Procedure

The subject is illuminated with polarized light (polarizing film ❶ in front of the light source) and photographed using a camera with a polarizing filter ❷placed in front of the lens. The latter filter is turned to identify the orientation that blocks the specularly reflected light (brightness of the part) to capture the picture.

Results

The left image is one captured using two lighting points, and the two areas of intense brightness are evident. In the right image, the same object is illuminated using the cross-polarization technique. It should be noted that this technique slightly changes the colour saturation and contrast. These effects can be corrected through a session-specific calibration using, for example, a standard colorchecker and generating a colour profile for the correction.

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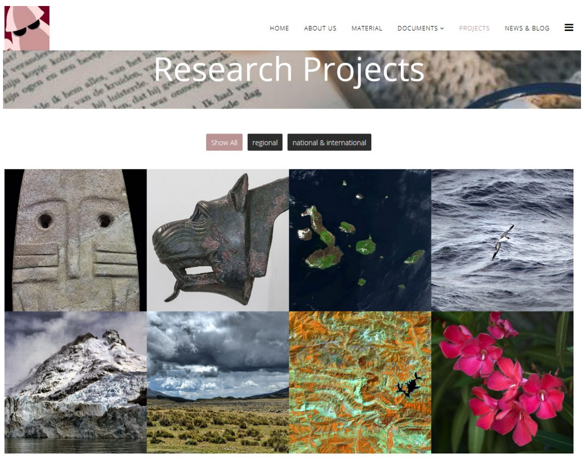
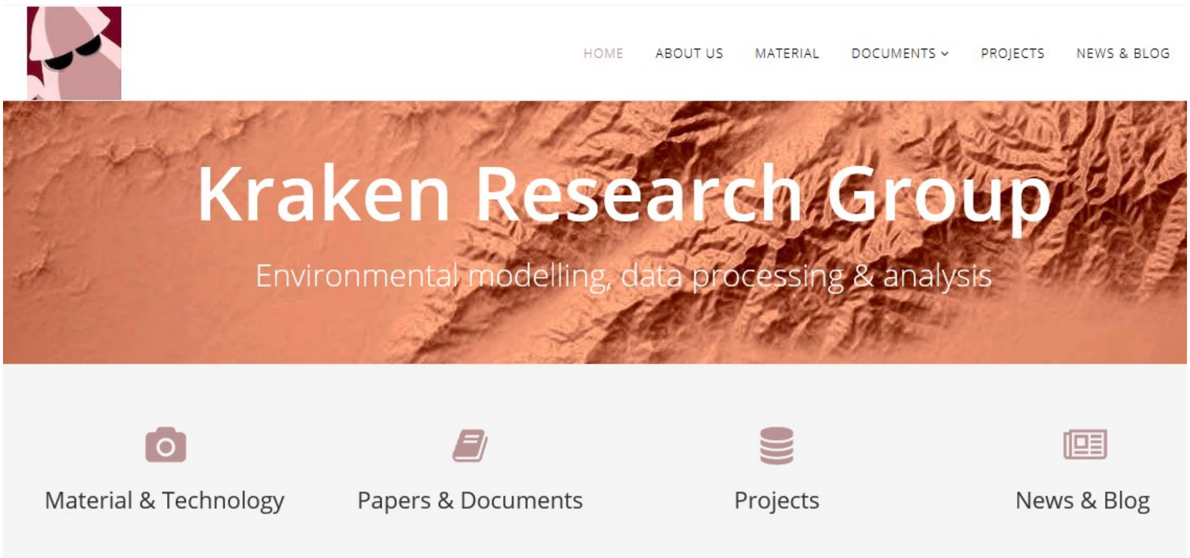
Kraken group web

The group's website hosts various documentation:

- Materials used in the investigations.
- Papers and communications to congresses, published by the members of the group.
- Results of teaching and tutoring as end of degree, master's works and doctoral theses.
- Completed and in-progress research projects.
- Latest news regarding the group's activities.





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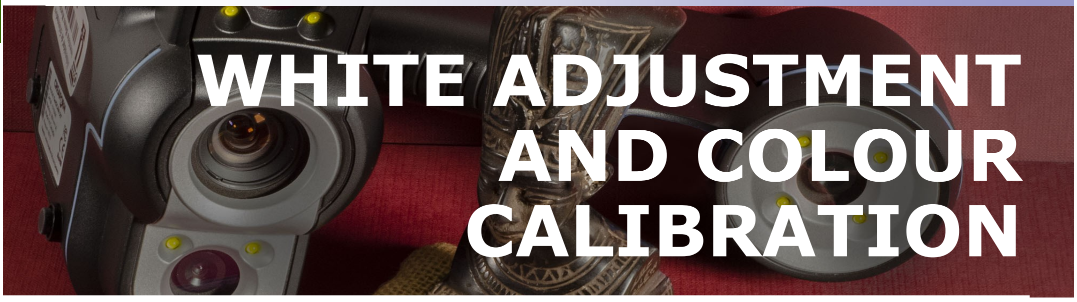
METHODOLOGY NOTEBOOKS



WHITE ADJUSTMENT AND COLOUR CALIBRATION

White adjustment and colour calibration

This notebook explains two techniques to improve the colour in photographs, intended, especially, for the construction of 3D models. Although other more complex procedures can be performed, the described techniques are easy to apply and sufficient in many application cases.

CMPLab is a laboratory at the University Centre of Mérida, at University of Extremadura in Spain. It was created as a result of a project presented to a call for Funding for Scientific and Technical Equipment and Infrastructures from the Secretary of State for Research, and began operating in 2016.

The CMPLab and its associated research groups use material for documenting cultural and archaeological heritage.

Special interest points:

- The colour fidelity depends on both the light and camera sensor.
- The overall light tone can be corrected through the so-called white adjustment, which changes the overall values of the colour components.
- A more accurate adjustment can be achieved by creating a colour profile, using which, both the light and camera sensor biases can be corrected in a given session.

Light problems

The perception of colour depends on several factors, especially, the type and characteristics of the light using which the object is illuminated. Illumination using an incandescent bulb or a flash yields different results. In the case of natural light, the illumination at midday on a clear day or in the evening on a cloudy day lead to considerably different results.

The key difference in these situations is the intensity of the light at each wavelength of the visible spectrum. If we illuminate a painting with an incandescent bulb, a dominant yellowish tint may be observed. This phenomenon occurs because the light involves mostly long wavelengths in the red to yellow area and contains only a few blue tones, which have a shorter wavelength.

According to this scheme, the ideal light exhibits the same intensity at all wavelengths. In a flash, the light is generated by the excitation of the xenon gas contained in a sealed tube, subjected to a high voltage discharge. This light contains all the wavelengths, with moderate peaks and valleys at certain frequencies. Therefore, this light is a white light and suitable as a light source.

According to another perspective, the ideal light imitates the emission spectrum of the Sun, and although certain

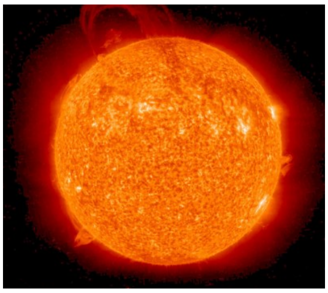


Image of the Sun in the ultraviolet region of the spectrum (NASA).

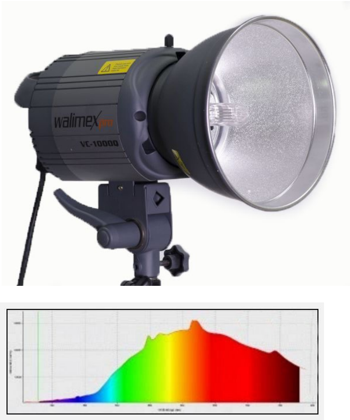
wavelengths with an intensity larger than that of the other wavelengths are present, the effect is more natural (similar to our usual perception).

Depending on the selected option, we can use the light source whose emission spectrum is closest to the "ideal" source. In addition to the flash, numerous light sources can be used in photography, from fluorescent tubes to LEDs.

Problems with cameras

The camera sensors are responsible for "translating" the light that falls on them to digital values proportional to the brightness. These values are used to construct the image observed by the camera. The sensors are not colour sensitive, and thus, each element is covered with a filter that only lets light pass through in a specific area of the visible spectrum: red, green and blue. According to these components and their intensity, the colour is reconstructed as accurately as possible. The problem is that the sensors are not equally sensitive to all the frequencies, and the subsequent combination to reconstruct a large tonal range is not exact: two images captured using different cameras are not be the same and do not reflect with absolute fidelity the colours of the original object. This problem is combined with the previous one concerning the light, and thus, even with a satisfactorily photographic material we can only obtain distorted images in terms of the colour fidelity.

Testing: light source and colorchecker



Pro VC-1000Q spotlight with halogen lamp. The emission spectrum shows a lack of short (blue) wavelengths.

To demonstrate the colour corrections, we used a 1000 W Walimex Pro VC-1000Q spotlight as an artificial light source, which uses a quartz halogen lamp with a colour temperature of 3200 K. The spectrum is clearly dominated by warm colours.

Photographs were captured using an X-Rite ColorChecker Passport in two versions: the white balance chart (with a homogeneous neutral grey colour) and the classic colour chart (with 24 different colour patches). Subsequently, the objects, which were included in the session and whose colour needed to be corrected through the white balance or profile, were photographed.

The Pentax 645Z medium format camera with a 51 million-pixel CMOS sensor, sized 43.8 × 32.8 mm, with a 14-bit dynamic range was used. The images were recorded in the DNG format, which the camera generated directly.

Above: grey card; below: X-Rite ColorChecker Passport.

White Balance

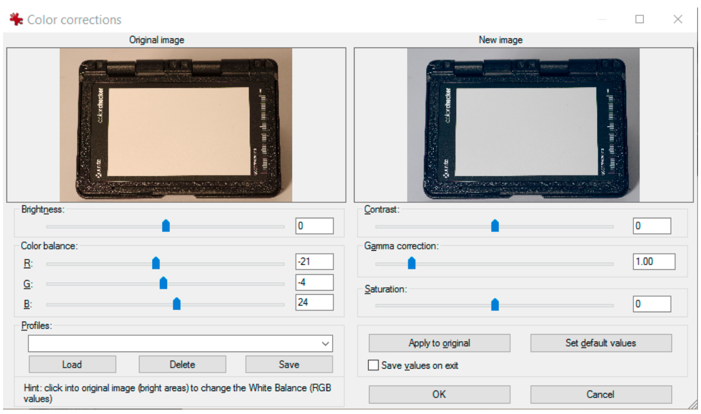
Colorcheckers include homogeneous and stable colour patches that serve as a template for creating profiles to improve the colour reproduction of devices such as cameras, displays, printers, and scanners ...

The operation of modifying the image to eliminate the tonal bias is known as the white balance or adjustment.

The modification is performed on the values of the entire image, and an area that is neutral grey is considered as a reference. The images on the right are the same grey card photographed using the abovementioned light source (above) and an LED panel (below). It can be seen that the latter image is considerably more "white" than the one illuminated with halogen light, which exhibits a general yellowish shade.

The RGB-values of the grey patch are equivalent; thus, the deviations indicate the generic correction that must be applied to the image to bring it to a neutral point.

White Balance in Irfanview



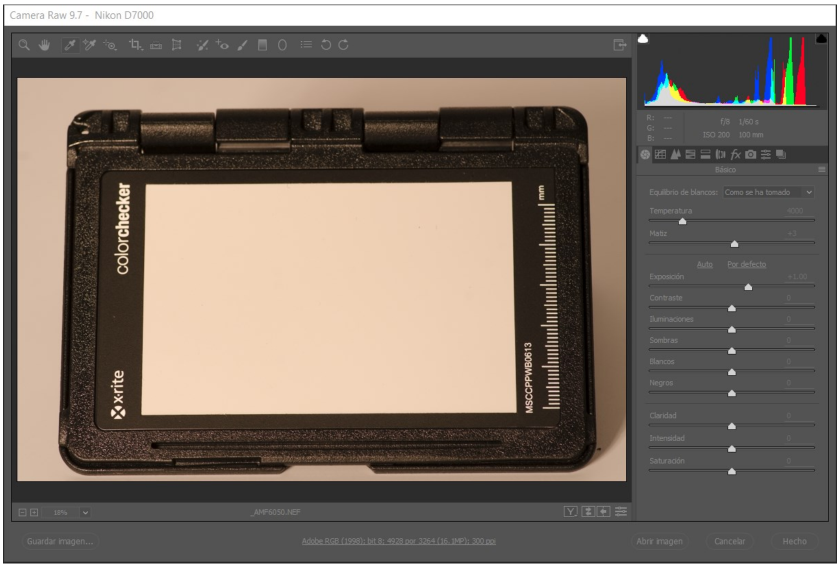
Irfanview is a free application that involves functionalities for basic image processing. The white balance is implemented as follows: through *Image* → *Colour corrections*, a window with two copies of the image is opened. To view the correction, click on any point in the grey area in the left image; the effect is visible in the other image.

The attached figure shows the result: The right image has lost its yellowish shade. The changes in the RGB values are in the following scales: -21, -4, and +24 for red (dominant), green and blue (represented insufficiently), respectively. The process is completed through the *Apply to original* and *OK* operations. To edit more images shot in the same light, the RGB changes can be implemented manually or in the batch mode to edit many images in a block.

White Balance in Adobe Photoshop

When using **Adobe Photoshop**, the white balance can be implemented when an image is read in the RAW format, such as DNG or any other format. The process is similar to the previously described process. The tool is known as White Balance, and it can be accessed on the top button bar of the **Camera RAW** application.

The image is automatically corrected when the tool is activated and a point in the grey area is clicked. The right panel indicates the colour temperature of the original image (in this case, 3000 K). When using non-RAW images, the same process can be conducted using the Camera Raw Filter (Filters menu).



Grey chart in the RAW image processing module before implementing the white balance.

Constructing the colour profile of a camera

Colour profiles are the most appropriate tools to correct both the tonality problems due to the light and camera sensor. Since a profile describes how to manage the colour of a camera in a given light, it is necessary to develop a profile for each combination of the camera and light source.

Once the profile has been built, the images are treated using the profile as a correction "template" for the whole photo session. A profile extends beyond the mere white adjustment correction, as it controls the capture of different colours and not only of a neutral grey.

The process using the aforementioned colorchecker with tungsten lamp illumination can be described as follows.

1. Photograph a colorchecker in the DNG (or generally, RAW) format, using the camera and light used in the photo session.

2. Install and activate the profile building programme that accompanies the chart (in the example, Colour Checker Passport).

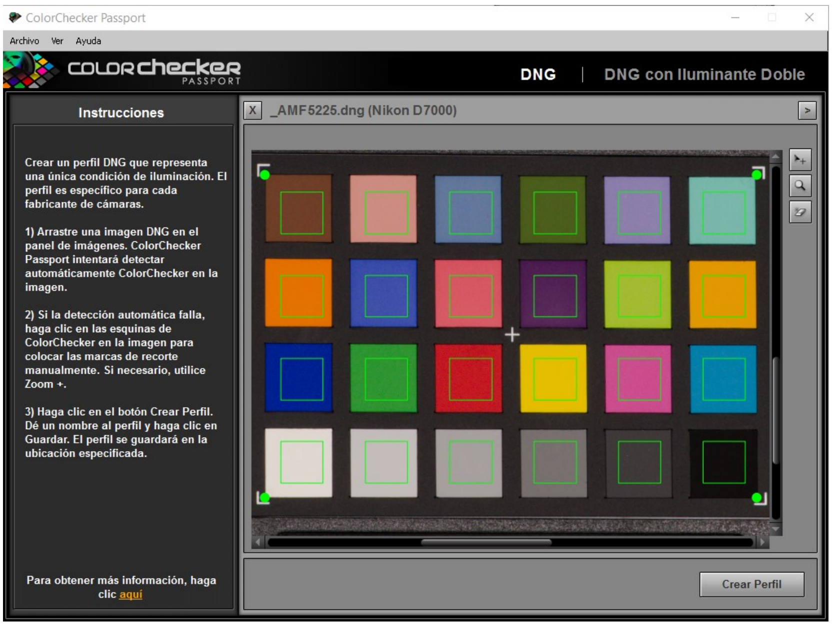
3. Drag the DNG image into the programme. The programme will recognize the colour patches and compare the RGB values captured by the sensor to the actual values.

4. Build the colour profile and save. When using the X-Rite software, the profile is automatically available in Adobe Photoshop.

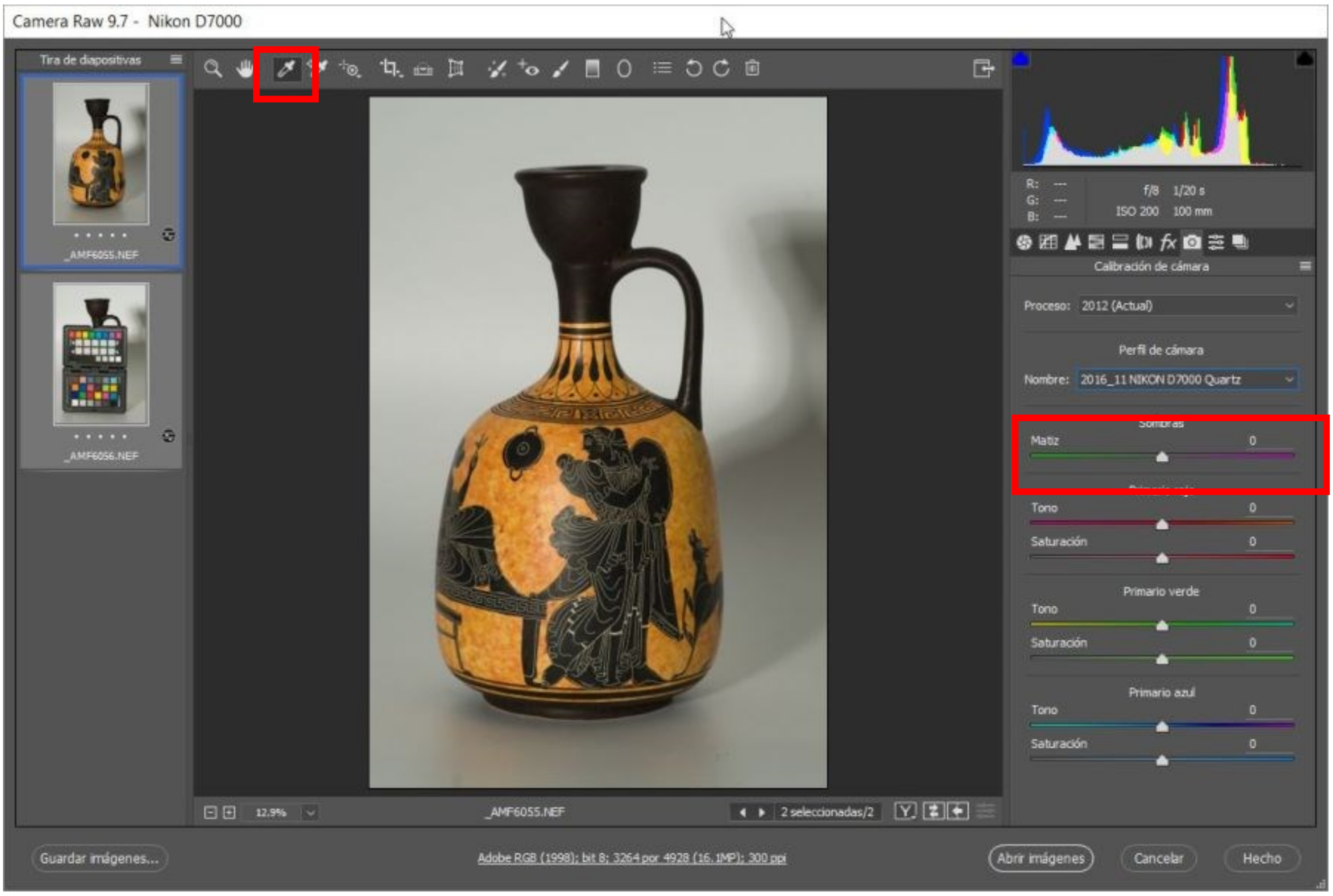
5. For all photographs from the session, the previously created profile is used, and the colours are automatically corrected. This correction is performed in the Adobe Camera RAW module.

6. After correction, the images must be saved in a suitable format through a lossless compression algorithm, e.g., TIF with LZW compression.

Below: image of the colorchecker dragged into the X-Rite profile building programme. The recognition of the colour patches is automatic, and the programme uses the RGB average values of each patch in the central area of the patch, marked in the figure with a square in green.



Example of treatment



Colorchecker and pot in the Adobe Camera RAW application. The white balance is implemented using the tool that appears in the red square, at the top left, and the profile created using the colorchecker is applied through the drop-down menu marked with the red rectangle on the right.

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KRAKENGROUP
SPATIAL DATA ANALYSIS, GIS AND REMOTE SENSING

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IMAGE-BASED MODELLING SYSTEMS

Image-Based Modelling Systems

This notebook is dedicated to image-based modelling (IBM) systems, which, together with 3D scanners (range-based modelling systems), allow the creation of 3D models of objects or scenes. The IBM systems are based on the photogrammetric process, **photogrammetry,** which represents a set of techniques to extract the metric properties of an object from the images recorded of the object.

How do IBM systems work?

IBM systems create a 3D model of an object or scene from a set of overlapping digital images that cover the entire object to be represented. The invariable elements are extracted from consecutive images, and the geometry of the object is resolved simultaneously.

These images are automatically oriented in an arbitrary coordinate system by using a series of algorithms that determine the parameters of the camera and generate a point cloud that is subsequently meshed with the addition of the texture.

The basic information source is a photograph, which is a flat image of an object, and the main problem to be solved is that of identifying the homologous points among adjacent photographs.

Pentax 645Z Camera.

The general process followed by image-based modelling systems is as follows:

- Obtaining a set of overlapping digital photographs of the object to be modelled.
- Uploading the photographs to the software or application.
- Executing the specific algorithms to create a point cloud that represents the object and calculates the parameters and position of the cameras.
- Triangulating the point cloud to create a mesh.
- Texturing the mesh with the photos.
- Debugging and exporting the model.

Tips for shooting photos:

- The pictures can be recorded using any camera, but we recommend the use of a medium or high resolution (10 MPx or more).
- In general, a calibrated camera does not need to be used.
- The focal length should be maintained at a constant value during shooting.
- The overlap between consecutive photos must be at least 60%.
- Obtaining a larger number of photos is preferred, although the processing time and file size increase.
- Avoid shooting transparent, bright, specular or moving objects.
- Controlled light conditions are preferable. When outdoors, the ideal conditions involve an overcast sky, thereby avoiding the casting of shadows.
- It is preferable to capture photos in RAW data, which retain all the information, and later convert the images to TIFF or JPG.

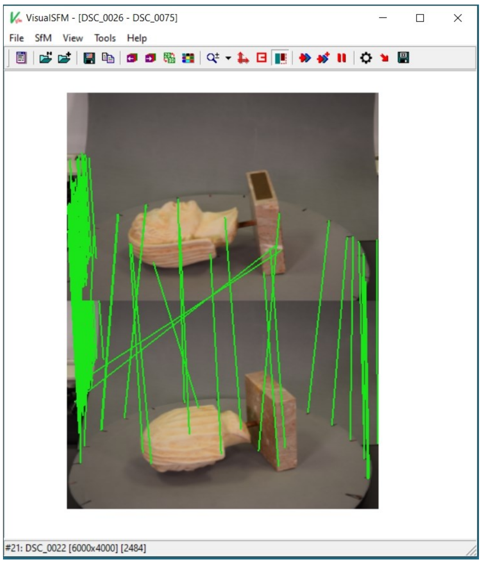
Point cloud obtained through IBM after processing 76 overlapping photographs of the subject shown in the image on the left.

The object was photographed both upright and lying down on a rotating platform that allowed a photo to be captured at a rate of 15º.

Algorithms

One of the most widely used algorithms in IBM systems is the **structure from motion** (SfM) algorithm, which produces volumetric models from photographs. This method automatically generates a schematic 3D model of an object or scene from a set of overlapping two-dimensional images obtained by the camera. To this end, the algorithm detects the characteristic points of each image (by seeking geometric similarities or specific details) and observed the movement of these points throughout the consecutive images. Thus, the location of these characteristic points in a local coordinate frame can be estimated, and a **sparse point cloud** is created.

The **multi-view stereo** (MVS) algorithm calculates a dense estimate of the scene geometry by operating at pixel values and not characteristic points, thereby allowing the creation of a detailed mesh or dense point cloud.



Identifying the common elements and characteristic points in the free IBM VisualSfM application.

As this technique is highly automated, the user has control over the system in the data collection phase, and thus, factors such as the number of photos, texture of the object, lighting or camera resolution notably influence the quality of the final result.

Software

Several commercial and free applications allow the automated generation of 3D models from a set of overlapping photographs. In general, the IBM applications running on a user's computer impose critical hardware requirements in terms of the processor, RAM and graphics card, especially when working with a large number of high-resolution photographs.

Web-based applications do not involve this problem since the data are not processed locally. In these cases, the system uses remote servers, to which the data are sent. After processing, the results are returned to the user. When working in the local mode, certain applications employ acceleration systems involving the use of GPUs or distributed computing techniques.

Sample of IBM applications:

Agisoft Metashape

PhotoModeler

Context Capture

3DF Zephyr

Reality Capture

Autodesk Recap Photo

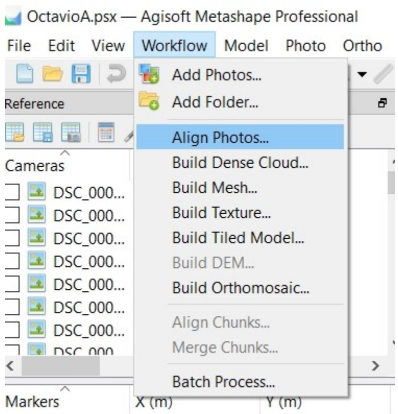
Regard3D

VisualSfM

Agisoft Metashape

One of the most popular applications to model all types of objects is Agisoft Metashape, formerly known as Agisoft PhotoScan. This software is a commercial desktop software with two versions, standard and professional, that helps process images to obtain textured 3D models.

The workflow of Agisoft Metashape is initiated with the **loading of the photographs** of the object to be modelled. The next step is the **alignment** of the images, in which the correspondence of the homologous points is determined by applying the SfM algorithm to obtain the positions of the cameras and orientation of each photograph at the moment of the shot, thereby creating a scattered point cloud. In the latest versions, the **mesh** can be created directly from the scattered point cloud without creating a dense cloud. Finally, the **texture** obtained from the photographic images is projected onto the mesh.



Workflow of Agisoft Metashape.

More tips for shooting photos

As discussed, the user has control over the system in the data collection phase, and thus, certain work patterns are of significance to obtain a quality result.

- When the piece has specific dimensions, it is advisable to place the piece on a turntable and fix the camera on a tripod to avoid undesired movements. The object can be rotated at regular intervals, for example, 15°, and an image can be captured in each position until the object to be modelled is completely covered. We can also keep the object fixed and move the camera around the object, with the same considerations.
- In terms of the lighting, the use of LED panels with diffusers and a white, grey or black background is preferred. The light can be measured using a photometer independent of the camera, and the exposure values are fixed for the whole session. In addition, although the existing cameras collect colour with reasonable fidelity, colour calibration methods must be applied to ensure that the colour representation is faithful to the original (see corresponding notebook).

- When modelling objects outdoors, it is preferable to capture the pictures on cloudy days with diffused light, to ensure that no shadows are cast on the object. Otherwise, the first or last hours of the day may be selected, as they involve a more uniform lighting.
- It is advisable to minimize the number of surrounding objects to minimize the processing and debugging time for the models.

Results

3D model of a Roman ceramic replica of black sigillata, with a diameter and height of 10 cm and 14 cm, respectively. Photographed using a Nikon D7000 camera with a 100 mm macro Tokina lens and processed using Agisoft Photoscan Standard. The model can be accessed at https://skfb.ly/VrYG

3D model of a replica of a Roman medallion with a diameter of 12 mm. Photographed using a Nikon D7000 camera with a 100 mm macro Tokina lens, and processed using Agisoft Photoscan Standard. The model can be accessed at https://skfb.ly/TzGI

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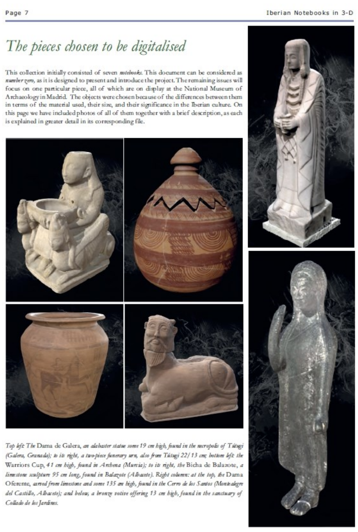
Other notebooks



In collaboration with the Institute of Archaeology of Mérida (Superior Centre for Scientific Research) and the National Archaeological Museum (Protohistory section), we published a collection of notebooks named Iberian Notebooks in 3D. This publication, in Spanish and English, which is composed of seven notebooks (the first is the introduction), describes the modelling process of six pieces exhibited in the Protohistory section of the National Archaeological Museum .

The modelled pieces are:

- The Dama de Galera
- The bicha de Balazote
- The Dama Oferente
- The Warrior Vessel
- A bronze votive offering

Dehesa › Investigación › Grupos de Investigación › Grupo de Investigación Kraken › KRAKEN - Informes / Documentos de trabajo

KRAKEN - Informes / Documentos de trabajo

The notebooks can be downloaded in [English]() and [Spanish]() from the Dehesa institutional repository of the University of Extremadura, which provides the Kraken group a space to store and download [other publications]().

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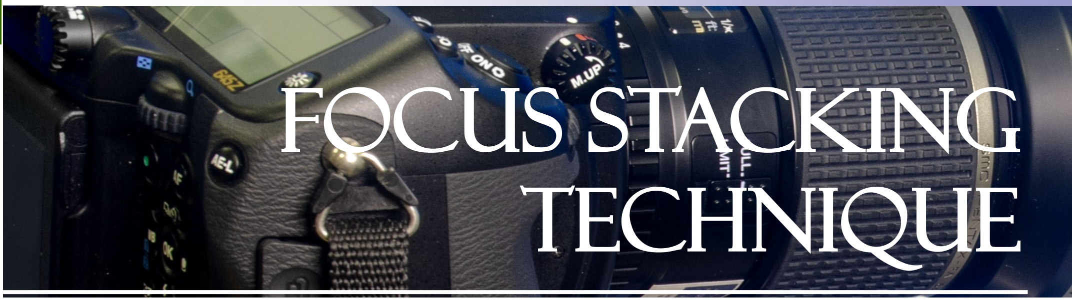


FOCUS STACKING TECHNIQUE

Focus stacking technique

Focus stacking is a photographic technique that solves the problem of the shallow depth of field in macro photography. The technique consists of merging the images of the object captured sequentially such that each image has a different area of focus. The fusion preserves only the area in focus of each photograph, thereby providing a completely clear final image of the entire object.

Decisions

If the object is relatively flat, macro photography can yield satisfactory results without the need for focus stacking.

If the object is large, it is necessary to decide between closing the diaphragm to the maximum value (which leads to a loss of quality) or using the aforementioned technique.

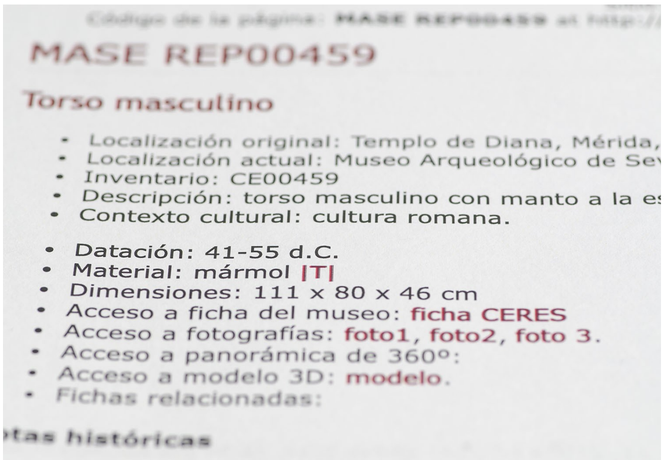
Focused stacking can be performed by changing the focus distance or moving the camera.

Special interest points:

- Small objects should be photographed from extremely short distances.
- In these cases, the depth of field is extremely limited to a few millimetres or tenths of a millimetres.
- One solution is to capture pictures by focusing on different parts of the subject and finally merging ("stacking") the images into a single image .
- This technique is known as "focus stacking", and "stacking" can be performed using three or four images to dozens of images, depending on the object.

Photography and depth of field

Below: image showing the focused area limited to a few lines of text.



The **depth of field**, or DoF, is the area between the closest and farthest distance from the camera that provides a sharp image. The factors that influence the DoF are the lens focal length, aperture of the diaphragm, and focusing distance.

The relationships among these parameters and the depth of field are as follows: The DoF increases with a shorter focal length, smaller aperture and larger focusing distance

The above image was recorded with an f:8 aperture, a 100 mm lens, and a focus distance of 85 cm. The DoF was 2.04 cm, distributed in a distance range of 83.99 and 86.03 cm to the camera's focal plane. Obviously, such a photo would not be valid as a document since blurring affects both the nearest and farthest areas.

Problem in macro photography

Macro photography is a type of specialty photography in which the scale ratio between the object and its projection on the sensor is 1:1 or less. The coin on the right is a typical example. In this case, the depth of field is not problematic because the object is in a single plane perpendicular to the optical axis of the shot. However, the contrasting case is problematic since the DoF in macro photography is extremely small, (see next page). For example, with an objective of 100 mm, aperture of f: 8, and object distance of 25 cm, the DoF is only 1.2 mm (24.94 to 25.06 cm). Any object beyond this range would be out of focus.

Fundaments

In image 1 (right, above) only the closest part of the piece appears sharp, while the back is clearly out of focus. The red rectangle includes the focused part.

Next, we recorded two more images (2 and 3), in which we moved the focus point to the middle and back, respectively.

At this time, three photos of the same object can be observed, in which the focused area is different; however, all the three images together cover the entire piece.

The next step is to fuse the three images with the focused part in each image exclusively preserved. The fusion process is conducted using specific software, usually in an automated manner.

The result is as shown at the bottom of the page (4), in which the object is completely sharp.

The optimal results are obtained using medium diaphragms (the optimal value is usually between f: 8 and f: 11) and by recording the photos in an absolute stable setup using a tripod; logically, the lighting should be constant.

Software

The following notable applications can automatically merge images for focus stacking::

- Adobe Photoshop (commercial).
- Helicon Focus (commercial).
- Zerene Stacker (commercial).

Free software are relatively limited:

- Picolay (free, non-commercial use).
- Hugin (open source, see instructions).

The examples shown in this notebook are obtained using Adobe Photoshop. Helicon Focus can be used with Helicon Remote to enable remote control of the camera (Canon or Nikon only), automated shooting of images, and subsequent processing of images.

When using the simplest technique, the camera is fixed and stationary on a tripod or stand, and the pictures are recorded by slightly varying the point of focus.

The alternative approach is to keep the focus steady and bring the camera closer to the subject on a manual or motorized track.

Both methods can be implemented manually or in an automated manner with specific hardware and software.

The result of the selective fusion of the three photographs obtained with sequential points of focus can be seen here. (Ref. MAN 28571).

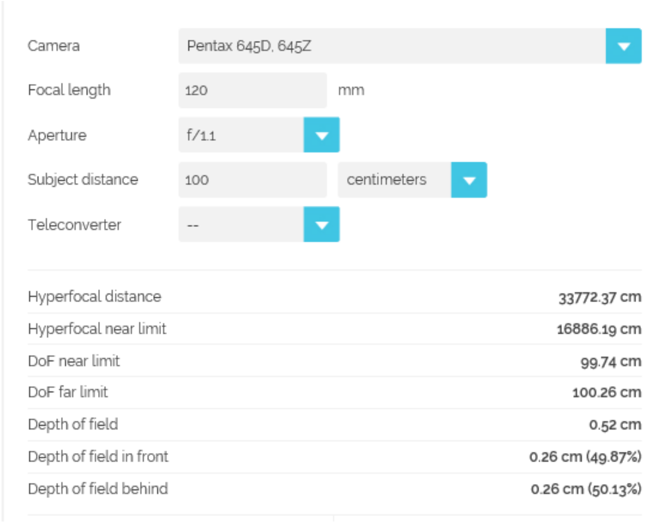
Manual estimation of the images

To realize focus stacking, it is necessary to know the depth of field of the images to be recorded. If this process is to be performed manually, certain applications that can calculate the parameters can be employed, for example, the [DoF Calculator](#) (right).

To obtain the values, simply enter the required data: camera model (to define the sensor size), focal length of the lens, aperture value and camera–subject distance.

In the presented example, the depth of field is 0.52 cm, which guides the control of the movement of the focus or the camera. If the subject is 5 cm deep, at least a dozen images must be captured, since the focus of consecutive photos should partially overlap.

By changing the parameters, the change in the values with the diaphragm, distance to the subject, etc. can be observed. Closing the diaphragm is the most notable approach to increase the depth of field; however, the sharpness may be deteriorated under extreme values, for both open and closed apertures.



Example of depth of field calculation.

Methods

The pictures can be captured using two approaches. In both the cases, the subject, lighting and camera settings (aperture and exposure) are fixed, and the focus must be in manual mode.

In the first method, the camera is held steady on a tripod or stand. The process is initiated by manually focusing on the closest part of the subject and capturing the first picture. Subsequently, the user focuses slightly backward (as recommended by the depth-of-field calculations) and captures the second picture. The process continues until the object is covered in its entire depth, and the last photo thus focuses on the farthest part.

The second method involves fixing the camera on a rail that can help move the camera towards the object. The camera is placed on a rail back position, the closest part of the subject is focused, and the first photo is recorded. To capture the second picture, it is not necessary to change the focus, and the camera is moved forward such that the point of focus is equally shifted on the subject. The process continues until the depth of the subject is covered. In this case, logically, the length of the rail must be, at least, equal to the depth to be measured.

A rail of this type usually measures between 20 and 30 cm and involves controls to move the camera over the guides with millimetric precision. If a higher resolution is required, motorized rails may be used, which can be controlled using software such as Helicon Remote, with programmable displacements of a few hundredths of a millimetre.

Medium format camera on a motorized track with programmable movement and triggering. The coin is fixed to a rotating base, which is also motorized.

Example of an image generated using focus stacking can be seen [here](#) (Ref. MAN 2855).

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Other notebooks in the series (3D scanner)

A **3D scanner** is a device that analyses an object to obtain data regarding the shape and geometry of the object. In general, objects are digitized to obtain their virtual form and to access more information. Two types of scanners were used in these notebooks:

- Structured light scanner (right image). It is a portable scanner that project a pattern on the object, similar to a QR code, which is read by photographic sensors.
- Low-cost desktop scanner (photo below). The operation is based on an original technology known as multi-stripe laser triangulation (MLT), which involves projecting a multiple laser band using two twin arrays of four lasers (red, 650 nm) and recording the position of the points through a CCD camera.

Go!Scan 3D structured light scan (above). The scanner has a light-structured emitter and three cameras framed in a set of four LEDs; two cameras capture the deformation of the pattern and generate a point cloud, with the possibility of texture information using the third camera.

ROLLOUT PHOTOGRAPHY AND DSTRETCH FILTER

What is rollout photography?

Peripherical photography or *rollout* is a technique that aims to "unroll" the surface of three-dimensional objects such as vases, jars or bottles to present them in a two-dimensional image such that the decoration on the objects can be observed in a continuous view. The technique is equivalent to cartographic cylindrical projections, such as Mercator, where geographic elements are projected onto a cylinder tangent to the Earth´s equator.

Background

- The rollout photography technique in archaeology was developed in the mid-20th century and consolidated in the 1970s when Justin Kerr developed a large series of hundreds of rollouts of Mayan vessels, today visible at http://www.mayavase.com/
- Justin Kerr´s technique, based on analogue photography, was highly complex, and thus, it was not widely applied. Today, the technique has been considerably simplified through digital processing.

Late classic period Mayan vessel (600-900 a.C.).

Process

The object is placed well-centred on a turntable such that the object can rotate on its central axis.

The camera is placed on a tripod with the optical axis perpendicular to the rotation axis of the object.

The use of homogeneous diffused lighting is recommended, at least in the central area of the object. If necessary, because of the brightness conditions, cross-polarized lighting can be used.

Colour calibration is ensured through an initial shot including a colorchecker.

A series of photographs is obtained by rotating the object at regular intervals such that each shot faithfully collects the central part of the object and overlaps with the previous and subsequent shots.

The photographs are merged into a single image by perfectly aligning the individual shots supported by the overlapping areas.

Below: rollout in analogue times; image of History of the Invention of Rollout Photography.

Warriors´ Vessel

The ideal objects to apply the aforementioned technique to are cylindrical as no distortion occurs in the two-dimensional representation. One of the objects used in the archaeological documentation projects is the "Warriors´ Vessel", exhibited in the National Archaeological Museum of Spain, with a reference number of 1918/69/1.

This vase belongs to the Iberian culture, with a height and maximum diameter of 41 cm and 36 cm, respectively, from Archena (Murcia, Spain) and has been dated to the 3rd century B.C. The painted decoration shows scenes from a battle, with foot soldiers, horsemen and animals (dog or wolf, boar). The shape indicates a moderate deformation in the projection.

Photographs

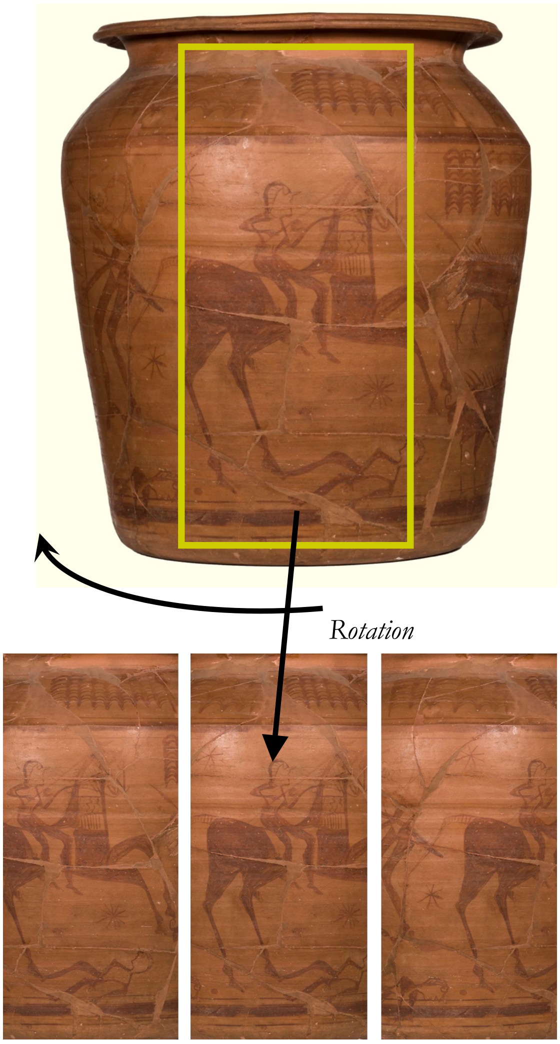
Photographs are obtained by rotating the vessel in preset increments. In this case, the interval is 15º, with a total of 24 images obtained. The shape of the subject determines the number of images to be taken, and thus, the angular interval.

After shooting, the set of photographs is processed by applying a white balance and colour profile of the session (see Colour Calibration Notebook).

Once the images have been converted to the TIF format, they are cut out such that the central part is preserved (yellow rectangle in the figure), and sufficient overlap is ensured with the previous and subsequent photos. All the cuts must be of the same size.

Subsequently, all the trimmed images are merged using photographic software to develop a single image. The overlapping areas allow this fusion, and if the employed lighting is homogeneous and diffused, the joints between the photos are not visible.

If the deformation due to the shape of the object is not excessive, it can be corrected through the software in the merge process.



Software

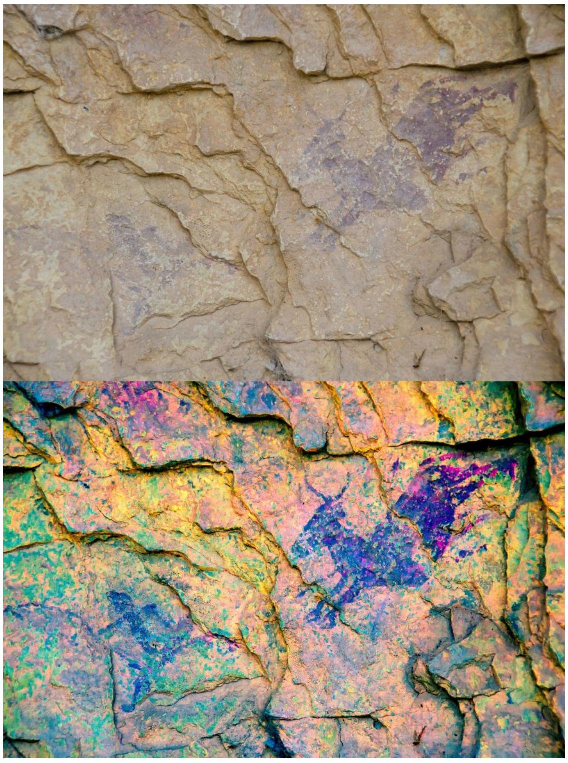
The images can be fused using any photographic application that can construct panoramic views:

- Adobe Photoshop (commercial).
- ICE Image Composite Editor (free, recommended).
- PTGui (commercial).
- Hugin (open source, free).
- Panorama Factory (commercial).

Applying filters to the image

The rollout of the Warriors´ Vessel is shown in two versions: the natural coloured and processed variants. This processing is not necessary for rollout photography; however, processing can be implemented to highlight the low visibility lines to achieve the complete information of the natural colour image.

For the realization of the mentioned image, DStretch, a plugin for ImageJ, a public domain image processing application developed by the National Institutes of Health (USA), was used. DStretch was originally developed to realize photo processing of prehistoric cave paintings and rock shelters through various transformations of the colour space of the images. Nevertheless, the use of the software is not limited to the originally intended application, and we used this software to enhance the decoration and motifs of the Warriors' Vessel.



Example of processing with Dstretch.

Left: image of the Warriors' Vessel in natural and processed colour, obtained using DStretch, LDS algorithm, and an LAB colour space modification (see details here).

Other rollouts (natural colour)

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The Kraken research group is formed by people from different knowledge domains: geomatic engineering, earth physics, biology, telematics, agronomy, etc. Our nexus pertains to the capturing and processing of spatial data both at a detailed (3D models, graphic documentation of objects) and territorial scale (geographic information systems, remote sensing, geophysics, etc.).

Part of the production of these notebooks has been financed through the project GR18028 (Research Group RNM026), co-financed by the European Regional Development Funds (ERDF) and Government of Extremadura (Spain).

Basic bibliography:

- Ángel M. Felicísimo. 2011. Vase rollout photography using digital reflex cameras. Technical Briefs in Historical Archaeology, 6, (2011), 28–32.
- Felicísimo, A. M.; Polo, M. E.; Durán Domínguez, G.; Tortosa, T.; Rodero, A. (2018). Rollout archaeological photography for the graphic documentation of cultural heritage. *Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018*, Vienna (Austria).
- Jon Harman. 2015. Using DStretch for rock art recording. INORA - International Newsletter on Rock Art, 72 (2015): 24-30.
- Justin Kerr. 2007. A short history of rollout photography. The Kerr collections, Foundation for the Advancement of Mesoamerican Studies, Inc. http://www.famsi.org/research/kerr/rollout.html .

Further information on the use of the rollout or peripherical photograph and the application of the DStretch filter can be found in the paper presented to the 23rd International Conference on Cultural Heritage and New Technologies in 2018 in Vienna, Austria.
The result of applying the DStretch filter to the Warriors' Vessel can be seen in Sketchfab.

CMPLab

Centro Universitario de Mérida

INFORMATION DISSEMINATION

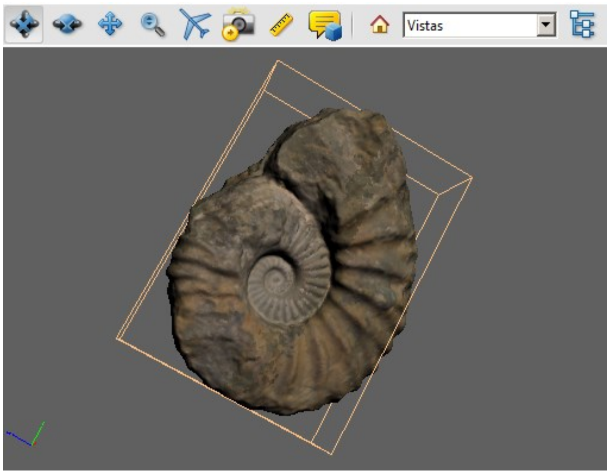
Dissemination of the models and photos

The previous notebooks highlighted the method to generate 3D models using scanners or digital photography techniques and image-based modelling systems. Moreover, high resolution photography techniques with colour calibration and specific techniques such as focus stacking or peripheral photography or rollout were explained. Herein, we describe the process of disseminating the generated information through the Internet on specific platforms.

Embedding a 3D model in a PDF file

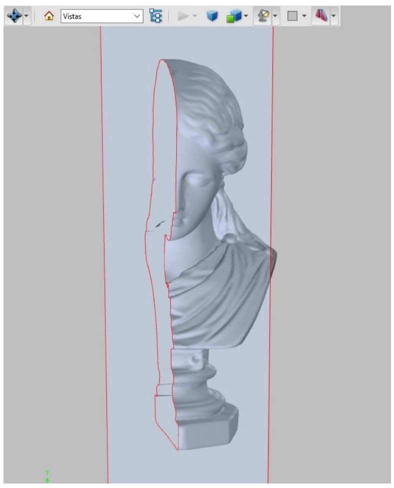
In this context, the condition for embedding 3D models in PDF documents is that the Universal 3D (U3D) format must be used. The process is simple when using objects without texture (only geometry), as the textures captured using cameras cannot be incorporated all circumstances. Once the 3D model has been completed, the following process is implemented:

- Export the model in the U3D format.
- Create a base page with a word processor in the desired format, including the texts and reserving the necessary space for the window in which the 3D object will be seen. This file is saved as a PDF.
- Open this PDF through Adobe Acrobat Pro.
- In View - Tools - Interactive objects - Add 3D, a rectangle is defined in the page with the desired size for the 3D window.
- Choose the U3D file to be inserted when the upload window appears and save the PDF.
- An example of an interactive PDF can be seen here.



3D model of an ammonite scanned using the Next Engine scanner and embedded in a PDF file.

When we click on the 3D model embedded in the PDF, it is activated, and a series of tools appear that make it possible to rotate the object, zoom, measure lengths and sections, make comments or change the lights and colour of the background.



Sketchfab

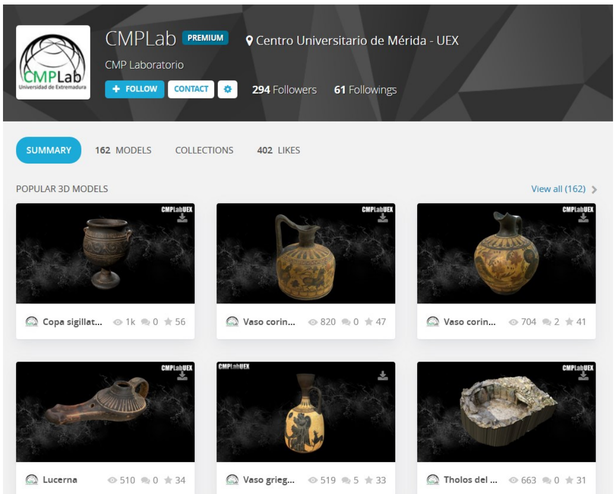
Sketchfab, founded in 2012 in France, is a website used to view and share 3D content online. The users of this website can create their own profile where they can upload their creations, which can be downloaded by other users. Certain uploaded models can be printed in 3D.

Many museums, modelling companies and organizations exhibit and share their virtual works within the social network frameworks.

Certain applications, such as Agisoft Metashape, allow the model created to be directly uploaded to this website.

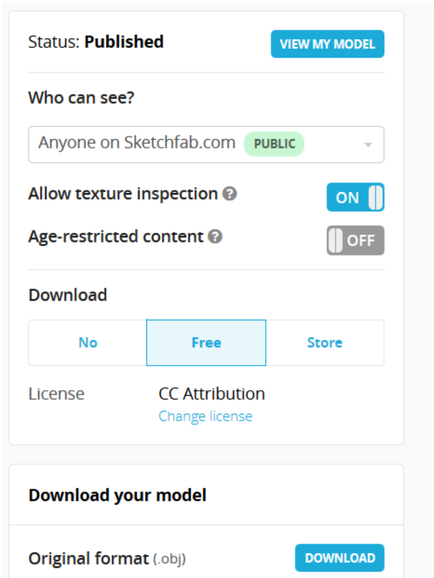
Many museum institutions upload models of their most iconic pieces to this website (see 3D modelling programme in museums in the 3D scanning notebook).

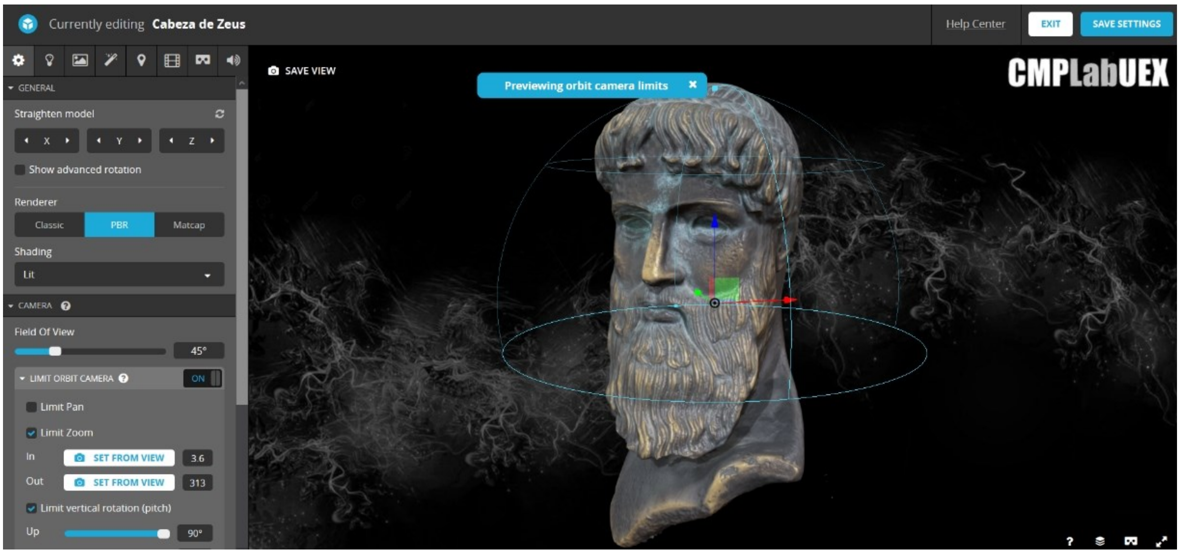
Our group, Kraken, publishes the developed 3D models at https://sketchfab.com/secad



Model upload

- Once the user has registered with the platform, the 3D model can be uploaded in a compatible format (OBJ, DAE, GLTF and STL, among other formats), and finally, the compressed model is uploaded.
- After loading and processing the model, the metadata must be completed by populating fields such as the title, description of the model, theme and tags to categorize the model.
- The model can be made visible and downloadable (or not) according to the Creative Commons licences.
- The settings of the 3D model refer to the manner of rotation of the object, light and shadow sets, inclusion of background, post-processing filters, possibility of generating annotations, and adding sound, among other options.





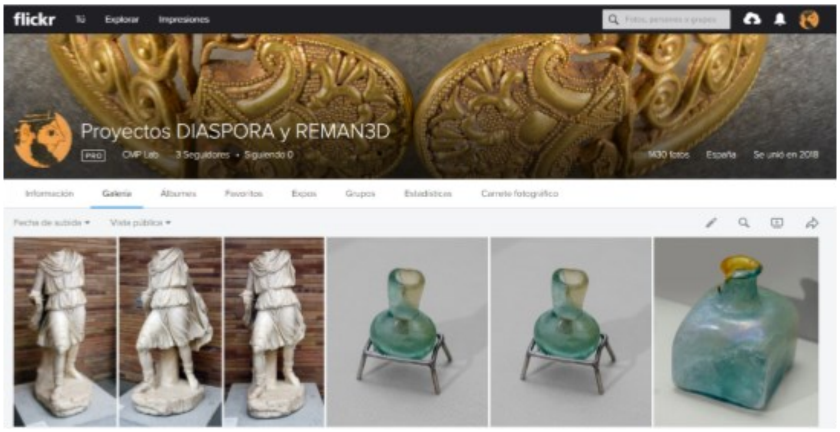
Edit the 3D model settings.

Flickr

Flickr is a website used to store, sell or buy and download photos and videos. This website was launched in 2004, and many professionals or amateur photographers use this website to share their creations. The user creates an account that can be free or paid, with different options in terms of the number and size of the photos to be stored.

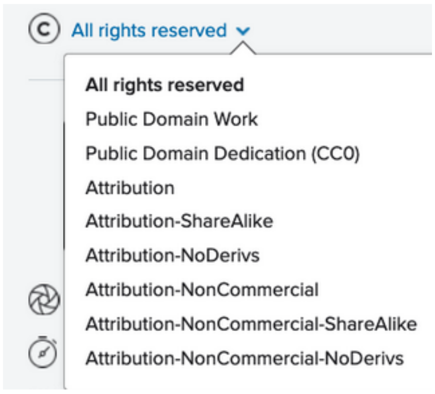
Both free and professional accounts can tag photos, add a description, geolocate the images and include metadata (right figure). Moreover, several types of licences, including Creative Commons are available.

Flickr also acts as a social network, allowing the users to comment and rate the images, to subscribe to other users, and to form theme groups.



Below: glass carved in agate sized 13 × 9 cm, representing the face of a silen. The object dates back to the 1st century and was originally found in Merida, Badajoz. The object is on display at the National Archaeological Museum and has been included in the Diaspora project. More information here.

The figures show some of Flickr's features as a photo repository: Diaspora and REMAN3D project site cover, album organization, a view of an image, types of licences available, and certain metadata for each image. The metadata are collected from the photograph itself, if they exist, and tags can be added in addition to a description that can be used to add information regarding the origin of the piece, time, materials, links to external documentation, etc.



CMPLab is the acronym for Data Capture, Virtual Modelling and Production/Prototyping Laboratory. CMPLab emerged from a project of the Infrastructure and Scientific-Technical Equipment Aid from the Secretary of State for Research and began operating in 2016. This laboratory works on research areas related to the construction of 3D models of archaeological objects, very-high-resolution photography, geophysical prospecting and applications of geomatics to cultural heritage.

Our physical headquarters are on the first floor of the research building of the **University Centre of Merida**.

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CMPLab
Universidad de Extremadura

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KRAKENGROUP
SPATIAL DATA ANALYSIS, GIS AND REMOTE SENSING

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Consejería de Economía, Ciencia y Agenda Digital

Unión Europea

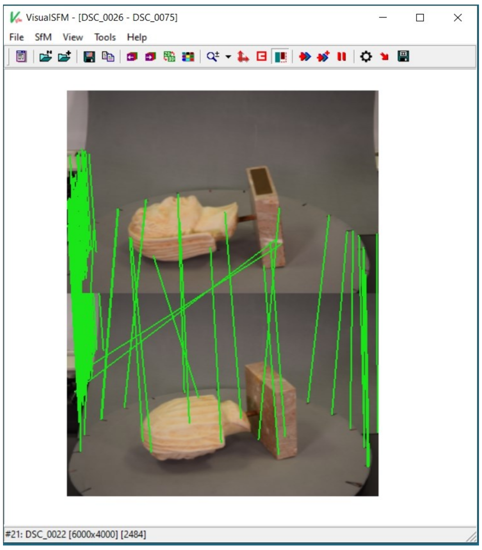
Basic bibliography:

Felicísimo, A.M. , Polo, M.E. and Peris, J.A. Three-dimensional models of archaeological objects: from laser scanners to interactive PDF documents. Technical Briefs in Historical Archaeology, 2013. 7: p.13-18.

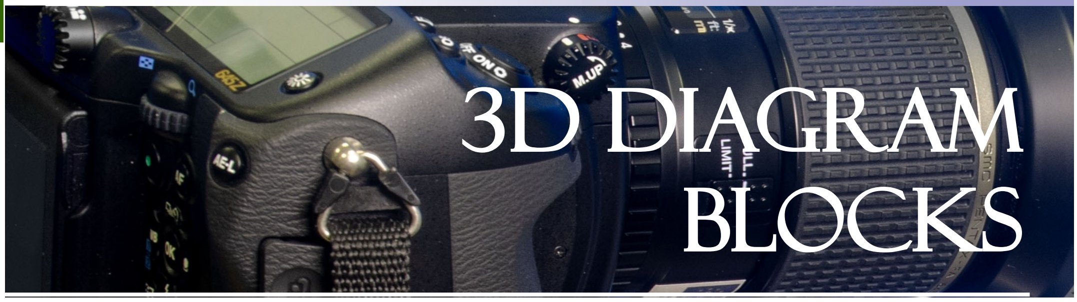
Polo, M.E. , Vaquero, J.M. and Felicísimo, A.M. Metric properties of sundials using 3d models from digital photography. Historical Archaeology, 2017. 5: p.557-562. https://doi.org/10.1007/s41636-017-0047-x

Tortosa, T.; De Soto, M. d. l. R.; Morán, C. J.; Polo, M. E.; Durán Domínguez, G. (2018). Proposal of virtual documentation and dissemination of the information of the archaeological object. *Visual Heritage*, Museen der Stadt Wien – Stadtarchäologie; Vienna (Austria). https://www.chnt.at/ebook_chnt23_tortosa-rocamora/

Other notebooks in the series



Left: point cloud in Image-based Modelling System.
Centre: Object to model in the photo shoot.
Right: Identification of common elements and characteristic points in the free IBM VisualSfM application.



3D DIAGRAM BLOCKS

Diagram Blocks

A block diagram is an image that represents the terrain in perspective, to better understand the topography, land cover or other features compared to that achieved using two-dimensional representations such as plans and maps. Commonly used in geology, geography and related disciplines, diagram blocks were usually drawn manually, thereby enabling the author's artistic and synthetic vision to be highlighted; however, considerable time was required to develop such graphics. The tools available at present allow the construction of such blocks using reasonably simple methods that can achieve a satisfactory graphic quality. Although certain aspects remain to be addressed, in this notebook, we describe the construction of graphic blocks by using free applications and public data, which can cover part of the teaching and dissemination needs.

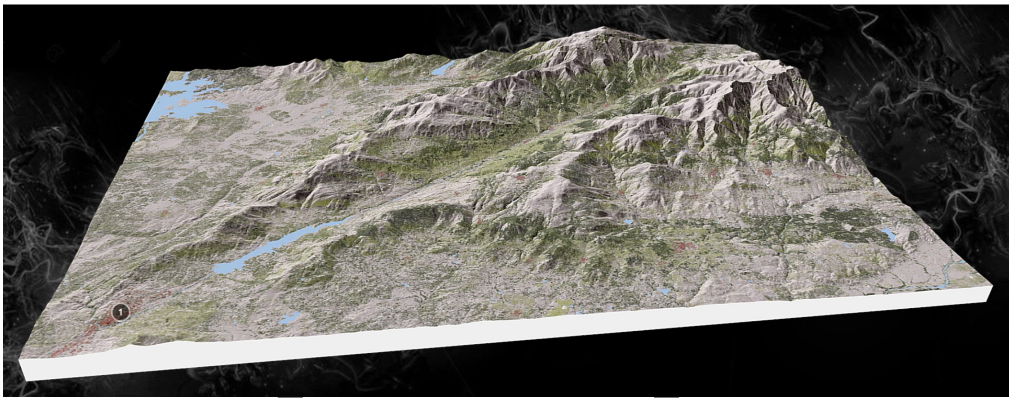
Licence

The procedure outlined here can be implemented using a variety of data; however, the licence for use must be compatible with the project. In our case, the data are extracted from the Download Centre of the CNIG (National Centre of Geographic Information of Spain) and has a licence compatible with CC-BY 4.0, which allows the use of the licence in recognizing and mentioning the origin and property of the products and services of the geographic information licensed as IGN, National Geographic Institute.

In accordance with the instructions, all the derivative works must bear a quotation similar to: Derived work from PNOA (National Plan of Aerial Orthophotography) 2010-2013 CC-BY scne.es.

Data

To construct a block diagram similar to the one shown below, two objects are required: a digital elevation model (DEM) and an image to overlay the DEM. The DEM can be downloaded from many repositories with different cell sizes. In this work, we used CNIG's MDT05, downloadable as sheets in the download centre with a 5 m cell. The employed images can be diverse, from a scanned map to orthoimages. The lower block was made using a LIDAR map, constructed by the CNIG and available in the same location as the DEM. The only condition is that both the "layers" have the same projection system such that they are perfectly superimposed. Any projection is valid, although geographical coordinates cannot be employed (EPSG 4326).



Digital Terrain Model - DTM25

Description: Digital Terrain Model with 1st Coverage 25 m grid spacing.

GRS: ETRS89 for the Iberian Peninsula, Balearic Islands, Ceuta and Melilla, and REGCAN95 for the Canary Islands (both systems are compatible with WGS84). UTM projection in the corresponding zone. Also zone 30 extended for sheets into zones 29 and 31. Orthometric heights.

Download Units: MTN50 sheets

Format: ASCII (.asc) ESRI array

Digital Terrain Model - DTM05

Description: Digital Terrain Model 1st Coverage with 5 m grid spacing.

GRS: ETRS89 for the Iberian Peninsula, Balearic Islands, Ceuta and Melilla, and REGCAN95 for the Canary Islands (both systems are compatible with WGS84). UTM projection in the corresponding zone. Also zone 30 extended for sheets into zones 29 and 31. Orthometric heights.

Download Units: MTN50 sheets

Format: ASCII (.asc) ESRI array

LIDAR Map 1st Coverage

Description: Shaded Digital Surface Model to which three layers have been overlayed. Two of these layers come from the rasterisation of the building and the vegetation classes of .LAS format point clouds. The other layer comes from hydrography.

GRS: WGS84, Web Mercator projection (EPSG:3857).

Download Units: MTN50 sheet

Format: ECW

Most recent PNOA orthophotos

Description: Mosaic of the latest orthophotos of the National Plan for Aerial Orthophotography.

GRS: ETRS89 for the Iberian Peninsula, Balearic Islands, Ceuta and Melilla, and WGS84 for the Canary Islands. UTM projection in the corresponding zone.

Download Units: Each mosaic covers a MTN50 sheet (National Topographic Map at 1:50 000 scale).

Format: ECW

Examples of data to make the diagram blocks, all downloadable in the CNIG website.
*The **asc** format for DEMs makes it necessary to assign the appropriate projection in the GIS. The **ecw** image format is directly readable by QGIS.*

Applications

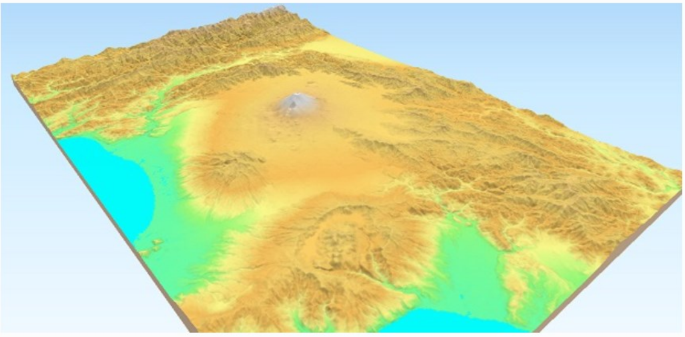
To build the diagram blocks, the geographic information system QGIS is used, which can be downloaded at https://qgis.org/. In this work, we used version 3.10.5 LTR. Complementary to QGIS, a plugin available in the official repository, known as **Qgis2threejs**, must be used.

This add-on or plugin is loaded into the QGIS through the menu *Plugins* → *Manage and install plugins*. The version used herein is 2.4.2.

Documentation of **Qgis2threejs**
https://qgis2threejs.readthedocs.io/en/docs/

How to install a plugin? Look at the section 10.1.2. Installing New Plugins from QGIS training manual.

Qgis2threejs Plugin Document



Qgis2threejs plugin is a QGIS plugin, which visualizes DEM data and vector data in 3D on a web view. You can build various kinds of 3D objects with simple settings panels and generate files for web publishing in simple procedure. In addition, you can save the 3D model in glTF format for 3DCG or 3D printing.

Process flow in the QGIS

1 When the area of interest has been chosen, we can access the CNIG Download Centre website, to find various product options.

2 In the Digital Elevation Models section, several options appear: 1st and 2nd generation LIDAR, LIDAR Map, DTM sized 2, 5, 25 and 200 m, and DSM with a cell size of 5 m.

3 The products can be selected according to the following categories: administrative division, MTN50 sheet and UTM or geographic coordinates.

4 As mentioned above, a DEM and an image must download. The most suitable images are the PNOA orthophoto and the LIDAR map. The products must be selected and downloaded.

Digital Elevation Models
- LIDAR 1st Coverage (2008-2015)
- LIDAR 2nd Coverage (2015–Present)
- LIDAR Map 1st Coverage
- LIDAR Map 2st Coverage
- Digital Surfaces Model - DSM05
- Digital Terrain Model - DTM02
- Digital Terrain Model - DTM05
- Digital Terrain Model - DTM25
- Digital Terrain Model - DTM200
- Slopes Digital Model - MDP05

Above: Example of product type selection for search.

Below: product example (DTM05) for sheet 56; file sizes can be large, up to 2.5 GB for PNOA images.

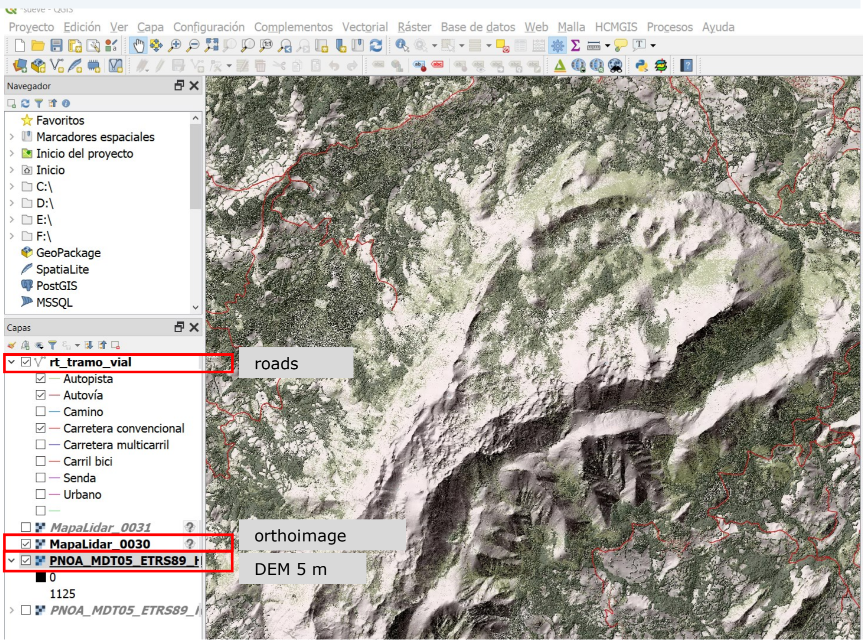
Name	Format	Size (MB)	Date	Locate	Download	
PNOA-MDT05-ETRS89-HU30-0056-LID.ASC	ASC	166.05	2010, 2012			Add

5 Both the DEM and image (several elements may be needed, depending on the location of the area of interest on the sheet) are loaded into the QGIS.

6 The necessary adjustments are made such that the loaded layers overlap exactly. In general, we use an ETRS89/UTM projection system (EPSG 25829, 25830, etc.).

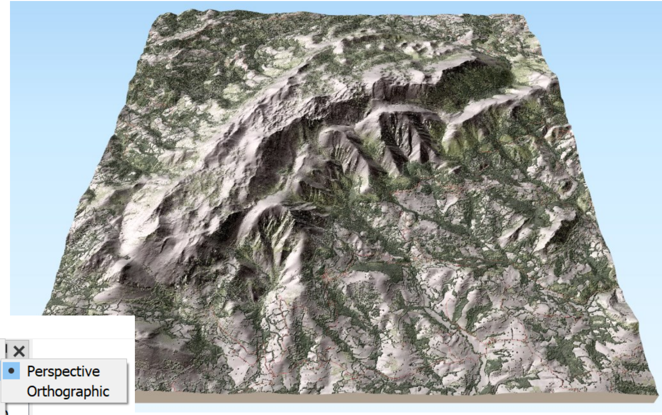
7 Any additional layer can be added if information is to be added, such as, communication paths (also available at the CNIG Download Centre).

8 The shape of the view (rectangular, square) and order and scale of the layers must be adjusted to view exactly what is be included in the block diagram.



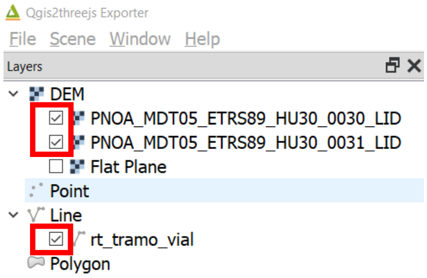
Right: view layout example in QGIS.

Procedure in Qgis2threejs



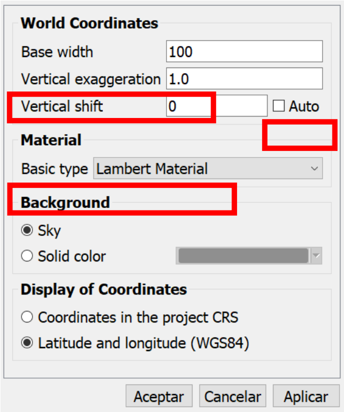
9 Qgis2threejs is activated in the web menu.

A new window appears with the first display of the block. If the window appears empty, check that the DEM and other layers are marked in the left panel Layers (see figure on the right).

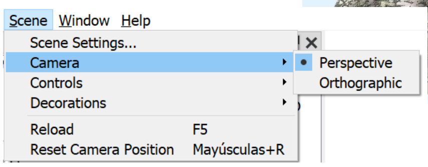


10 The main configuration options are:

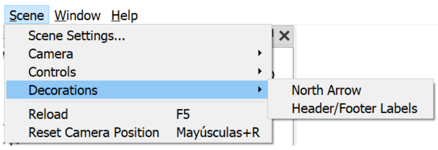
At Scene → Scene Settings:



At Scene → Camera:



At Scene → Decorations:



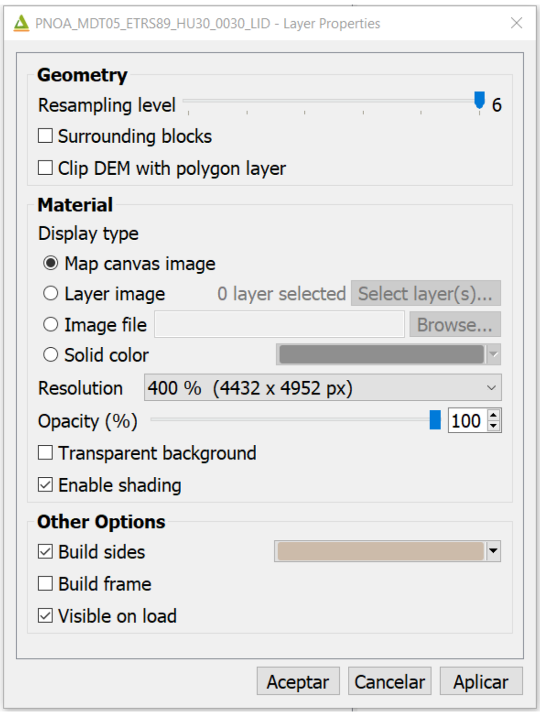
The options to be used in each case are:

- *Vertical exaggeration*: between 1.0 and 1.2. In mountainous areas, a value of 1 is sufficient. In the case of slight relief, a value of up to 1.2 is acceptable.
- *Vertical shift*: zero or automatic (regulates the vertical shift of the DEM with respect to the other layers).
- *Basic type*: involves three options for the material reflectance: *Lambert, Phong* and *Toon*. With the images considered herein, no appreciable difference exists, and thus, the default option is accepted.
- *Background*: irrelevant since it is not included in the export of the block.
- *Display of coordinates*: returns the coordinates of a selected point; irrelevant for the export.
- *Scene Camera*: select the option Perspective for a natural effect; irrelevant for the export of the block.
- *Scene Decoration*: adds a North symbol or text; irrelevant since it is not included in the block export.

11 Right-clicking on the DEM provides access to other key options (image on the right):

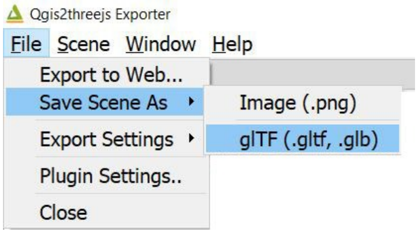
- *Resampling level:* defines the generalization of the DEM (in these models, we do not have access to the complete resolution). Below, we see two axes of the resampling levels (a total of 6 can be observed). We use level 6 to obtain the minimum cell size possible.

Level 3	Level 6
Grid Size: 284 x 318	Grid Size: 568 x 635
Grid Spacing: 41.43581 x 41.33176)	Grid Spacing: 20.68136 x 20.66588)



- *Material:* allows the user to select the image to overlay, which, in this case, is already in the view (canvas), and thus, the first option can be selected.
- *Resolution:* defines the generalization of the image; as in the case of the DEM, we choose the maximum possible value (400%).
- *Enable shading:* adds analytical shading to the view. Both options should be tested, and the most visually acceptable one should be chosen. Usually, shading is not applied if the image already incorporates an actual shading, as in the case of orthophotos.
- *Build sides*: adds vertical sides and a base plane to build a closed block; usually, the configuration is visually acceptable, and thus, the user can select the colour of the faces in the drop-down menu.

12 The last step is to export the block to a 3D format readable by other programmes, in particular, by **Sketchfab**, which is used as a repository and catalogue. The only option that exists is **glTF** (*GL Transmission Format*), a format for scenes and 3D models based on the JSON standard that packages geometry and texture in a single file. Our files measure between 50 and 100 MB and can be uploaded directly to Sketchfab, where other characteristic parameters of the platform can be configured to ensure the optimal visualization of the block diagram.



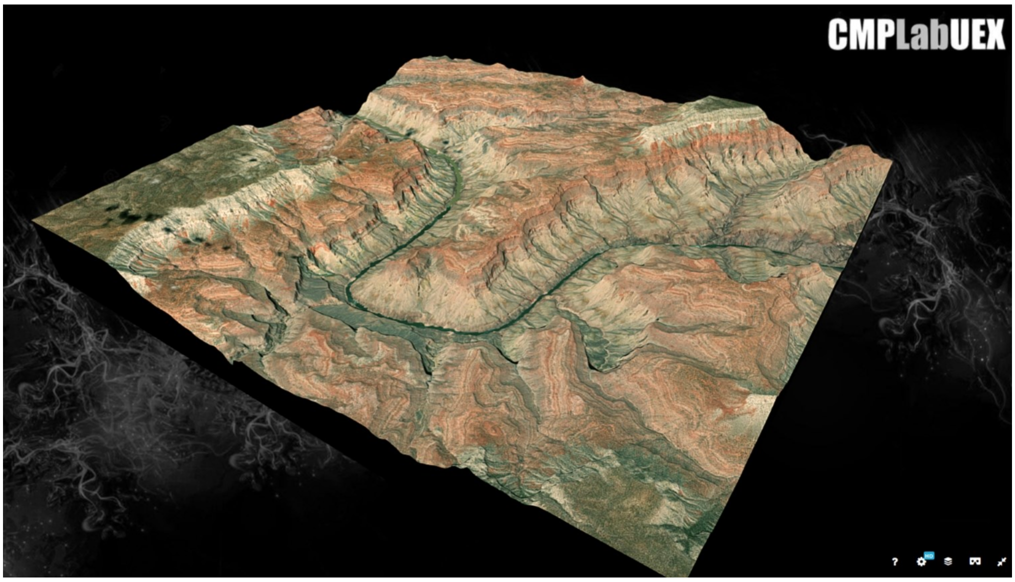


Figure: Grand Canyon, Colorado River, Arizona, USA
The Grand Canyon, excavated by the Colorado River, is located in the National Park with the same name, declared a World Heritage Site in 1979.
Model generated by QGIS and Qgis2threejs.
Derived from ALOS Global Digital Surface Model (AW3D30)) and Landsat image from ArcGIS World Imagery service online.

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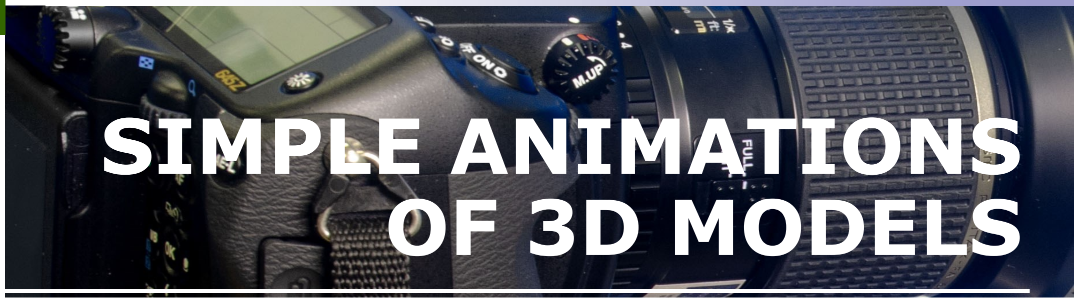


SIMPLE ANIMATIONS OF 3D MODELS

Interactive 3D models vs. animations

The CMPLab publishes the 3D models in Sketchfab (https://sketchfab.com/secad/models) because of its capabilities in configuring the visualization and quality of reproduction, wherein these models can be rotated, enlarged and examined from all the points of view allowed in the configuration. However, in certain cases, it may be more convenient to present a 3D object as a simple animation that undergoes a 360º rotation without further complications. This resource avoids having to navigate Sketchfab's website and may be sufficient for a sample or catalogue of pieces that would be shown in universal video formats visible with the default applications instead of computers (although in certain cases, this setting may be recommended). This notebook proposes a simple solution to build these animations.

Data

The animations are developed using 3D models previously uploaded to Sketchfab. It is understood that the display settings that Sketchfab allows are already adjusted for high quality: lights, environment, materials, etc.

Software

The videos are developed using an experimental application known as *GIF Export*, available in the *Sketchfab Labs Experiments* section. *GIF Export* is mostly automatic and allows only a few options, although the options are sufficient for the given context.

Pre-processing

The 3D model must be well centred and oriented in its local coordinate system, and the view must exploit the available space since *GIF Export* works directly, without any changes, in terms of this aspect.

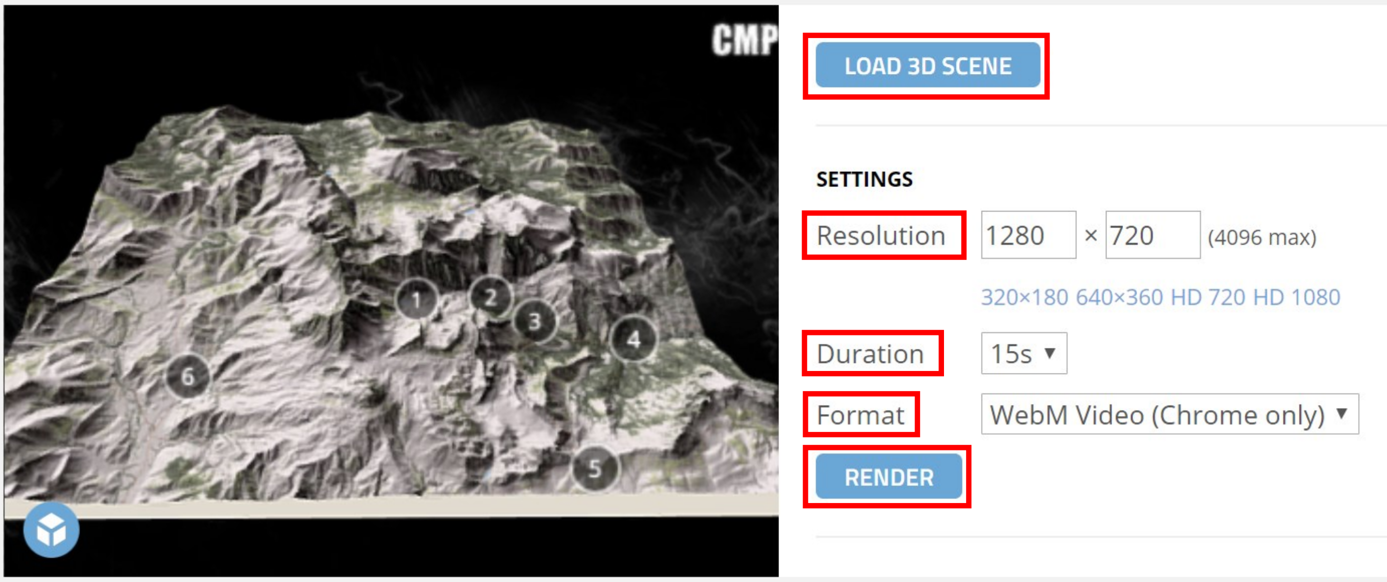
1

Load 3D Scene

The model can be defined in two ways: *Search* and *From URL*.

Search seeks for keywords and usually does not provide satisfactory results (this problem is commonly encountered in *Sketchfab*).

In *From URL,* the access is direct as the explicit address of *the 3D model is provided.*



2

Settings: Resolution

Several values can be defined for the size of the video frames. The recommendation is a minimum of HD 720 (1280×720) and, in the case of high sharpness, HD 1080 (1920×1080). The processing time increases with the resolution and duration, as well as the final size of the video.

3

Settings: Duration

The values for the duration of the video are predefined: 1, 2, 5, 10, 15, 20 and 30 s. Small durations correspond to a lower graphic quality, with more visible "jumps" between frames. In our experience, since the object always exhibits a complete rotation, the minimum recommended is 15 s.

4

Settings: Format

Two output formats are allowed: GIF and WebM Video. Except for extremely short videos, we recommend the use of WebM Video, an open format, developed by Google, and oriented to be used with HTML5. The limitation of this format is that it must be generated using *Google Chrome.*

5

Render

Pressing the Render button starts the video generation. The progression can be followed approximately on the screen as the model rotates. At the end, the video is automatically downloaded to the computer, in the *Downloads* folder.

CONTINUE... ⇨

6
Observations

The videos do not include any annotations regarding the models in *Sketchfab*.

The point of origin of the video is not the one that appears in the *Sketchfab* view, and it is significantly rotated.

The processing time can be several minutes. For the model shown on the previous page, 2:30 min are required for a 15 s HD720 video to be generated.

The process is performed on the server, and thus, it can be launched from any device regardless of its performance (although downloading aspects must be considered).

7
Observations

The videos can be "heavy". For HD1040 videos with a duration of 20–30 s, the size ranges from 45 to 120 MB.

The WebM Video format is compatible with *Youtube* and *Vimeo*.

We recommend that the visualization is performed using *VLC Media Player* as several viewers expand the video to the whole screen by default, which may lead to a lower quality.

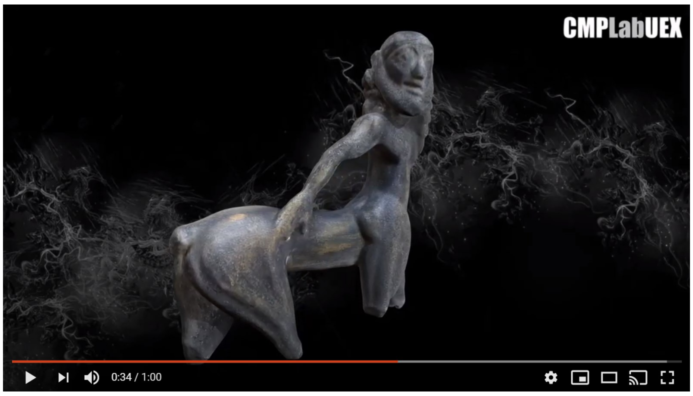
Corresponding to the format, the video codec is *VP8*, developed by On2 Technologies and released by Google after the acquisition of the company. At present, the programme is open source.

YouTube playlist

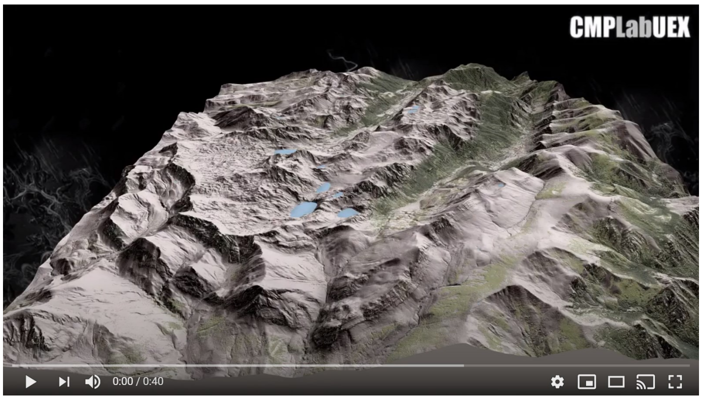
We have created a YouTube channel with thematic playlists such as REMAN3D, GEO3D and PREHISTORY. The first playlist includes videos of the national research project REMAN3D and the second playlist includes diagram blocks derived from digital models of elevations and different layers of ground cover (satellite images, orthophotographs, analytical shading, etc.). Certain examples are as follows.

Espigüete Peak , Palencia, Spain [link]

Centauro de Royos (National Archaeological Museum) [link]



Somiedo Natural Park, Asturias, Spain [link]

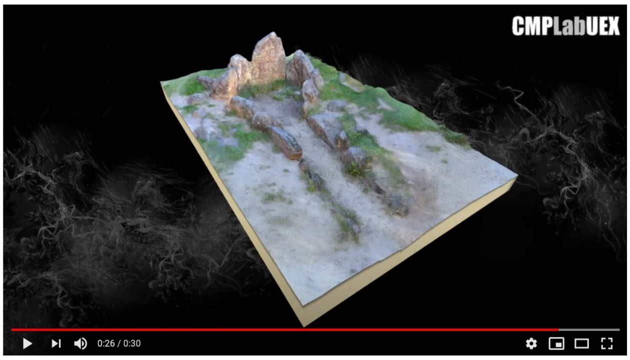


Dama de Galera (National Archaeological Museum) [link]

Other collections of archaeological objects organized by distribution lists will be added to this YouTube account. In addition to these videos, 3D models and high-resolution photographs are public in the following websites:
Sketchfab (https://sketchfab.com/secad/collections) and **Flickr** (https://www.flickr.com/photos/163276198@N08/albums).

The Bicha de Balazote (National Archaeological Museum) [link]

Dolmen of Carmonita, Carmonita, Badajoz [link]



Warriors´ Vessel (National Archaeological Museum) [link]

Dolmen of The Tremedal, Montehermoso, Cáceres [link]

CMPLab is the acronym for Data Capture, Virtual Modelling and Production/Prototyping Laboratory. CMPLab emerged from a project of the Infrastructure and Scientific-Technical Equipment Aid from the Secretary of State for Research and began operating in 2016. This laboratory works on research areas related to the construction of 3D models of archaeological objects, very-high-resolution photography, geophysical prospecting and applications of geomatics to cultural heritage.

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KRAKENGROUP
SPATIAL DATA ANALYSIS, GIS AND REMOTE SENSING

The Kraken research group is formed by people from different knowledge domains: geomatic engineering, earth physics, biology, telematics, agronomy, etc. Our nexus pertains to the capturing and processing of spatial data both at a detailed (3D models, graphic documentation of objects) and territorial scale (geographic information systems, remote sensing, geophysics, etc.).

Part of the production of these notebooks has been financed through the project GR18028 (Research Group RNM026), co-financed by the European Regional Development Funds (ERDF) and Government of Extremadura (Spain).

JUNTA DE EXTREMADURA
Consejería de Economía, Ciencia y Agenda Digital

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These notebooks explain, in an informative way, the process of creating 3D models of different objects or scenes through 3D scanners and digital photography techniques, as well as specific photography techniques and virtual dissemination of the information generated. Certain examples used to illustrate the techniques were extracted from the Diaspora and REMAN3D research projects.

The project "Diaspora. Cultural and identity heritage of Extremadura" (IB16212) aims at elaborating a catalogue of archaeological objects of Extremadura origin (from Prehistory to the 8th century) which, at present and due to different circumstances, are deposited outside Extremadura. This project was submitted to the call for research projects in the public R+D+i centres of the Autonomous Community of Extremadura (General Secretariat of Science, Technology and Innovation, Ministry of Economy and Infrastructure, Government of Extremadura) and was developed between 2017 and 2020. The researchers of this project belong to the Institute of Archaeology of Mérida (Spanish National Research Council) and to the University of Extremadura.

REMAN3D is the acronym of the project "Relocating the Iberian objects of the National Archaeological Museum: of rituals, biographies and observations through 3D models" (HAR2017-87897-P). This project was presented to the State Programme for the Promotion of Scientific and Technical Research of Excellence (State Research Agency, Ministry of Economy, Industry and Competitiveness). Researchers from the Institute of Archaeology of Merida, University of Extremadura, National Archaeological Museum and Autonomous University of Madrid are participating in this project.

ACKNOWLEDGEMENTS

The authors of these notebooks would like to thank the Archaeological Museum of Badajoz and the National Archaeological Museum for the facilities provided for the photography and construction of the 3D models outlined in the previous pages.

Glass carved in agate sized 13 × 9 cm, representing the face of a silen. The object dates back to the 1st century and was originally found in Merida, Badajoz. The object is on display at the National Archaeological Museum and has been included in the Diaspora project.

3D scan using the light scanner structure of the Jarro de Siruela (6th century BC), which is located in the Archaeological Museum of Badajoz .

Example of an image generated using the focus stacking technique. The object is a bracelet belonging to the treasure of Aliseda (Cáceres), and it is located in the National Archaeological Museum, Protohistory section (Ref. MAN 28558).