

D3.2: Final Report on Data Acquisition

Author:
G. Guidi (POLIMI)



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Authors:

G. Guidi (POLIMI)

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Executive Summary

Deliverable 3.2 “Final Report on Data Acquisition” is the final overview of all the activities related with digitization (WP3), at the final month of the 24 allocated for WP3 (M6 to M30). This final report shows how the WP3 activity has, at project level, mostly achieved its goal.

The information for this report was taken from the Progress Monitoring Tool and by supplementary data delivered by some of the partners, integrated by an on-line questionnaire about the methods and technologies used during their WP3 activity. The analysis of the questionnaire responses show that a wide range of data acquisition technologies are being used with the most popular one being photogrammetry (used by thirteen of the fourteen partners). Laser scanning for large volumes is also widely used (nine partners), whilst only five are using small volume laser scanning. Only two partners have produced 3D content with CAD modelling, starting from pre-existing documentation/surveys and then creating hypotheses for how the monuments may have looked at specific periods in time. An overview of both the passive and active scanning technologies is provided to aid the understanding of the current work being undertaken in WP3 of 3D-ICONS.

Regarding the progress of WP3, the global situation shows that, although some delays have influenced the initial activity of a few partners, the project has been completed at WP3 level with a number of digitizations (2,987), higher than that declared in the digitization planning contained in the DOW (2,958).

Although in the initial phase of WP3, some of the partners – especially those less technically skilled or experienced with 3D modelling - needed a few months for setting up the most optimized 3D acquisition strategy, tailored to the work each partner is expected to carry out in the WP3 period, their action – forecast in the previous interim report – accelerated abruptly in the last months of WP3, recovering most of the initial gap.

The few outstanding digitizations that are required are mainly due to delays caused by gaining IPR/access permissions and requirements for specialist scanning techniques such as aerial scans using UAVs. All planned digitizations will be completed by December to enable the 3D models and associated media and metadata to be completed.

D3.2 - Final report on data acquisition

1. Introduction

The digitization action expected as output of WP3 is referred to the collection of the three-dimensional data needed for creating, in the framework of WP4, the 3D models that will be then converted in a form suitable for publication (WP5), enriched with both technical and descriptive metadata (WP4), structured as defined in WP6. The 3D models are then loaded into a repository that each partner provided to set-up. These repositories allows each partner to store their 3D content and define a Uniform Resource Locator (URL) to be associated with the model. Such a URL, included in the metadata record uploaded into EUROPEANA, allows users to connect the data records accessible through the EUROPEANA portal to the actual 3D content or a simplified representation of it, as shown by the block diagram in Figure 1.

The 3D-ICONS project involves two complementary “channels” for collecting 3D data.

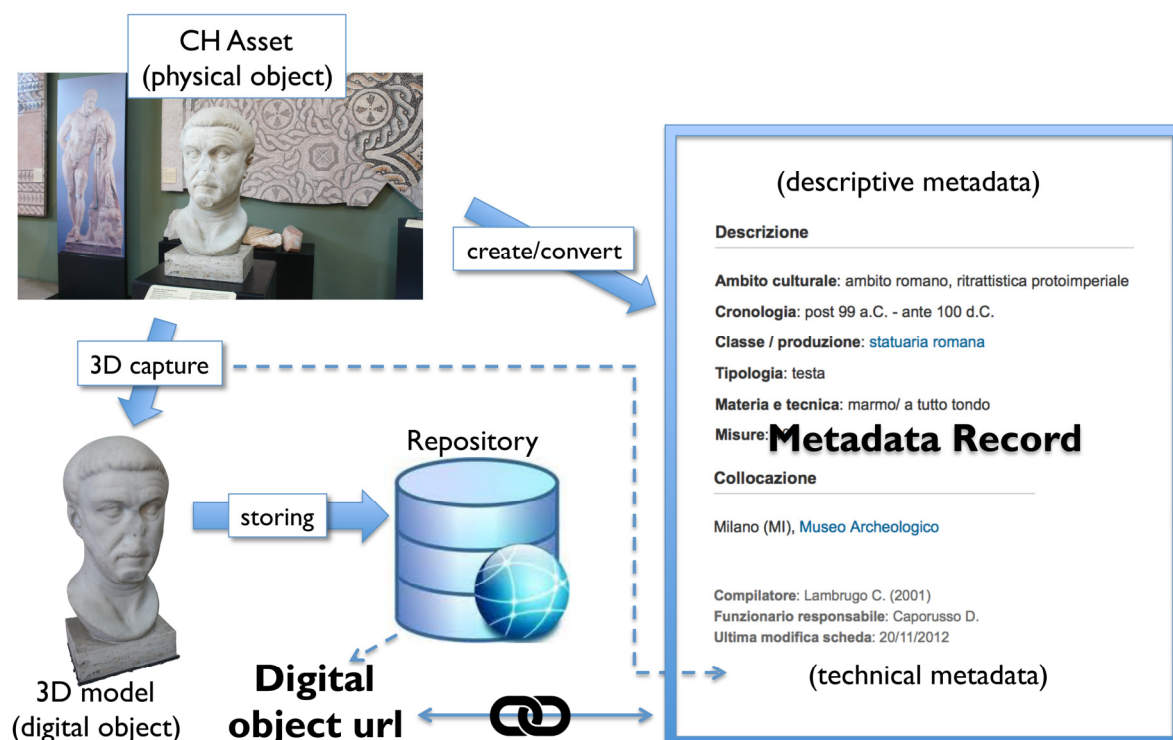


Figure 1 - Synthetic representation of the whole data collection involved in the 3D-Icons project. The activity of WP3 is part of those involved in the “3D capture” block. The metadata record and an iconic representation of the model (thumbnail image) are ingested into EUROPEANA.

On the one hand, the project takes account of a set of pre-existing 3D models of significant Cultural Heritage assets originated by both 3D acquisition and CAD modeling

in the framework of previous works/projects whose purposes were different from the generation of 3D content for EUROPEANA. In this way, a patrimony of data, otherwise unused, acquired over the years by some of the project partners, can usefully be put at the disposal of the community. The WP3 activity in this case consists in properly checking and converting already existing datasets, in order to have them available for the project.

Finally, the project pursued the 3D acquisition of new Cultural Heritage assets that will allow, at the end of the ingestion process planned in the 3D-ICONS pipeline, to add more than 3,000 new 3D items to EUROPEANA.

The main tool that has been used for evaluating the WP3 state of advancement is the Database developed by the CETI unit (http://orpheus.ceti.gr/3d_icons/), available to project partners and the EU commission for checking the progress of the whole project, also by comparing the actual target objectives with what is expected from the project DOW. This was complemented by direct inquiries for those partners that were not able to update their situation in time on Orpheus, and an on-line questionnaire (https://docs.google.com/forms/d/1ciBxCs3ygbYldTUeyVNIP_9Z5G-y_Dj7FE0EBVUC0Co/viewform) that allowed these figures to be integrated with complementary information related to the 3D technologies employed by the various partners for carrying out the digitization phase.

As shown in Table 1, from such tools, it was possible to see that the total number of pre-existing 3D items is 565, while 2,469 new 3D acquisitions were expected to be acquired with different 3D technologies, providing a total of 3,034 3D acquisitions planned within the end of the project.

As shown in Table 1, this actualization of data also involved some adjustments with respect to the figures reported in the DOW. The reason for such changes are due to several aspects related with the actual acquisition rate possible on the field, especially for those units involved in the 3D acquisition of large historical or archaeological sites (ARCHEOTRANSFERT, CMC, MAP-CNRS, UJA-CAAI).

As reported in D 3.1 at M24 such contraction was exactly compensated by an increased production of 3D acquisitions from some of the partners. But differently from what reported in D3.1, the number of total expected 3D acquisitions was increased at M30 from a value exactly equal to what was planned in the DOW (2958), to a value slightly larger (3034). This is due to some of the partner, namely CISA, CNR-ISTI, CNR-ITABC, CYI-STARC, DISC, KMKG and POLIMI, that produced more 3D acquisitions than expected, allowing the project as a whole to have $3034-2958=76$ additional 3D acquisitions planned.

Partner	Number of 3D acquisitions declared in DOW	Number of 3D acquisitions declared At M30	Difference	Of which	
				Pre-existing	New (M30)
ARCHEOTR.	258	207	-51	62	145
CETI	30	18	-12	0	18
CISA	33	128	95	50	78
CMC	53	20	-33	0	20
CNR-ISTI	42	210	168	81	129
CNR-ITABC	143	155	12	92	63
CYI-STARC	71	71	0	20	51
DISC	85	117	32	4	113
FBK	57	57	0	13	44
KMKG	450	455	5	0	455
MAP-CNRS	366	349	-17	133	216
MNIR	80	80	0	0	80
POLIMI	527	531	4	55	476
UJA-CAAI	763	586	-177	5	581
VisDim	0	50	50	50	0
Total	2958	3034	+76	565	2469

Table 1 – Overview of the numbers of digitizations expected by partner, as specified in the DOW in the planning phase and as actualized to the numbers updated by partners at M30, evidencing pre-existing and new 3D models.

2. 3D capturing technologies actually employed for 3D-ICONS

The technologies actually employed in the framework of the WP3 lie in the taxonomy already shown in D 2.1, section 7, where a first broad distinction has been made between technologies based on passive or active measurement methods. Both principles fall in the category of non-contact measurement methods, very appropriate for Cultural Heritage objects, being generally delicate and not always suitable for handling.

The absence of contact between the measurement device and Cultural Heritage artifact is obtained because the probing element, instead of a physical tip touching the surface to be measured for collecting its 3D coordinates at the contact point (as, for example, in the so-called Coordinate Measurement Machines or CMMs), is a beam of radiating energy projected onto the surface to be probed. This beam interacts with the surface and is deflected and measured by the scanning device, enabling the relative position of the current scanned point to be calculated. In this way, a complete set of co-ordinates or “point cloud” is built up which detects the geometrical structure of the scanned object. When the form of energy employed is light (including non-visible radiation like Infra Red), we talk of optical 3D methods, where the main difference between active and passive lies in the way such light is provided.

2.1 Passive technologies

In a passive device, light is used just for making clear the details of the scene. These details have to be clearly visible elements contrasting with the background and richly present on all the points of the surface of interest for capture. This is a characteristic, for example, of photogrammetry, a typical passive method based on multiple images of the same scene, taken from different positions. Here the measurement process requires, first of all, to recognize the same points in different shots of a scene, and this is possible only if the measured object is provided with a contrasted texture, or - when the object is uniformly coloured with no salient points - if the operator has added a reference target over the surface of interest in a number of points sufficient for estimating its 3D shape.

The typical pipeline for creating a 3D model with photogrammetric methods involves the following steps:

1. **Calibration** – The camera distortions (radial, tangential and affine) are estimated through a proper calibration procedure. If the camera has interchangeable lenses like a reflex or a last generation mirrorless camera, each camera-lens combination needs to be calibrated.
2. **Image acquisition** – A suitable set of images of the object to be surveyed are taken with the same setting that has been calibrated, considering that for collecting the 3D information of a point at least two images must contain that point. The number of images needed to carry out the complete 3D measurement

of a CH object is highly influenced by its size, the resolution needed, and the way resection, the next step, is implemented.

3. **Resection** - This phase calculates the orientation in the 3D space of the camera while taking the images acquired in the step 2. The means for estimating such orientation is identifying a suitable number of correspondence points in adjacent images using their coordinates as input to a non-linear optimization process (bundle adjustment), minimizing the re-projection error on the actual image points of their corresponding 3D estimates. In traditional photogrammetry, this phase is quite lengthy because, unless coded targets are used, the identification of correspondences is a manual operation. In the last few years a more modern approach has been developed, allowing automatically identification of correspondence points by analyzing the image content (Structure From Motion or SFM). This requires that adjacent images cannot differ too much, so the level of superposition of such shots has to be high (at least 60%), and consequently the number of shots to be taken is much higher than in traditional photogrammetry. However, the need to find correspondences generally discourages the use of passive methods for objects with little or no texture.
4. **Intersection** – This phase calculates the 3D coordinates of corresponding points by the intersection of two rays associated with the same point seen on two different images (triangulation). Also, in this case, the process can be extremely time consuming if the end-user has to manually identify the points of interest, generating in this way a specific selection of 3D points taken in suitable positions (sparse 3D cloud). A more modern process implemented in recent years, and usually associated with SFM, is the so-called “dense image matching”, that – given a certain orientation - automatically finds a regular set of correspondences between two or more images, thereby calculating a dense cloud of evenly spaced 3D points. The interesting aspect of this approach is that each group of 3D points, is “naturally” oriented in a single coordinate system;
5. **Scaling** – The cloud of 3D points generated by steps 1-4 is a relative estimation of coordinates. There is no metric correspondence with the physical reality they are representing. In order to obtain a set of metric 3D points, one or more reference measurements from the scene have to be provided and the 3D points have to be scaled accordingly;
6. **Modeling** – This phase involves the generation of the 3D model starting from the measured points. Again, its implementation can be done manually on sparse 3D clouds, or automatically on dense cloud of 3D points. In this latter case, a topological revision and an editing phase is usually needed.

The quality of the result – like for photography - greatly depends on the optical quality of the equipment used. Good digital reflex cameras with high quality lenses, used by skilled operators, provide the best image quality for the following 3D processing.

The two implementations of this method used in 3D-CONS are as follows.

2.1.1 Traditional Photogrammetry

All the 6 steps listed previously for the photogrammetric pipeline are done separately by an operator that has to:

- a) calibrate the camera by photographing a specific certified target (e.g. a 3D grid of some tens of known points) and processing the images with a software capable of providing the distortion parameters from them;
- b) take photos of the subject, taking into consideration a proper distance between shots in order to have a large base for triangulation (the rule of the thumb is to use a distance between shooting positions approximately equal to 1/3 of the camera-target distance);
- c) orient all images in the set identifying a suitable number of correspondence points (at least 8-10) for each of the images involved, finally applying bundle adjustment;
- d) identify some points of the object needed for reconstructing its shape over the oriented images, and collect their 3D coordinates;
- e) scale the obtained 3D data set and export to 3D modeling software;
- f) draw a 3D model over the measured 3D points.

This method is implemented in both open source and commercial photogrammetry software packages. Although the image acquisition phase needs a proper planning, it is rather simple. But the following post-processing is quite cumbersome and needs a considerable amount of time and skilled operators. The required time is further increased if the object has no salient reference points and its surface needs to be prepared with specific targets attached to it (not always possible on Cultural Heritage assets).

2.1.2 SFM/Image matching

This process has been greatly developed in the last ten years and is now a standard operating tool. It implements the six step photogrammetric pipeline using a high level of automation, reducing significantly the time needed for generating a 3D model from a set of images. It is based on the automatic identification of image elements in photographs, possible if the images have a short base of triangulation (i.e. they are very similar each other). The process can be implemented through an on-line service (Autodesk 123D Catch, Microsoft Photosynth, etc.) taking as input a set of images and providing as output a texturized 3D model, with no user control.

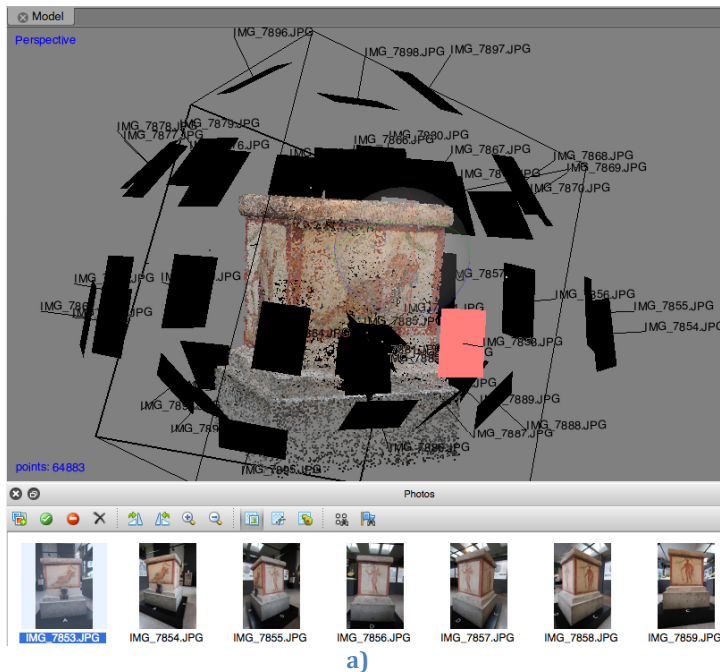


Figure 2 – SFM digitization made by the POLIMI unit of a Roman altar conserved at the Archaeological Museum of Milan through AGISOFT Photoscan: a) images automatically oriented in 3D; b) rendering of the 3D model originated by this method.

But Within the 3D-ICONS project an alternative commercial solution has been widely adopted by many of the partners (AGISOFT Photoscan). Although this works in a similar way, it is a piece of software installed locally by the end-user that allows a certain level of user control over the process.

The operator only needs:

- a) to acquire a number of images all around the object with a sufficient overlap (suggested 60%) between adjacent shots as indicated in step 2;
- b) launch the process that automatically identifies many (in the order of some thousands) corresponding points and automatically performs the steps 1 and 3 of the photogrammetric pipeline, generating a first quality feedback about image orientations;
- c) if the orientations are acceptable, a second process can be launched, performing steps 4 and 6 of the photogrammetric pipeline. The set of points obtained is a dense cloud of 3D points including colour information that the software can mesh automatically.

The last point (step 5.) has to be done afterwards in order to provide a metric 3D model. The result obtained at this step – with the exception of a few editing operations – represents the final 3D result (Figure 2).

This method produces particularly effective results and has been used by many of the 3D-ICONS project partners, as shown in detail in section 3.

2.2 Active technologies

In an active device, light is not uniformly distributed like a passive device, but is coded in such a way to contribute to the 3D measurement process. The light used for this purpose might be both white, as a pattern of light generated with a common LCD projector, or single wavelength as in a laser. Active systems, particularly those based on laser light, make the measurement result almost independent of the texture of the object being photographed, projecting references onto its surface through a suitably coded light. Such light is characterized by an intrinsic information content recognizable by an electronic sensor, unlike the environmental diffuse light, which has no particularly identifiable elements. For example, an array of dots or a series of coloured bands are all forms of coded light. Thanks to such coding, active 3D sensors can acquire in digital form the spatial behaviour of an object surface. At present, 3D active methods are quite popular because they are the only ones capable of metrically acquiring the geometry of a surface in a totally automatic way, with no need to resize according to one or more given measurements taken from the field. In the 3D-ICONS project such devices have been largely used in the different implementations described in the following sections.

2.2.1 Triangulation based range devices

For measuring small volumes, indicatively below a cubic meter, scanners are based on the principle of triangulation. Exceptional use of these devices have been made in Cultural Heritage (CH) applications on large artifacts like, for example, the Portalada 3D scanning performed within this project by the CNR-ISTI unit. In such cases, these are typically integrated with other types of devices.

The kind of light that was first used to create a 3D scanner is the laser light. Due to its physical properties, it allows generation of extremely focused spots at relatively long ranges from the light source, relative to what can be done, for example, with a halogen lamp. The reason for this is related to the intimate structure of light, which is made by photons, short packets of electromagnetic energy characterized by their own wavelength and phase. Lasers generate light which is monochromatic (i.e. consisting of photons all at the same wavelength), and coherent (i.e. such that all its photons are generated in different time instants but with the same phase). The practical consequence of mono-chromaticity is that the lenses used for focusing a laser can be much more effective, being designed for a single wavelength rather than the wide spectrum of wavelengths typical of white light. In other words, with a laser it is easier to concentrate energy in space. On the other hand, the second property of coherence allows all the photons to generate a constructive wave interference whose consequence is a concentration of energy in time. Both these factors contribute to making the laser an effective illumination source for selecting specific points of a scene with high contrast

respect to the background, allowing measurement of their spatial positions as described below.

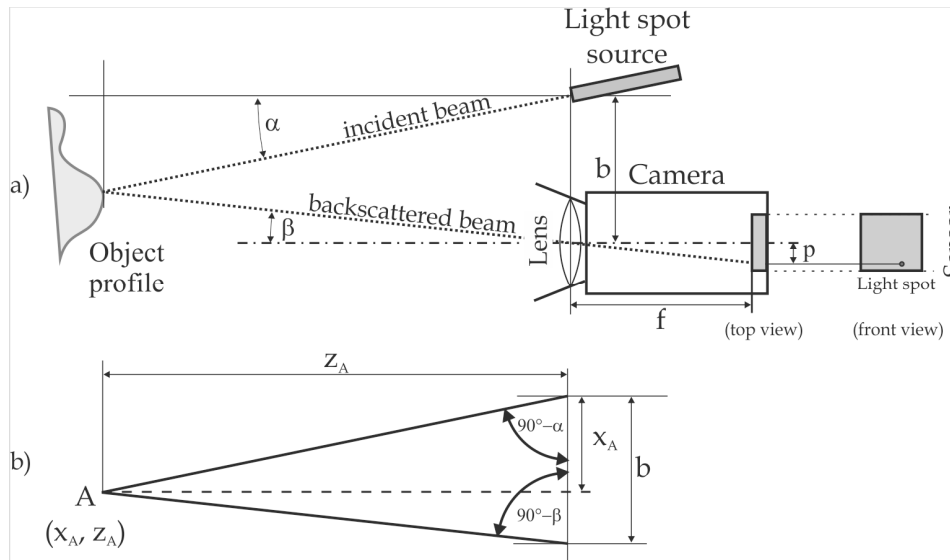


Figure 3 – Block diagram of a range measurement device based on triangulation: a) a laser beam inclined with angle α respect to the reference system, impinging on the surface to be measured. The light source is at distance b from the optical centre of a camera equipped with a lens with focal length f . Evaluating the parallax p from the captured image it is possible to evaluate β ; b) combining α and b (known for calibration) and β , the distance Z_A can be easily evaluated as the height of this triangle.

A triangulation 3D sensor is a range device made by the composition of a light source and a planar sensor, rigidly bounded to each other. In the example of Figure 3, the laser source generates a thin ray producing a small light dot on the surface to be measured. If we put a digital camera displaced with respect to the light source and the surface is diffusive enough to reflect some light also towards the camera pupil, an image containing the light spot can be picked up. In this opto-geometric set-up, the light source emitting aperture, the projection centre and light spot on the object, form a triangle as the one shown in Fig. 3b, where the distance between the image capturing device and light source is indicated as baseline b . In such conditions, the sensor-to-object distance (Z_A) can be easily evaluated, and from this the other value X_A calculated.

The principle described above can be extended by a single point of light to a set of aligned points forming a segment. Systems of this kind use a sheet of light generated by a laser reflected by a rotating mirror or a cylindrical lens. Once projected onto a flat surface, such a light plane produces a straight line which becomes a curved profile on complex surfaces. Each profile point responds to the rule already seen for the single spot system, with the only difference being that the sensor has to be 2D, so that both horizontal and vertical parallaxes can be estimated for each profile point. These parallaxes are used for estimating the corresponding horizontal and vertical angles, from which, together with the knowledge on the baseline b and the optical focal length f , the three coordinates of each profile point can be calculated with a high degree of

accuracy. This process therefore allows to the calculation of an array of 3D coordinates corresponding to the illuminated profile for a given light-object relative positioning. The described set of the laser sheet generator and camera represent the scanner head. By moving the sheet of light according to a rotational or translation geometry, the whole set of 3D profiles collected represent a 3D view of the scene.

A similar result is obtained if, instead of moving a single profile over the surface, several profiles are projected at once. This is in the method used by pattern projection sensors, where multiple sheets of light are simultaneously produced by a special projector generating halogen light patterns of horizontal or vertical black and white stripes. An image of the area illuminated by the pattern is captured with a digital camera and each Black-to-White (B-W) transition is used as geometrical profile, similar to those produced by a sheet of laser light impinging on an unknown surface. Even if the triangulating principle used is exactly the same as for the two laser devices, the main difference is that here no moving parts are required since no actual scan action is performed. The range map is computed through digital post-processing of the acquired image.

The output attainable from both kind of triangulation devices can be seen as an image having in each pixel the spatial coordinates (x, y, z) expressed in millimetres, optionally enriched with colour information (R, G, B) or by the laser reflectance (Y). This set of 3D data, called “range image” or “range map”, is generally a 2.5D entity (i.e. at each couple of x, y values, only one z is defined).

In metrological terms these kind of devices provide low uncertainty (below 0.1 mm), but can only work in a limited range of distances, generally between 0.5 to 2 metres. So they are very suitable for small objects with little or no texture, and not too shiny or transparent.

2.2.2 Direct distance measurement devices based on Time of Flight (TOF)

With active range sensing methods based on triangulation, the size of volumes that can be easily acquired ranges from a shoe box to a full size statue. For a precise sensor response, the ratio between camera-target distance and camera-source distance (baseline), has to be maintained between 1 and 5. Therefore, framing areas very far from the camera would involve a very large baseline, that above 1m becomes difficult to be practically implemented. For larger objects like buildings, bridges or castles, a different working principle is used. It is based on optically measuring the sensor-to-target distance, having the *a priori* knowledge of angles through the controlled orientation of the range measurement device.

TOF range sensing is logically derived from the so-called “total station”. This is made by a theodolite, namely an optical targeting device for aiming at a specific point in space, coupled with a goniometer for precisely measuring horizontal and vertical orientations, integrated with an electronic distance meter. TOF, or time of flight, refers to the method used for estimating the sensor-to-target distance that is usually done by measuring the

time needed by a pulse of light for travelling from the light source to the target surface and back to the light detector integrated in the electronic distance meter.

A 3D laser scanner is different from a total station in that it does not need a human operator to aim at a specific point in space and therefore it does not have such a sophisticated crosshair. On the other hand, it has the capability to automatically re-orient the laser on a predefined range of horizontal and vertical angles with an assigned angular resolution, in order to select a specific area in front of the instrument. The precise angular estimations are then returned by a set of digital encoders, while the laser TOF gives the distance. By combining this information representing the polar representation of each point coordinate, the corresponding Cartesian coordinates can be easily calculated.

For ground-based range sensors, the angular movement can be 360° horizontally and close to 150° vertically, with an operating range from less than one meter to several hundred meters or more (depending on the actual implementation), allowing a huge spherical volume to be captured from a fixed position. As for triangulation based range sensors, the output of such devices is again a cloud of 3D points originated by a high resolution spatial sampling of an object. The difference with triangulation devices is often in the data structure. In TOF devices, data is collected by sampling an angular sector of a sphere, with a step that is not always fixed. As a result, the data set can be formed by scan lines that are not necessarily all of the same size. Therefore, the device output may be a simple list of 3D coordinates not structured in a matrix.

In terms of performances, contributions to measurement errors may be made by both angular estimation accuracy and distance measurements. However, due to the very high speed of light, the TOF is very short, and this means that the major source of randomness is due to its estimation that becomes a geometrical uncertainty once time is converted in distance. Generally, a strength of this kind of device is that the only distance limiting factor is the laser power, so that the principle can be used also for very long range devices, like those used in Airborne Laser Scanning (ALS), capable of collecting 3D data from thousands of metres.

2.2.3 Direct distance measurement devices based on Phase Shift (PS)

In this technique distance is estimated with a laser light whose intensity is sinusoidally modulated at a known frequency, generating a continuous wave of light energy directed toward the target. The backscattering on the target surface returns a sinusoidal light wave delayed with respect to the transmitted one, and therefore characterized by a phase difference from it.

Since the phase is directly proportional to the distance, from this value the range can be evaluated similarly as in the previous case. This indirect estimation of distance allows a better performance in terms of uncertainty for two main reasons: a) since the light sent to the target is continuous, much more energy can be transmitted respect to the TOF case, and the consequent signal-to-noise ratio of the received signal is higher; b) the

low-pass filtering required for extracting the useful signal component involves an attenuation of the high frequency noise, resulting in a further decrease of noise with respect to signal.

A peculiar aspect of this range measurement technique is the possibility of ambiguous information if the sensor-to-target distance is longer than the equivalent length of a full wave of modulated light, given by the ambiguity range $r_{\text{amb}} = \pi c / \omega_0$, due to the periodical repetition of phase. Such ambiguity involves a maximum operating distance that is in general smaller for PS devices rather than TOF. For this reason PS are generally used for medium range operating distances, while TOF are used for long range.

However, the scanning mechanism remains the same as TOF devices, allowing an horizontal angular scan of 360° and a vertical one around 150° , covering almost a whole spherical view.

2.3 Relationship between technology and applicative scenarios

The different working principles allow implementation of 3D capturing solutions for various applicative situations. Figure 4 provides an overview of the device-to-target distance that is implicitly related to the device's field of view.

As shown in Figure 4, the low range devices are those based on triangulation, like laser scanners based on a sheet of light (e.g. Minolta Vivid 910), or on pattern projection (e.g. Breuckmann Smartscan HE). All these are generally used on a tripod and require a significant post-processing effort for aligning the various range maps required to cover the whole surface of an object. As an alternative for fast 3D capture, recent triangulation-based devices offer on-the-flight evaluation of their position and orientation with respect to the scene. Therefore, they can be handheld and used more easily for fairly larger scanning volumes (e.g. Artec EVA; Z-Corp Z-Scanner 800). Consequently, these are commonly used for small archaeological artifacts, object museums, etc.

For medium range applications, PS laser scanners work well for interiors or small/medium architectural structures and archaeological sites. Their speed, in the range of 1 million of points per second, allows them to be used in complex structures where several scanner positioning are needed.

For long range applications, TOF laser scanners are the most suitable. Even if usually slower than PS devices, they can be used as terrestrial devices, in the same way as PS laser scanners, for capturing large structures or even natural landmarks (e.g. the FBK unit used this device for capturing a famous rocky mountain in the Dolomites). But since they have no intrinsic range limitations, they can also be mounted on flying vehicles for capturing large sites from above with the so-called Airborne Laser Scanner (ALS).

Finally Photogrammetry, both in its traditional implementation and in the more recent SFM/image matching version, covers the widest range of applicative situations. In

principle, there are no intrinsic range limitations. The only parameter to be taken into account is the required resolution (or GSD – Ground Sampling Distance), which is influenced by the lens used (wide-angular vs. teleobjective), and by the camera-to-target distance. This flexibility probably explains why this method is the most widely used among the 3D-ICONS partners, as shown in section 3.

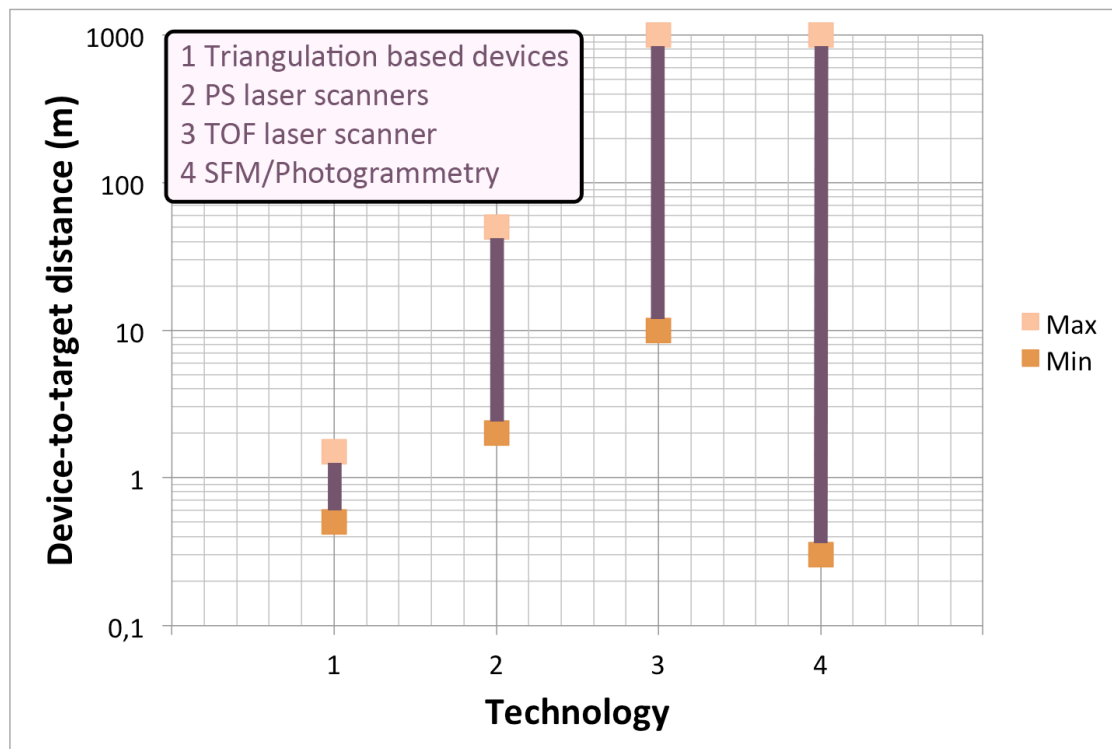


Figure 4 – Field of applicability of the various 3D technologies used in the 3D-ICONS project. The upper limit of 1000 metres is just indicative of a long range, since TOF LS and Photogrammetry can work even from longer distances.

3. Distribution of 3D capturing technologies among the partners

According to the questionnaire completed by the partners, a survey about the 3D technologies employed by the various partners has been conducted, revealing a diffusion of many different approaches, with a predominance of SFM/Photogrammetry for its ease of use and speed. All the partners answered the questionnaire, showing an interesting coverage of the whole 3D digitization area. The results are reported as follows.

3.1 ARCHEOTRANFERT

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Traditional photogrammetry (sparse 3D cloud)

Which of them you used more?

SFM/Photogrammetry (dense 3D cloud)

Which Camera/Lens did you use?

Nikon D800E

3.2 CETI

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), TOF/PS laser scanner

Which of them you used more?

SFM/Photogrammetry (dense 3D cloud)

Which Camera/Lens did you use?

DSLR Nikon D40 at 6.1MP with an 18–55 mm lens; Canon EOS350d at 8.1MP with an 18–55 mm lens; Samsung NX1000 at 20MP with an 20-50 mm; Nikon D320 at 24MP with an 10-20mm

Which range sensing which devices did you use?

Optec Ilris 36D

3.3 CISA

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), TOF/PS laser scanner, CAD Modeling

Which of them you used more?

We use a bit of everything

Which Camera/Lens did you use?

Nikon D90/ 18-55 mm

Which range sensing which devices did you use?

Zoller & Frolich Imager 5003

3.4 CMC

Which 3D acquisition technology have you used in WP3?

TOF/PS laser scanner

Which range sensing which devices did you use?

We are using data acquired by 3rd parties, who primarily used Leica hardware.

3.5 CNR-ISTI

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Triangulation range sensor, TOF/PS laser scanner

Which of them you used more?

Triangulation range sensors

Which Camera/Lens did you use?

Nikon D 5200, Nikon D70, various compact cameras

Which range sensing which devices did you use?

long range: Leica Scan Station / Leica 2500 / Leica 3000, RIEGL LMS-Z, FARO Photon 120

triangulation: Minolta Vivid Vi 910, Breuckman Smartscan-HE, NextEngine Desktop Scanner"

3.6 CNR-ITABC

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), TOF/PS laser scanner

Which of them you used more?

SFM/Photogrammetry

Which Camera/Lens did you use?

Canon 60D 17mm; Canon 650D 18-50 mm; Nikon D200 (fullframe) 15mm

Which range sensing which devices did you use?

Faro focus 3D

Other technologies?

Spherical Photogrammetry (Canon 60D 17 mm)

3.7 CYI-STARC

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Traditional photogrammetry (sparse 3D cloud)

Which of them you used more?

We use a bit of everything

3.8 DISC

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Triangulation range sensor, TOF/PS laser scanner, Airborne Laser Scanner (ALS)

Which of them you used more?

TOF/PS Laser scanners

Which Camera/Lens did you use?

Canon 5D MK II/ 24mm - 105mm/ 20mm

Which range sensing which devices did you use?

Faro Focus 3D, Fli MAP-400 ALS, Artec EVA

3.9 FBK

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Traditional photogrammetry (sparse 3D cloud), Triangulation range sensor, TOF/PS laser scanner

Which of them you used more?

SFM/Photogrammetry

Which Camera/Lens did you use?

Nikon D3X/ 50mm; Nikon D3100/ 18 mm; Nikon D3100/ 35mm

Which range sensing which devices did you use?

Leica HDS7000; ShapeGrabber SG101; Leica ScanStation2; FARO Focus3D

3.10 KMKG

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud)

Which Camera/Lens did you use?

Canon, different cameras and lenses

3.11 MAP-CNRS

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Traditional photogrammetry (sparse 3D cloud), Triangulation range sensor, TOF/PS laser scanner

Which of them you used more?

We use a bit of everything

Which Camera/Lens did you use?

Nikon D1x, D2x and D3x with 20mm, 35mm, 50mm, 105mm, 180mm

Which range sensing which devices did you use?

Faro Focus 3D, Faro Photon 80, Konica Minolta Vivid 910, Trimble Gx, Mensi GS200

3.12 MNIR

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Traditional photogrammetry (sparse 3D cloud)

Which of them you used more?

SFM/Photogrammetry

Which Camera/Lens did you use?

Canon EOS 40D, 17-40mm; Nikon D3100, 18-105mm

3.13 POLIMI

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Triangulation range sensor, TOF/PS laser scanner

Which of them you used more?

SFM/Photogrammetry

Which Camera/Lens did you use?

Canon 5D Mark II/20 mm and 50 mm; Canon 60D/20 mm, 50 mm and 60 mm; Canon 20D/ 20 mm; Sony Nex-6/Zeiss 24 mm

Which range sensing which devices did you use?

Minolta Vivid 910; Faro Focus 3D; Leica HDS3100

3.14 UJA-CAAI

Which 3D acquisition technology have you used in WP3?

SFM/Photogrammetry (dense 3D cloud), Traditional photogrammetry (sparse 3D cloud), Self positioning handheld 3D scanner

Which of them you used more?

SFM/Photogrammetry

Which Camera/Lens did you use?

Canon EOS 40D/SIGMA DC 18-200mm and EOS APO MACRO 350mm

Which range sensing which devices did you use?

Z-Scanner 800

3.15 VisDim

Which 3D acquisition technology have you used in WP3?

Virtual Reconstruction

Other technologies?

3D virtual reconstruction based upon archaeological plans, publications, measurements and observations on site, interpretation by experts.

The 3D models were built in ArchCAD, improved and retextured in Blender. The terrain and vegetation is done in Vue.

3.16 Considerations about the 3D technologies employed

A wide range of technologies are used within the project due to the type of objects to be digitized which range from entire archaeological sites to buildings, sculptures and smaller museum artifacts as shown in Table 2.

	Traditional photogrammetry	SFM with Image matching	Triangulation range sensors	TOF/PS laser scanners	CAD + old 3D data
ARCHEOTR.	■	■			
CETI		■		■	
CISA		■		■	■
CMC				■	
CNR-ISTI		■	■	■	
CNR-ITABC		■		■	
CYI-STARC	■	■			
DISC		■	■	■	
FBK	■	■	■	■	
KMKG		■			
MAP-CNRS	■	■		■	
MNIR		■			
POLIMI		■	■	■	
UJA-CAAI	■	■	■		
VisDim					■
<i>Total</i>	5	13	5	9	2

Table 2 - Overview of 3D acquisition technologies used by partners

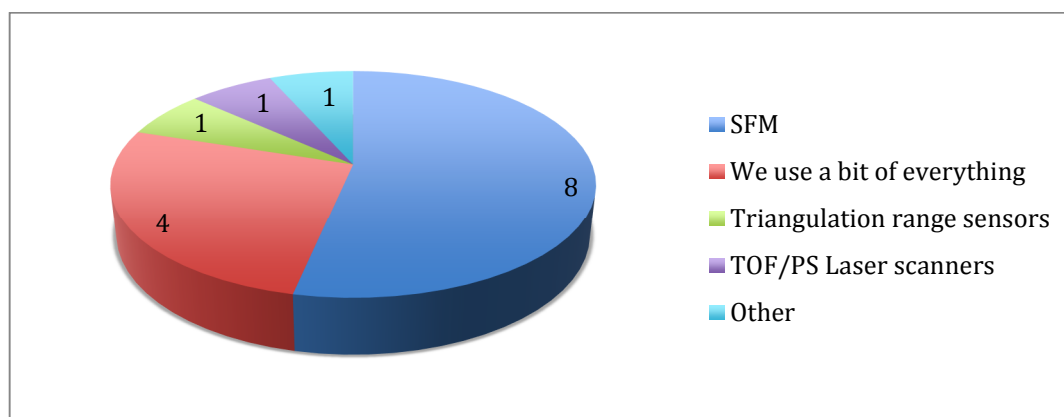


Figure 5 - Most commonly used data acquisition methods for the various 3D-ICONS units.

As shown in Table 2, nearly everyone is using SFM/Photogrammetry (dense cloud) with no partners using Traditional Photogrammetry (sparse cloud) alone. Nine partners are using TOF/PS laser scanners, eight in conjunction with photogrammetry and one as a

sole technology (for a large archaeological site). A further five partners use triangulation range sensors in addition to the two other technologies. The exceptions are VisDim who creating virtual reconstructions (so no actual digitization of a real object), and UJA-CAAI and DISC who are also using a hand-held scanners, and CISA, using CAD in addition to Photogrammetry.

Partner	Digital Single Lens Reflex (SLR) cameras	Lens	Mirrorless/Compact cameras	Lens
ARCHEOTR.	Nikon D800E	18-55mm		
CETI	Nikon D40, D320 Canon 350D	18-55mm, 10-20mm 18-55mm	Samsung NX1000	20-50mm
CISA	Nikon D90	18-55mm		
CMC				
CNR-ISTI	Nikon D5200, D70		Various models	
CNR-ITABC	Canon 60D, 650D Nikon D200	17mm, 18-50mm 15mm		
CYI-STARC				
DISC	Canon 5D MkII	24-105mm, 20mm		
FBK	Nikon D3x, D3100	50mm, 18mm, 35mm		
KMKG	Canon, various models	Various lenses		
MAP-CNRS	Nikon D1x, D2x, D3x	20mm, 35mm, 50mm, 105mm, 180mm		
MNIR	Canon 40D; Nikon D3100	17-40mm; 18-105mm		
POLIMI	Canon 5D MkII, D60, D20	20mm, 50mm macro, 60mm macro	Sony Nex-6	35mm
UJA-CAAI	Canon 40D	Sigma 18-200mm, APO macro 350mm		
VisDim				

Table 3 - The range of digital cameras used by partners for image-based 3D acquisition.

From Figure 5 it's interesting to note that eight units out of the fifteen in total actually involved in 3D digitization indicated SFM/Photogrammetry as the most commonly used technique, four make use of multiple approaches with no special preferences, one is mostly involved with triangulation range devices, and one – DISC, the most active on large sites – indicated TOF/PS Laser scanners as their main tool, including Airborne Laser Scanning. In addition, two units indicated the use of a triangulation-based self-positioning range device, suitable for reducing the post processing effort needed for aligning the acquired range maps.

With regard to the cameras shown in Table 3, many different models were used with a large majority of digital Single Lens Reflex (SLR) belonging to the professional segment with full frame sensor (Nikon D800E, D3x; Canon 5D Mark II), to the semi-professional segment with APS-C sensor (Nikon D90, D70, D1x, D2x; Canon 60D, 40D and 20D), and a few consumer SLRs also with APS-C sensor (Nikon D3100, D5200; Canon 350D). Canon and Nikon were, therefore, by far the most dominant brands in this area – twelve of the partners used one or both of these makes. A few smaller cameras have also been used,

belonging to the Mirrorless and Compact segment, like Samsung NX1000 and Sony Nex-6. Several types of lens have been used, with a majority of zoom lenses ranging from 10 to 350mm by most of the partners, but with a rigorous use of fixed length lenses by the groups most traditionally involved with photogrammetry, mostly with focal length ranging from very short (15mm, 18mm and 20mm), to medium (35mm, 50mm, 50mm macro and 60mm macro), with a couple of tele lenses (105mm and 180mm).

Partner	Triangulation range sensors	PS lasers scanners	TOF laser scanners
ARCHEOTR.			
CETI			Optec ILRIS-36D
CISA		Zoller & Froelich Imager 5003	
CMC		Leica HW from 3 rd parties	Leica HW from 3 rd parties
CNR-ISTI	Minolta Vivid Vi 910, Breuckman Smartscan-HE, NextEngine	Faro Photon 120	Leica Scan Station, HDS2500, HDS3000; RIEGL LMS-Z
CNR-ITABC		Faro Focus 3D	
CYI-STARC			
DISC	Artec EVA (handheld)	Faro Focus 3D	FLI-MAP400
FBK	ShapeGrabber SG101	Leica HDS7000; Faro Focus 3D	Leica ScanStation2
KMKG			
MAP-CNRS	Minolta Vivid 910	Faro Photon 80, Focus 3D	Trimble Gx; Mensi GS200
MNIR			
POLIMI	Minolta Vivid 910	Faro Focus 3D	Leica HDS3100
UJA-CAAI	Z-Scanner 800 (handheld)		
VisDim			

Table 4 - The range of active range sensors used in WP3 by the 3D-ICONS partners, in order of operating distance.

The 3D active devices used by the partners are listed in Table 4. Among these, the Faro Focus 3D was used by five different partners, and other Phase Shift devices by Faro and other manufacturers (Z+F and Leica) by a total of 8 partners. Long range TOF devices have been used by 7 partners. Six partners used short range active devices, two of which handheld (Artec EVA and Z-Scanner 800).

4. Status of WP3 at the end of the project

The work analyzed here is related exclusively to the 3D digitization activity within the framework of the whole 3D model generation. Considering the various technologies mentioned above, this means, for each object to be modeled:

- with **Traditional Photogrammetry**, the shooting of images, their orientation, the selection and collection of 3D coordinates on interest;
- with **SFM/image matching**, the shooting of images, their automatic orientation, the automatic identification of a dense cloud of 3D points up to the final mesh model (being – in the SFM software more widely used in the project - mixed in the same process the 3D data collection and the mesh generation);
- with **Triangulation range devices** (both laser and pattern projection), the collection of the necessary range images around the objects of interest;
- with **TOF and PS range devices** (both terrestrial and aerial), the collection of laser scans on the field and possible complementary information (GPS, 2D/3D alignment targets, etc.).

4.1 General Overview

Table 5 shows that WP3 has been completed at M30 with 2987 3D acquisitions on an updated planning of 3034 (98.4%), which represent a large majority of the total. These data can be also checked on the *Progress Monitoring Tool* of the project (http://orpheus.ceti.gr/3d_icons/).

However, if compared with the figures of the DOW, indicating a more conservative planning of 2958 3D acquisitions, the percentage of completed 3D acquisition of the total that the 3D-ICONS project was committed to complete is more than 100%.

Even if WP3 officially concluded at M30, the project still has six months available to the end, and considering that some partners have been delayed in the last six month period by a difficult start of the ingestion phase, it is likely that the partners that have not yet completed their goals will easily reach the updated planning targets as reported in the *Progress Monitoring Tool*, largely overcoming the planned targets made in the DOW (+76 digitizations).

	3D Digitizations planned (Orpheus)	3D Digitization completed	3D Digitizations not done	WP3 % not completed
ARCHEOTRANS.	207	207	0	
CETI	18	18	0	0
CISA	128	117	11	8.6%
CMC	20	20	0	
CNR-ISTI	210	210	0	
CNR-ITABC	155	138	17	11%
CYI-STARC	71	70	1	1.4%
DISC	117	117	0	
FBK	57	57	0	
KMKG	455	455	0	
MAP-CNRS	349	331	18	5.2%
MNIR	80	80	0	
POLIMI	531	531	0	
UJA-CAAI	586	586	0	
VisDim	50	50	0	
Total	3034	2987	47	1.6%

Table 5 – Final results of the 3D digitization phase achieved by the project at the end of WP3 (M30).

The missing digitizations are:

CISA experienced delays in gaining permission to access their designated monuments and those monuments still to be acquired will be completed by December 2014.

CNR-ITABC – the models yet to be digitized are mainly from Sarmizegetusa, Romania which will be acquired this month.

CYI-STARC has only one outstanding dataset to be acquired (Tomb of the Kings) and MAP-CNRS have some more datasets to acquire for the Pont Avignon and the Treasury of Marseille and the Tholos at Delphi.

All digitizations will be completed by M36 as planned; some “slack” was built in to the original schedule to accommodate delays such as these caused by access/IPR problems and special requirements such as aerial scanning which requires UAVs.

4.2 Detailed state of digitization by unit

ARCHEOTRANSFERT	3D digitizations planned	3D digitizations completed
Blaye Citadel	15	15
La Sauve-Majeure Abbey	24	24
Abbadia Castle in Biarritz	9	9
Historic Centre of Rome: Piazza Navona.	5	5
Non-prehistorical heritage of the V	21	21
Historic Centre of Rome : Circus Maximus.	11	11
Tipasa	5	5
Gallien Amphitheater	2	2
Pey Berland Cathedral	6	6
Saint Emilion	4	4
Delos	28	28
Sphinx of Naxos	3	3
Xanthos	19	19
Karnak	3	3
Moissac	2	2
Reims sculptures	50	50
Total	207	207

CETI	3D digitizations planned	3D digitizations completed
Monastery of Kosmosotira	4	4
Monastery of Panagia Kalamou	2	2
Church of Acheiropoietos	2	2
Church of Agioi Apostoloi	5	5
Rotunda	3	3
Kioutouklou Baba, Bekctashic Tekke	2	2
Total	18	18

CISA	3D digitizations planned	3D digitizations completed
Historical Center of Naples: Roman Theatre	5	5
Archaeological Museum of Naples: Statues from Farnese Collection	31	31
Historical Center of Naples: Thermae (Carminiello ai Mannesi)	6	6
Historical Center of Naples: Walls (Piazza Bellini)	2	2
Hercolaneum: Sacello degli Augustali	5	0
Pompei: Necropolis of Porta Ercolano	7	7
Hercolaneum: Augusteum	4	4
Hercolaneum: Roman Boat	2	0
Etruscan Objects (small statues, small findings)	50	50
Paestum, Comitium and Circular Building	4	0
Archaeological Museum of Naples: Sarcophagi	6	6
Pompeii, Domus Regio I, Insula 6	6	6
Total	128	117

CMC	3D digitizations planned	3D digitizations completed
CMC - Skara Brae	11	11
CMC - Skara Brae House 01	2	2
CMC - Skara Brae House 02	3	3
CMC - Skara Brae House 04	2	2
CMC - Skara Brae House 07	2	2
CMC - Skara Brae Artefacts	0	0
Total	20	20

CNR-ISTI	3D digitizations planned	3D digitizations completed
Loggia dei Lanzi	8	8
Piazza della Signoria	12	12
Tempio di Luni	27	27
Piazza dei Cavalieri	4	4
San Gimignano	10	10
Certosa di Calci	2	2
Badia Camaldolese	4	4
Ara Pacis	5	5
Duomo di Pisa	26	26
Portalada	4	4
Ipogeo dei Tetina	24	24
David_Donatello	4	4
Sarcofago degli Sposi	6	6
Ruthwell Cross	14	14
Pompeii	16	16
Villa Medicea Montelupo	2	2
San Leonardo in Arcetri	14	14
Capsella Samagher	4	4
DELOS statues	10	10
Groppoli Stele Statues	14	14
Total	<u>210</u>	<u>210</u>

CNR-ITABC	3D digitizations planned	3D digitizations completed
Historical Centre of Rome	21	20
Cerveteri necropolis	24	24
Appia Archaeological Park	29	22
Villa of Livia	52	52
Sarmizegetusa	9	0
Via Flaminia	11	11
Villa of Volusii	4	4
Lucus Feroniae	1	1
Estense Castle	4	4
Total	<u>155</u>	<u>138</u>

CYI-STARC	3D digitizations planned	3D digitizations completed
Ayia Marina church in Derynia, Famagusta District (Buffer Zone)	10	10
The Cenacle (room of last supper), Israel	4	4
Santa Cristina archaeological area	10	10
Hala Sultan Tekke archaeological excavation	6	6
Tombs of the Kings	11	10
Paphos Gate	10	10
Church of Panagia (Our Lady) tis Aggeloktistis, Kiti	10	10
Sanctuary of Apollo Hylates (baths)	10	10
Total	71	70

DISC	3D digitizations planned	3D digitizations completed
BNB_LANDSCAPE	3	3
TARA	11	11
DA_ROYAL	1	1
NAVAN_ROYAL	1	1
SKELLIG	14	14
POULNABRONE	1	1
BNB_KNW	23	23
DUN_AONGHASA	1	1
BNB_NG	7	7
DUN_EOCHLA	1	1
DUN_EOGHANACHTA	1	1
DUCATHAIR	1	1
STAIGUE	1	1
AN_GRIANAN	1	1
CAHERGAL	1	1
CLONMACNOISE	16	16
DERRY_WALLS	12	12
GLENDALOUGH	16	16
GALLARUS_ORATORY	1	1
DROMBEG	1	1
TUROE_STONE	1	1
KILMAINHAM	1	1
LOUGHCREW	1	1
Total	117	117

FBK	3D digitizations planned	3D digitizations completed
Three Peaks of Lavaredo	1	1
Buonconsiglio Castle	3	3
Buonconsiglio Castle Museum	6	6
Drena Castle	1	1
Etruscan Tombs	12	12
Valer Castle	3	3
Stenico Castle	1	1
Paestum Archeological Site	6	6
Paestum Archeological Museum	8	8
Etruscan Museum - Roma Villa Giulia	2	2
Etruscan Museum - Vulci	4	4
Etruscan Museum - Chianciano	6	6
Ventimiglia Theatre	1	1
Austro-Hungarian Forts	3	3
Total	57	57

KMKG	3D digitizations planned	3D digitizations completed
Almeria	114	114
Almeria (Antas)	185	185
Almeria (Cuevas de AlmanzGolda)	44	44
Almeria (Mojacar, Turre, Zurgena)	14	14
Almeria of Murcia	44	44
Other Models	54	54
Total	455	455

MAP-CNRS	3D digitizations planned	3D digitizations completed
Chateau Comtal de Carcassonne	15	15
Saint-Guilhem-le-Desert	52	52
Trophee des Alpes	7	7
Chartreuse de Villeneuve-lez-Avignon	29	29
Petit Trianon	92	92
Saint Michel de Cuxa	80	80
Centre Pompidou	12	12
Amphiteatre Arles	1	1
Saint-Trophime Gate	2	2
Fontains-Church	2	2
StJean-Fountain	1	1
Vieille-Charite	1	1
Chapelle-imp	1	1
TPLB	6	6
Pont_Avignon	12	8
Fort Saint Jean	13	13
Pompei - theaters area	3	3
Tholos - Delphi	7	1
Treasury of Marseille - Delphi	13	5
Total	349	331

MNIR	3D digitizations planned	3D digitizations completed
MNIR - Saint Michael Romano Catholic Cathedral	23	23
MNIR - Sarmizegetusa (UNESCO WH site)	4	4
MNIR - Lapidarium	7	7
MNIR - Romanian National History Museum's Collections	46	46
Total	80	80

POLIMI	3D digitizations planned	3D digitizations completed
Chartreuse of Pavia	46	46
The roman church of San Giovanni in Conca (Milan)	9	9
Civico Museo Archeologico di Milano	370	370
Castello Sforzesco Museum	106	106
<u>Total</u>	<u>531</u>	<u>531</u>

UJA-CAAI	3D digitizations planned	3D digitizations completed
Oppidum Puente Tablas	76	76
Cemetery of La Noria (Fuente de Piedra, Málaga)	69	69
Cemetery of Piquias (Arjona, Jaén)	49	49
Sculptoric group of Porcuna	78	78
Burial Chamber of Toya (Jaén)	5	5
Rockshelter of Engarbo I and II (Santiago-Pontones, Jaén)	7	7
Archaeological area of Tutugi and Castellón Alto (Galera, Granada)	100	100
Burial Chamber of Hornos de Peal (Peal de Becerro, Jaén)	2	2
Sculptoric group of El Pajarillo	18	18
Sanctuary of Castellar	42	42
The Provincial Museum of Jaén	63	63
The archaeological site and the museum of Castulo	40	40
Hill of Albahacas	35	35
Wall of Ibros	1	1
Wall of Cerro Miguelico	1	1
<u>Total</u>	<u>586</u>	<u>586</u>

VisDim	3D digitizations planned	3D digitizations completed
Historical reconstruction of Ename village, Belgium	50	50
<u>Total</u>	<u>50</u>	<u>50</u>